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Monitoring of environmental contaminants in air and precipitation

Annual report 2019

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ABSTRACT

This report presents environmental monitoring data from 2019 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 2019

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 2019 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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Contents

Summary

This report presents monthly and annual concentrations of selected environmental contaminants in air and precipitation at Norwegian background sites in 2019. The monitoring is done for the Norwegian monitoring programme "*Long-range atmospheric transported contaminants",* together with the programmes for "*Long-term dataseries*" and "*the Norway-Russia measurements*". The overall purposes of the monitoring are to i) increase the knowledge on long-range transported contaminants as a source for pollution in Norway, ii) assess spatial variabilities of environmental contaminants in Norway, and iii) provide data for international conventions, programmes and networks.

The monitoring programme in 2019 continued in accordance with the programme in 2017-2018. 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 for mercury and POPs in precipitation was conducted at one site (i.e. Birkenes). In 2019, the monitoring programme was further extended with measurements of i) phthalates, new brominated flame retardants (nBFRs) and organophosphorous flame retardants (OPFRs) at Birkenes; ii) dechloranes at Zeppelin and Birkenes, and iii) testing of air sampling methodologies for volatile fluorinated substances and data-mining.

Long-term monitoring data of regulated organic contaminants

A number of regulated POPs and POP-like substances have been monitored in air for about 15 years or more, before the Stockholm Convention came into force: Hexachlorobenzene (HCB) at Birkenes and Zeppelin, hexachlorohexanes (HCHs) at Birkenes and Zeppelin, dichlorodiphenyltrichloroethane (DDTs) at Zeppelin, chlordanes at Zeppelin, polychlorinated biphenyls (PCBs) at Zeppelin, and polycyclic aromatic hydrocarbons (PAHs) at Zeppelin. Long-term data is also available for HCHs and HCB in precipitation from Birkenes. The results from the long-term monitoring, including trend analyses, show decreasing concentrations over time for HCHs and DDTs with short estimated half-lives around 5 years during the whole monitoring period. No significant changes in trends (expressed as half-lives) are seen in the period after the Stockholm Convention came into force (2004-2019). 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. For HCB, increasing concentrations in air have been observed during a period of 15 years at Zeppelin and seven years at Birkenes, but this trend has turned during the last three years when the concentrations instead are lower than previous years. The concentration of HCB in 2019 were one of the lowest since 2003. For PAHs and benzo(a)pyrene (B(a)P), there are annual fluctuations but generally stable concentrations over the last years.

Short-term monitoring of organic contaminants

For some compounds and some stations, the air monitoring has been performed for shorter time-periods than 15 years (i.e. 10 to 14 years), and monitoring started after 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 are grouped and presented together even if not all the compounds 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, only PFOA is detected at all three sites. The annual mean concentrations of PFOA in 2019 is similar at all three stations (0.1 pg/m^3). Trend analysis has thus only been performed for PFOA. The trend analyses for PFOA over the monitoring periods (7-13 years) show decreasing concentrations with small half-lives at all sites.

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 concentrations for the three cVMS oligomers at Zeppelin in 2019; D4 (1.3 ng/m^3), D5 (2.8 ng/m^3) and D6 (1.0 ng/m^3), were higher than in 2017 and 2018, but the concentrations during summer (July-August) were still significantly lower than the concentrations measured in previous years (2013-2016). The annual mean concentrations measured for SCCPs at Zeppelin do not show any significant difference between the years (2013-2019), but the MCCPs at Birkenes and Zeppelin in 2019 were higher than previous years indicating an increase of MCCPs.

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. In 2019, the nBFRs, OPFRs and phthalates were monitored in sampling campaigns in summer and winter at Zeppelin and Birkenes, the volatile PFAS were monitored every month at Birkenes, Andøya and Zeppelin, and one additional group, dechloranes, were monitored weekly at Zeppelin and monthly at 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. The concentrations of the detected individual OPFRs in air were, however, high, in the same range as the S/MCCPs (100s pg/m^3). Of the volatile PFAS, only FTOHs were detected in more than 50% of the samples and the dominant PFAS-compounds were 6:2 and 8:2 FTOH at all sites. Few of the targeted nBFRs were detected at Birkenes and Zeppelin (five and three of 14, respectively). The detected concentrations of nBFRs in air were 100-1000 times lower than OPFRs and phthalates, in the same range as the legacy POPs. 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.

The finding of volatile fluorinated substances in air samples from Zeppelin in 2018 resulted in a need for testing air sampling methodologies for these volatile substances as well as for data-mining analyses. In 2019, the ABN (Acid Base Neutral) adsorbent, used in 2018, was compared to a novel charcoal adsorbent in one summer and one winter campaign. The results from these campaigns show that a modified version of the ABN sampler, with more ABN adsorbent, currently provides the best results for the volatile fluorinated substances and is recommended for future use.

Spatial distribution of organic contaminants

For µ-HCH, DDTs, and PAHs, the concentrations in air were higher at Birkenes in southern Norway than at Zeppelin in the Arctic. 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; cVMS, MCCPs, 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 2019, 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 2019, however, was highest at Birkenes in southern Norway due to more precipitation at this location. The lowest concentrations of heavy metals in precipitation were observed at Kårvatn, which is furthest away from emission sources. In general, the air concentrations of heavy metals were two-three times lower at Andøya and Zeppelin in the North than at Birkenes in the South, mainly due to closeness to the potential emission sources in continental Europe. For mercury, no significant spatial distribution is observed in Norway. This indicates that this pollutant has a large potential to be transported far from emission sources due to its longer atmospheric lifetime, and a lack of regional primary sources.

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In 2019, the concentrations of heavy metals were in general somewhat lower than in 2018 at Birkenes and somewhat higher at Hurdal and Kårvatn. In a long term perspective, the concentrations of lead in precipitation at Birkenes have been largely reduced; almost 100% between 1980 and 2019; 38-98% since 1990, and 58-61% since 2000. Also for cadmium in precipitation, there are substantial reductions: 95-99% between 1980 and 2019; 50-76% since 1990, and 54-68 % since 2000. When combining the datasets from Lista and Birkenes, mercury in precipitation has been significantly reduced by 64% since 1990, and by 44% since 2000.

The air concentrations at Birkenes and Andøya in 2019 were slightly lower or equal compared to 2018. In contrast, somewhat higher concentrations in air were observed at Zeppelin in 2019. At Lista/Birkenes there has been a significant reduction of the concentrations for all the measured metals in air for the period 1991 to 2019. At Zeppelin, there has also been a significant reduction since 1994 for several elements (Arsenic, Cadmium, Lead, Vanadium). The reduction for lead has been 88% and 65% respectively at Birkenes and Zeppelin. For cadmium, the reductions were 69% and 55%, respectively. For mercury, small decreasing trends are observed at Birkenes (22%) and Zeppelin (13%)

Sammendrag

Denne rapporten presenterer månedlige and årlige data i luft og nedbør fra norske overvåkingsstasjoner i rural bakgrunn i 2019. Overvåkingen utføres for det nasjonale overvåkingsprogrammet for langtransporterte atmosfæriske miljøgifter, sammen med programmene «lange tidsserier» og «Norge-Russland overvåkning». Formålet med overvåkingen er å i) øke kunnskapen om langtransport av miljøgifter som kilde til forurensning i Norge, ii) fremskaffe informasjon om romlig fordeling av miljøgiftnivåer i Norge, og iii) ivareta rapportering til internasjonale konvensjoner, programmer og nettverk. Fra 2017 har overvåkingen spesielt fokus på å fremskaffe luftdata om nye miljøgifter som ennå ikke er regulert på internasjonalt nivå. Dette for å støtte fremtidige tiltak på nasjonalt og internasjonalt nivå.

Overvåkingsprogrammet i 2019 var det samme som i 2017 og 2018. 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 2019 inkluderer 200 organiske komponenter og 11 tungmetaller. Nye miljøgifter i 2019 inkluderer: Flyktige PFAS, nye bromerte flammehemmere (nBFR), fosfororganiske flammehemmere (OPFR), ftalater og dekloraner. Alle ble målt med aktiv luftprøvetaking. I tillegg ble en opsjon gjennomført der to typer av aktive prøvetakere for flyktige fluororganiske stoffer ble testet ut.

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

For HCB, har overvåkningen påvist økende nivåer i en periode på 15 år på Zeppelin og syv år på Birkenes, men de siste tre årene ser det ut til at trenden har snudd. I 2019 var nivåene av HCB de laveste noensinne eller de laveste siden 2003 på alle stasjonene. For PAHer og B(a)P ser man ikke noen tydelig økende eller avtagende trend uten konsentrasjonene varierer fra år til år.

Korte tidsserier for regulerte organiske miljøgifter
For noen organiske miljøgifter og noen stasjoner har overvåkingen pågått i kortere perioder enn 15 år (fra 10 til 14 år). Dette inkluderer PBDE på Birkenes og Zeppelin, HBCD på Birkenes og Zeppelin, og ioniske PFAS på Birkenes, Andøya og Zeppelin. Ingen ioniske PFAS er regulert, men inngår her sammen med den regulerte PFOA. Flere PBDE-, HBCD- og PFAS-komponenter blir ikke detektert i luftmålingene som viser at det er lave konsentrasjoner av disse i luft på norske bakgrunnsstasjoner. PFOA og PFHpA er detektert i alle prøver på alle tre stasjonene. Konsentrasjonene er det samme på alle tre stasjonene. Korte tidstrendsanalyser viser en svak reduksjon av BDE-47 med halveringstider på ca 10 år.

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

I 2019 var konsentrasjonene av D4 (1.3 ng/m^3), D5 (2.8 ng/m^3) og D6 (1.0 ng/m^3) på Zeppelin høyere enn i 2017 og 2018 hvilket tyder på en årlig økning. Konsentrasjonenene om sommeren er fortsatt lavere enn de første årene i tidsserien (2013-2016). For SCCPs ses ingen forskjell i perioden 2013-2019 på Zeppelin, mens nivåene av MCCPs i 2019 var noe høyere enn tidligere år hvilket indikerer en økning av MCCPs.

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 2019, ble nBFRs, OPFRs og ftalater målt i en sommer- og en vinterkampanje på Zeppelin og Birkenes. Resultatene viser at det er høye konsentrasjoner av ftalater i luft, på samme nivå som siloksaner (ng/m^3). De OPFR som er detektert i prøvene måles i høye konsentrasjoner, på samme nivåer som klorparafiner (100-talls pg/m^3). Kun et fåtall nBFR er detektert i prøvene og da i konsentrasjoner som er 100-1000 ganger lavere enn OPFR og ftalater.

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

Dekloraner ble i 2019 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

Test av prøvetakingsmetode for flyktige fluorerte komponenter (PFTBA, TCHFB and DCTFB) i arktisk luft viser at en modifisert versjon av ABN gir best resultater.

Romlig fordeling av organiske miljøgifter

Det observeres høyere konsentrasjoner av HCH, DDT og PAH i Sør-Norge på Birkenes sammenlignet med den nordlige stasjonen (Zeppelin). For disse komponentene sammenfaller høye episoder med forekomst av luftmasser fra kildeområder på kontinentet på stasjonen. Også siloksaner, MCCPs, 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 2019 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 2019 var konsentrasjonen i nedbør generelt noe lavere enn i 2018 på Birkenes, men noe høyere på Hurdal og Kårvatn. I et lengre perspektiv har det vært en betydelig reduksjon av tungmetaller i nedbør i Norge siden 1980; for bly opp mot 100% på Birkenes og Kårvatn. Fra 1990 har det for Birkenes og Kårvatn vært en reduksjon av bly mellom 38-98% og 58-61% for perioden 2000 til 2019. Det er også store reduksjoner for kadmium i nedbør, mellom 95% og 99% fra 1980 til 2019; 50-76% fra 1990, og

55-68% fra 2000. For kvikksølv har det vært en signifikant reduksjon på 64% siden 1990 og 44% fra 2000 når man kombinerer datasettene fra de nærliggende observatoriene Lista og Birkenes.

Luftkonsentrasjonene av de fleste metallene på Birkenes og Andøya var noe lavere i 2019 sammenlignet med 2018. For de andre stasjonene var det større variasjoner avhengig av komponent. For kvikksølv var det veldig små forskjeller. På Lista/Birkenes har det vært en betydelig reduksjon i luftkonsentrasjon for tungmetaller som er målt for perioden 1991 til 2019. På Zeppelin har det også vært en betydelig reduksjon siden 1994 for flere tungmetaller (Arsen, Kadmium, Bly, Vanadium). Reduksjonen av bly har vært på 88% og 65% henholdsvis på Birkenes og Zeppelin. For kadmium er det lignende store reduksjoner, henholdsvis 69% og 55%. For elementært kvikksølv i luft er det en svak nedadgående trend på 22% og 13% på hhv. Birkenes og Zeppelin.

Monitoring of environmental contaminants in air and precipitation

Annual report 2019

1 Monitoring programme for long-range transported atmospheric contaminants

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

1.1 Background

The data from 2019, presented in this report, are a compilation of data from four different national projects and programs:

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

Heavy metals and POPs can undergo long-range environmental transport, are toxic, bioaccumulative and persistent in the environment. Due to their harmful impacts on the human health and/or on the environment together with their transboundary nature, monitoring of these contaminants is of high priority for Norwegian authorities. For many of these contaminants, long-range transport via air is the most important source to pollution in remote areas where there are few or no local sources. Recognition of long-range atmospheric transport of environmental contaminants to remote areas, such as the Arctic, has been vital in our understanding of the presence and environmental behaviour of POPs. This in turn has contributed to the regulation of several of these contaminants both on a regional and global scale (Rottem et al., 2017; Downie & Fenge, 2003).

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

Stockholm Convention on POPs (Stockholm Convention, 2007) and on a European scale by the 1998 Aarhus Protocol on POPs; “the POP-protocol”, under LRTAP (UN/ECE, 1998b). The two POP conventions today includes 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).

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

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

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

1.2 Monitoring strategies

To document the long-range transport of the environmental contaminants, the monitoring stations/observatories in this report have been placed/located, as far as possible, in areas that are not influenced by local sources for the regulated and long-term monitored contaminants. For example, the occurrence of organic contaminants in the Arctic region has mostly been attributed to long-range transport from distantly located, industrial and agricultural areas. However, for the organic contaminants of emerging concern, it is important to evaluate possible influences of local sources in comparison to long-range transport since these contaminants still are in use and present in materials and products. Some organic contaminants of emerging concern have been found at elevated levels near Arctic settlements, indicating that these settlements may serve as point sources of new organic contaminants to the Arctic region (Warner et al., 2010; Carlsson et al., 2018).

The number of observatories and the geographical distribution are selected in order to represent different parts of Norway, and areas that receive air from different source regions globally. The observatories included in this monitoring programme are to a large extent coordinated and thereby the same ones as those within "the national measurement programme of long-range transported air pollutants for main components in air and precipitation", which like this monitoring programme is conducted by NILU on behalf of the Norwegian Environment Agency, and the Ministry of Climate and Environment (Aas et al., 2019). Three observatories are used for the monitoring of POPs and heavy metals in air, two of these are located on the mainland of Norway: Birkenes in southern Norway, and Andøya in northern Norway, and one is located on Svalbard in the Arctic: Zeppelin (Figure 1, Table 1). POPs in precipitation is only monitored at Birkenes while heavy metals in precipitation is monitored at four sites: Birkenes and Hurdal in the southern parts of Norway, Kårvatn and Svanvik in Finnmark in northern Norway (Figure 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 are available at:
http://www.nilu.no/projects/ccc/sitedescriptions/.

Table 1: Information about the monitoring stations in the programme and list of measured contaminants at each station in 2019.

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				
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

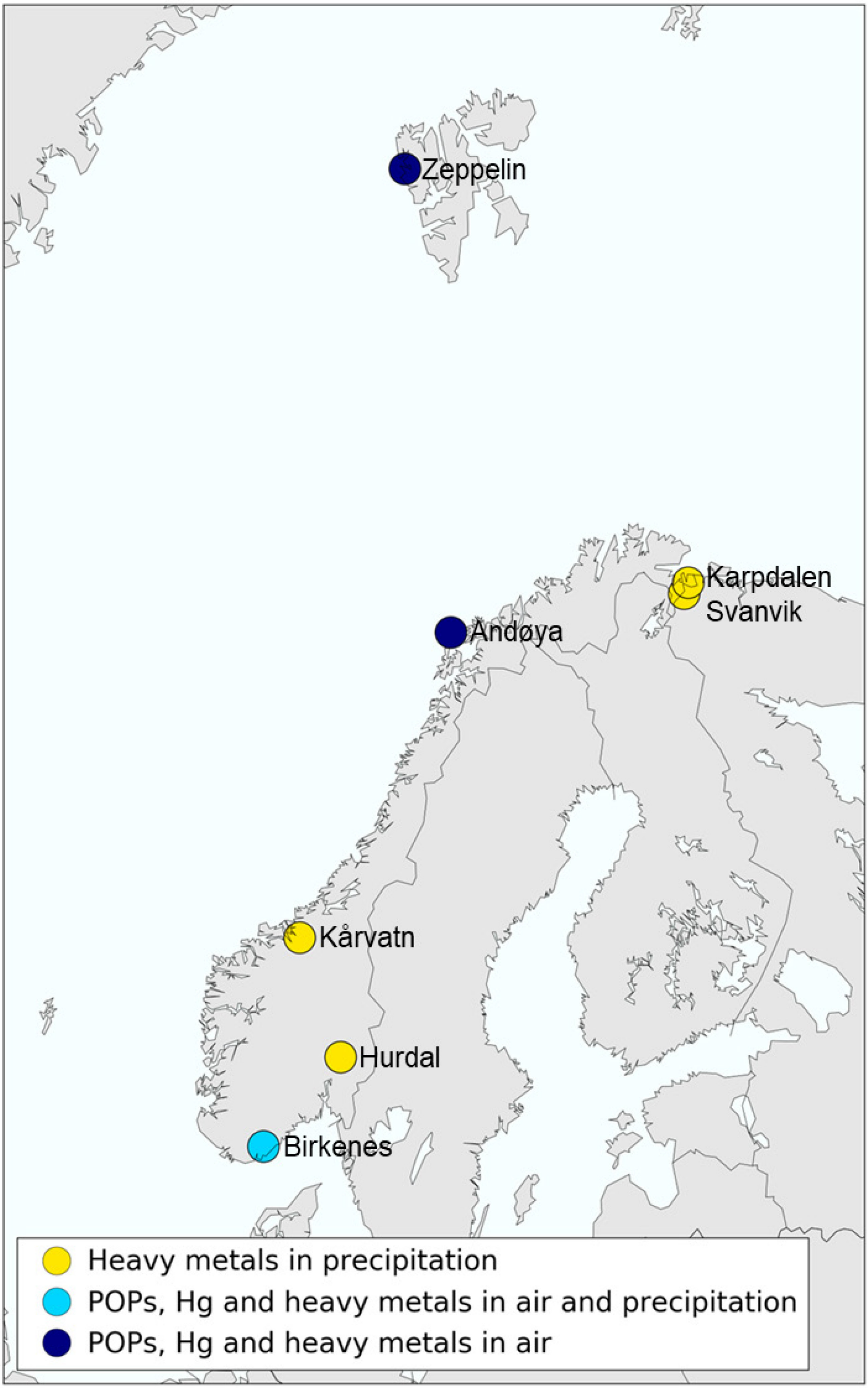


Figure 1: Norwegian background stations measuring environmental contaminants in 2019.

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

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

The monitoring programme have included regulated organic contaminants (e.g. POPs) since the beginning of 1990s at Birkenes and Zeppelin and from 2009 at Andøya (Table 2). In 2017, the monitoring programme for the regulated contaminants was revised according to Table 2. The updated programme includes seven classes and one individual compound classified as POPs, and one POP-like class (i.e. PAHs). Most of the regulated contaminants are measured once per week at Birkenes and Zeppelin with some exceptions. Air samples for PBDEs, HBCD and the ionic PFOS (perfluorooctane sulfonic acid) are collected two times per month (every second week) and the two samples are combined in the lab to give an aggregated monthly concentration. The aim of this change was to improve detection of these compounds that previous years often have been below detection limit. At Birkenes, the measurements of HCHs and DDTs were reduced to one sample per month and chlordanes were excluded. At Andøya, only HCB and PFAS are monitored from 2017. 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 contaminants (e.g. POPs) in 2019.

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
PFOS (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 national screening programmes (van Bavel et al., 2016; Schlabach et al., 2017a+b). The purpose for including these contaminants in the monitoring programme is to obtain data in air that can be used for possible future regulations on national and global level. Another aspect is that if monitoring is initiated before a regulation/measure enters into force it may also be possible to get a more complete picture of the time trends, and the effect of the regulations.

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

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

Table 3: Organic contaminants of emerging concern included in the monitoring programme "Long-range transported atmospheric contaminants" in 2019, year of first monitoring, sampling frequency and sample matrix at the different observatories.

		Zeppelin		**Birkenes**		**Andøya**	
Organic contaminants of emerging concern, Class	Matrix	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		

*New sampling frequency from 2017.

**Six samples per campaign.

***Three sampler per campaign.

In 2019, the monitoring programme included test of two different adsorbents for analyses of air samples using data mining approaches used in 2018 to identify new organic contaminants of potential Arctic concern and in the national screening programme from 2017, conducted by NILU and NIVA for the Norwegian Environment Agency (Schlabach et al., 2018). Air samples were collected using the same sampling technique as in the screening programme from 2017 and the data mining from this programme in 2018: Active air sampling using ABN as adsorbent (Schlabach et al., 2018). In addition, parallel samples were collected using charcoal as adsorbent. All samples were collected for 72 hrs. One set was collected in May-June and another set was taken in November-December.

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 2019.

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 contaminants

The Stockholm Convention and the Aarhus protocol under the Convention on Long-range Transboundary Air Pollution regulates organic contaminants that show properties that can cause risk for human health or the environment. For example, the POPs regulated under the Stockholm Convention are characterized by being persistent in the environment, bio-accumulative, toxic to humans and wildlife, and having potential for long-range atmospheric transport (Stockholm Convention, 2007). Most of the regulated contaminants included in this monitoring are classified as POPs; hexachlorobenzene (HCB), hexachlorohexanes (HCHs), dichlorodiphenyl-trichloroethane (DDTs), chlordanes, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) hexabromocyclododecanes (HBCDs), and PFOS and PFOS related substances (ionic PFAS). In addition to those, also polycyclic aromatic hydrocarbons (PAHs) are included. The PAHs are listed in the Aarhus protocol, but not in the Stockholm Convention and are thereby not defined as a POP. The monitored regulated organic contaminants represent a range of different sources such as intentionally produced chemicals used as pesticides, biocides, flame retardants, etc., and unintentionally produced chemicals generated as by-products of various industrial/combustion processes. The intentionally produced POPs are released to the environment in different ways depending on their application; from industrial point sources; by direct spreading in the nature (e.g. pesticides); by emission/release from products in which they are used; and waste.

Data for the individual POP classes at each observatory are presented as annual mean concentrations, and as monthly mean concentrations in section 2.1-2.3. 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. Detailed data (monthly mean concentrations for individual components within each class) are presented in Annex 1 (Table A1.1-A1.17). 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 is 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). It is also listed on Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015). 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 2019, 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). HCB was detected in all samples from all sites in 2019 (i.e. 100% >LOD). The weekly concentrations ranged between: 17-62 pg/m^3 at Birkenes and 32-80 pg/m^3 at Zeppelin. The monthly concentrations at Andøya ranged between 15-44 pg/m^3. The annual mean concentration of HCB in 2019 at Zeppelin (63 pg/m^3) is the same as in 2018, and the concentrations of HCB during the last two years are the lowest since 2004. The increase in HCB concentrations at Zeppelin that was observed between 2003 and 2016 have flattened out or even turned to a reduction during the last years. This is confirmed by trend analysis which now show stable concentrations at Zeppelin since the last 15 years. A similar trend is observed at Birkenes, where the annual mean concentration in 2019 (41 pg/m^3) is lower than in 2018 and the lowest measured during the monitoring period (1996-2018). This low concentration is in contrast to the increasing time-trend observed the previous years (2010-2016) and trend analyses at Birkenes show slow decrease of HCB during the last 15 years. The reason for this changes is unknown. At Andøya, the annual mean concentrations in 2019 (30 pg/m^3) is comparable with the last decade (Figure 2). The annual mean concentrations of HCB in 2019 were, as previous years, lowest at Andøya (30 pg/m^3) and highest at Zeppelin (63 pg/m^3). The higher concentrations observed in the Arctic for HCB are in line with what is observed within EMEP (Aas et al., 2018). 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., 2018).

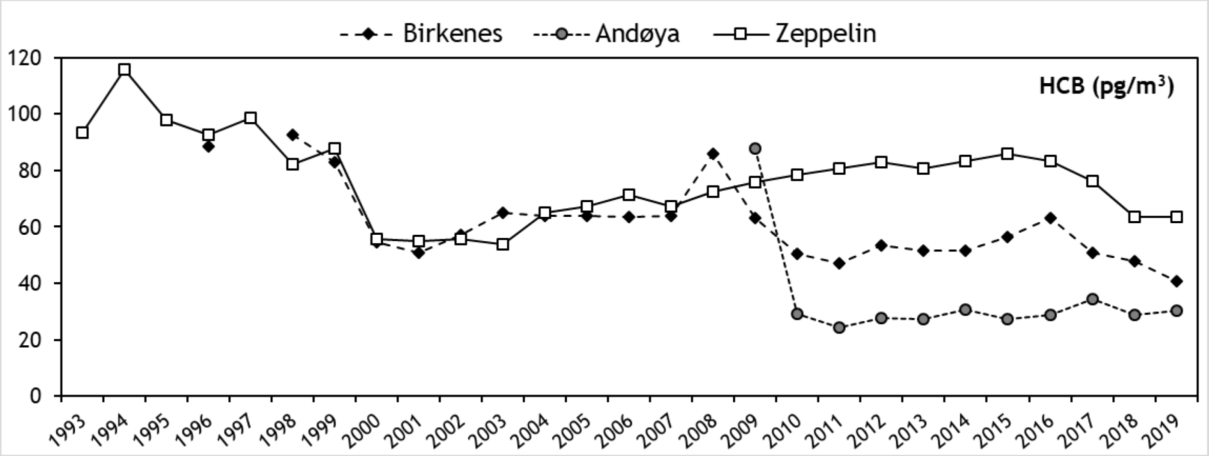


Figure 2: Annual mean concentrations of HCB (pg/m^3) in air.

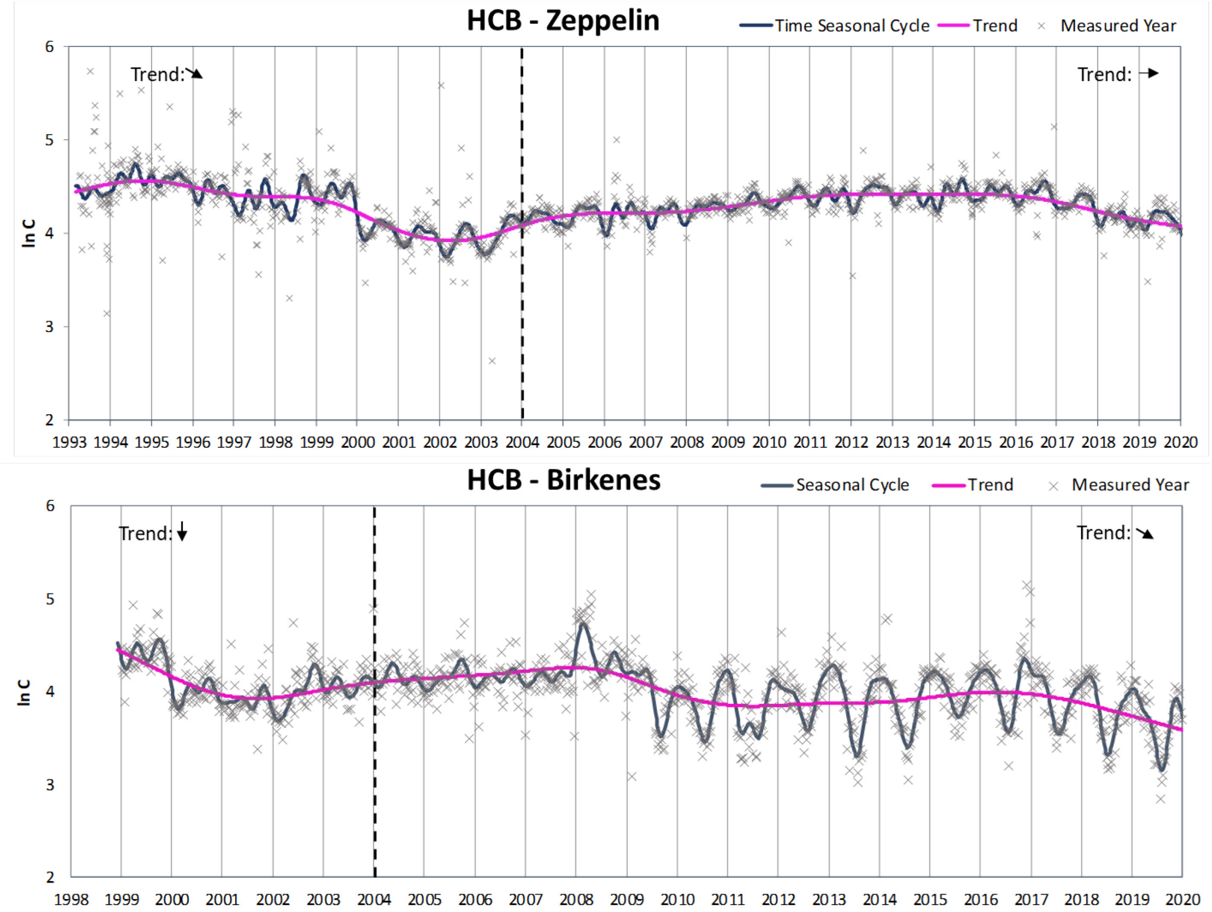


Figure 3: Temporal trends of HCB at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for HCB (2004). The results of trend analyses: before and after HCB was listed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

Seasonal variations of HCB are observed at Birkenes and at Andøya, with a factor of two-three lower concentrations in summer than in winter (Figure 3). The seasonal variations at Birkenes and Andøya may be a result of higher emissions from combustions during colder periods and thereby higher levels in wintertime or 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. A seasonal variation was also observed at Zeppelin in 2019. In contrast to Birkenes and Andøya, at Zeppelin the highest concentrations are observed in summer (Figure 4) and the lowest concentrations are observed during the coldest season. The variability between the lowest and highest monthly concentrations is smaller at Zeppelin (1.5) than at Birkenes and Andøya (2-3).

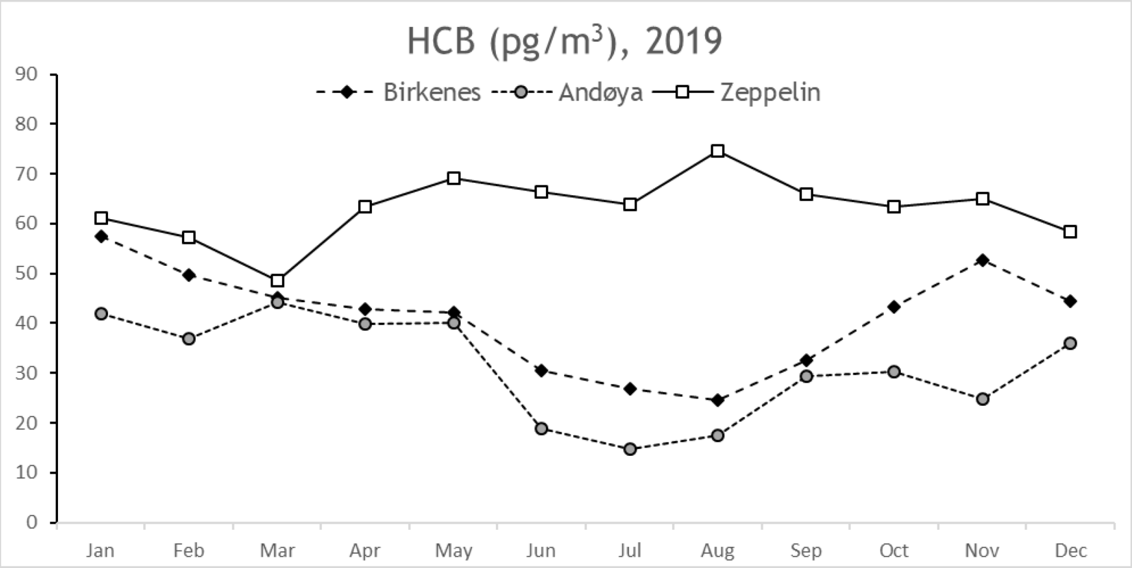


Figure 4: Seasonal variability of HCB at Birkenes, Andøya and Zeppelin in 2019.

2.1.2 Hexachlorohexanes (HCHs)

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

Two HCH isomers; α- and γ-HCH, have been monitored at Birkenes since 1991, at Zeppelin since 1993, and at Andøya since 2010. In 2019, monitoring of HCHs at Zeppelin continued with weekly samples as in previous years, while the monitoring at Birkenes consisted of one sample per month. 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 HCH isomers were above detection limit in all samples from Zeppelin and Birkenes in 2019 (i.e. 100% >LOD). The monthly concentrations of sum HCHs (α+γ) in 2019 ranged from: 2.8-14 pg/m^3 at Birkenes (including one high episode in April). A high episode in April also occurred in 2018. The high episode and the other high concentrations measured at Birkenes are associated with air masses coming from the European continent (Figure 5). The weekly concentrations of sum HCHs at Zeppelin ranged between 1.6-5.2 pg/m^3 in 2019. At Zeppelin, the annual mean concentration of sum HCHs (3.4 pg/m^3) and the individual isomers are higher than in 2018 but lower than previous years continuing the slow decreasing trends (6). At Birkenes, the annual mean concentration of sum HCHs (6.1 pg/m^3) and γ-HCH (2.3 pg/m^3) was lower than 2018 and similar to 2016-2017 while α-HCH was similar to the last years (Figure 6). 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 (Figure 7-8, see section 3). The decrease is continuing also in 2019 as the half-lives did not change since 2017. The two monitored isomers; α- and γ-HCH, have declined with similar patterns at both observatories although a somewhat larger reduction has been observed for γ-HCH than for α-HCH.

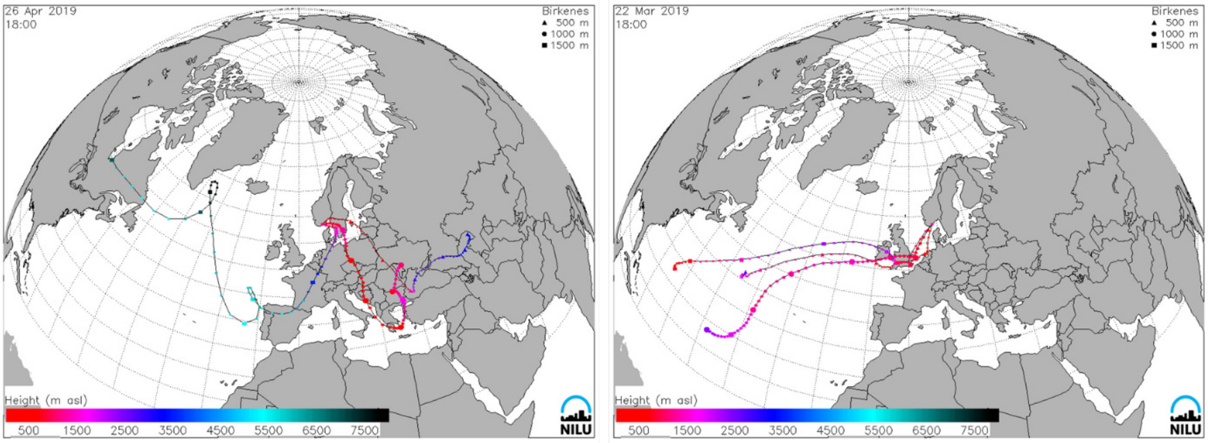


Figure 5: Air mass trajectories calculated using the FLEXTRA model and using meteorological data provided from ECMWF (European Centre for Medium Range Weather Forcast) (https://projects.nilu.no/ccc/trajectories/). Air mass trajectories from the European continent (left) are seen when high concentrations of HCHs are measured at Birkenes while Atlantic air mass trajectories 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; 7.6 (3.8-15.1) at Zeppelin; and 1.9 (0.5-4.0) at Birkenes. Even lower ratios are observed at more southern sites in continental Europe (Aas et al., 2018). The larger ratios 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 of γ-HCH being less prone to long-range transport and more efficiently scavenged by wet deposition, which in turn is a result of its lower Henry's law constant (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 episodic high concentrations of HCH occur. 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, the ratios at Zeppelin are higher in summertime than in wintertime. The concentrations observed in Norway are similar to those observed in Sweden while up to an order lower than those observed at some sites in continental Europe (Aas et al., 2018).

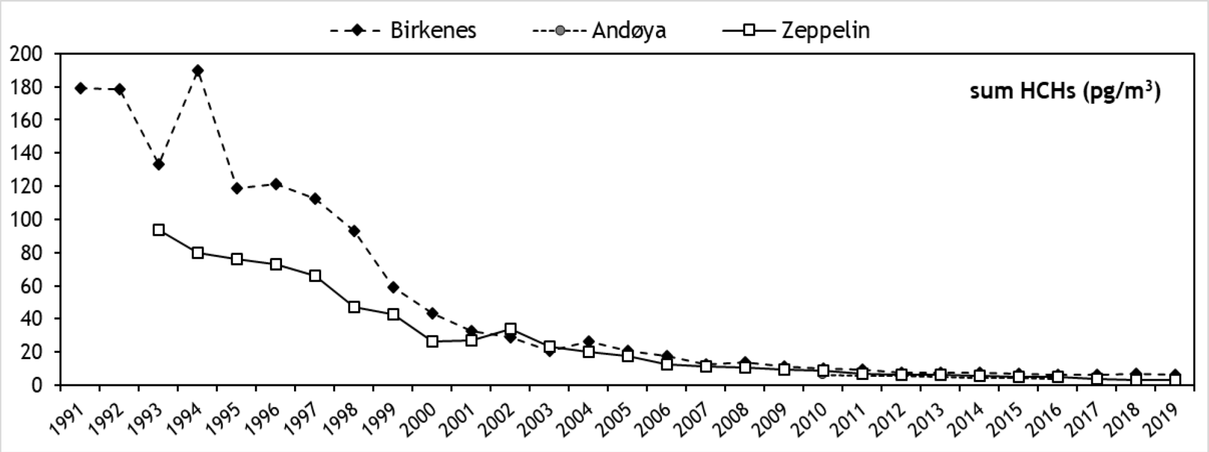


Figure 6: Annual mean concentrations of sum HCHs (pg/m^3) in air.

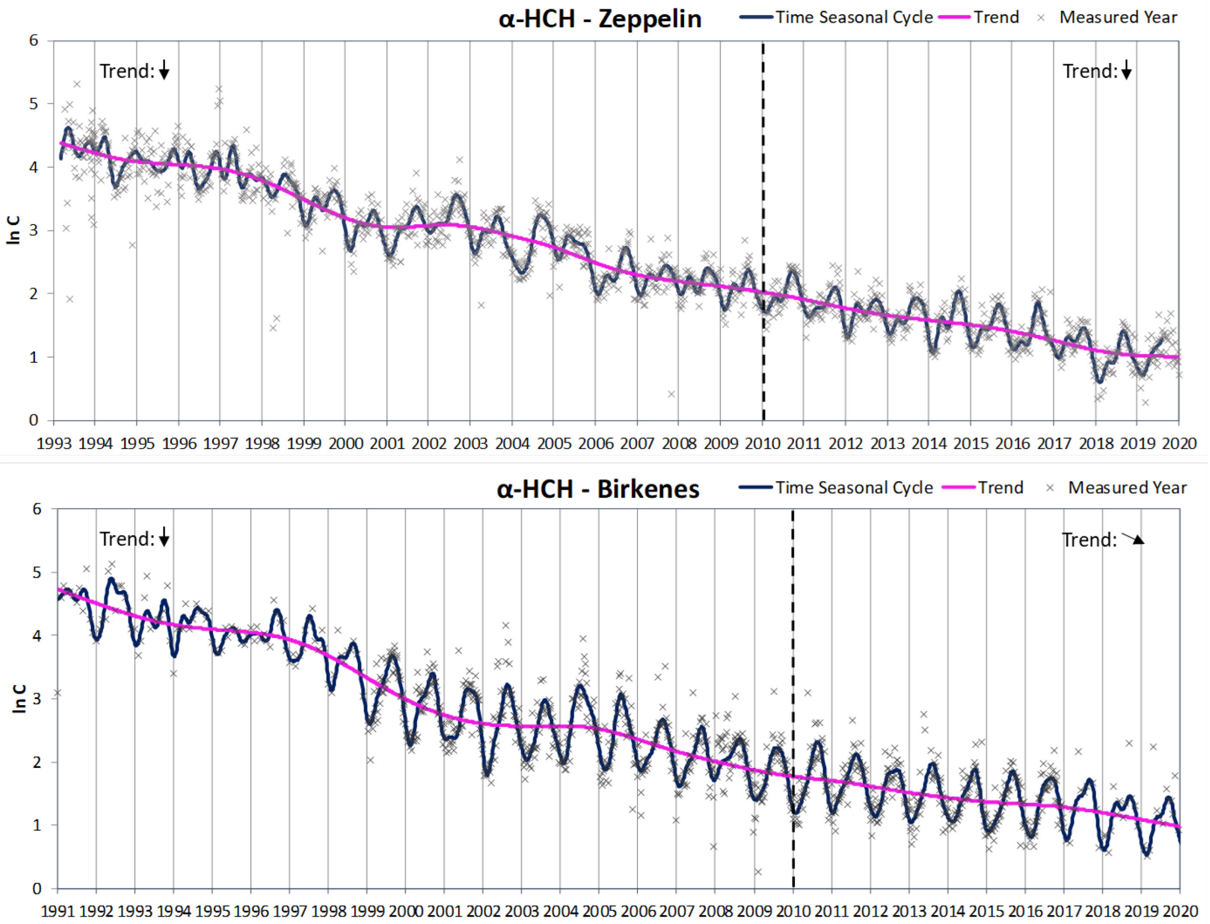


Figure 7: Temporal trends of α-HCH at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for HCHs (2010). The results of trend analyses: before and after the HCHs were listed in the Stockholm Convention, are indicated by four types of arrows (↓: decrease, ↘: small decrease, ↗: small increase and ↑: increase) or NST when no significant trend was detected.

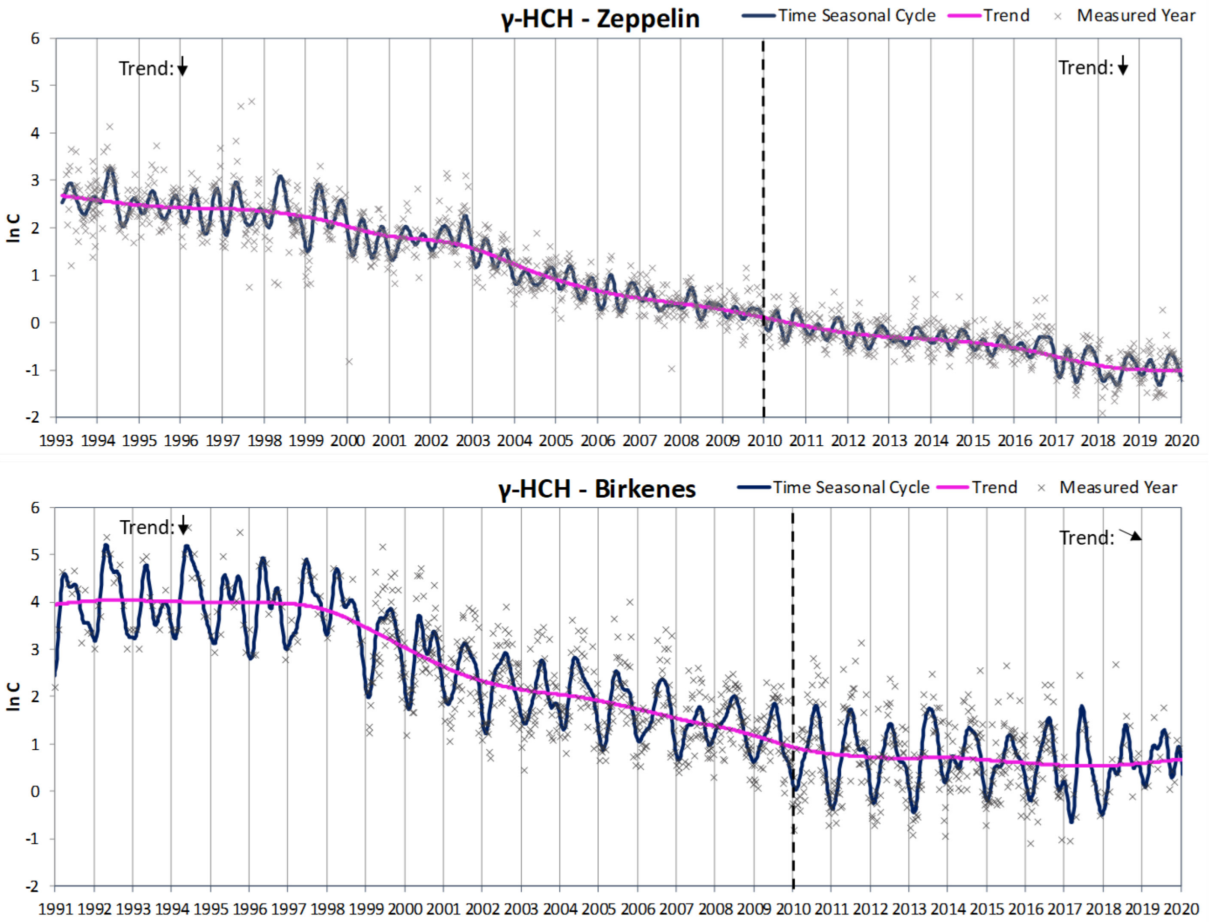


Figure 8: Temporal trends of γ-HCH at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for HCHs (2010). The results of trend analyses: before and after the HCHs were listed in the Stockholm Convention, are indicated by four types of arrows (↓: decrease, ↘: small decrease, ↗: small increase and ↑: increase) or NST when no significant trend was detected.

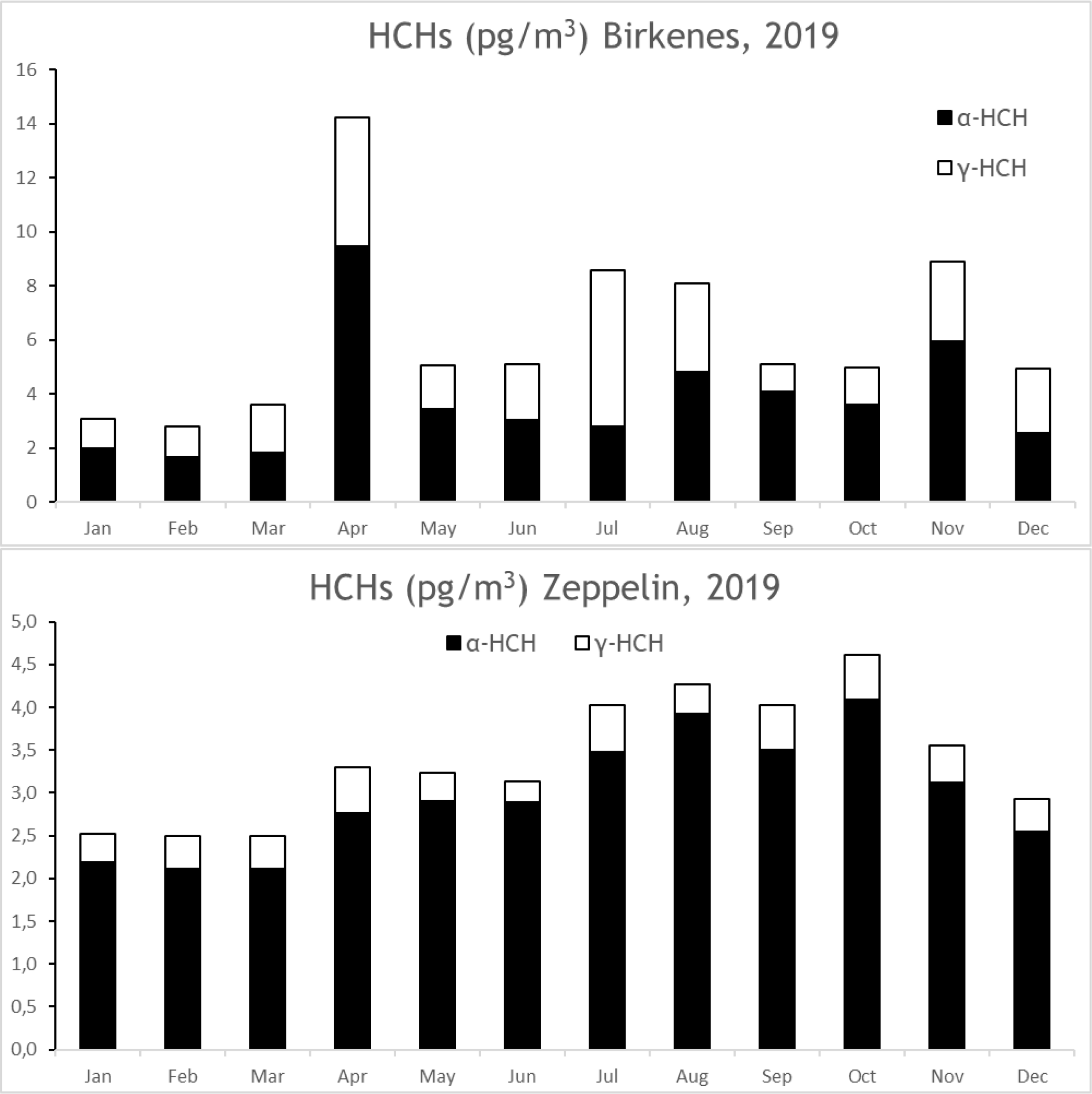


Figure 9: Seasonal variability of α- and γ-HCH at Birkenes and Zeppelin in 2019.

As in 2018, there was not a strong seasonality of the HCHs concentrations at Birkenes (Figure 9). This is in contrast with previous years when the concentrations during summer were higher than in wintertime. The reason for this is not known. A small seasonality was observed at Zeppelin with higher concentrations in late summer (Figure 9).

2.1.3 Dichlorodiphenyltrichloroethane (DDTs)

DDTs are intentionally produced chemicals that have been used worldwide as a pesticide to protect humans and agricultural crops from vector-borne diseases. The production and use of DDTs were banned in Europe, the United States and Canada during 1970s to 2000 and is regulated by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). It is still in use in some parts of the world for disease vector control (primarily malaria). The Stockholm Convention allows the production of DDT for use in disease vector control and as an intermediate in the production of dicofol, although the latter use is anticipated to cease globally in the near future due to the inclusion of dicofol in the Stockholm Convention in May 2019. Furthermore, the World Health Organization (WHO) recommends indoor residual spraying with DDT as one of three primary means of malaria control, the others being use of insecticide treated bednets and prompt treatment of confirmed cases with artemisinin-based combination therapies (WHO, 2006). The Conference of the Parties to the Stockholm Convention on POPs evaluates the continued need for DDT for disease vector control approximately every second year in consultation with WHO.

The six DDT congeners; o,p'- and p,p'- DDT, DDD, and DDE, have been monitored at Zeppelin since 1994, and at Birkenes and Andøya since 2010. In 2019, 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 2019 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 frequencies (i.e. more than 50% of the samples <LOD) were observed for p,p'-and o,p'-DDD at Zeppelin and o,p'-DDD at Birkenes. This suggests low concentrations of these DDT-congeners at the Zeppelin and Birkenes. Instead, p,p'-DDE was the most abundant congener followed by o,p'-DDT at the two sites. The weekly concentrations of sum DDTs at Zeppelin in 2019 ranged between 0.04-1.1 pg/m^3. The monthly concentrations of sum DDTs at Birkenes ranged between 0.56-13 pg/m^3 (including one extreme measurement in November and one high measurement in April). All DDT congeners were 5-10 times higher during the measurement in November 2019 than the other months. The reason for this is unknown. The analytical quality parameters for this sample do not suggest any analytical anomalities.

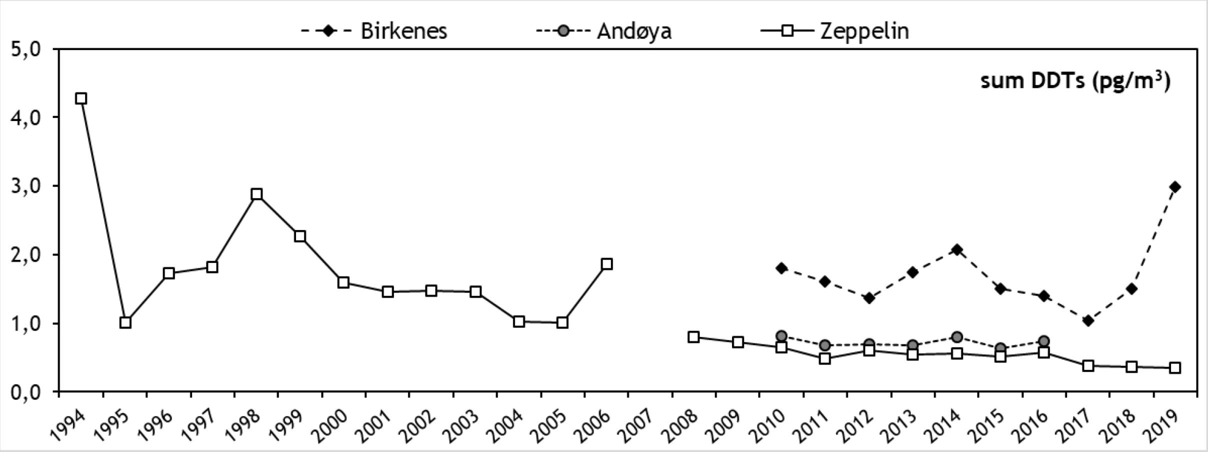


Figure 10: Annual mean concentrations of sum DDTs (pg/m^3) in air. 2007 at Zeppelin is excluded as it is an unexplained high outlier. The annual mean includes all six congeners although some congeners are <LOD in most samples at some sites and for some years.

The annual mean concentrations of sum DDTs and the individual congeners in 2019 were as in previous years higher at Birkenes (3.0 pg/m^3) than at Zeppelin (0.3 pg/m^3) (Figure 10). 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., 2018). The annual mean concentrations of sum DDTs and all congeners at Zeppelin were the same as the last two years (2017-2018), which are also the lowest concentrations measured at Zeppelin (Figure 10). At Birkenes, instead, the annual mean concentration in 2019 was the highest ever observed. This is biased by the high monthly measurement in November and April. This shows the limitation of having one sample per month as one individual high value (out of twelve) has a high influence on the annual concentration. Whether the high annual concentration is an outlier or not will be evaluated over time.The annual concentrations observed at Birkenes and Zeppelin during the last years suggest that the concentrations of DDTs in air are in slow decline or have reached a temporal remote state, where reduction rates are controlled by degradation in secondary repositories (Stroebe et al., 2004). The indicator ratio (p,p’-DDE+p,p’-DDD/p,p’-DDT) were high (3-12) at both sites in winter, spring and autumn indicating input only from aged DDT. The ratios were lower in summertime at Birkenes (2).

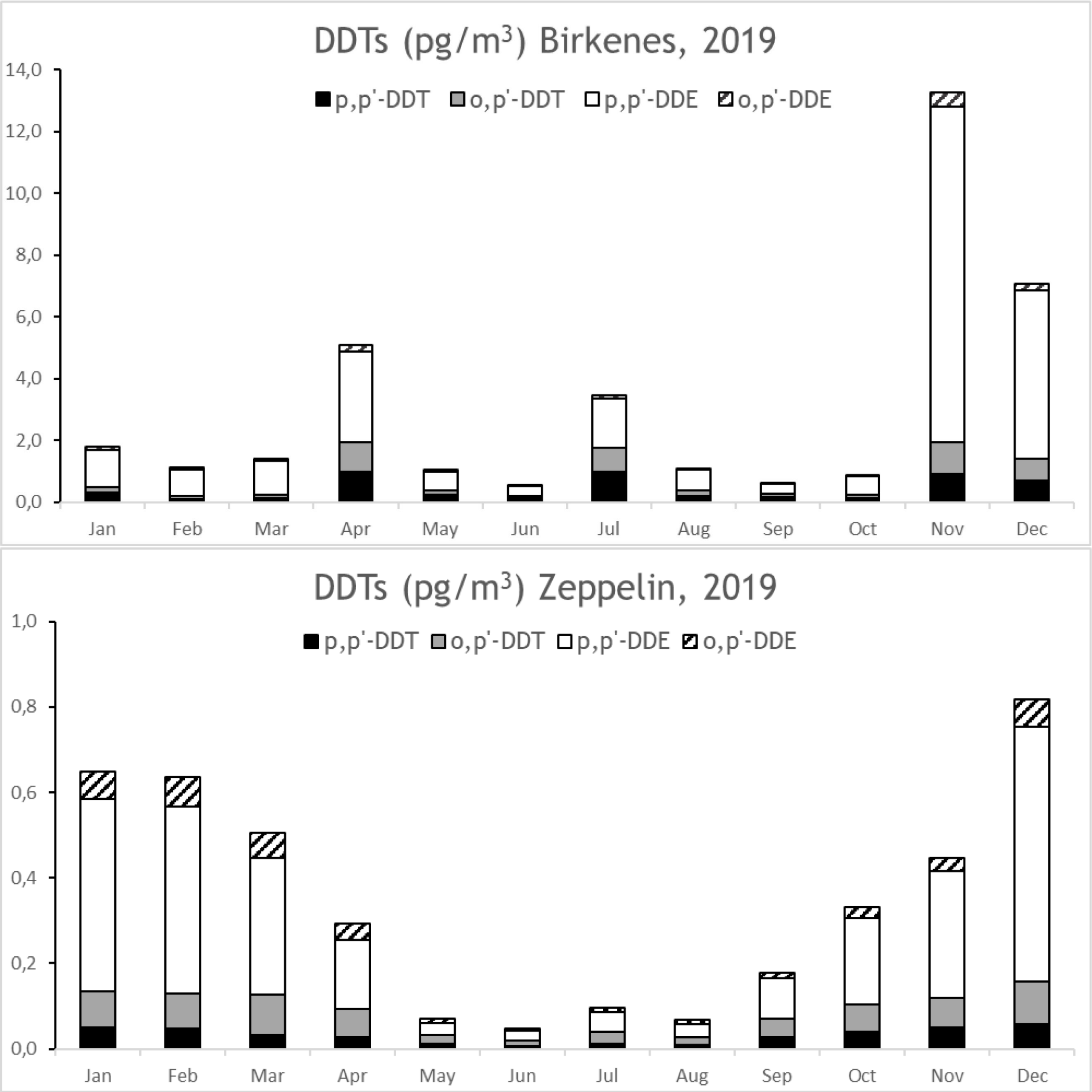


Figure 11: Seasonal variability of sum DDT and the four detected individual congeners at Birkenes and Zeppelin in 2019.

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 11). This seasonality was seen for sum DDTs as well as o,p’- and p,p’-DDE and DDT, but not for DDD. No such seasonality was observed at Birkenes where DDT only is measured in only one sample per month. The higher concentrations in winter at Zeppelin can be connected to the Arctic Haze season in the Arctic area during winter time in which the transportation of particles to the Arctic is higher and removal rates of the DDTs are lower than in summer time (Hung et al., 2016). However, this may not be the full explanation as DDTs tend to be found to larger extent in gas-phase than in particle phase. The lower temperature in winter may however shift the partitioning towards more particle bound DDTs which supports the explanation of the Arctic haze.

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 2019. 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 2019 (i.e. 100% >LOD). The fourth isomer, cis-NO was, in 2019, <LOD in 10% of the samples, all of those in the winter months. The major isomers at Zeppelin in 2019 were the cis-CD and trans-NO, contributing to ~40% each to the sum of chlordanes. The weekly concentrations of sum chlordanes at Zeppelin in 2019 ranged between 0.4-0.9 pg/m^3. The annual mean concentrations of sum chlordanes (0.6 pg/m^3) and the individual stereoisomers at Zeppelin in 2019 were the same as in 2018. Together 2018 and 2019 show the lowest concentrations of chlordanes so far observed. This suggests that the concentrations of chlordanes still are declining or may have entered temporal remote state where the decline is controlled by degradation in and emission from secondary repositories (Figure 12).

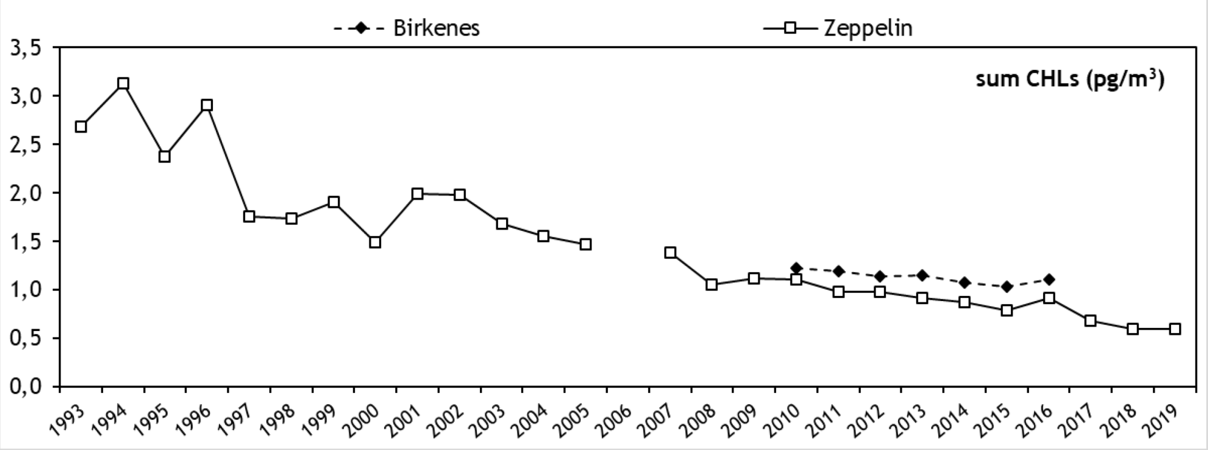


Figure 12: Annual mean concentrations of sum chlordanes (pg/m^3) in air. The data from 2006 at Zeppelin is excluded as it is an unexplained high outlier.

The ratio of trans-CD and cis-CD was, as previous years, low at Zeppelin also in 2019 (0.2-0.5 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 (0.4-0.5). This is caused by lower concentrations of trans-CD in summertime than in wintertime and stable concentrations of cis-CD over the year. 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 sum chlordanes, cis-CD and trans-NO, no seasonal trends were observed.

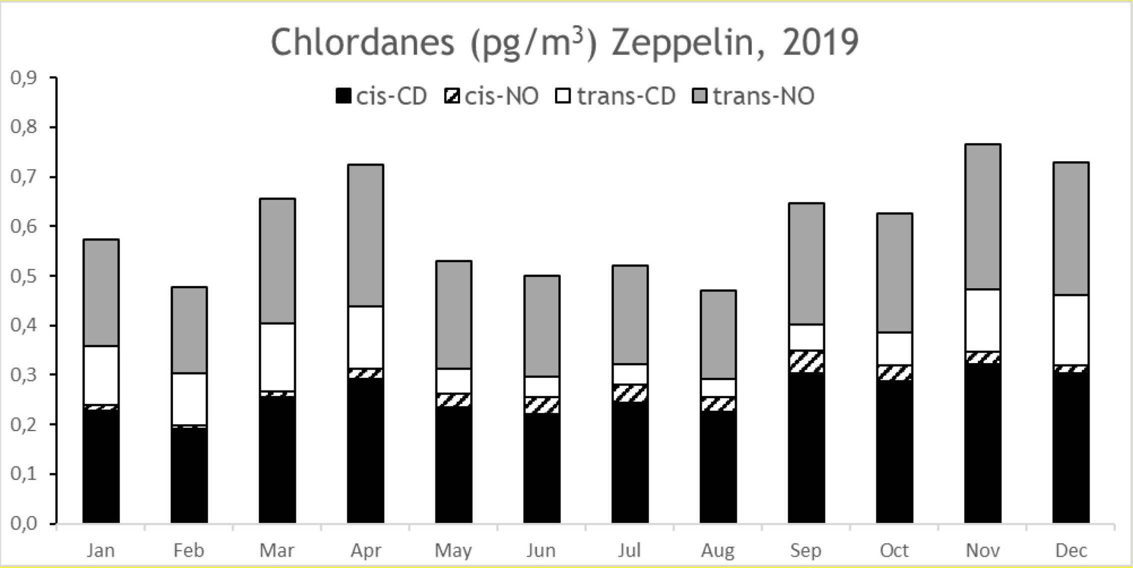


Figure 13: Seasonal variability of sum chlordanes and the four individual isomers at Zeppelin in 2019.

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). They are also listed on Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015). According to the Stockholm Convention, the production and new use of PCB is no longer allowed. Parties may however continue to use PCB containing articles that were already in use when the global regulation entered into force. By 2025, Parties shall have identified and removed from use, equipment containing greater than 0.005% PCB and volumes greater than 0.05 L. As soon as possible, but no later than 2028, Parties shall also make determined efforts designed to an environmentally sound management of PCB containing waste by management of liquids containing PCB and equipment contaminated with PCBs having a PCB content above 0.005% in accordance with paragraph 1 of Article 6 of the Convention. Current sources of emissions of PCBs to the environment are mainly from places where they have been disposed or stored, such as landfills or exposed soils, or from open burning of products containing PCBs, waste incinerations and accidental fires (Breivik et al., 2002; Cousins and Jones, 1998).

The PCBs theoretically consists of a group of 209 congeners. 32 of these (=sum PCB-32) were measured at Birkenes and Zeppelin in 2019. These 32 congeners include the seven congeners (PCB-7) that are typically used as indicators in Europe; PCB 28, 52, 101, 118, 138, 153, 180, as well as eight of the dioxin-like and most toxic congeners according to WHO; PCB 105, 114, 118, 123, 156, 157, 167, 189. Data are reported for sum of 32 PCBs (sum PCB) as well as sum of PCB-7 (sum PCB_7). PCBs have been monitored at Zeppelin since 2001. At Birkenes, the seven indicator PCBs have been monitored since 2004 and all the 32 PCBs since 2010. The monitoring in 2019 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 in this monitoring programme 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 tri-penta PCBs (until PCB 105) at both sites while low detection frequencies (>50% of the samples being <LOD) were observed for some of the penta-hepta PCBs (i.e. PCB, 114, 122, 123, 157, 167, 189, 194, 206, 209). As previous years, the tri- and tetra-PCBs were the most common PCBs, comprising 60-90% of sum PCB. The most abundant individual compounds were PCB 18, 28, 31, 47, 52. At Zeppelin also PCB 33 was abundant.

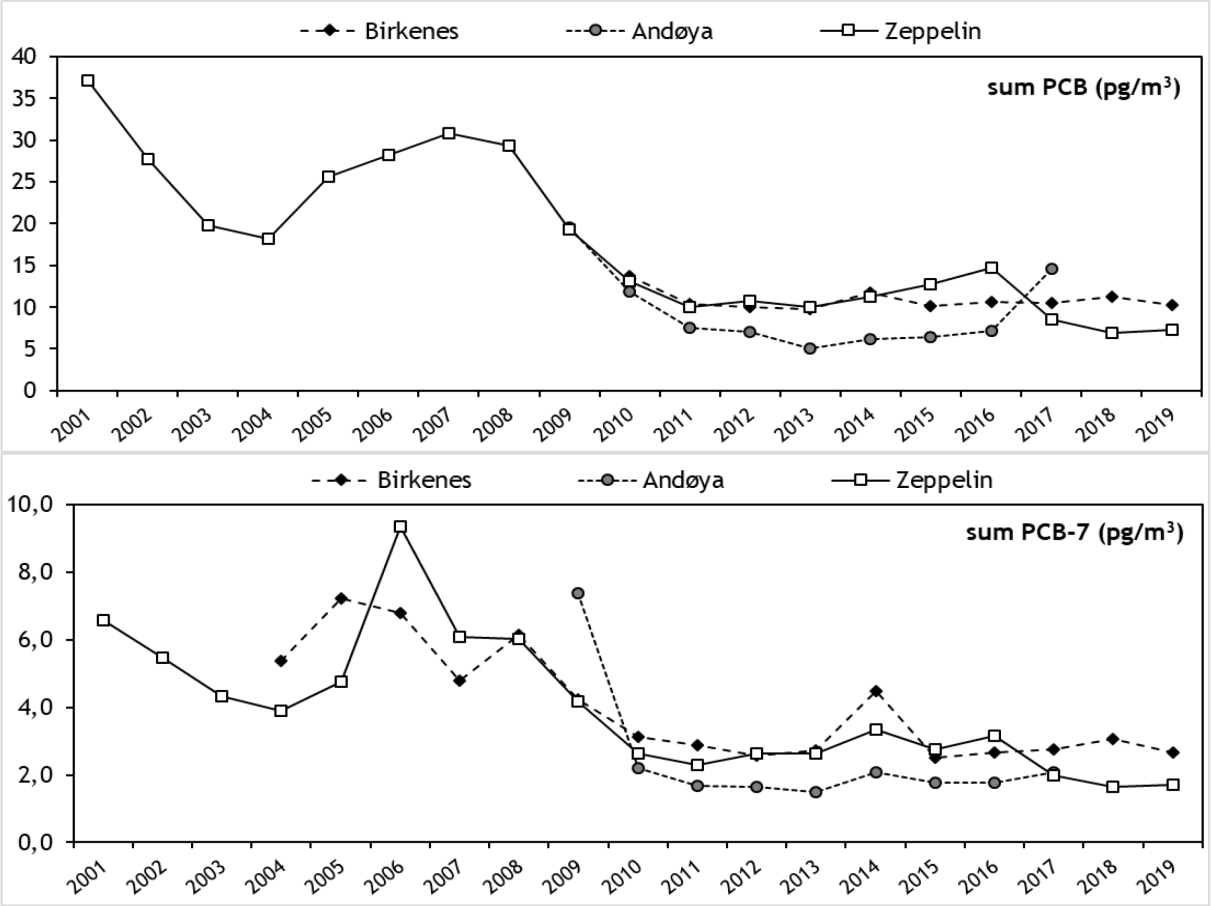


Figure 14: Annual mean concentrations of sum PCBs and sum PCB-7 (pg/m^3) in air. Sum PCBs represents the sum of all detected PCB peaks.

The weekly concentrations of sum PCB and sum PCB_7 at Birkenes in 2019 ranged between: 2.6-30 pg/m^3 and 0.7-8.2 pg/m^3, respectively. The ranges at Zeppelin were smaller than at Birkenes: 3.3-15 pg/m^3 and 0.7-3.0 pg/m^3, respectively. The annual mean concentrations of sum PCB and sum PCB_7 in 2019 were lower at Zeppelin than at Birkenes (Figure 14). The concentrations of PCBs were similar at Birkenes and Zeppelin between 2008-2016 but since 2017 lower concentrations are observed at 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 (sum PCBs: 7.3 pg/m^3, sum PCB_7: 1.7 pg/m^3) in 2019 were similar to 2018 and 2017. This confirms a change in the increasing trend that was observed between 2011 and 2016 at Zeppelin. At Birkenes, the annual mean concentrations in 2019 (10.2 pg/m^3 and 2.7 pg/m^3) were also similar to previous years. 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 and 153 over the last 15 years but in comparison to the results in 2017 the decreasing speed has been lowered until 2019 (Figure 15-16). This is in agreement with the stable concentrations observed during the last years. The concentrations of sum PCB_7 at the Norwegian sites are up to one order of magnitude lower than the concentrations of sum PCB_7 reported to EMEP from sites in Germany and the Czech Republic (Aas et al., 2018).

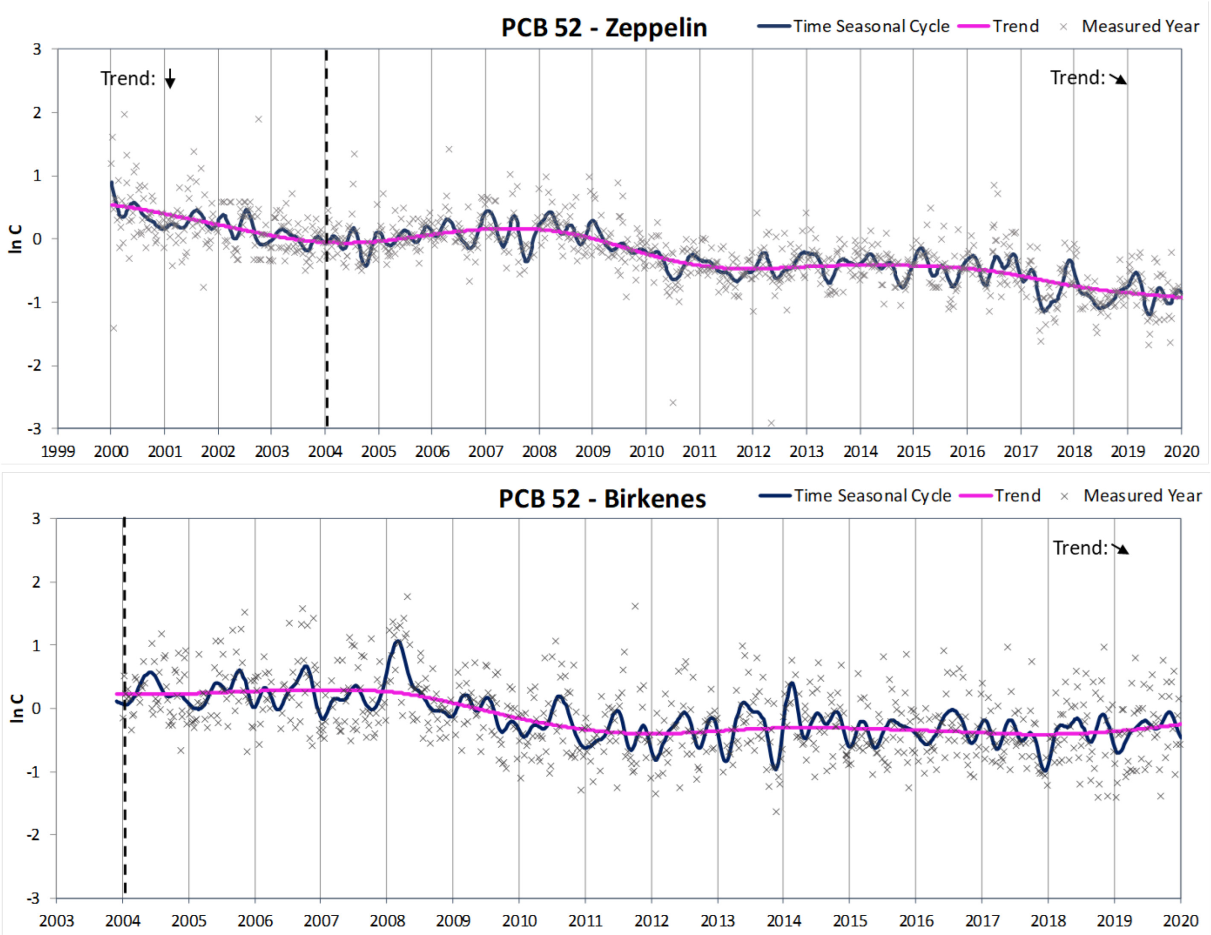


Figure 15: Temporal trends of PCB 52 at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for PCBs (2004). The results of trend analyses: before and after the 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.

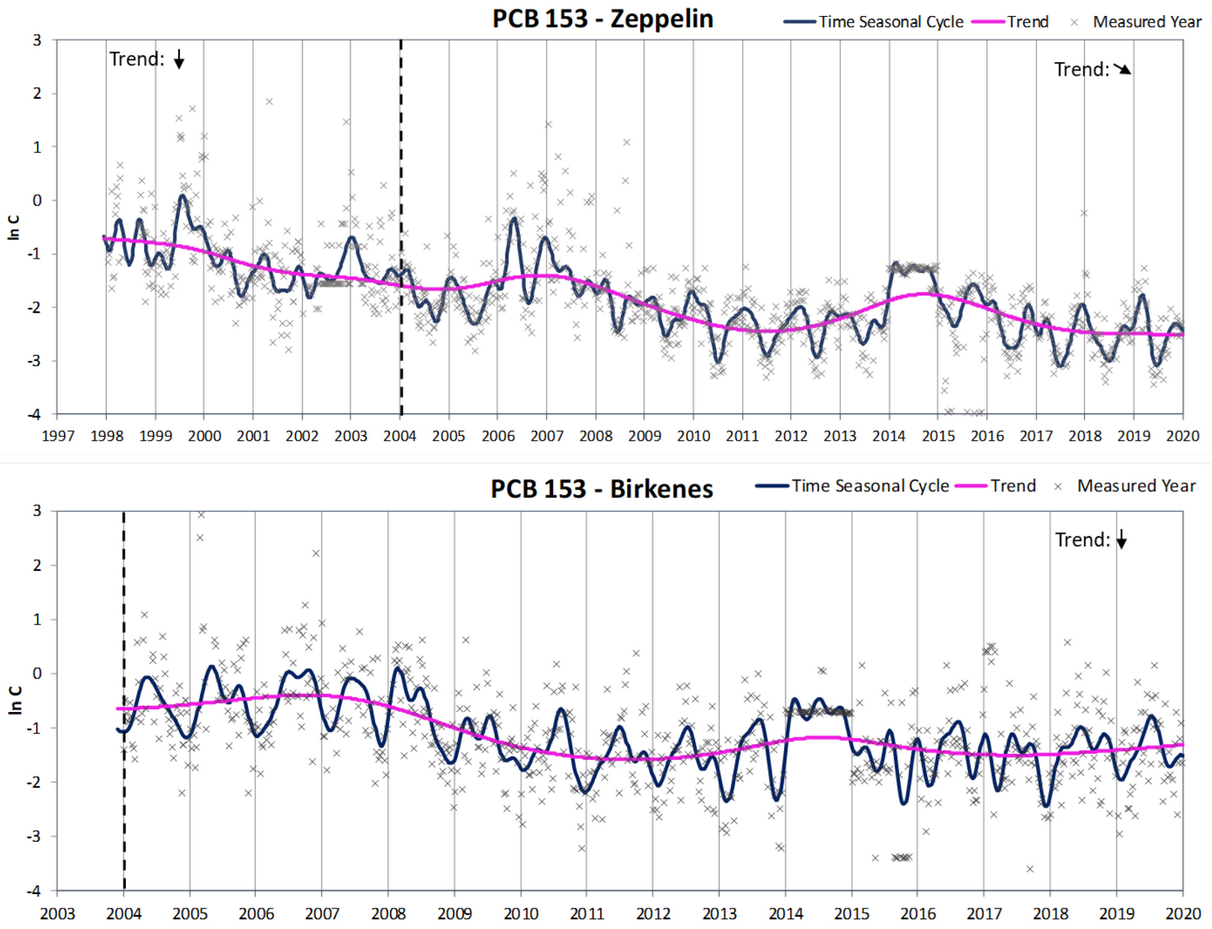


Figure 16: Temporal trends of PCB 153 at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for PCBs (2004). The results of trend analyses: before and after the PCBs were listed in the Stockholm Convention, are indicated by four types of arrows (↓: decrease, ↘: small decrease, ↗: small increase and ↑: increase) or NST when no significant trend was detected.

No clear seasonality was observed for sum 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).

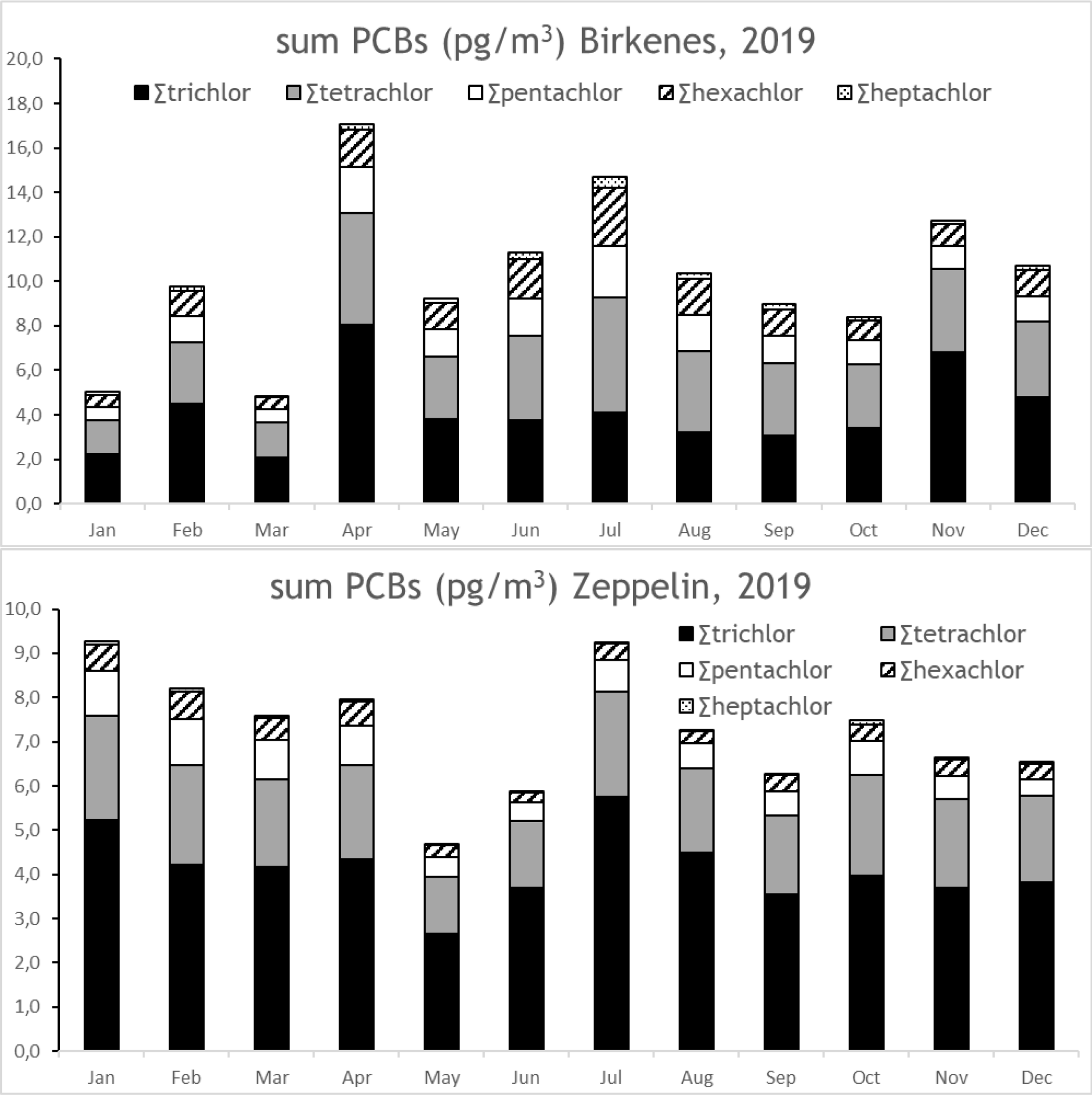


Figure 17: Seasonal variability of sum PCBs (the sum of all detected PCB peaks) and homologue groups at Birkenes and Zeppelin in 2019.

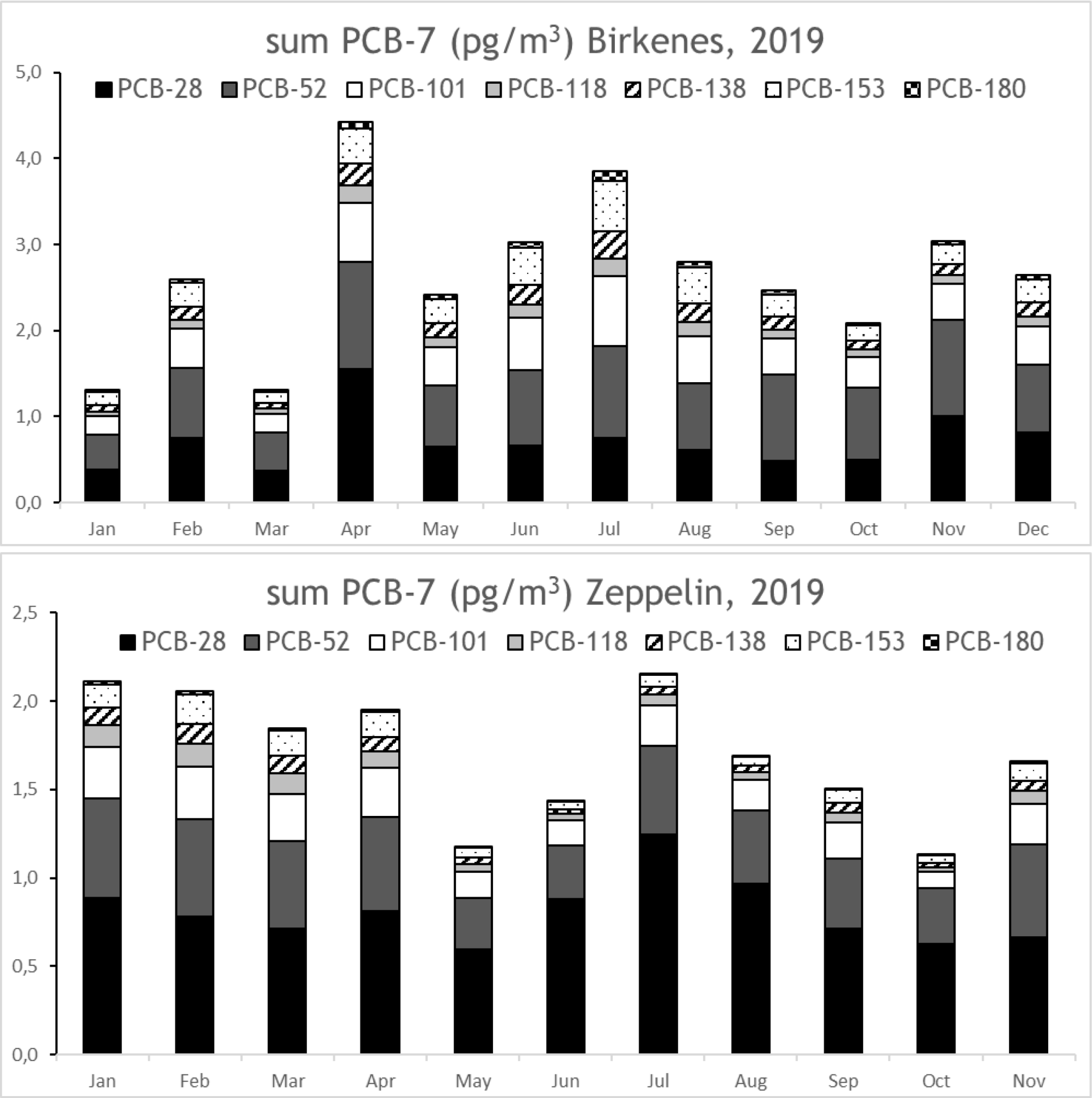


Figure 18: Seasonal variability of sum PCB_7 and the individual congeners at Birkenes and Zeppelin in 2019.

2.1.6 *Polycyclic aromatic hydrocarbons (PAHs)*

PAHs are mainly produced through incomplete combustion of organic materials, both through anthropogenic (i.e. industrial and domestic use) and natural processes. They are regulated in the Aarhus protocol on POPs (UN/ECE, 1998b) and the EU air quality directive (AQD) (EU, 2004). They are also listed on Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015). They show POP like characteristics, but are less persistent than other POPs.

Seven methyl-PAH and 32 PAHs (=sum PAHs) including the 16 EPA-PAHs (=sum PAH_{16}) were measured in weekly samples at Birkenes and Zeppelin in 2019. 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 (60% of the PAH compounds were below the detection limit in more than 50% of the samples) than at Birkenes (~20% 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 (0.7 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 (0.3 ng/m^3), biphenyl (0.3 ng/m^3), fluorene (0.1 ng/m^3) together with 1- and 2-methylnaphthalene (0.06-0.07 ng/m^3, respectively). The weekly concentrations of sum PAH in 2019 ranged between: 1.2-5.8 ng/m^3 at Birkenes; and 0.2-4.0 ng/m^3 at Zeppelin. The weekly concentrations of sum PAH$_{16}$ in 2019 ranged between: 0.8-3.3 ng/m^3 at Birkenes; and 0.09-1.7 ng/m^3 at Zeppelin. The annual mean concentrations of sum PAH (1.3 ng/m^3) and sum PAH$_{16}$ (0.50 ng/m^3) at Zeppelin in 2019 were higher than in 2018. At Birkenes, the annual mean concentrations of sum PAHs and sum PAH$_{16}$ in 2019 (3.4 and 2.0 ng/m^3) were lower than in 2018 but higher than in 2017, showing fluctuating concentrations over the last years. The concentrations observed at Birkenes are about three to four times higher than those at Zeppelin (Figure 19). 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).

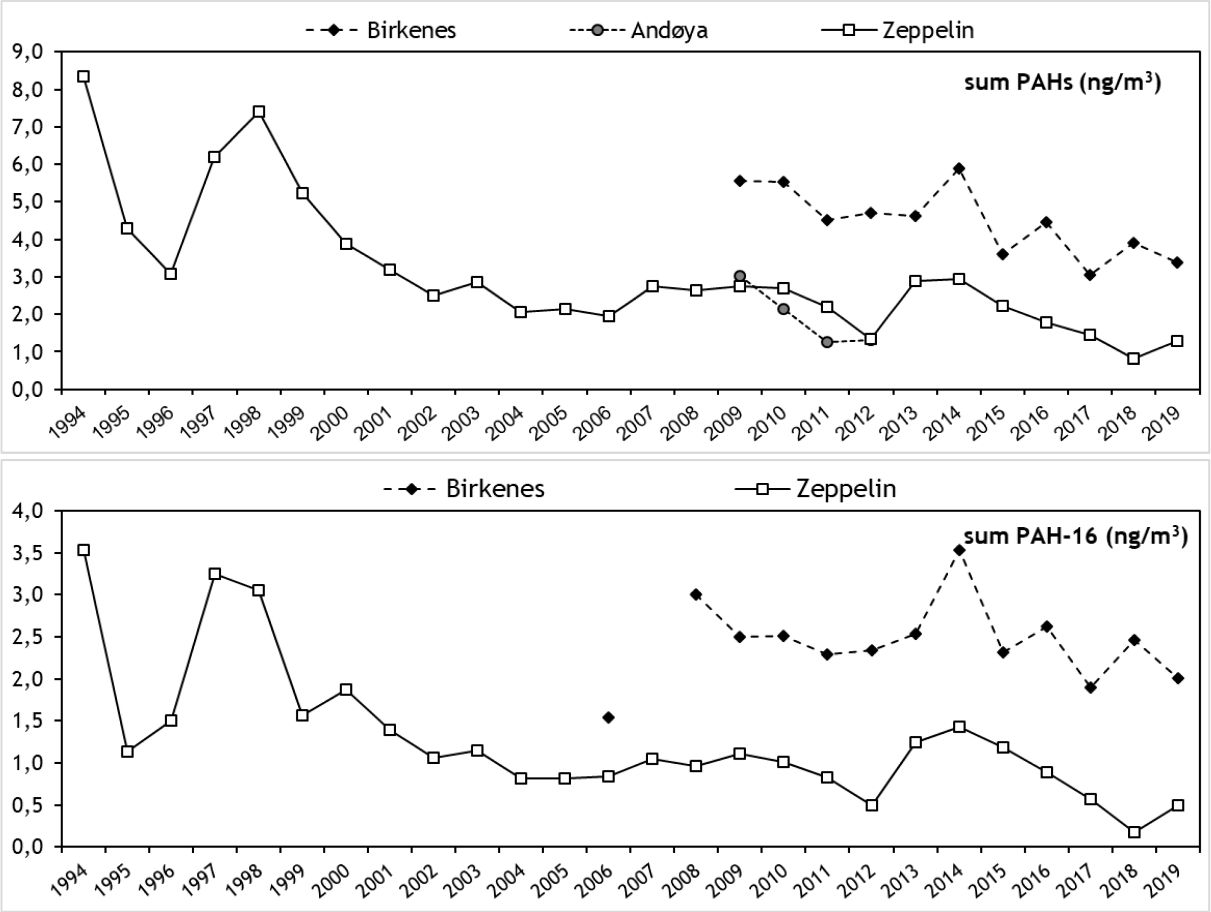


Figure 19: Annual mean concentrations of sum PAH and sum PAH-16 (ng/m^3) in air.

A strong seasonality was observed for all PAHs at Zeppelin and Birkenes with up to one order of magnitude higher concentrations at Zeppelin in wintertime (November-March) than in summertime (Figure 20). The difference was smaller for Birkenes (factor of 3) but still significant. The same seasonality was seen for sum PAHs and the individual PAHs.

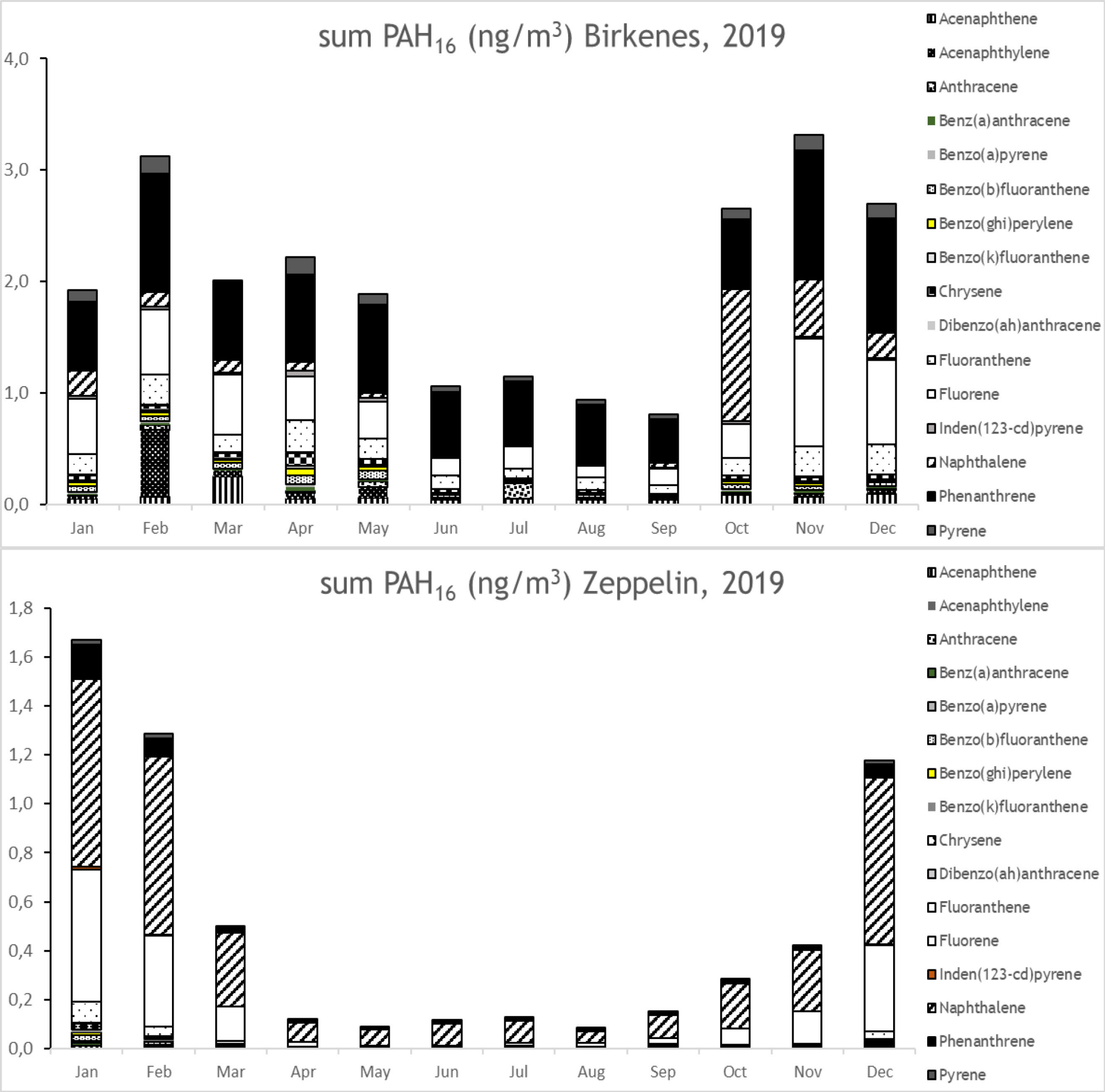


Figure 20: Seasonal variability of sum PAH16 at Birkenes and Zeppelin in 2019.

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. They are also listed on Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015). The commercial PBDE mixture, deca-BDE, was included as a POP in the Stockholm Convention in May 2017. The global regulation entered into force in 2018, but includes several specific exemptions for production and use such as in vehicles and aircrafts. In Norway the use of deca-BDE, except for in means for transportation, have been banned since 2008.

PBDEs theoretically comprise 209 congeners with different degrees of bromination from tetra- to deca-BDE. 17 of the BDE-congeners (=sum PBDEs) have been monitored at Zeppelin since 2006, at Birkenes since 2008, and at Andøya between 2009 and 2016. In 2019, the monitoring included PBDEs 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. This strategy resulted in a better detection than previous years at Birkenes with 12 congeners detected in more than 50% of the samples (i.e. 28, 47, 49, 66, 99, 100, 119, 153, 154, 183, 196, and 206). The detection frequencies were still low for the other four congeners; BDE-71, 77, 85, and 138, at Birkenes. At Zeppelin seven congeners (i.e. 28, 47, 49, 66, 99, 100, and 206) were detected in more than 50% of the samples while nine congeners (i.e. BDE-71, 77, 85, 119, 138, 153, 154, 183 and 196) were detected at low frequencies. The combination of low detection frequency and low detection limits for many of the PBDE congeners at Zeppelin indicates low concentrations of many PBDEs in Arctic air. 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 are therefore considered invalid. The highest concentrations at Birkenes and Zeppelin in 2019, when excluding BDE-209, were observed for BDE-206 and -47.

The weekly concentrations of sum PBDEs (excl. BDE-209) ranged between: 0.09-0.27 pg/m^3 at Birkenes, and 0.18-0.59 pg/m^3 at Zeppelin. The annual mean concentrations of sum PBDEs (excluding BDE-209) in 2019 at Zeppelin was 0.73 pg/m^3 and at Birkenes 0.57 pg/m^3. The concentrations of sum PBDEs and the individual congeners (except BDE-209) measured at Birkenes and Zeppelin in 2019 were higher than 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 show decreasing trends for BDE-47 over the monitoring period.

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

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 21 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 21). The reason for the individual high levels are not known.

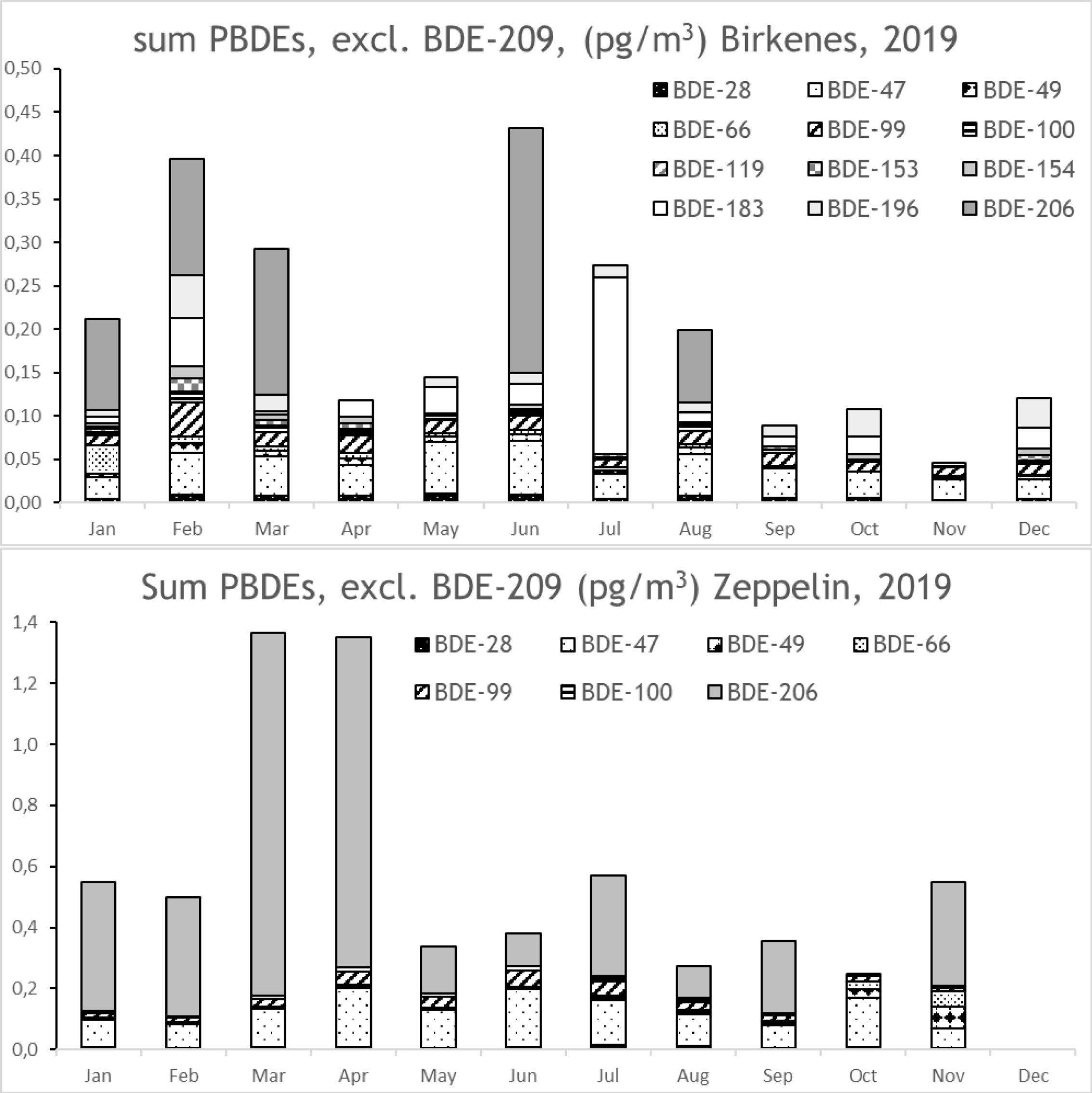


Figure 21: Seasonal variability of sum PBDEs, excl. BDE-209 (detected congeners) at Birkenes and Zeppelin in 2019.

2.2.2 Tribromoanisol (TBA)

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

TBA has been monitored at Birkenes and Zeppelin since 2007 and at Andøya between 2010 and 2016. TBA 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 2019 (100% of all samples >LOD) and the monthly concentrations at Birkenes ranged between: 2.4-7.4 pg/m^3; and the weekly concentrations at Zeppelin ranged between 0.06-40 pg/m^3. The annual mean concentrations of TBA in 2019 were 4.0 and 9.8 pg/m^3 at Birkenes and Zeppelin respectively (Figure 22). 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.

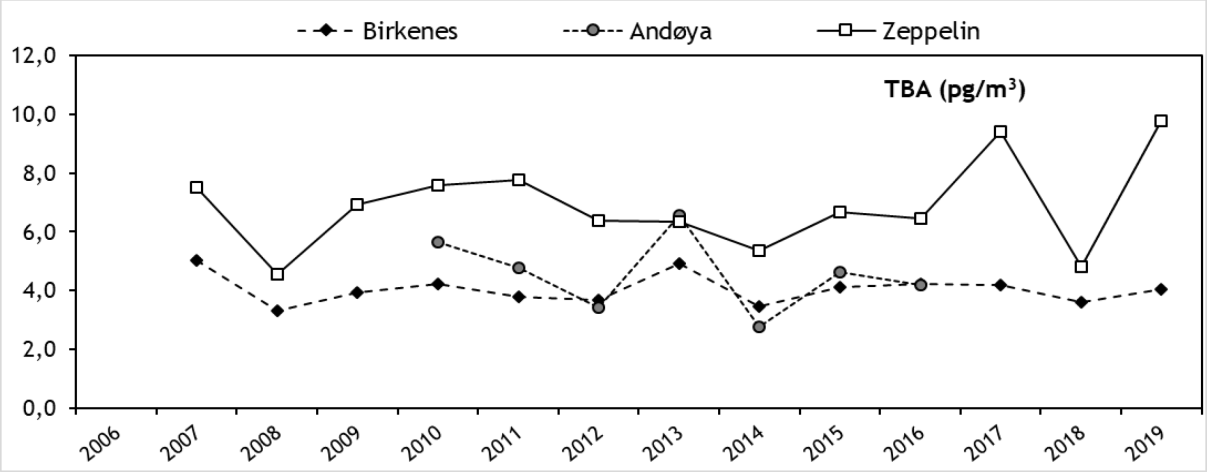


Figure 22: Annual mean concentrations of TBA (pg/m^3) in air.

At Zeppelin, the same seasonal trend as previous years was observed, lowest concentrations during winter and spring and increasing concentrations (5-10 times higher) during the summer and autumn (Figure 23). The higher concentrations in summertime may be a consequence of increased algal bloom during this period. In contrast to Zeppelin, at Birkenes in 2018 and 2019 the highest concentrations were observed in autumn-wintertime (September, October, November and December) and the lowest concentrations in summertime. The reason for this seasonality is not known.

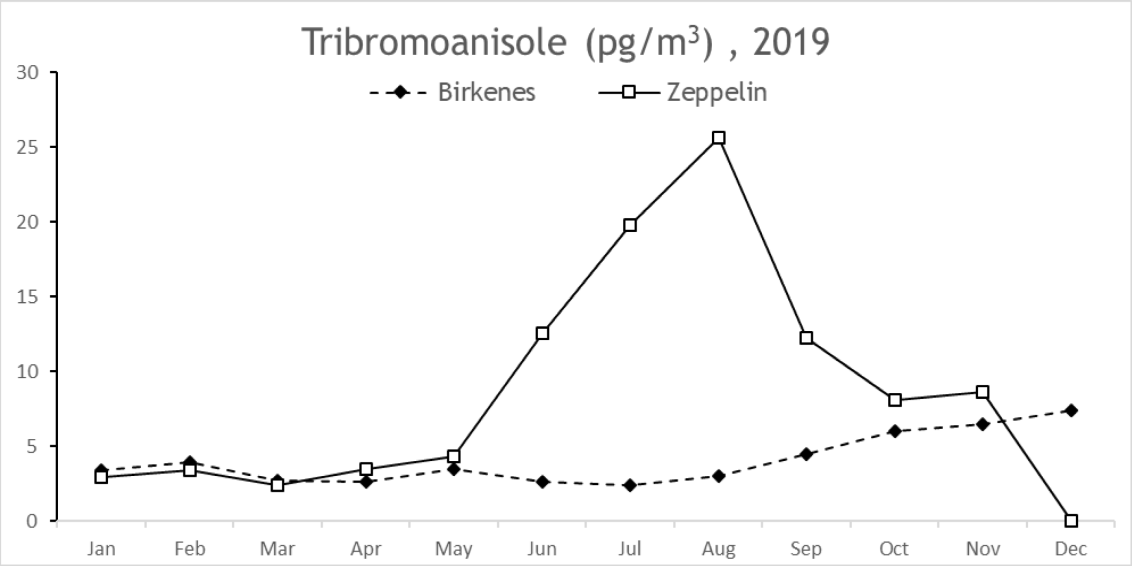


Figure 23: Seasonal variability of TBA at Birkenes and Zeppelin in 2019.

2.2.3 Hexabromocyclododecanes (HBCDs)

HBCD is an additive brominated flame retardant, with many applications. The main use is in extruded and expanded polystyrene used in building and construction materials for thermal insulation. HBCD was listed in the Stockholm Convention on POPs in 2013 with a time-limited exemption for production and use in expanded and extruded polystyrene in buildings. The global ban entered into force in November 2014 (Stockholm Convention, 2013). They are also listed on Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015).

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 still detected with a low frequency at both sites. At Birkenes, none of the HBCDs were detected in any of the samples in 2019 (100% <LOD) nor the previous years. At Zeppelin, α- and β-HBCD were detected in most samples while low detection was obtained for γ-HBCD (<LOD in 84% of the samples). Although detected at Zeppelin, the observed concentrations for α- and β-HBCD were still low (0.009-1.14 pg/m^3 and 0.002-0.22 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 24 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.

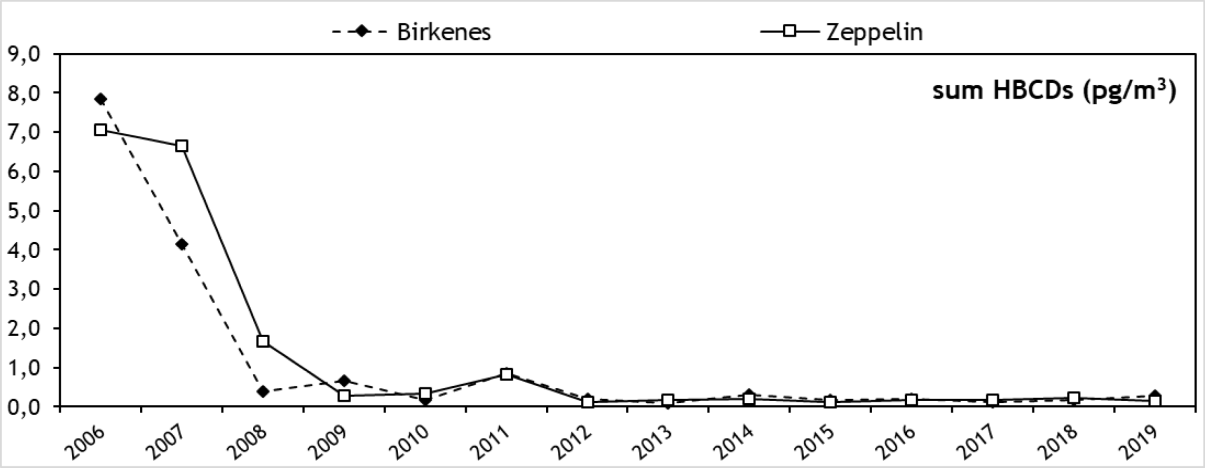


Figure 24: Annual mean concentrations of sum HBCDs (pg/m^3) in air. The annual mean includes all three diastereomers although some are <LOD in most samples at some sites and for some years. Specifically, from 2008-2019, most of the measurements are <LOD and the annual mean concentrations represents the 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 ("Prioritetslisten"): PFOS, PFOA, PFHxS, PFBS, PFHxA, HFPO-DA, and C9-C14 PFCAs (Norwegian Environment Agency, 2015).

Ionic PFASs have been monitored at Birkenes and Zeppelin since 2006 and at Andøya since 2009. The measurements of ionic PFAS (=sum PFASs) under the monitoring programme of "*Long-range atmospheric transported contaminants*" 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, $n \geq 6$, PFSAs, and CnF2n+1COOH, $n \geq 7$, PFCAs) (Buck et al., 2011, ITCR, 2020.

Table 5: Full names and abbreviations of targeted ionic PFAS in air at Birkenes, Andøya and Zeppelin in 2019.

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

Despite combining two samples to one and thereby increasing the sampling time, the detection was still low in 2019. At Zeppelin, three PFAS were detected in most samples in 2019 (PFHpA, PFOA and PFDA) and in addition PFHxA and PFNA were also detected in some samples. At Birkenes, PFOA together with 6:2 FTOH, PFHpA, PFHxA, and PFNA were detected in more than 50% of the samples. At Andøya, only PFOA and PFHpA were detected in a majority of the samples while also PFHxA, PFNA and PFOS were detected in some samples. That means that only PFOA and PFHpA were detected in more than 50% of the samples at all sites. The other targeted ionic PFAS were <LOD in more than 50% of the samples (for details see Annex 1). The annual mean concentrations of PFOA were the same at all three sites in 2019; Birkenes (0.14 pg/m^3), Andøya (0.12 pg/m^3) and Zeppelin (0.14 pg/m^3) (Figure 25). This is in contrast to 2018 when the concentrations of PFOA at Birkenes was higher than at Andøya and Zeppelin. Also PFHpA and PFHxA had similar concentrations at all sites. 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 (Figure 26).

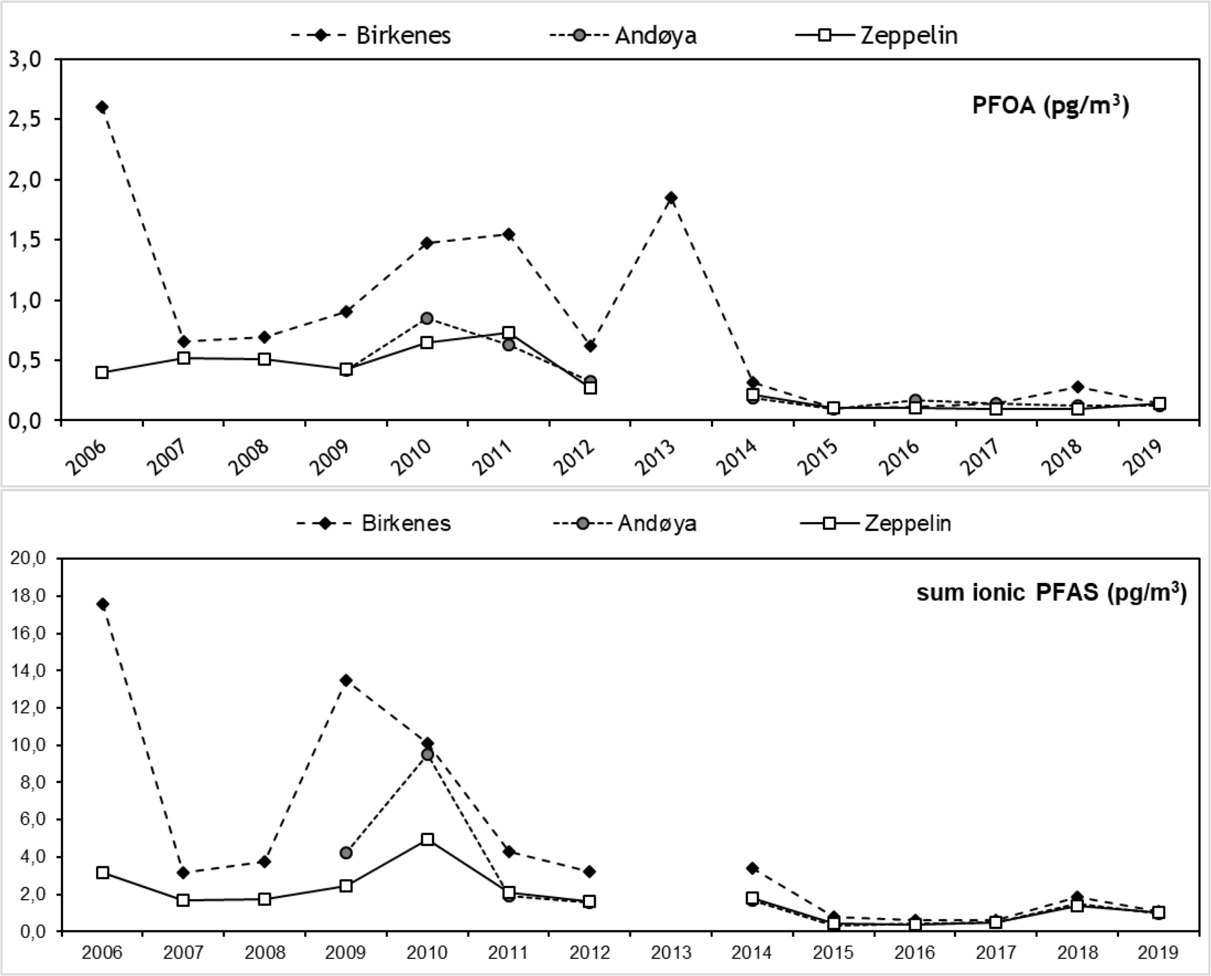


Figure 25: Annual mean concentrations of PFOA and sum ionic PFAS (pg/m^3) in air. The annual mean for sum ionic PFAS includes all targeted ionic PFAS, both those detected in most samples and those below the LOD (as LOD/2).

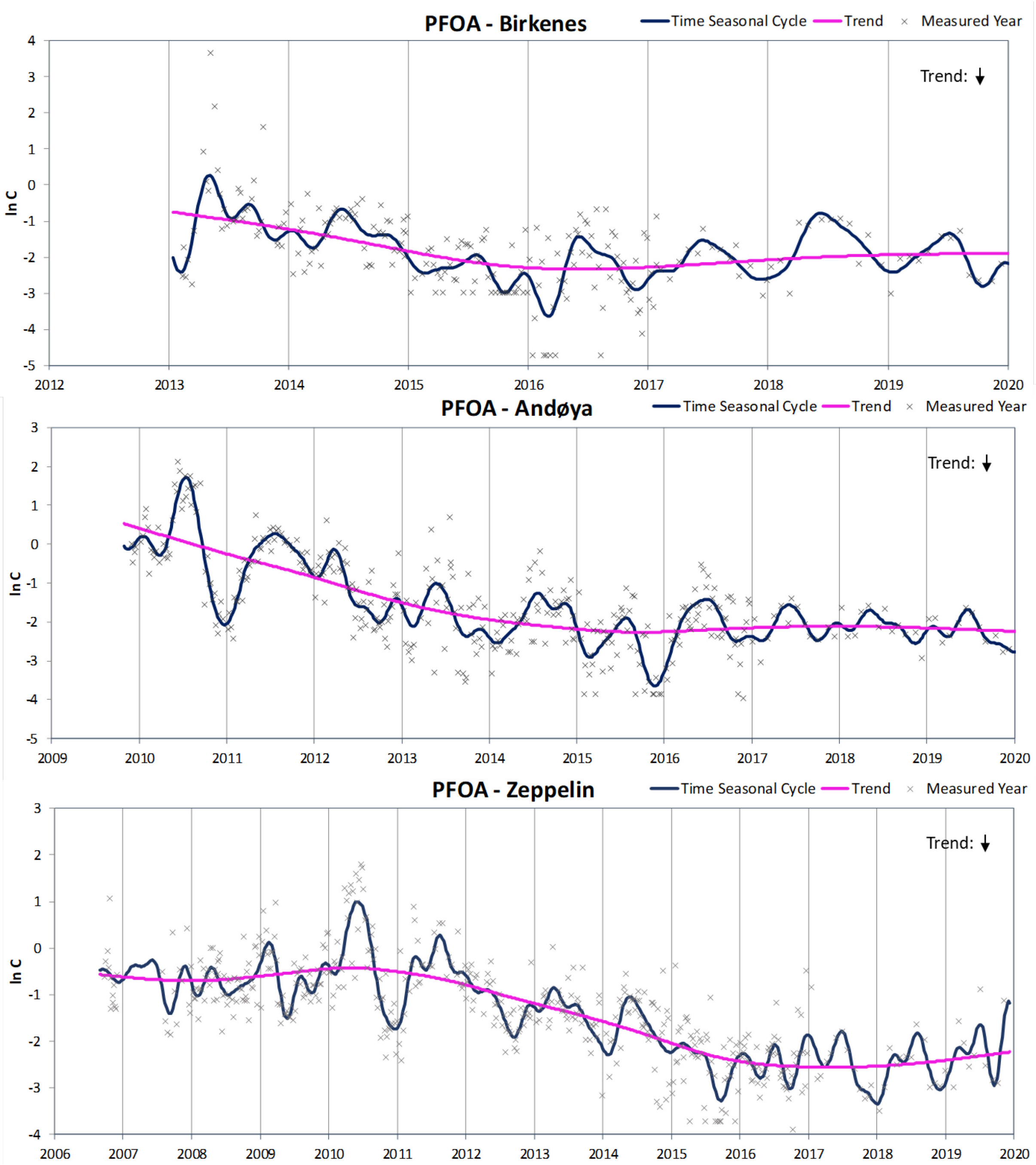


Figure 26: Temporal trends of PFOA at Birkenes, Andøya and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The results of trend analyses, are indicated by four types of arrows (↓: decrease, ↘: small decrease, ↗: small increase and ↑: increase) or NST when no significant trend was detected.

A seasonal trend was observed at Birkenes and Andøya with more frequent detection and higher concentrations in summer than in winter (Figure 27). At Zeppelin, the seasonality was not as clear, but the highest concentrations of PFOA were observed in the warmer month also at these stations.

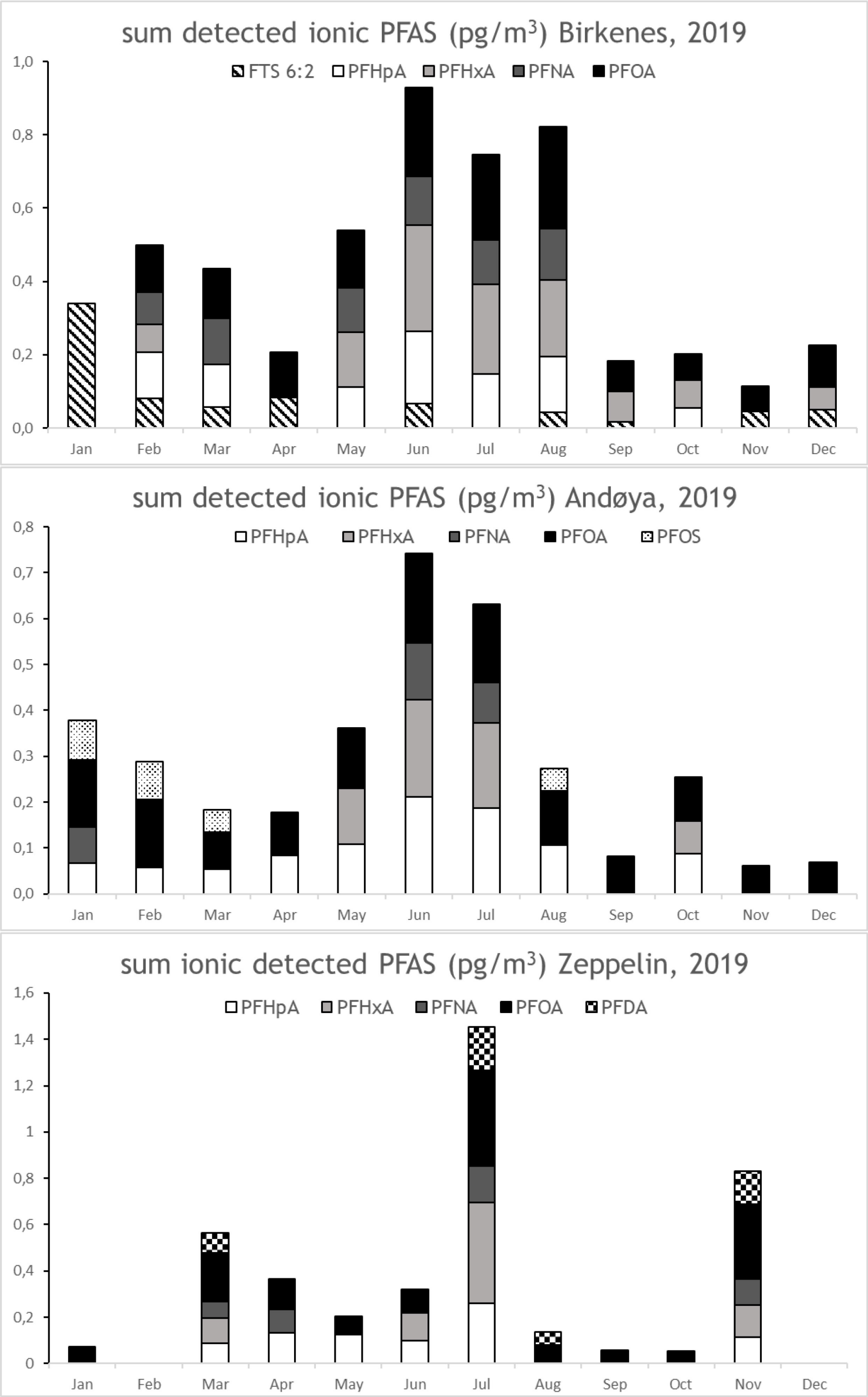


Figure 27: Seasonal variability of sum PFAS (based on detected congeners) at Birkenes and Zeppelin in 2019.

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 (P), bioaccumulation (B), toxicity (T), and long range transport (LRT) potential (Brooke et al., 2009a; Brooke et al., 2009b; Brooke et al., 2009c; Canada, 2008a; Canada, 2008b). As D4 and D5 meet the criteria for very bioaccumulative (vB) and persistent (vP) substances defined in the REACH Regulation (EC) No 1907/2006 (ECHA, 2015), their content in wash-off personal care products is now restricted within European Unioin (not to exceed 0.1%) as of February 2020 (ECHA, 2018). The restrictions has also been proposed to include D6 which also meet the vPvB criteria (ECHA, 2019). In addition, ECHA started consultation on extending this proposed restriction to D4-D6 in "leave-on" personal care products. All the three oligomers; D4-D6, are on Norway's Priority List of Hazardous substances ("Prioritetslisten") with the aim to stop emissions of these compounds by 2020 (Norwegian Environment Agency, 2015) and they are considered as chemicals of emerging Arctic concern by AMAP (AMAP, 2017).

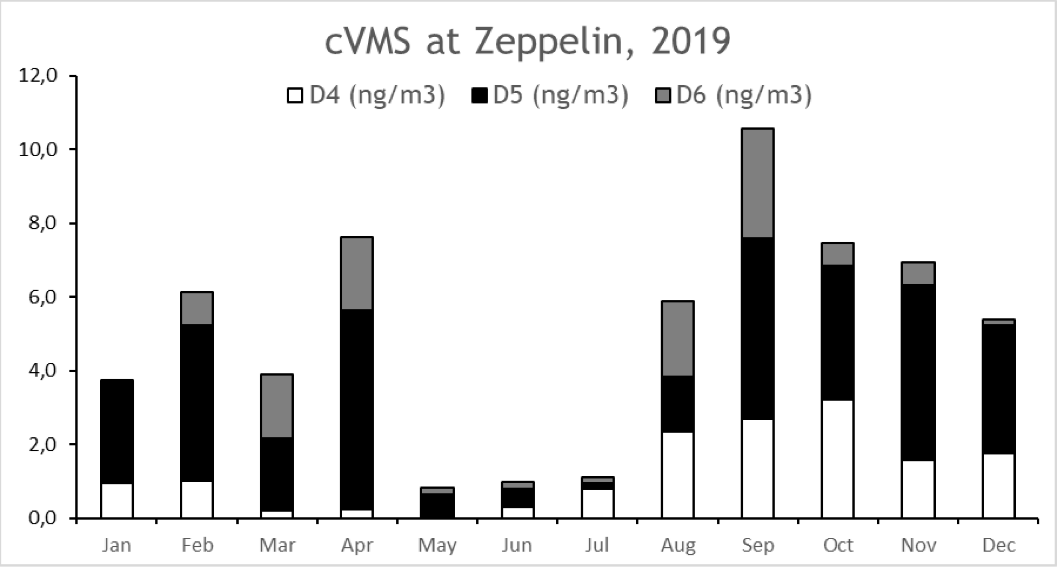
The three oligomers D4, D5, and D6 have been monitored at Zeppelin since 2013. The monitoring in 2013-2016 was conducted in two sampling campaigns per year, one in summer and one in winter, with each campaign covering six-seven samples. From 2017, the monitoring was expanded so that D4-D6 are sampled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

Long-range atmospheric transport of cVMS to Arctic regions has been suggested by a few studies that have reported their presence in Arctic air (Genualdi et al., 2011; Krogseth et al., 2013). These findings have been further supported by mechanistic model simulations (Krogseth et al., 2013). The monitoring results from 2013-2019 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 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 2019 were, as in 2018, obtained by using the new adsorbent (ABN) which is less affected by degradation during sampling and storage (Warner et al.

2020). While D5 and D6 has been shown to be degraded during storage in the previously adsorbent (ENV+), the results from previous years are storage corrected in a semi-quantitative way, and the data for D4 is more uncertain as it has been shown to undergo losses (through volatilization) and be formed (through degradation of D5) during storage (Kierkegaard and McLachlan, 2013; Krogseth et al., 2013). Thus, the presence and the actual levels of D4 in the air at Zeppelin during the first year's measurements (2013-2017) is therefore uncertain as D4 might be have been present in the samples only as a degradation product from D5. The degradation process is related to the adsorbent in the sampler (ENV+) and the source of the degradation is expected to be a result of an acid catalysed reaction with a substituted OH group located in the phenyl substructure of the ENV+ sorbent. This interaction causes the hydrogen to be acidic and facilitate breakdown of the siloxanes (as they are not stable under acidic conditions). Due to the uncertainties introduced by ENV+-sorbent mediated degradation/formation mechanisms we introduced a new adsorbent in 2017 (ABN) that was fully implemented for all air sampling of cVMS in 2018. The ABN adsorbent is less affected by degradation and therefore a better option for the monitoring. This allows for reporting of more accurate data for D4 from 2018 (Warner et al. 2020).

D5 and D6 were detected in all samples from Birkenes in 2019. At Zeppelin, D5 was detected in most samples while D6 was <LOD in 50% of the samples from Zeppelin. D4 was <LOD in 25% of the samples from Birkenes and Zeppelin. The concentrations of D5 and D6 were higher at Birkenes than at Zeppelin for most months of the year. For D4 there was no difference between the sites. The range and the annual mean concentrations of D4, D5 and D6 at Zeppelin were 0.06-3.2 ng/m^3 (1.3 ng/m^3), 0.2-5.4 ng/m^3 (2.8 ng/m^3), and 0.07-3.0 ng/m^3 (1.0 ng/m^3) , respectively. The highest levels were measured in wintertime (November-April) and the lowest in summertime (May-September), especially for D5 (Figure 28). The concentrations of D4, D5 and D6 at Birkenes were 0.07-6.9 ng/m^3 (1.6 ng/m^3), 3.8-21 ng/m^3 (11 ng/m^3) and 0.51-2.4 ng/m^3 (1.3 ng/m^3), respectively. Similar to the observations made at Zeppelin station, the lowest concentrations at Birkenes were observed in summer (July-August) and the highest in winter (November-January) (Figure 28). 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.



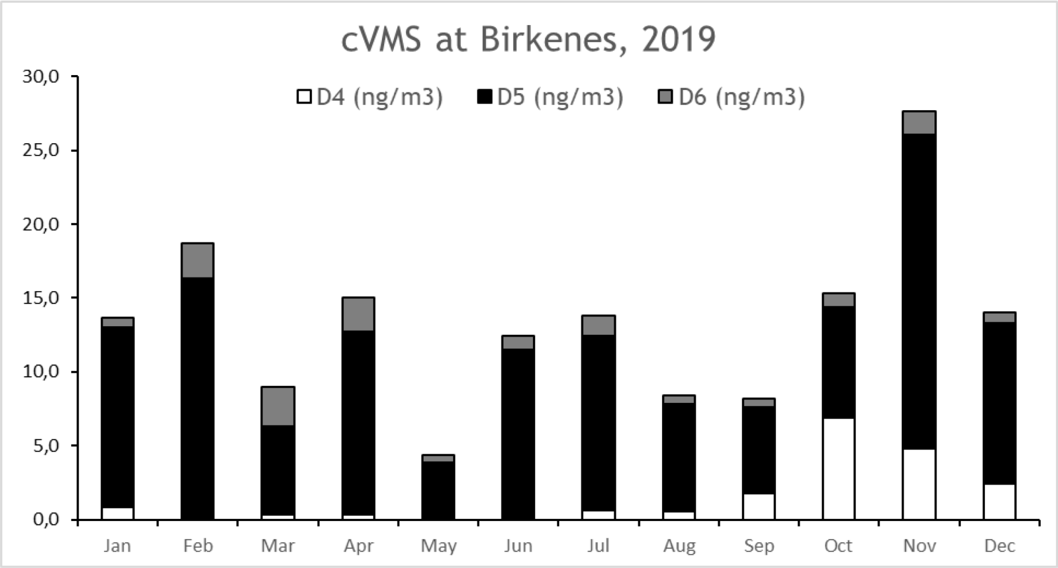


Figure 28: Monthly mean concentrations (ng/m^3) of D4, D5 and D6 at Zeppelin (top) and Birkenes (bottom) in 2019. Zeppelin represents the average of weekly samples while Birkenes represents one sample per month.

Comparing the concentrations over the last three years when samples have been collected weekly at Zeppelin provides a better picture of the time trend than when comparing to previous years when samples only were collected in summer and winter campaigns. These trends indicate an increase in cVMS concentrations over this time period, for all oligomers (Figure 29). The higher concentrations of D4 in 2017 may be influenced by the sampler used in 2017 (ENV+).

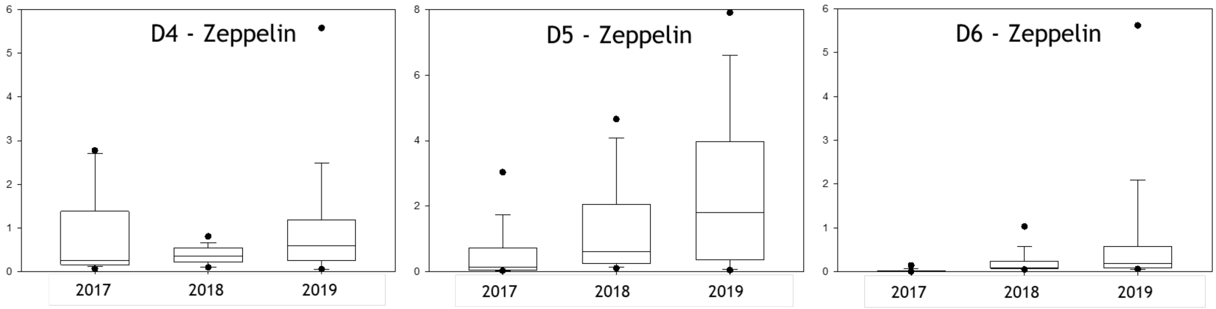


Figure 29: Box-plots of measured concentrations of D4, D5 and D6 (ng/m^3) at Zeppelin in 2017-2019 when weekly sampling has been conducted. The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively

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 under LRTAP (UN/ECE, 2010) and are listed on Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015). In May 2017, the SCCPs were also included as POPs in the Stockholm Convention (Stockholm Convention, 2017). Information on levels and distribution of SCCPs is still limited, mainly due to analytical challenges (Tomy et al., 1997). The atmosphere is usually considered to be the main transport medium for SCCP, but overall very few studies have been conducted to investigate the atmospheric levels and distribution of SCCPs.

SCCPs (C10-C13) and MCCPs (C14-C17) were included in the monitoring programme at Zeppelin in 2013 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 conducted on a monthly basis. At both sites M/SCCPs are sampled together with sampling of PCBs and OCPs on glass fiber 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 monitoring data for M/SCCPs at Zeppelin are the first measurements of M/SCCPs in Arctic air. As in other published studies, the blank levels for the SCCPs and MCCPs are variable and high, resulting in relatively high average blank values (10-50% of detected masses). All samples are therefore blank corrected for the average blanks. ~30% of the measurements for MCCPs were below the average blank while none of the measurements for SCCPs were below the average blank. The presented data should be considered as semi-quantitative as the contribution of possible contamination during sampling and analyses have not yet been fully validated. Ongoing work at NILU aims to further improve the quality control in the future, possibly by the use of new sampling methodologies (i.e. new adsorbents).

The annual mean concentrations at Zeppelin for 2019 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, median and range of SCCPs were 230 pg/m^3 (median 225 pg/m^3, range: 21-420 pg/m^3) (Figure 30). For MCCPs two outliers were observed in 2019 resulting in annual mean concentration of 270 pg/m^3 (median 72 pg/m^3, range <44-3900 pg/m^3) (Figure 30). Excluding the two outliers the annual mean concentration for MCCPs at Zeppelin was 170 pg/m^3 (median 72 pg/m^3, range <44-720 pg/m^3). The annual mean concentrations measured for SCCPs do not show any significant difference between the years (2013-2019). In contrast, the concentrations of MCCPs are higher during the last years, indicating an increasing trend for MCCPs. As previous years, the concentrations of SCCPs are significantly higher than those of MCCPs (2-7 times) in a majority of the samples (55%), especially during the summer months. Interestingly, the dominance of SCCPs are smaller in 2019 than in previous years. In 2019, the concentrations of MCCPs are higher or similar to the SCCPs in 42% of the samples, with a dominance of those being observed during the winter period. This is a change to all previous years when only <10% of the total samples had higher or similar concentrations of MCCPs than SCCPs. This together with the increase of concentrations as observed in Figure 30 may suggest higher emission of MCCPs. This needs to be confirmed by further studies.

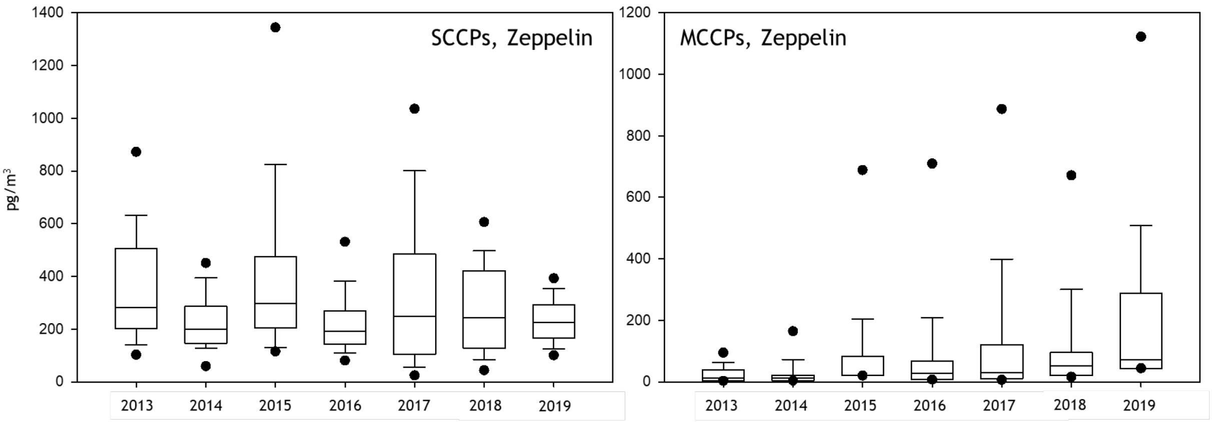


Figure 30: Box plot of measured SCCP and MCCP concentrations in air at Zeppelin in 2013-2019. The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively.

The annual mean concentrations at Birkenes in 2019 for SCCPs were 220 pg/m^3 (mean and median, range 74-350 pg/m^3) (Figure 31). The annual mean concentration for MCCPs were lower in 2019 than in 2018; 330 pg/m^3 including one outlier (range <95-1500 pg/m^3). Excluding this outlier the annual mean concentration for MCCPs in 2019 was 230 pg/m^3 (range <95-730 pg/m^3) (Figure 31). The higher concentrations in 2018 was mainly attributed three extreme concentrations observed in 2018. The concentrations of SCCPs are similar at Birkenes and Zeppelin in 2019. The concentrations of MCCPs were however higher at Birkenes than at Zeppelin. The MCCPs were higher than SCCPs in ~50% of the samples at Birkenes, similarily to previous years.

The concentrations of SCCPs and MCCPs measured at Zeppelin in 2013-2019 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).

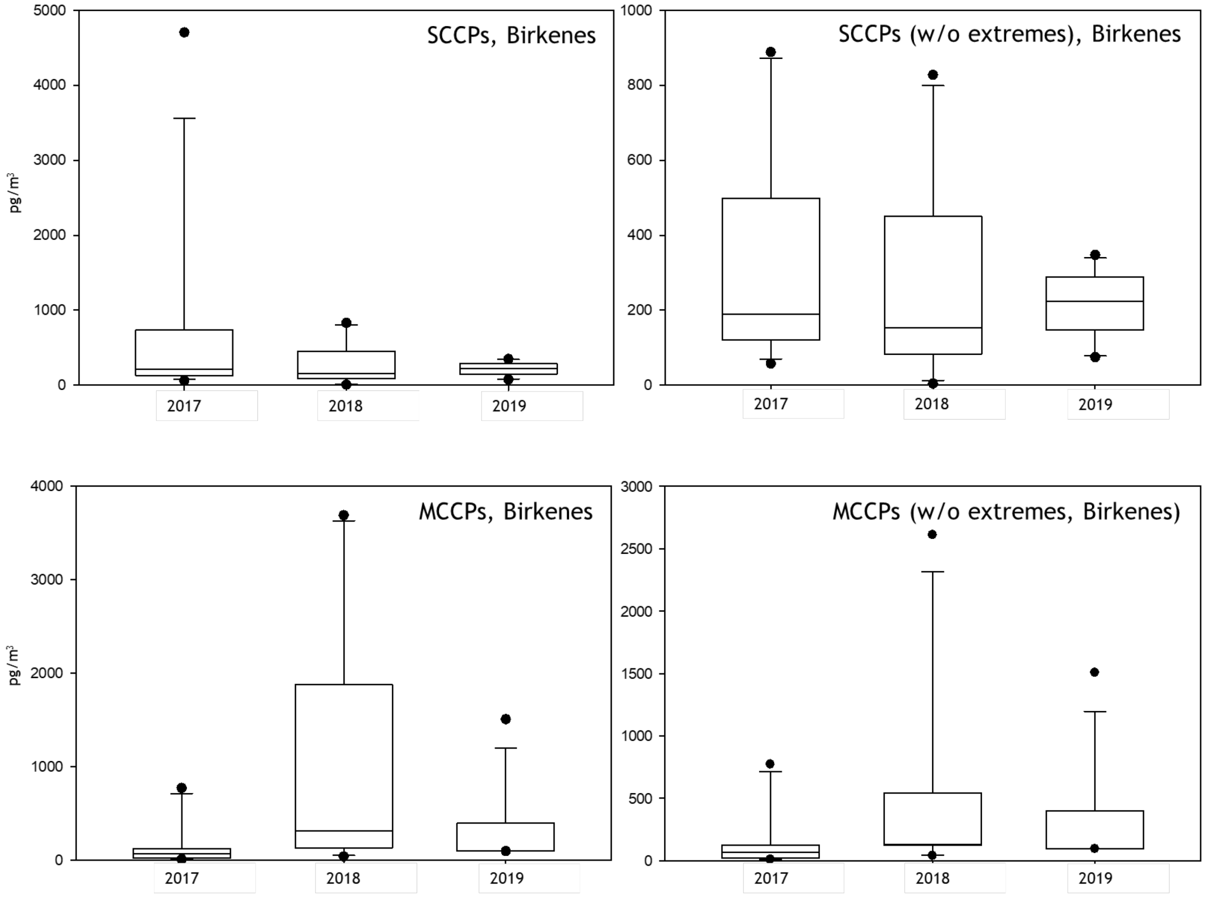


Figure 31: Box plot of measure SCCP and MCCP concentrations in air at Birkenes in 2017-2019 (with and without an extreme values for SCCPs in 2017 and for MCCPs in 2018). The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively.

No strong seasonality was observed for SCCPs at any of the two observatories (Figure 32). MCCPs at Zeppelin were lowest in summer and highest in winter but fluctuating from month to month at Birkenes.

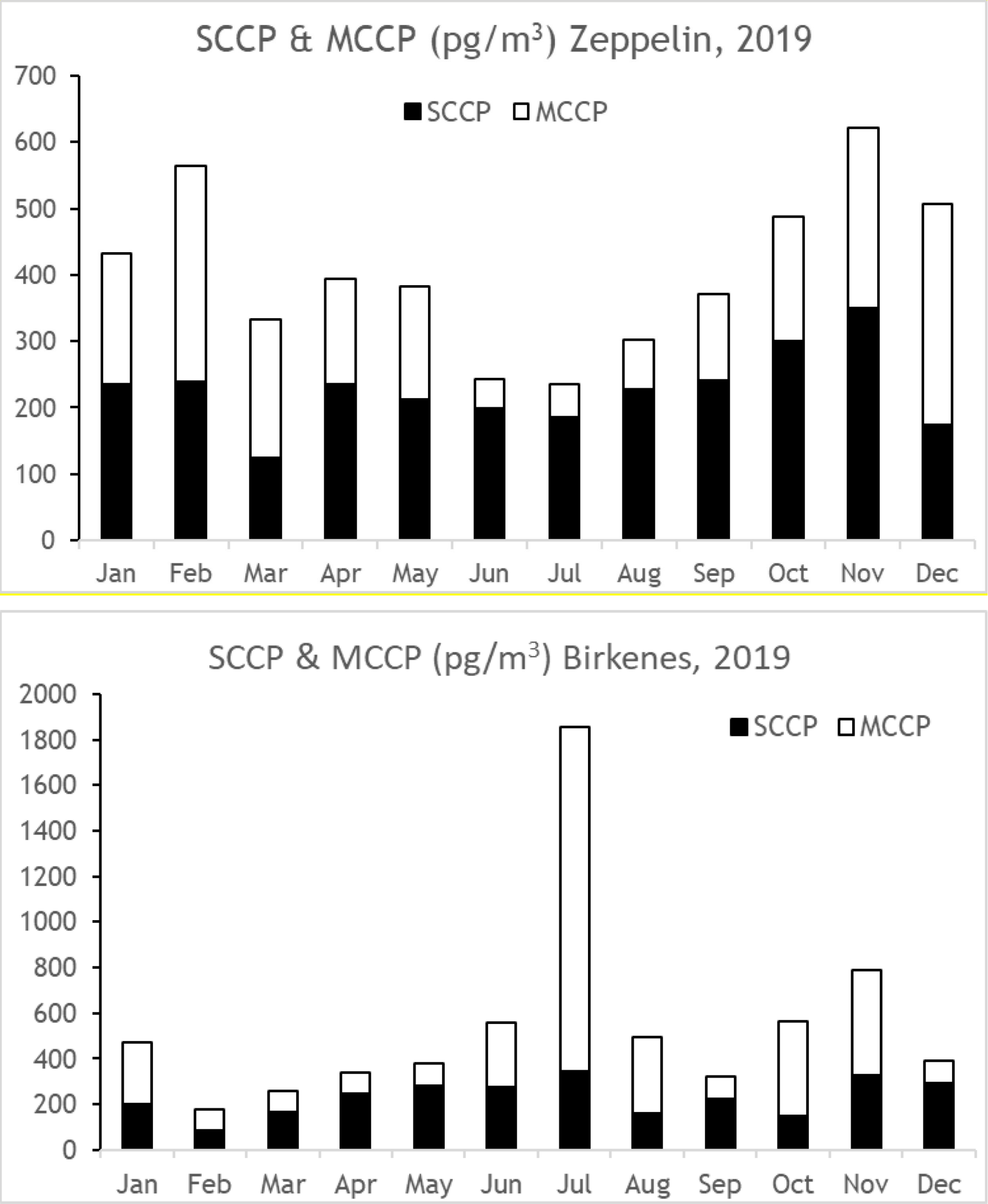


Figure 32: Seasonal variability of SCCPs and MCCPs at Birkenes and Zeppelin in 2019.

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.

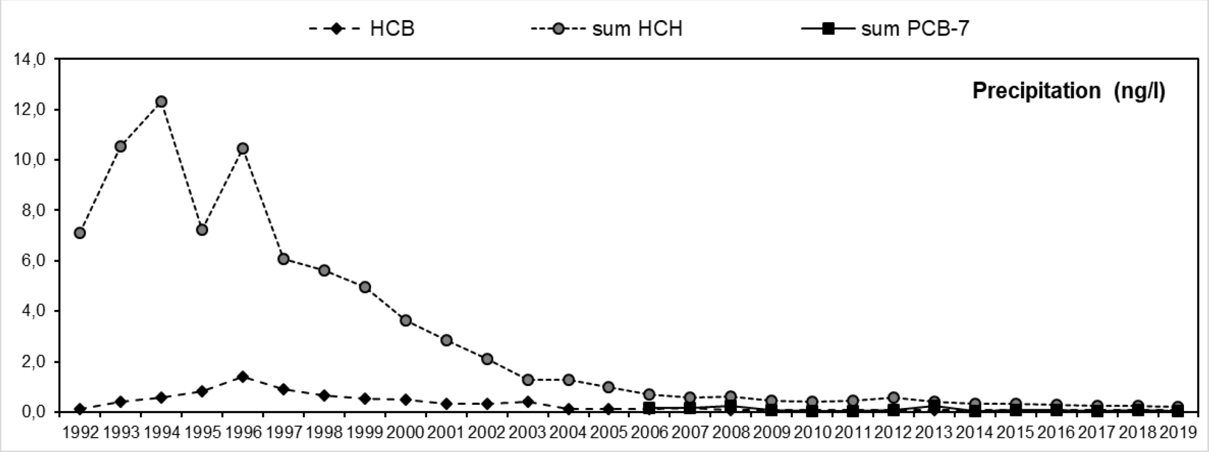
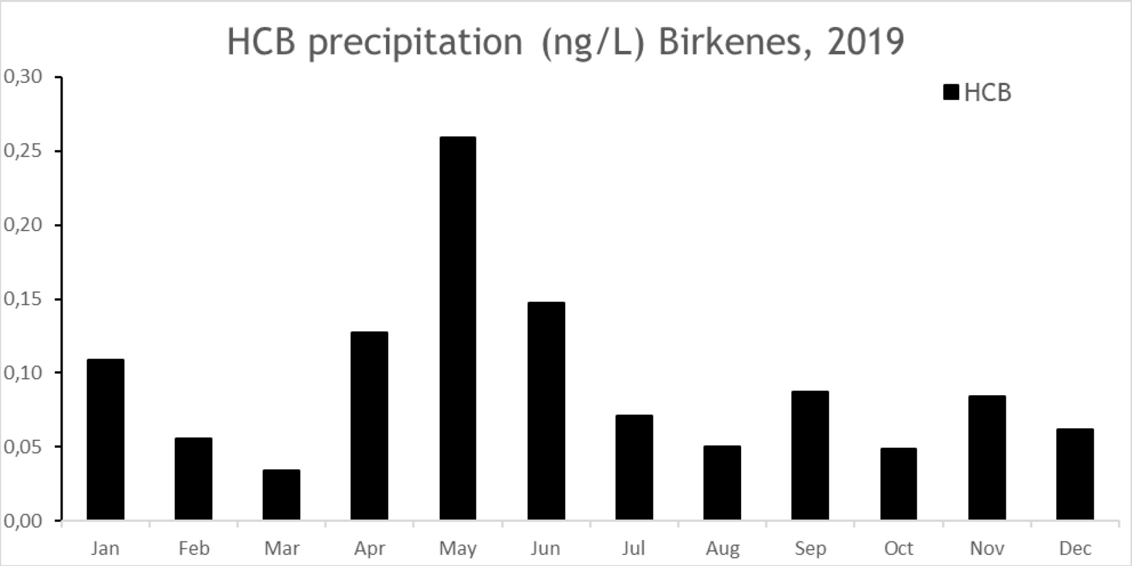
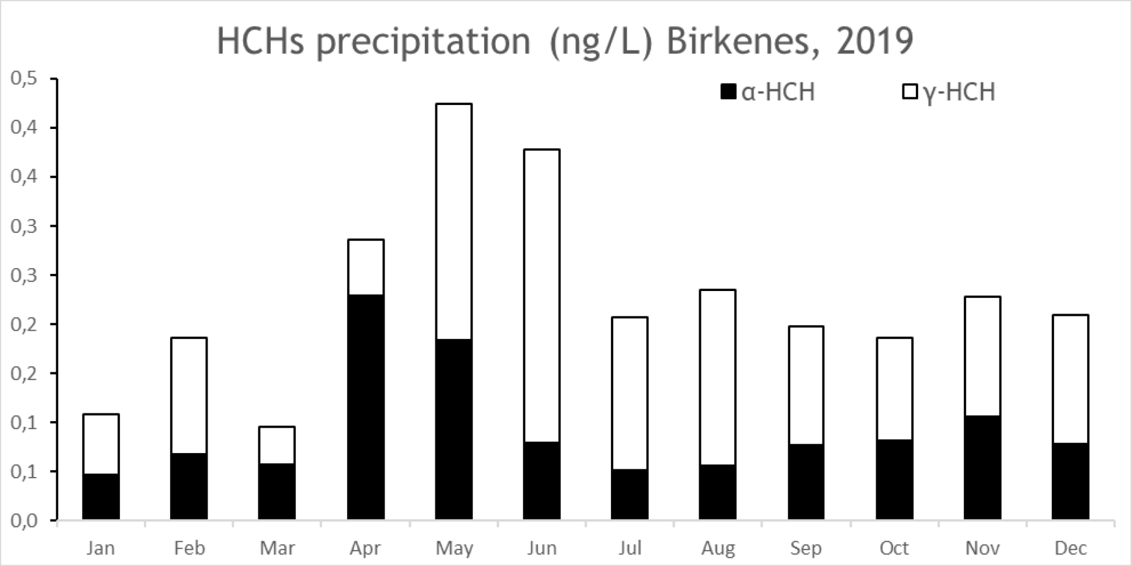


Figure 33: Annual mean concentrations of HCB, sum HCH and sum PCB-7 (ng/l) in precipitation at Birkenes. The annual mean concentrations include all targeted compounds, both those detected in most samples and those below the LOD (as LOD/2).

HCB were below detection limit in 47% of the samples in 2019. The annual mean concentrations of HCB in precipitation in 2019 were similar, but just lower than those observed during the last eight years. Stable annual mean concentrations are a result of low detection. A significant reduction of HCB concentrations was observed during the 1990s and the beginning of 2000 while the concentrations seem to have reached a plateau during the last eight to eleven years (Figure 33). No seasonal variability was observed for HCB, mainly due to low detection. The two HCH-isomers (α and γ) were detected in most of the samples in 2019. The annual mean concentration for sum HCHs was the lowest since the beginning of the monitoring (in 1992) 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 25-70% of the precipitation samples depending on congener. The annual mean concentration of PCB-7 in 2019 was similar to the previous years. No clear seasonality was observed (Figure 34).





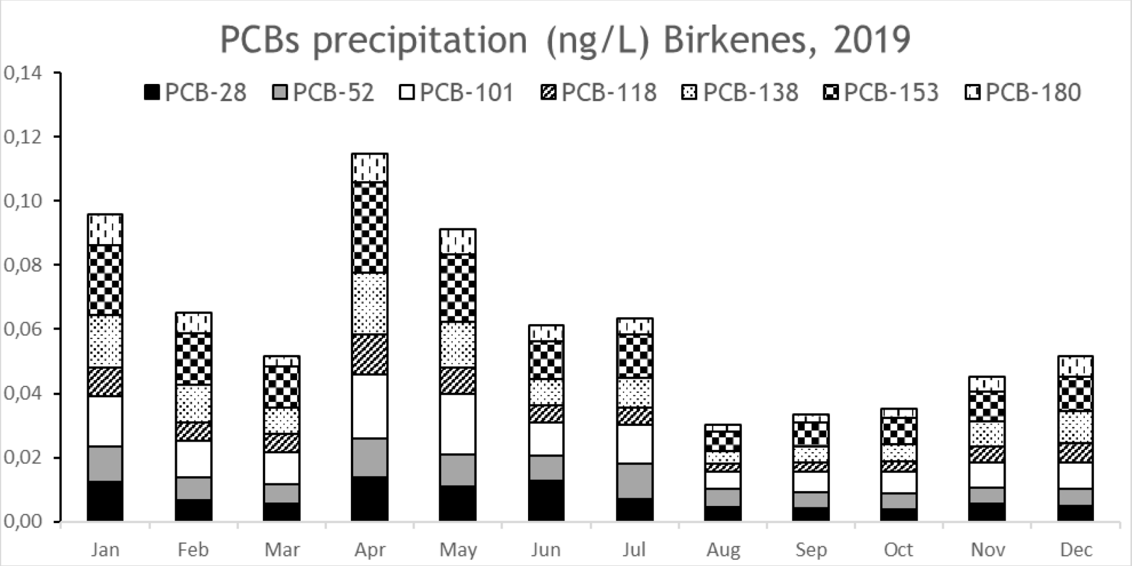


Figure 34: Seasonal variability of HCB, HCHs and PCBs (detected congeners) in precipitation (ng/L) at Birkenes in 2019.

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 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 does not give precise information, but can be used to compare the relative rates of decline or increase of concentrations between the compounds, e.g. a smaller positive number means that the decrease has been sharper than a larger positive number. In contrast, negative values indicate increasing trends. The absolute values of these half-lives or doubling times should be used with caution. 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, 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), 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 2019. 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 (2018-2019). The half-lives for a selection of individual POPs at Birkenes, Andøya and Zeppelin are presented in Table 6 while seasonal cycles and time trends are presented in Figures under the individual POP classes above.

The results from the trend analysis using DF show that HCB at Zeppelin are stable since the introduction of Stockholm Convention, but when analyzing scenario ii (until 2004) instead a small decrease is seen. At Birkenes, a decrease is seen for HCB during the first 12 years as well as for all the period. The decrease has been reduced after the SC entered into force. This is opposite to the aim of the SC and the reason is not known. The other organochlorine pesticides; here shown for HCHs, PCBs and PFOA decline at all scenarios at Zeppelin and Birkenes with small half-lives that indicate sharp declines. At Zeppelin and Birkenes, the decline of HCB, HCHs and PCBs is somewhat sharper during the first period (before SC) than the second period (after SC). No clear change is observed during the last three years, only HCB has now changed from increasing to being stable over the monitoring period.

Table 6: Long-term time trends for individual POPs and three different time periods: 1) the whole monitoring period (Table 2); 2) from the starting year of the monitoring to the year global regulation was taken into force for the individual compound, and 3) from the year global regulation was taken into force for the individual compounds until the end of 2019. 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**		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$
HCB	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 ↓
PCB-52	14* ↘		14* ↘				11 ↘	5.3 ↓	11 ↘
PCB-153	10* ↓		10* ↓				9.5* ↘	4.1 ↓	12* ↘
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 or for use in new materials as a demand for new technological needs and properties. Some of these chemicals have similar physical-chemical properties as regulated POPs and have thus received attention from regulatory agencies as well as the scientific community. Detection of such chemicals in screening programmes or case-studies have identified a need for environmental monitoring of these chemicals. The monitoring programme "Long-range atmospheric transported contaminants" is therefore continuously adapted to include new organic contaminants of emerging concern.

Five groups of non-regulated organic contaminants of emerging concern, covering 58 individual compounds, were monitored in 2019 (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 Kjeller to test sampling methodology for 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) and a new charcoal 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 2019.

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

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

Full name	Abbreviation
Dechloranes	
Dechlorane plus syn	syn-DP
Dechlorane plus anti	anti-DP
Dechlorane 601	Dec-601
Dechlorane 602	Dec-602
Dechlorane 603	Dec-603
Dechlorane 604	Dec-604
Dibromo-aldrin	Dba

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 2017-2019. Two samples were taken per month and combined in the laboratory to provide monthly bulk concentrations. The volatile PFAS in air are sampled on XAD/PUF/XAD only and thus the concentrations of the volatile PFAS in air in this monitoring programme represent the gas phase.

In 2019, 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 special sampler unit consisting of PUF/XAD/PUF in sandwich was used to sample the volatile PFAS as PUFs alone do not retain the volatile PFAS. A new analytical method with cold extraction was tested and developed in 2017 and used for all the volatile PFAS. This was done to limit the loss of volatile PFAS caused by evaporation and degradation during normal soxhlet extraction methodologies.

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, 2019. The LOD presented is based on average air sample volumes.

		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	67	<0.4-177	38	58	<0.4-160	37	50	<0.4-240	43
6:2 FTOH	2.3	92	<2.3-30	13	92	<2.3-10	6.0	100	3.2-12	5.9
8:2 FTOH	0.9	100	3.4-300	37	100	2.7-58	12	100	1.2-16	4.6
10:2 FTOH	1.5	75	<1.5-140	16	33	<1.5-14	*3.6*	33	<1.5-5.8	*2.1*
N-EtFOSA	0.3	17	<0.3-0.9	*0.3*	16	<0.3-0.5	*0.3*	0	<0.3	<0.3
N-EtFOSE	0.7	0	<0.7	*<0.6*	0	<0.7	<0.7	0	<0.7	<0.7
N-MeFOSA	0.8	17	<0.8-1.0	*0.8*	8	<0.8-1.0	*0.8*	0	<0.8	<0.8
N-MeFOSE	0.3	8	<0.3-0.5	*0.3*	0	<0.3	<0.3	17	<0.3	*0.3*
Sum FTOHs			12-463	103		8.7-169	59		9.5-251	55

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 4:2 FTOH (50-70%) and 10:2 FTOH (30-75%). N-EtFOSE was not detected in any samples from any site. The detection frequency was also low for N-Et-FOSA, N-Me-FOSA and N-Me-FOSE (0-20%). 8:2 FTOH together with 6:2 FTOH and 4:2 FTOH were detected at highest concentrations of the volatile PFAS (Table 8). The annual mean concentration of FTOHs in 2019 were highest at Birkenes (103 pg/m^3) and similar at Andøya (59 pg/m^3) and Zeppelin (55 pg/m^3). No clear seasonal variability were observed for the volatile PFAS, instead there are episodes with high concentrations of individual FTOHs over the year (Figure 35). The concentrations measured at the three Norwegian sites in 2017-2019 are similar to those measured in the atmosphere above the Chinese Sea (Zhao et al., 2017) and in rural Germany (Dreyer et al., 2008) for 6:2, 8:2 and 10:2 FTOH while lower for 12:2 FTOH. The obtained LODs for FOSE and FOSA are higher than the previously reported concentrations in air which reduce the comparability between new measurements and previous measurements.

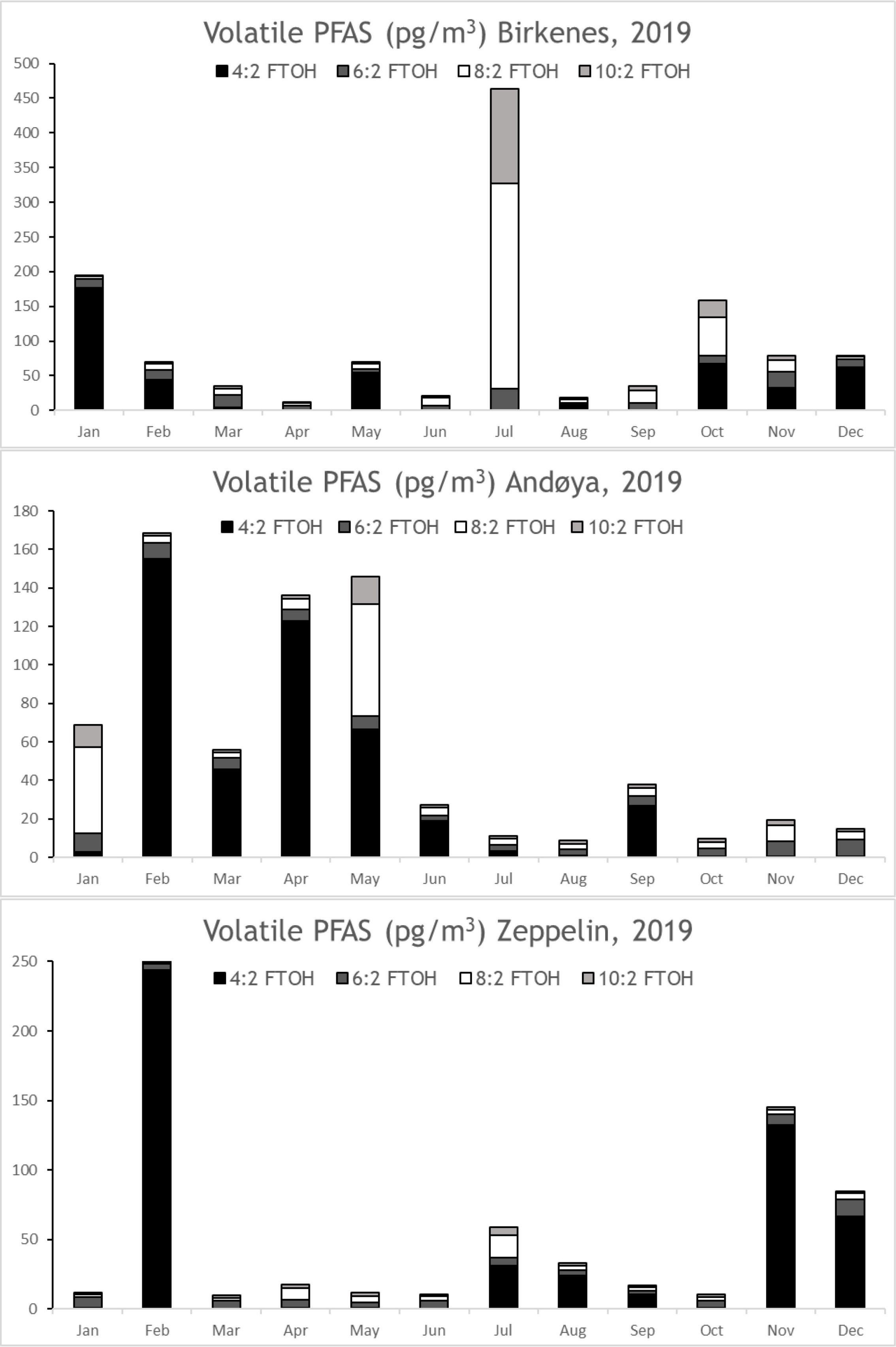


Figure 35: Seasonal variability of the detected volatile PFAS (i.e. 4:2-10:2 FTOH) at Birkenes, Andøya and Zeppelin in 2019.

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 2017-2019, in one summer campaign (July-August) and one winter campaign (November-December) using active air sampler. At Birkenes, they have been monitored in 2018-2019 in one summer and one winter campaign. Each campaign consisted of six samples taken over 48-72 hr at each station. 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), only four were detected in more than 50% of the active air samples at Zeppelin in 2019 (Table 9): PBT, HBB, DPTE, and EHTBB. Also α- and β-TBECH were detected in 42% of the samples (100% in summer but in none of the winter samples) and are included in Table 9. BTBPE and DBDPE were detected in 36 and 45% of the samples, but the results are uncertain due to elevated field blank levels. Low detection for BATE is attributed degradation during the chemical analysis and does not necessarily mean low presence in Arctic air. The highest detection frequency and highest concentrations were observed for HBB (0.45 pg/m^3 in summer, and 0.13 pg/m^3 in winter) and PBT (0.26 pg/m^3 in summer, and 0.05 pg/m^3 in winter). The detection frequency and most of the detected concentrations were higher during the summer campaign than the winter campaign suggesting seasonality in air concentrations at Zeppelin (Table 9, Figure 36). The profiles in the samples are however consistent in summer and winter time. The measured concentrations of the individual nBFRs are 100-1000 times lower than the concentrations of the individual OPFRs and phthalates. The same has also been observed in Arctic air samples by Salamova et al. (2014) and Rauert et al. (2018).

Table 9: Detected nBFRs in air (pg/m^3) from active air sampling at Zeppelin in 2017-2019, presented as detection frequencies and average concentrations of individual measurements in summer and winter. The LOD presented is based on average air sample volumes.

		α-TBECH	ß-TBECH	PBT	PBBZ	HBB	DPTE	EHTBB	Sum detected nBFRs
		LOD (pg/m^3)							
		0.01	0.01	0.01	0.1	0.04	0.004	0.003	
		Detection frequency (%) in 2019							
		42	42	100	17	92	67	83	
Year	**Sampling period**	Concentration (pg/m^3)							
2019	10.07-26.08	0.04	0.02	0.26	0.12	0.45	0.01	0.15	0.9
2019	06.11-23.12	<0.03	<0.03	0.05	<0.11	0.13	0.006	0.04	0.4
2018	06.07-27.08			0.24	0.09	0.39	0.02	0.20	0.9
2018	05.10-17.12			0.52	0.09	0.56	0.02	0.23	1.7
2017	28.06-18.08			0.06	0.03	0.07	0.02	0.22	0.4
2017	10.11-18.12			0.05	0.03	0.08	0.01	0.03	0.2

*Results uncertain due to elevated levels in field blanks.

At Birkenes, five of the fourteen targeted nBFRs were detected in 50% or more of the samples in 2019: PBT, PBEB, PBBZ, HBB and DPTE (Table 10). In addition, α-, β-, and γ/δ-TBECH, BATE, EHTBB, and TBPH were detected in 25-42% of the samples. DBDPE was detected, but strongly influenced by high levels in field blanks. The highest concentrations were observed for HBB (1.1 pg/m^3 in summer, and 0.23

pg/m^3 in winter) contributing to 56 and 32% in summer and winter time respectively. For most detected compounds there were higher concentrations in summer than in winter resulting in two times higher concentration of detected nBFRs in summer than in winter. This together with higher detection frequencies in summer suggest seasonality for the nBFRs also at Birkenes (Figure 36). The detected concentrations and the detection frequencies were higher at Birkenes than at Zeppelin.

Table 10: Detected nBFRs in air (pg/m^3) from active air samplers at Birkenes, 2018-2019, 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.

		α-TBECH	**ß-TBECH**	**PBT**	**PBEB**	**PBBZ**	**HBB**	**DPTE**	**Sum detected nBFRs**
		LOD (pg/m^3)							
		0.01	0.01	0.01	0.007	0.01	0.04	0.003	
		Detection frequency in 2019 (%)							
		42	42	100	75	67	100	100	
Year	**Sampling period**	Concentration (pg/m^3)							
2019	24.06-02.08	0.10	0.07	0.23	0.03	0.39	1.07	0.03	2.0
2019	15.11-19.12	0.12	0.09	0.09	0.01	0.13	0.23	0.02	0.8
2018	06.07-27.08	0.19	0.09	0.55	0.22	0.83	2.67	0.04	4.6
2018	29.10-17.12	0.10	0.05	0.07	0.07	0.10	0.32	0.02	0.7

*Results uncertain due to elevated levels in field blanks.

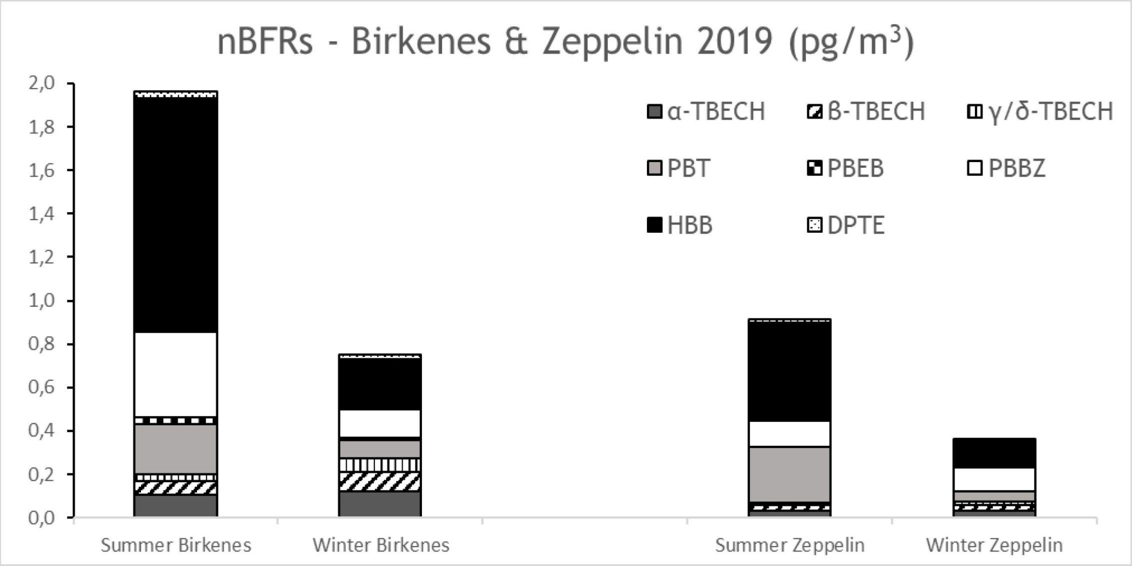


Figure 36: Mean concentrations of detected nBFRs in air at Birkenes and Zeppelin in 2019.

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 2017-2019, in one summer campaign (July-August) and one winter campaign (November-December) using active air sampler. At Birkenes, they have been monitored in 2018-2019 in one summer and one winter campaign. Each campaign consisted of six samples taken over 24-48 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).

The analysis included a list of 17 OPFRs (Table 7). Of these, only two OPFRs were detected in 50% or more of the active air samples from Zeppelin (i.e. TDCPP and EHDP) (Table 11), while three others were detected in a few samples (i.e. TPP, TBEP and TEHP) and the rest below LOD in all or most of the samples. High and inconsistent concentrations are found in blanks resulting in elevated LODs for many OPFRs, e.g. TCEP, TPP, TCPP, TiBP, TBEP, TCP, EHDP, TTBPP, and TEHP. This is probably a result of presence in the sample matrix and/or products used during lab procedures. It should not be excluded that these compounds are present in the air at levels below these elevated LOD. NILU is testing options for sampling and analysis to reduce the blank contamination.

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 a consequence of the high levels in blanks. The obtained concentrations over the two sampling periods (summer and winter) ranged from 4 1200 pg/m^3 (mean: 350 pg/m^3, median: 290 pg/m^3). The dominant OPFRs at Zeppelin were EHDP (39-750 pg/m^3) and TDCPP (<LOD-8.5 pg/m^3) (Table 11). A few high measurements were also observed for other OPFRs. Some OPFRs were observed at higher concentrations in summer and others in winter showing no clear seasonality. The detection frequencies were however higher in summer than in winter.

Table 11: Detected OPFRs in air (pg/m^3) from active air samplers at Zeppelin in 2017- 2019, 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.

Year	Sampling period	TCEP	TCPP	TiBP	DBPhP	TnBP	TDCPP	EHDP	TEHP	Sum detected OPFRs
			LOD (pg/m^3)							
		26	133	8.0	0.6	11	1.6	71	1.2	
			Detection frequency (%) in 2019							
		10	10	17	17	8	67	90	33	
		Concentration (pg/m^3)								
2019	05.07-21.08	*52*	*190*	*9.6*	<0.6	<*11*	4.9	190	1.5	240
2019	04.11-18.12	<26	<133	<*8.0*	*2.5*	<*11*	*2.1*	460	<1.2	460
2018	13.07-06.09	101	235	16	<0.8	*13*	<7.2		37	410
2018	29.10-10.12	127	240	*15*	<1.1	*18*	11		83	490
2017	30.06-11.08	41	107	5.2	0.4	11	4.9		*0.2*	170
2017	10.11-18.12	*15*	<36	9.5	<0.5	<3.0	<10		<40	160

At Birkenes, seven OPFRs were detected in 50% or more of the samples in 2019 (i.e. BdPhP, TPP, DBPhP, TnBP, TDCPP, TCP and EHDP) (Table 12). The low and inconsistent detection hamper the comparison over season, year and between Birkenes and Zeppelin.

Table 12: OPFRs in air (pg/m^3) from active air samplers at Birkenes, 2018-2019, 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.

Year	**Sampling period**	**TCEP**	**TCPP**	**TPP**	**TiBP**	**DBPhP**	**TnBP**	**TDCPP**	**TCP**	**TEHP**	**Sum detected OPFRs**
		LOD (pg/m^3)									
		28	143	5.8	8.6	0.7	12	1.7	0.2	1.2	
		Detection frequency (%) in 2019									
		0	0	100	0	33	0	100	100	17	
		Concentration (pg/m^3)									
2019	26.06-09.08	<28	<143	83	<8.6	<0.7	<12	5.7	0.85	<1.2	190
2019	02.11-23.12	<28	<143	<5.8	<8.6	12	<12	7.4	3.0	<1.2	190
2018	09.07-03.09	<40	*67*		*14*	1.8	<11	<18	20	<990	48
2018	24.10-21.12	<45	*72*		*15*	*1.4*	15	<20	<10	<1100	42

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

4.4 Phthalates

Phthalates were included in the monitoring programme in 2017. In 2019, they were measured in one summer campaign and one winter campaign at Zeppelin and Birkenes using active air samplers. Each campaign aimed at a number of six samples taken over 24-48 hr. 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 only four of the twelve targeted phthalates (Table 7) were detected in all or most of the active air samples in the summer and winter campaign (Table 13); DIBP, DBP, DEHP, and BzBP. Four compounds; DMP, DEP, DAIP, and DnHP were detected in samples in summer but not in any samples in winter. DINP was detected in a few samples in summer and a few in winter. The other three compounds; DPP, DcHP and DPHP were below LOD in all samples (2, 9, and 1 pg/m^3, respectively). In the winter campaign at Birkenes, lower levels and lower detection frequencies were observed for most compounds indicating a seasonality of phthalates. In contrast to Birkenes and to the findings from 2017, no strong seasonality was observed at Zeppelin.

The observed concentrations for the detected phthalates were high, even exceeding the individual concentrations for the OPFRs. At Zeppelin in 2019, the highest concentrations were observed for DiBP (<0.08-2.6 ng/m^3), followed by DEHP (<0.1-9.5 ng/m^3), DnBP (<0.08-1.4 ng/m^3), and BzBP (0.007-1.15 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 from 0.40-9.5 ng/m^3 (mean: 4.3 ng/m^3, median 4.0 ng/m^3) in summer and 0.18-9.6 ng/m^3 (mean: 2.3 ng/m^3, median 0.8 ng/m^3) in winter.

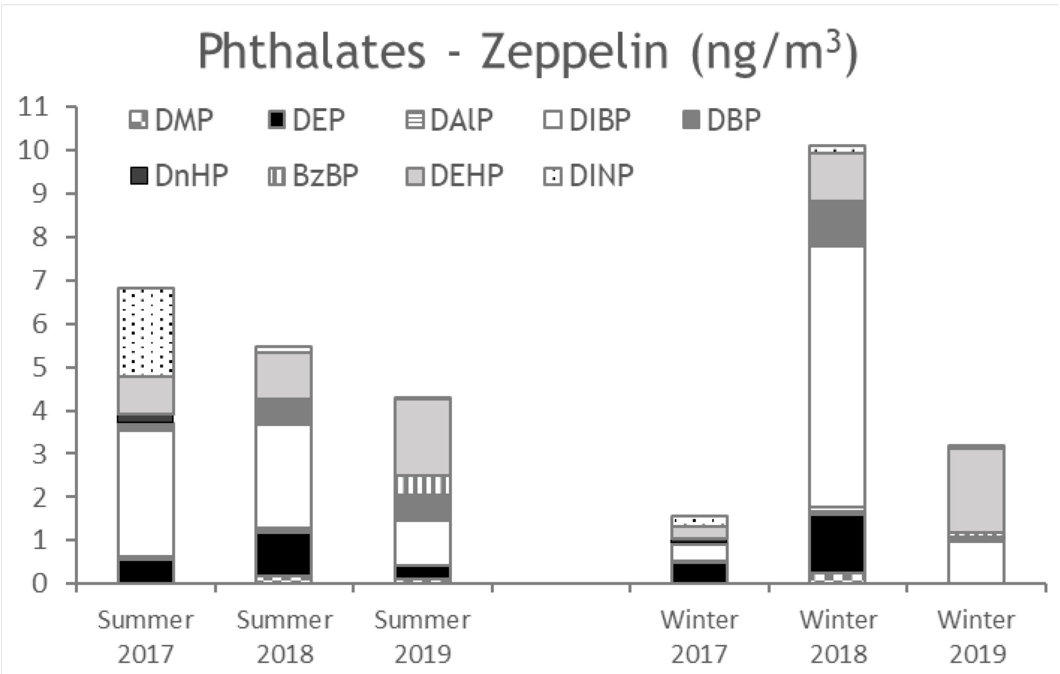


Figure 37: Mean concentrations of detected phthalates in air at Zeppelin in 2017-2019.

Table 13: Mean concentrations of detected phthalates in air (ng/m^3) from active air samplers at Zeppelin in 2017-2019. Concentrations in summer and winter are average of samples taken during each sampling campaign. The LOD presented is based on average air sample volumes.

Sampling period											
Year	**Sampling period**	**DMP**	**DEP**	**DAIP**	**DiBP**	**DBP***	**DnHP**	**BzBP**	**DEHP**	**DINP**	**Sum phthalates**
		LOD (ng/m^3)									
		0.02	0.01	0.002	0.008	0.02	0.004	0.002	0.1	0.3	
		Concentration (ng/m^3)									
2019	28.06-23.08	0.12	0.29	0.006	1.02	0.61	0.006	0.42	1.78	0.04	4.3
2019	15.11-12.30	<0.02	<0.01	<0.002	<0.008	0.08	<0.004	0.10	1.97	0.07	2.3
2018	20.07-03.09	0.19	0.98	0.12	2.39	0.59	<0.001	<0.002	1,05	0.15	5.5
2018	28.11-07.12	0.26	1.34	0.17	6.02	1.01	<0.001	<0.002	1,13	0.15	10
2017	26.07-01.09	n.a.	0.57	0.06	2.90	0.19	0.20	0.002	0,87	2.05	6.9
2017	15.11-17.12	n.a.	0.48	0.06	0.35	0.08	0.07	0.02	0,29	0.21	1.6

*Italic: Influenced by blank levels.

At Birkenes in 2019, the highest concentrations were observed for DEHP (<0.1-3.9 ng/m^3), followed by DiBP (0.08-1.2 ng/m^3), DnBP (<0.08-0.5 ng/m^3) and DEP (<0.01-2.4 ng/m^3). The concentrations of the sum of the targeted phthalates (sum phthalates) were lower than at Zeppelin with ranges from 1.4-4.6

ng/m^3 (mean: 2.5 ng/m^3, median 2.3 ng/m^3) in summer and 0.3-5.6 ng/m^3 (mean: 1.7 ng/m^3, median 0.6 ng/m^3) in winter (Table 14). Higher concentrations are observed in summer than in winter (Figure 38).

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

Table 14: Mean concentrations of detected phthalates in air (ng/m^3) from active air samplers at Birkenes, 2018-2019. Concentrations are average of samples taken during each sampling campaign. The LOD presented is based on average air sample volumes.

Sampling period												
Year	**Sampling period**	**DMP**	**DEP**	**DAIP**	**DiBP**	**DBP***	**DnHP**	**BzBP**	**DEHP**	**DPHP**	**DINP**	**Sum phthalates**
		LOD (ng/m^3)										
		0.02	0.01	0.002	0.008	0.02	0.004	0.002	0.1	0.001	0.04	
		Concentration (ng/m^3)										
2019	06.07-12.08	0.04	0.06	<0.002	0.74	*0.36*	*0.005*	*0.01*	*1.18*	0.005	0.07	2.5
2019	11.11-18.12	0.05	0.57	<0.002	0.32	*0.18*	*0.002*	*0.007*	*0.54*	0.006	0.05	1.7
2018	27.07-31.08	0.03	0.19	0.004	1.57	*0.20*	*0.002*	*0.001*	*0.87*	0.02	0.15	3.0
2018	16.11-19.12	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.

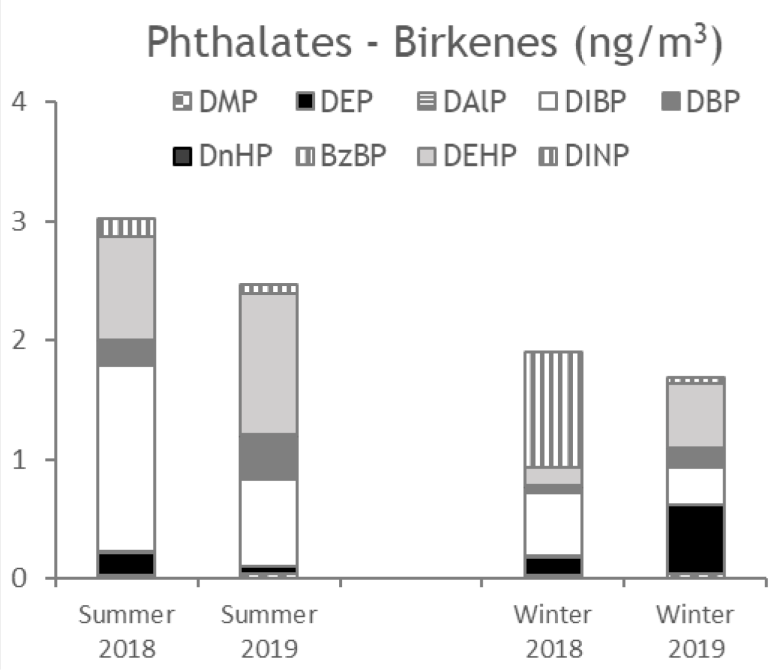


Figure 38: Mean concentrations of detected phthalates in air at Birkenes in 2018-2019.

4.5 Dechloranes

Dechloranes were included in the monitoring programme of Zeppelin and Birkenes in 2019. They were measured in weekly samples at Zeppelin and monthly samples at Birkenes using active air samplers. The sampling time at Zeppelin was 48 hr while only 24 hr at Birkenes. The samples were analysed for seven dechloranes (Table 15). 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).

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. 25% and 44% of the samples, respectively. The concentrations of anti-DP (<0.06-1.04 pg/m^3) were higher than those measured for syn-DP (<0.05-0.32 pg/m^3) (Table 15). Compared to 2017, when dechloranes also were measured at Zeppelin as a part of this monitoring programme, the detection frequencies of syn-DP and anti-DP are lower in 2019 but instead the detected concentrations in 2019 are higher than in 2017. Syn- and anti-DP have been detected in Arctic air at concentrations between 0.02 and 4.1 pg/m^3 (Møller et al. 2010) with the lowest concentrations measured outside Svalbard in the Greenland sea.

Table 15: Dechloranes in air (pg/m^3) from active air samplers at Zeppelin, 2019

	Dba	Dec-602	Dec-603	Dec-604	Dec-601	syn-DP	anti-DP
LOD	<0.03-<0.06	<0.006	<0.007	<0.15-<0.25	<0.015-<0.043	<0.05-<0.08	<0.06-<0.09
Detection frequency (%)	0	0	0	0	0	25	44
Detected concentrations (pg/m^3)	<0.03-<0.06	<0.006	<0.007	<0.15-<0.25	<0.015-<0.043	<0.05-0.32	<0.06-1.04

Also at Birkenes, only DP-syn and DP-anti were detected while the other dechloranes were below the detection limit. The concentrations of syn-DP were similar to those measured at Zeppelin while the anti-DP were similar or lower at Birkenes than at Zeppelin.

Table 16: Dechloranes in air (pg/m^3) from active air samplers at Birkenes, 2019

	Dba	Dec-602	Dec-603	Dec-604	Dec-601	syn-DP	anti-DP
LOD	<0.12	<0.009	<0.010	<0.45	<0.03-<0.09	<0.12	<0.18
Detection frequency (%)	0	0	0	0	0	17	83
Detected concentrations (pg/m^3)	<0.12	<0.009	<0.010	<0.45	<0.03-<0.09	<0.12-0.18	<0.18-0.27

4.6 Test of sampling methodology for volatile fluorinated substances and data mining

This part of the monitoring aims at testing an improved sampling methodology for volatile fluorinated substances, including those detected in data mining in 2018 (Table 17).

Table 17. Compounds, discovered by data-mining at Zeppelin in 2018.

		CAS	Concentration range (pg/m^3)
1	1,1,2,3,4,4-hexachloro-1,3-Butadiene	87-68-3	4500-20 000
2	1,2-dichlorobenzene	95-50-1	3000-14 000
3	dichlorobenzene	95-50-1	890-3100
4	hexachloroethane	67-72-1	640-4600
5	1,4-dichloro-2-methylbenzene	19398-61-9	570-2500
6	1,2,4-trichlorobenzene	120-82-1	320-1600
7	hexachlorobutadiene, unknown isomer		340-1800
8	1,3,5-trichloro-2-methoxybenzene	87-40-1	270 1500
9	dichlorobenzene	95-50-1	240-1090
10	Hexachlorobenzene	118-74-1	160-1200
11	2,4-dichloro-1-methoxybenzene	553-82-2	150-750
12	1,2,4-trichlorobenzene	120-82-1	100-490
13	1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	100-700
14	Ethane, 1,1,2,2-tetrachloro-	79-34-5	100-540
15	1,2,4-trichloro-3-methylbenzene	2077-46-5	80-470
16	1,2,4,5-tetrachloro-3,6-dimethoxybenzene	944-78-5	50-270
17	1,2-dichloro-4-(chloromethyl)-benzene	102-47-6	50-300
18	2,3-Dichloro-5-trifluoromethylpyridine	69045-84-7	50-220
19	1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	60-370
20	1,2,4,5-tetrachlorobenzene	95-94-3	50-240
21	1,2,3,5-tetrachlorobenzene	634-90-2	40-200

Air samples were collected at NILU's facilities at Kjeller using i) the same sampling methodology as in 2018 (ABN) but slightly modified, and ii) a new adsorbent (charcoal). The ABN method was modified with larger amounts of ABN and alternatives for extraction (Table 18). Two sampling campaigns were performed; one in spring (April-May) and one in winter (November-December).

Table 18. Sampling methodologies tested in 2019.

	ABN 2018	ABN 2019, vers. 1	ABN 2019, vers. 2	Charcoal
Sorbent amount	140 mg	140 mg	250 mg	4 cm disk
Transportation condition	ambient	ambient	frozen	frozen
Extragent 1	4 mL hexane	4 mL pentane	4 mL Ether	4 mL Ether
Extragent 2	none	4 mL ether + 4mL methanol	4 mL ethylacetate	4 mL ethylacetate
Evaporation	to 100 mL	to 100 mL	to 100 mL, advanced	to 100 mL, advanced

The primary extracts (pentane in sampling campaign 1, April-May and ether in sampling 2, November-December) were analyzed for nine fluorine containing substances (Table 19). In addition, a total area of all peaks corresponding to an ion C3F5 (one of the characteristic ions for perfluoroaliphatic subtances) was calculated to evaluate the part of undetected non-polar volatile PFAS. Results are summarized in table 20.

Table 19. Per- and polyfluorinated substances for analysis.

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
PFPHP	Perfluoroperhydrophenanthrene	306-91-2	C14F24
PFBcH	Perfluorobutylcyclohexane	374-60-7	C10F20
DCPFcH	Dichloroperfluorocyclohexene	336-19-6	C6F8Cl2
PFBB	pentafluorobromobenzene	344-04-7	C6F5Br
bisTFMBB	3,5-bis-(trifluoromethyl)bromobenzene	328-70-1	C8H3F6Br
DCTFP	Dichlorotrifluoropyridene	1737-93-5	C5NF3Cl2
*Total Fvol**	*C3F5 ion**		

*This is a provisional parameter for evaluation of total content of perfluoroaliphatic substances in the air.

Table 20. Concentrations of Volatile Fluorinated compounds (PFTBA-like) in air in Kjeller, weeks 15, 18, 19 and 48-50, 2019

Sampling period	**09-11.04 2019**	**30.04-02.05 2019**	**06-08.05 2019**	**25-28.11.2019, week 48**		**02-05.12.2019, week 49**		**10-13.12.2019, week 50**	
	ABN	ABN	ABN	ABN	Charcoal A	ABN	Charcoal B	ABN	Charcoal BL
Analyte	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
PFTBA	**2658**	**2331**	**1868**	**522**	**367**	**1281**	**833**	**548**	**356**
TCPFB	**125**	**37**	**89**	**19**	**84**	**18**	<39	**23**	**106**
PFTPeA	**n.a.**	**n.a.**	**n.a.**	**48**	**13**	**85**	<1.3	**53**	**22**
PFPHP	**70**	**51**	**42**	**28**	**19**	<19	<25	**31**	**16**
PFtBcH	**n.a.**	**n.a.**	**n.a.**	<3	<45	<20	<27	<8.3	<57
DCPFcH	**n.a.**	**n.a.**	**n.a.**	<1.2	<1.3	<1.2	<1.3	<1.1	<1.3
PFBB	<1	<1	<1	<1.2	<1.3	<1.2	<1.3	<1.1	<1.3
bisTFMBB	<1	<1	<1	<1.2	<1.3	<1.2	<1.3	<1.1	<1.3
DCTFP	<1	<1	<1	<1.2	<1.3	<1.2	<1.3	<1.1	<1.3
Total Fvol*	***2963***	***2663***	***2049***	***793***	***657***	***1787***	***1079***	***841***	***558***
PFTBA/Total FVol, %	***90***	***88***	***91***	***66***	***56***	***72***	***77***	***65***	***64***

PFTBA was found in high concentration in all samples and comprised 56-91% of the "Total FVol" (the ratio of peak area of ion 131 for PFTBA to combined area of all peaks of ion 131). The concentrations were higher in spring than in winter. In addition, there was variation between samples from the same season (ca 1.4 times in Spring and ca 2.5 times in Winter between maximal and minimal values). TCPFB and PFTPeA were detected in all but one sample, though at much lower levels (due to technical problems PFTPeA was not measured in Spring). PFPHP was detected in all but two samples. The other targeted substances were not detected (LOD: 1-57 pg/m^3).

A careful conclusion can be made that PFTBA is likely a major contaminant of its class. Nevertheless, more careful search for other non-polar PFAS shall continue, as potentially ozon-depleting substance may not produce C3F5 ion during GC-MS analysis.

The results of the data mining shows that there is a clear advantage of using ABN as adsorbent for air sampling for non-target screening, as the aromatic substances were poorly detected on charcoal samples. The poor results for charcoal is due to high retention of such compounds on the charcoal sorbent.

Table 21. Levels of chlorinated substances from data-mining in the air using two different adsorbents at Kjeller in weeks 38-40, by order of concentration.

	CAS	ABN 1	ABN 2	ABN 3	Charcoal A	Charcoal B	Charcoal BL
		pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3
dichlorobenzene	95-50-1	1947	1986	1683	47	188	98
1,1,2,3,4,4-hexachloro-1,3-Butadiene	87-68-3	773	525	668	261	264	378
1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	596	429	338	2	3	2
1,2-dichlorobenzene	95-50-1	560	518	555	20	80	35
2,4-dichloro-1-methoxybenzene	553-82-2	305	177	97	9	10	6
1,3,5-trichloro-2-methoxybenzene	87-40-1	302	228	206	4	5	3
1,2,4-trichlorobenzene	120-82-1	199	229	237	4	7	3
hexachloroethane	67-72-1	193	140	192	129	178	202
1,4-dichloro-2-methylbenzene	19398-61-9	193	365	539	2	11	8
dichlorobenzene	95-50-1	193	215	143	11	37	12
hexachlorobutadiene, unknown isomer	unknown	115	62	119	15	19	20
1,2,4,5-tetrachloro-3,6-dimethoxybenzene	944-78-5	72	23	32	2	<1	<1
1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	72	134	87	1	5	2
1,2,4-trichlorobenzene	120-82-1	58	47	48	1	1	<1
1,2,4-trichloro-3-methylbenzene	2077-46-5	30	36	59	<1	<1	<1
2,3-Dichloro-5-trifluoromethylpyridine	69045-84-7	29	17	18	<1	<1	4
1,2,4,5-tetrachlorobenzene	95-94-3	28	20	24	<1	<1	<1
Hexachlorobenzene	118-74-1	23	11	22	<1	<1	<1
1,2,3,5-tetrachlorobenzene	634-90-2	20	11	15	<1	<1	<1
1,2-dichloro-4-(chloromethyl)-benzene	102-47-6	18	19	49	<1	<1	<1
Ethane, 1,1,2,2-tetrachloro-	79-34-5	0	45	10	2	7	7

The results from 2019 cannot be directly compared to those from 2018 due to different internal standard and different quantification approaches as well as different sampling locations (Kjeller in 2019 and Zeppelin in 2018). As already emphasized in 2018, results from 2018 are likely overestimates while the method established in 2019 is more accurate (e.g. consistent results) and applicable for future studies at the monitoring sites.

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 2019 are presented in Table 22.

Table 22: Annual mean concentrations in air for all targeted organic contaminants in 2019. 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	41	30	63
HCHs	6.1		3.4
DDTs	3.0		0.3
Chlordanes			0.6
PCB$_7$	2.7		1.7
PCB$_{sum}$	10		7.3
PAH-16	2000		500
PBDEs (excl. BDE-209)	0.6		0.7
TBA	4.0		9.8
HBCD	0.3		<0.2
PFOA	0.1	0.1	0.1
cVMS	13400		4800
SCCPs/MCCPs	550		500
PFAS (volatile)	100	60	60
nBFRs	1.4		0.7
OPFRs	180		350
Phthalates	2100		3300
Dechloranes	0.3		0.1

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 2019 show that the concentrations of most legacy POPs in air and precipitation are declining or have stabilized (reached temporal remote state conditions) during the last years. Significant for temporal remote state is that the primary emissions has stopped and that the long-term slow decline (removal rate) of a chemical in the environment is controlled by degradation rates in secondary repositories (Stroebe et al., 2004).

For HCB, an increase in concentrations has been observed at Zeppelin, Svalbard, during the last ten years, and at Birkenes during the last five years. However, the measurements from 2017-2019 suggests that the increasing trend for HCB has turned and is now apparently declining at Zeppelin and Birkenes.

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 2019 are presented in Table 23. The wet depositions are obtained by multiplying the volume weighted concentrations with the precipitation amounts (ng-mg/m^2) and the results for 2019 are presented in Table 24. 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 due to high emissions from the smelters in Nikel (Russia) close to the Norwegian border. Significantly higher levels of the heavy metals are observed when there is easterly wind from Russia and the Kola Peninsula. 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., 2019).

The levels and deposition of lead, cadmium and zinc observed are highest at Birkenes followed by Hurdal and Kårvatn reflecting the decreasing distances to the main emission sources in continental Europe (EMEP, 2019).

Table 163: Annual average volume weighted mean concentrations of heavy metals (µg/l) and mercury (ng/L) in precipitation in 2019.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	0.44	0.014	3.1	0.16	0.06	4.5	0.02	0.09	1.4	0.5	-	3.8
Hurdal	0.38	0.027	3.8	-	-	-	-	-	-	-	-	-
Kårvatn	0.50	0.007	2.6	-	-	-	-	-	-	-	-	-
Svanvik	1.01	0.090	4.4	40.9	0.7	56.0	1.18	0.39	-	0.8	88.9	-
Karpdalen	1.06	0.038	6.5	14.9	0.3	21.9	0.43	0.31	-	0.4	125.9	-

Table 174: Total wet deposition of heavy metals (µg/m^2) and mercury (ng/m^2) in 2019.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	842	27	5854	297	121	8674	31	178	2633	287	-	7660
Hurdal	513	37	5125	-	-	-	-	-	-	-	-	-
Kårvatn	393	10	3753	-	-	-	-	-	-	-	-	-
Svanvik	350	31	1507	14138	224	19390	409	136	0	266	30751	
Karpdalen	510	18	3125	7157	152	10523	208	149	0	191	60625	

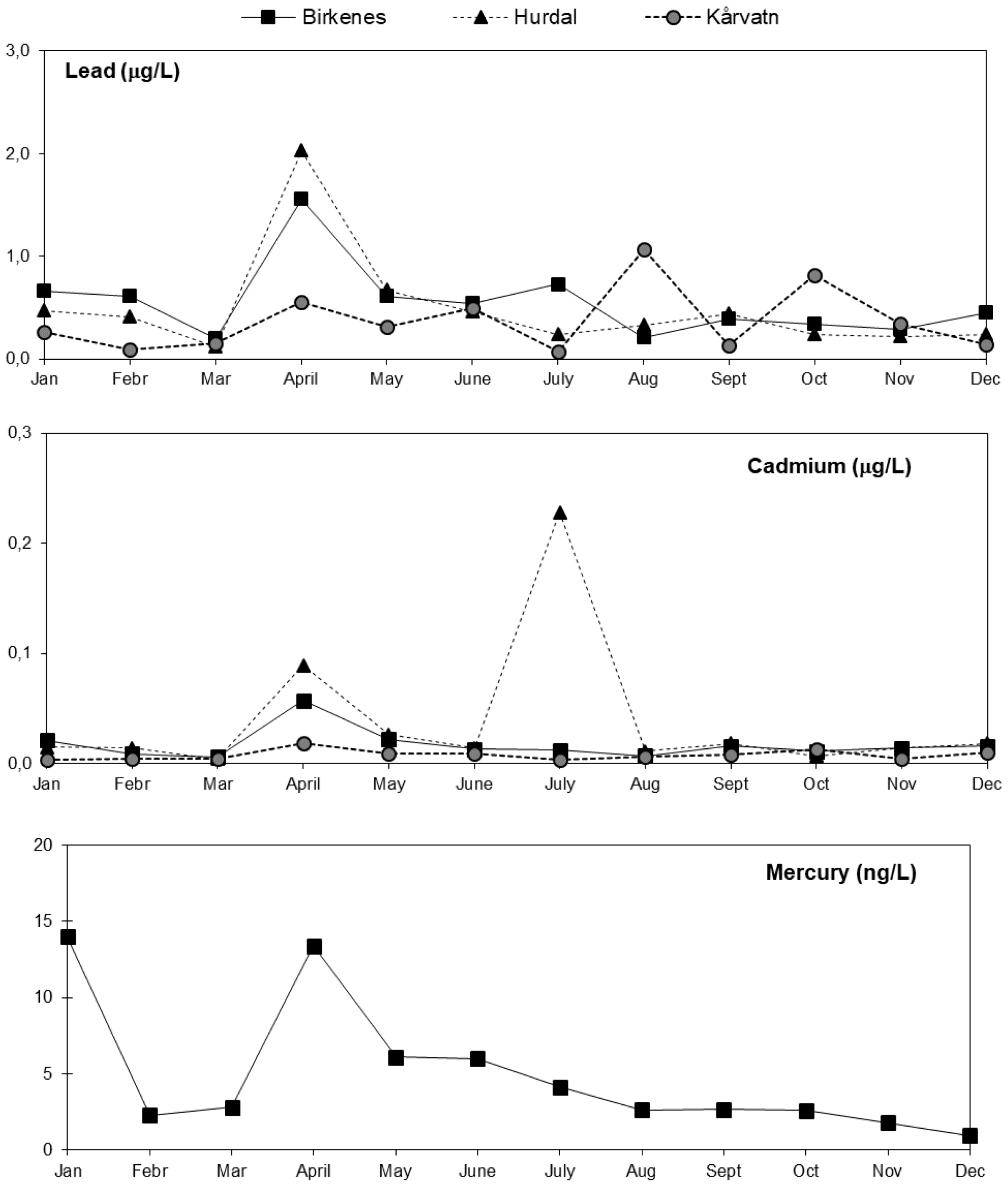


Figure 39: Volume weighted monthly mean concentrations of lead, cadmium and mercury in precipitation in 2019.

The monthly mean concentration for lead, cadmium and mercury are shown in Figure 39. There is no clear visual seasonal variation, but elevated levels for most components and sites are seen in April, and of cadmium at Hurdal in July. The spring peaks are also seen for heavy metals in aerosols and likely connected to episodes with long range transport of air pollution from the European continent. In 2019, there was an unusual large-scale event during April, which caused high concentrations of many pollutants at several of the mainland sites. April 2019 was the second warmest and second driest April in Norway since 1900 caused by a persistent high-pressure system in Europe with warm and dry air for a long period. The episode carried pollution from extensive fires in Eastern Europe, as well as dust from probably Sahara, and pollution from traffic and industry in continental Europe.This event is described in more details in the report on long-range transported air pollutants in Norway (Aas et al., 2020).

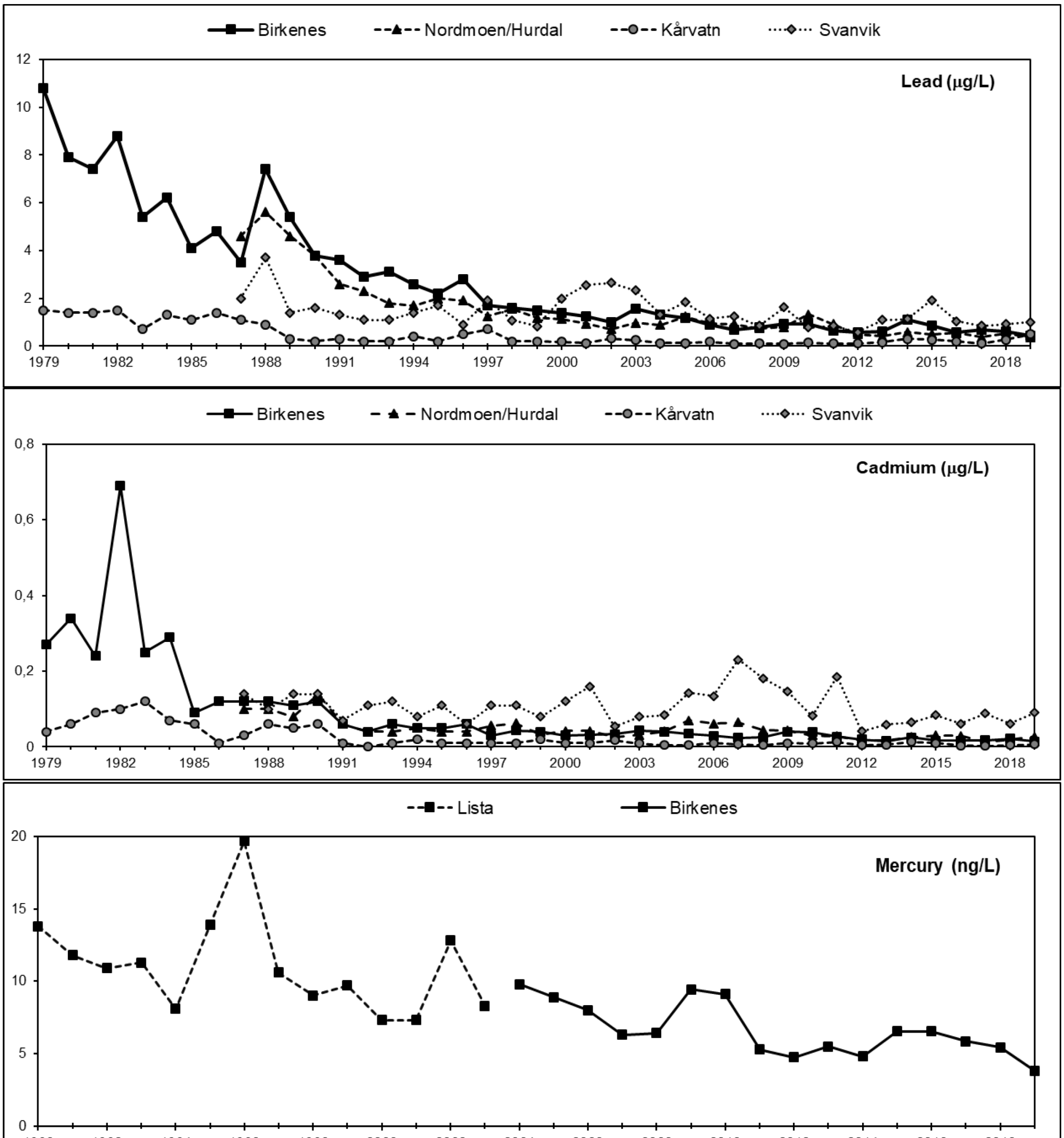


Figure 40: Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.

Figure 40 and Table A.2.26 show volume weighted annual mean concentrations in precipitation from 1979 to 2019. In 2019, the concentrations were in general somewhat lower than in 2018 at Birkenes an somewhat higher at Hurdal and Kårvatn.

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 at Birkenes and Kårvatn, (and Hurdal since 1990) have been largely reduced; almost 100% between 1980 and 2019; 38-98% since 1990, and 58-61% since 2000 (except at Hurdal with no significant trend since 2000) (Table 23). Also for cadmium in precipitation, there are substantial reductions: 95-99% between 1980 and 2019; 50-76% since 1990, and 54-68 % since 2000. except at Hurdal with no significant trend since 2000)

When combining the datasets from Lista and Birkenes, mercury levels appear to have been significantly reduced (64%) since 1990. However, this reduction might be influenced by different precipitation amounts and deposition rates at the two sites. For example, when comparing the precipitation amount at the two sites, slightly lower 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. There is also a decrease in mercury concentration at Birkenes from 2004 to 2019 with 44%. While the concentration of mercury in precipitation have decreased in a long term perspective, the precipitation depth have increased in the same time period. (Figure 41 and Table 2). Wet deposition is a combination of the two and has decreased at the same pace as concentration.

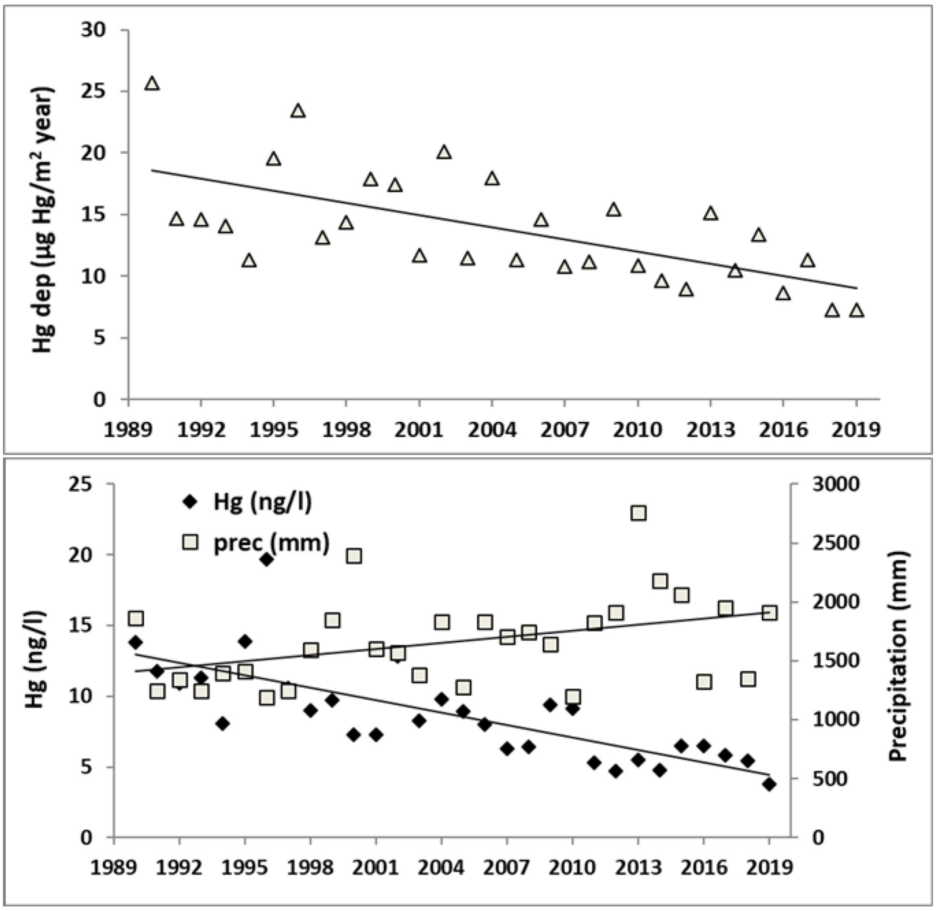


Figure 41. Time series of volume weighted annual mean concentration of mercury and the precipitation amount (bottom), and the wet deposition (top) at Lista (1989-2003) and Birkenes (2004-2019).

The concentrations of zinc in precipitation have been reduced by 68% since 1980 and 42% since 1990 at Birkenes. In contrast, a significant increase of zinc has been observed in precipitation at Kårvatn during the last periods (Table 23). There One should notice that the concentration level at Kårvatn is relativly 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 resuspention 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 and arsenic from 1990 and 2000 while no significant reduction trends for cadmium and the other trace elements, except of zinc from 2000. There are large annual variations in the concentration levels at this site, and this may be due to meteorological variations as well as changes in the composition of the ore used at the smelters in the Kola Peninsula. For further discussion, it is referred to the report by Berglen et al. (2019).

6.2 Heavy metals in air

The annual mean concentrations of the heavy metals measured in air in 2019 are given in Table 25, and the weekly concentrations of lead and cadmium are illustrated in Figure 44. 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 2019 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, 2019). 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 suggest nearby sources in Russia as discussed by Berglen et al. (2019).

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

Table 185: Annual average mean concentrations of heavy metals in air and aerosols in 2019 Unit: ng/m^3.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Fe	Hg(g)
Birkenes II	0.65	0.028	4.3	0.18	0.14	0.41	0.020	0.29	-	0.32	-	-	1.45
Andøya	0.20	0.007	1.1	0.21	0.04	1.14	0.015	0.20	0.51	0.23	-	-	1.41
Zeppelin	0.29	0.021	2.1	0.23	0.05	0.46	0.015	0.32	0.56	0.08	-	-	1.42
Trollhaugen	-	-	-	-	-	-	-	-	-	-	-	-	1.00
Svanvik	1.82	0.108	5.2	6.62	0.79	5.68	0.28	0.2	0.55	1.99	26.3	43.6	-
Karpdalen	2.47	0.171	7.4	7.2	1.3	6.4	0.28	0.20	0.41	2.6	17.3	34.4	-

As in previous years, the annual mean concentrations at Andøya and Zeppelin in 2019 are comparable; some elements are higher at one of the sites while others are higher at the other site. I.e. cadmium is relatively high at Zeppelin while cupper higher at Andøya (Table 25). These differences are due to individual episodes with elevated concentrations of heavy metals arriving to Zeppelin and Andøya, especially during the winter at Zeppelin in 2019, 2. The episodes with high levels of cadmium and lead are well correlated at the individual sites -especially for Birkenes and Andøya, Figure 42. 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. As mentioned for precipitation, it was an unusual episode in April with two waves of high concentrations of air pollution in large areas of Norway caused by a long dry period carrying air pollution from Europe, as illusted in Figure 42 and described in more details in Aas et al. (2019).

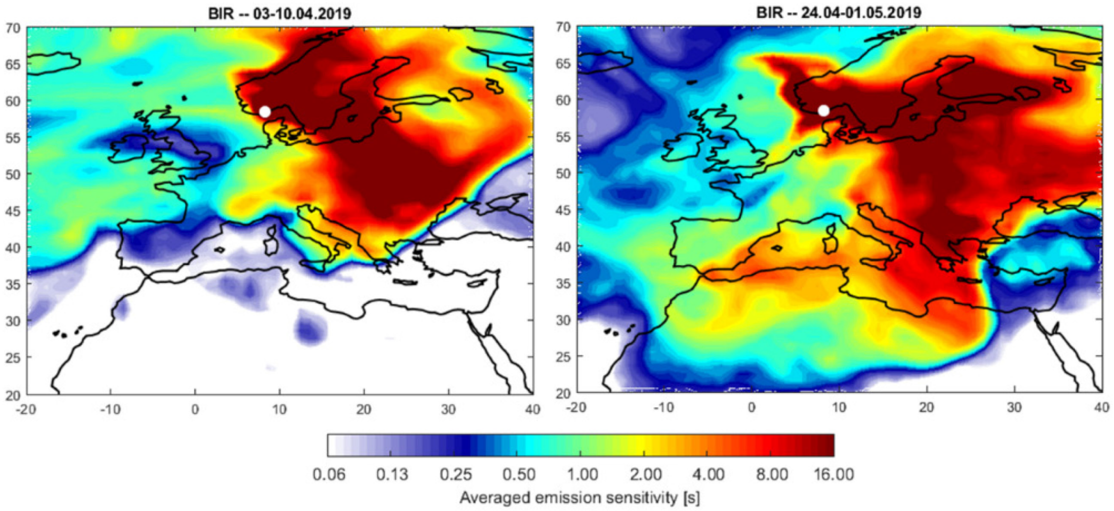


Figure 42. Footprint emission sensitivities calculated using the Flexpart model (Pisso et al., 2019) for the periods 3-10 April (top left) and 24 April-1 May (top right) at the Birkenes Observatory.

At Zeppelin there are some episodes of especially cadmium during the summer which are difficult to explain - maybe from nearby sources, while one very high episode of lead and cadmium in December (SO_2 is also elevated during this episode, Aas et al. 2020) when the air masses comes from Russia, Figure 43.

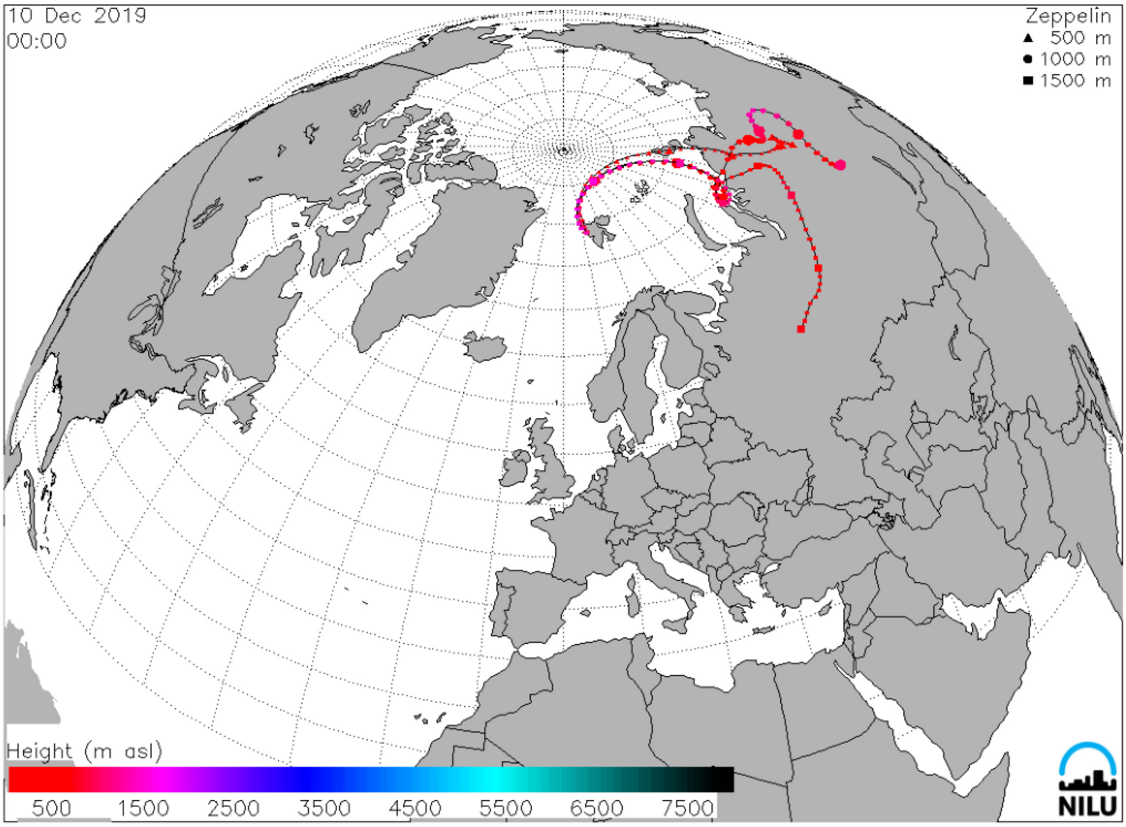


Figure 43. Air mass trajectories calculated using the Flextra model showing air masses arriving at Zeppelin the 10. December 2019.

The air concentrations at Birkenes and Andøya were slightly lower or equal in 2019 compared to 2018 while somewhat higher at Zeppelin. The long-term time series of the annual mean concentrations of lead, cadmium and mercury are shown in Figure 45, and the annual concentrations for all the elements for all years and sites can be found in Table A.2.28 - Table A.2. 34

At Lista/Birkenes there has been a significant reduction in air concentrations for all the measured elements for the period 1991 to 2019. At Zeppelin, there has also been a significant reduction since 1994 for several elements (As, Cd, Pb, V). The reduction for lead has been 88% and 65% respectively at Birkenes and Zeppelin (Table 27). For cadmium, the reductions were 69% and 55%, respectively. For mercury, a relatively small decreasing trends are observed both at Birkenes (22%) 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 Cr, Mn and Ni.

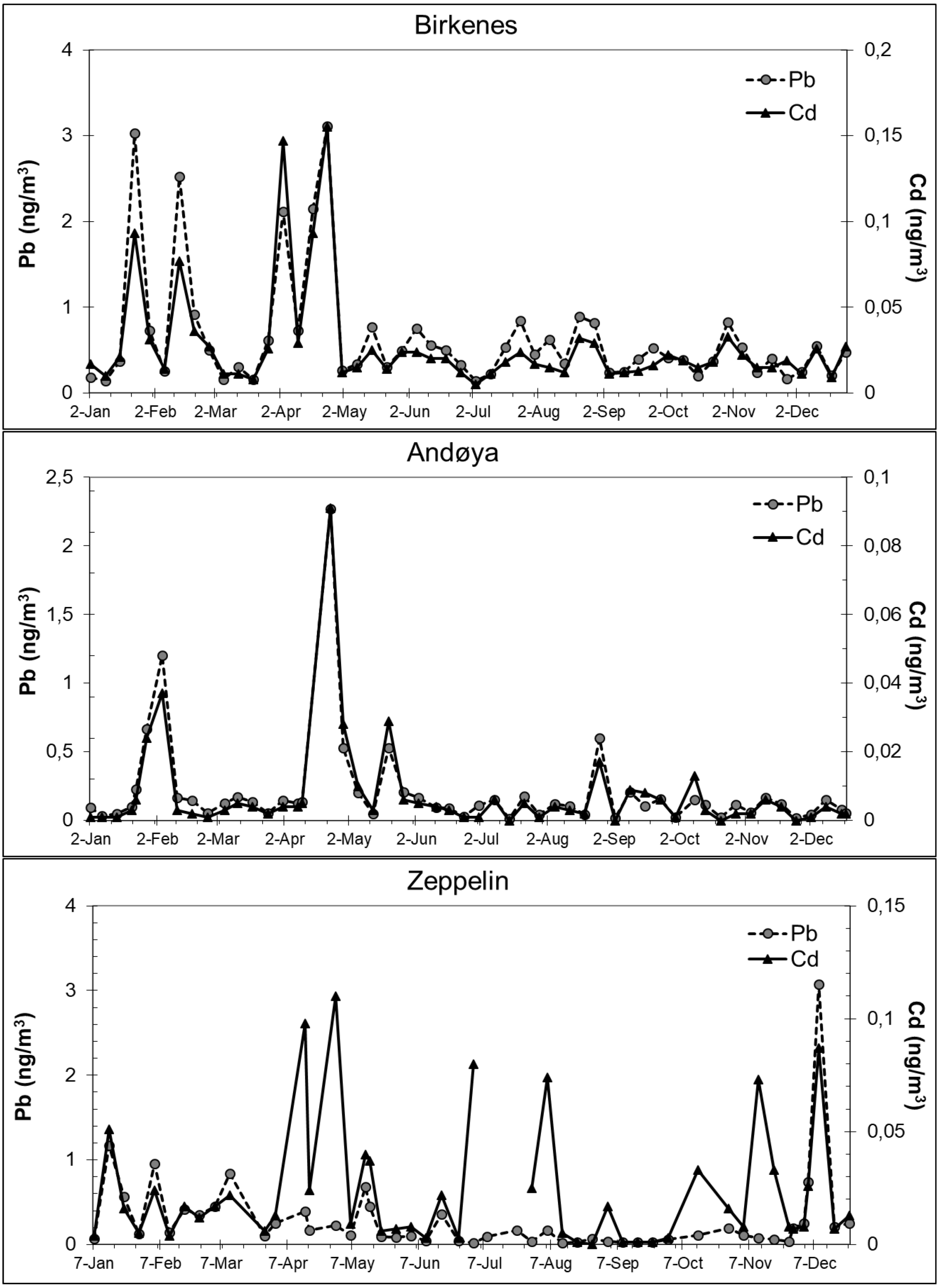


Figure 44: Weekly concentrations of lead and cadmium in air at Norwegian background stations in 2019, Unit: ng/m^3.

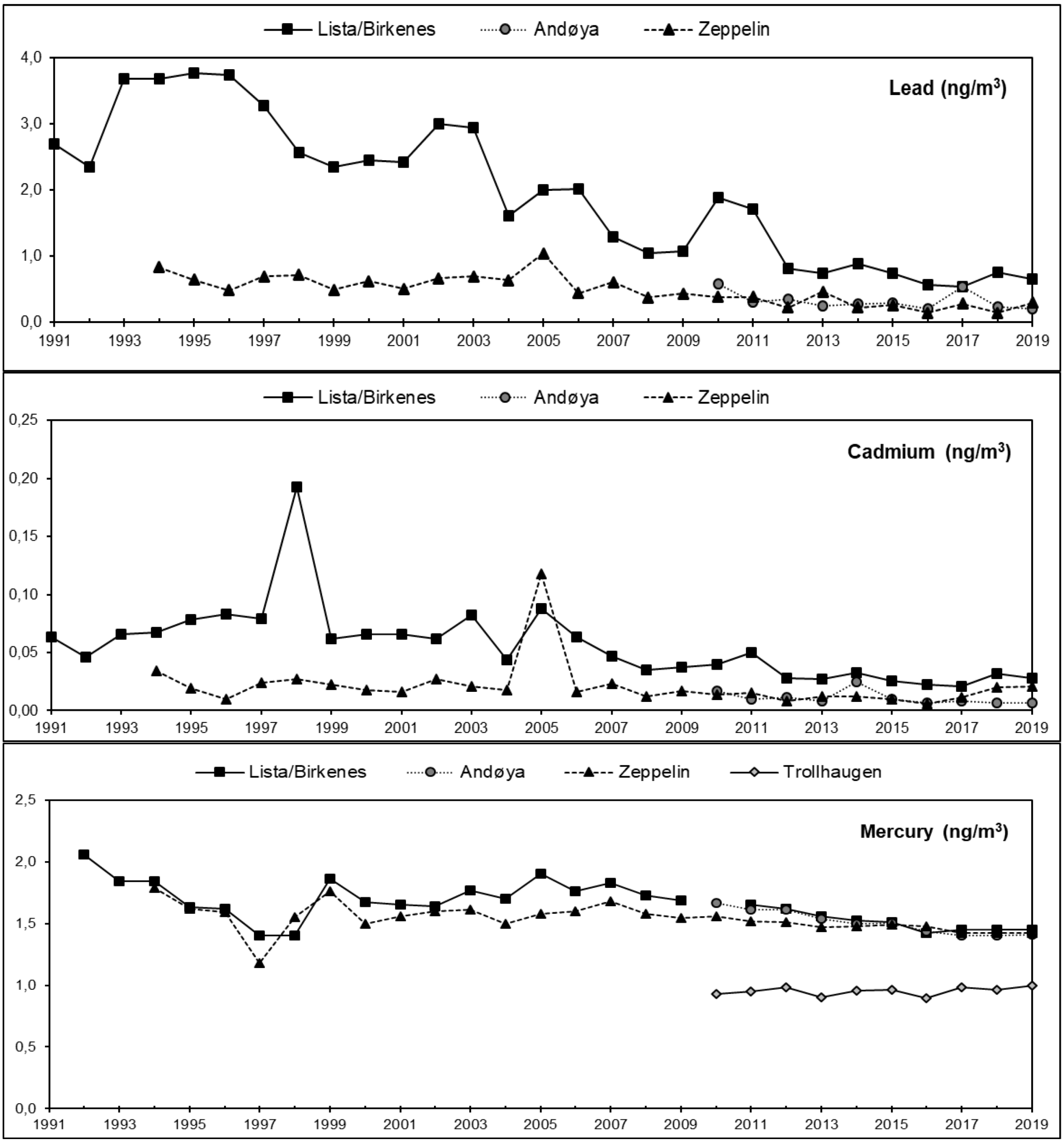


Figure 45: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2019, Unit: ng/m^3.

Table 196: Trends in heavy metal concentrations in precipitation, only significant (p=0.1) trends are shown. Positive trends shown in red.

Trends in precipitation, per cent change										
	Pb	**Cd**	**Zn**	**As**	**Co**	**Cr**	**Cu**	**Ni**	**Hg**	**mm (Hg)**
1980-2019										
Birkenes$^{1)}$	almost -100	almost -100	-68							24
Kårvatn	-98	-95	Not sign							Not sign.
1990-2019										
Birkenes$^{1)}$	-98	-76	-42						-64	40 (82)
Hurdal$^{2)}$	-87	-67	Not sign							41
Kårvatn	-38	-50	140							Not sign
Svanvik	-34	not sign	not sign	not sign	134	-34	211	163		Not sign
2000-2019										
Birkenes$^{1)}$	-61	-54	Not sign						-44	Not sign (43)
Hurdal	-58	-68	not sign							Not sign
Kårvatn	Not sign	Not sign	183							Not sign
Svanvik	-59	not sign	-40	-38	not sign	not sign	not sign	not sign		Not sign

1) Observations of Hg at Lista from 1990-2004

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

Table 207: Time trends of heavy metal concentrations in air (in %), only significant (p=0.1) trends are shown. Increasing trends are shown in red and decreasing trends are shown in black.

Trends in air, per cent change											
	Pb	**Cd**	**Zn**	**As**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**V**	**Hg**
1991(4)-2019											
Birkenes (from 1991)	-88	-69	-32	-69	-59	-82	-48		-76	-93	-22
Zeppelin (from 1994)	-65	-55	not sign	-68	not sign	not sign	not sign	76	not sign	-63	-13
2000-2019											
Birkenes	-84	-75	-48	-63	-50	-68	-58	-	-79	-97	-22
Zeppelin	-74	-51	not sign	-75	not sign	407	not sign	108	97	-40	-12

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Annex 1

Description of methods for sampling, chemical analysis and quality control

Table A.1.1: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides (OCPs) in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
HCB	57.4	49.7	45.1	42.9	42.2	30.5	26.9	24.5	32.6	43.3	52.7	44.5	40.9
α-HCH	1.99	1.66	1.83	9.48	3.46	3.05	2.80	4.84	4.08	3.63	5.97	2.54	3.76
γ-HCH	1.08	1.13	1.76	4.75	1.61	2.06	5.76	3.27	1.03	1.37	2.94	2.42	2.35
sum HCHs	3.07	2.79	3.59	14.23	5.07	5.11	8.56	8.11	5.11	5.00	8.91	4.96	6.11
pp-DDT	0.30	0.10	0.13	0.97	0.22	0.13	0.97	0.22	0.15	0.12	0.90	0.71	0.39
op-DDT	0.17	0.11	0.12	0.96	0.17	0.09	0.81	0.15	0.11	0.11	1.03	0.71	0.36
pp-DDE	1.22	0.85	1.08	2.96	0.60	0.30	1.59	0.67	0.32	0.61	10.90	5.43	2.08
op-DDE	0.10	0.06	0.07	0.22	0.05	0.02	0.09	0.03	0.02	0.04	0.45	0.21	0.11
pp-DDD	0.04	*<0.009*	*<0.009*	0.05	*<0.009*	*<0.009*	0.04	NaN	0.01	*<0.009*	0.05	0.05	*0.02*
op-DDD	0.03	0.01	0.02	0.06	0.02	0.01	0.05	0.03	0.02	0.02	0.05	0.04	0.03
sum DDTs	1.86	1.14	1.43	5.21	1.07	0.56	3.55	1.11	0.63	0.91	13.37	7.16	2.99

Table A.1.2: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
PCB-18	0.679	1.450	0.639	2.346	1.052	0.932	0.933	0.702	0.889	1.100	2.075	1.337	1.174
PCB-28	0.385	0.746	0.367	1.547	0.653	0.660	0.748	0.615	0.484	0.499	1.004	0.808	0.710
PCB-31	0.335	0.684	0.331	1.249	0.620	0.639	0.752	0.555	0.454	0.453	0.928	0.748	0.647
PCB-33	0.188	0.372	0.177	0.689	0.332	0.344	0.401	0.314	0.254	0.255	0.518	0.422	0.356
PCB-37	0.028	0.047	0.026	0.092	0.053	0.070	0.081	0.069	0.045	0.040	0.079	0.076	0.059
PCB-47	0.276	0.458	0.303	0.793	0.590	0.954	1.402	0.939	0.623	0.442	0.523	0.614	0.660
PCB-52	0.408	0.823	0.444	1.252	0.703	0.872	1.068	0.768	0.998	0.838	1.123	0.794	0.835
PCB-66	0.075	0.133	0.079	0.287	0.176	0.211	0.276	0.206	0.147	0.130	0.185	0.193	0.175
PCB-74	0.068	0.111	0.064	0.250	0.130	0.150	0.204	0.150	0.114	0.104	0.149	0.144	0.136
PCB-99	0.074	0.158	0.081	0.249	0.146	0.186	0.231	0.182	0.140	0.126	0.148	0.157	0.156
PCB-101	0.205	0.450	0.222	0.679	0.446	0.613	0.814	0.554	0.423	0.356	0.411	0.443	0.466
PCB-105	0.018	0.028	0.016	0.065	0.031	0.041	0.056	0.046	0.028	0.024	0.029	0.033	0.034
PCB-114	*<0.003*	*<0.003*	*<0.003*	0.007	*0.005*	*0.003*	*0.005*	*0.004*	*0.004*	*0.003*	*0.004*	*0.004*	*0.004*
PCB-118	0.057	0.108	0.054	0.213	0.113	0.151	0.201	0.157	0.102	0.083	0.105	0.114	0.121
PCB-122	*0.002*	0.004	<0,002	0.004	*0.004*	*0.004*	0.009	0.004	*0.005*	0.004	0.004	*0.005*	*0.004*
PCB-123	<0,002	0.003	*0.003*	*0.004*	0.005	*0.009*	0.005	0.006	*0.004*	0.003	0.004	0.007	*0.005*
PCB-128	0.013	0.018	0.009	0.036	0.018	0.028	0.044	0.029	0.019	0.017	0.016	*0.019*	0.022
PCB-138	0.078	0.146	0.069	0.247	0.167	0.232	0.327	0.222	0.153	0.106	0.134	0.161	0.170
PCB-141	0.020	0.035	0.017	0.064	0.049	0.071	0.130	0.063	0.044	0.031	0.034	0.042	0.048
PCB-149	0.133	0.283	0.133	0.377	0.298	0.431	0.642	0.390	0.283	0.214	0.231	0.292	0.307
PCB-153	0.146	0.278	0.133	0.411	0.288	0.433	0.586	0.416	0.250	0.179	0.218	0.271	0.301
PCB-156	0.006	0.007	0.003	*0.014*	0.011	0.010	0.018	0.009	0.007	0.005	0.009	0.008	0.009
PCB-157	<0,001	*0.001*	<0,001	0.002	*0.002*	0.002	*0.003*	*0.001*	*0.002*	0.002	0.002	*0.002*	*0.002*
PCB-167	0.003	0.004	*0.002*	0.008	0.004	0.006	0.009	0.005	0.005	0.003	0.004	0.005	0.005
PCB-170	0.011	0.015	0.007	0.023	0.016	0.022	0.034	0.019	0.017	0.009	0.016	0.016	0.017

Table A.1.2 (cont.):

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
PCB-180	0.033	0.048	0.019	0.070	0.049	0.068	0.104	0.062	0.051	0.029	0.044	0.050	0.052
PCB-183	0.013	0.019	0.009	0.028	0.020	0.031	0.048	0.028	0.021	0.016	0.017	0.021	0.023
PCB-187	0.032	0.059	0.030	0.068	0.057	0.089	0.129	0.079	0.063	0.049	0.043	0.067	0.063
PCB-189	*0.002*	*0.002*	<0.002	*0.002*	<0.003	<0.002	*0.003*	<0.002	*0.002*	<0.002	<0.002	*0.002*	*0.002*
PCB-194	*0.006*	*0.004*	*0.003*	0.009	*0.003*	0.004	*0.005*	0.003	0.005	0.002	0.004	0.004	0.004
PCB-206	*0.005*	<0,003	<0.003	*0.004*	<0.004	<0.003	*0.004*	<0.003	<0.003	<0.003	<0.003	*0.004*	*0.004*
PCB-209	<0.002	0.004	*0.002*	0.005	*0.002*	*0.002*	*0.003*	*0.002*	0.002	0.002	*0.002*	*0.002*	*0.002*
sum-trichlor	2.24	4.47	2.08	8.07	3.79	3.76	4.11	3.20	3.07	3.42	6.80	4.80	4.15
sum-tetrachlor	1.54	2.76	1.57	5.00	2.83	3.81	5.14	3.64	3.24	2.85	3.76	3.39	3.28
sum-pentachlor	0.56	1.18	0.61	2.06	1.23	1.69	2.34	1.66	1.25	1.07	1.03	1.13	1.31
sum-hexachlor	0.56	1.18	0.51	1.68	1.16	1.77	2.63	1.60	1.17	0.90	0.99	1.20	1.27
sum-heptachlor	0.11	0.19	0.08	0.28	0.20	0.29	0.47	0.27	0.22	0.15	0.16	0.20	0.22
sum-PCB7	1.31	2.60	1.31	4.42	2.42	3.03	3.85	2.79	2.46	2.09	3.04	2.64	2.66
sum PCB	5.03	9.80	4.85	17.10	9.22	11.32	14.70	10.38	8.96	8.39	12.76	10.72	10.23

Table A.1.3: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
BDE-28	0.004	0.009	0.007	0.007	0.010	0.009	0.005	0.008	0.006	0.006	0.003	0.004	0.006
BDE-47	0.025	0.048	0.046	0.035	0.060	0.062	0.028	0.049	0.034	0.030	0.024	0.022	0.038
BDE-49	0.003	0.012	0.007	0.008	0.007	0.008	0.005	0.008	NaN	NaN	0.002	0.004	0.006
BDE-66	0.034	0.007	0.004	0.006	0.004	0.005	0.003	0.004	0.003	<0.002	0.002	0.002	0.007
BDE-71	0.003	0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
BDE-77	<0.001	0.003	0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
BDE-85	*0.001*	0.003	0.002	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	*0.001*
BDE-99	0.011	0.039	0.016	0.021	0.015	0.017	0.009	0.015	0.015	0.012	0.010	0.012	0.016
BDE-100	0.003	0.011	0.006	0.006	0.005	0.006	0.003	0.005	0.004	0.003	0.002	0.003	0.005
BDE-119	0.004	0.002	0.002	0.002	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002
BDE-138	*0.003*	0.010	0.005	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.009	<0.002	<0.003	*0.004*
BDE-153	0.004	0.016	0.007	0.006	<0.002	NaN	0.003	0.003	0.004	<0.002	<0.002	0.007	0.005
BDE-154	0.003	0.013	0.006	0.008	0.003	0.004	<0.002	0.003	NaN	0.006	<0.002	0.007	0.005
BDE-183	0.008	0.057	0.004	0.018	0.030	0.025	0.204	0.012	0.011	0.021	0.003	0.024	0.034
BDE-196	0.007	0.049	0.018	NaN	0.011	0.012	0.013	0.010	0.012	0.031	<0.003	0.034	0.018
BDE-206	0.106	0.135	0.169	<0.079	<0.079	0.282	NaN	0.083	<0.079	<0.079	<0.077	<0.103	0.417
BDE-209	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
sum BDE													
sum BDE (excl. 209)	0.22	0.41	0.30	0.20	0.23	0.44	4.02	0.20	0.17	0.20	0.14	0.23	0.57
TBA	3.3828	3.95	2.67	2.65	3.44	2.61	2.42	3.01	4.48	5.99	6.51	7.38	4.04

Table A.1.4: Monthly and annual mean concentrations (pg/m³) for HBCDs in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
α-HBCD	<0.12	<0.12	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	0.02	0.05	0.01	*0.10*
β-HBCD	<0.04	<0.04	<0.05	<0.05	<0.09	<0.05	<0.05	<0.05	<0.05	<0.001	0.010	<0.005	*0.04*
γ-HBCD	<0.15	<0.15	<0.15	<0.15	<0.58	<0.15	<0.15	<0.15	<0.15	<0.001	0.009	<0.002	*0.15*
sum HBCD	*0.32*	*0.32*	*0.32*	*0.32*	*0.79*	*0.33*	*0.33*	*0.32*	*0.32*	*0.02*	*0.07*	*0.02*	*0.29*

Table A.1.5: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
1-Methylnaphthalene	0.081	0.059	0.067	0.046	0.023	0.016	0.014	0.012	0.018	0.508	0.185	0.083	0.111
1-Methylphenanthrene	0.038	0.062	0.035	0.049	0.040	0.026	0.018	0.016	0.018	0.037	0.054	0.050	0.037
2-Methylanthracene	<0.002	<0.002	<0.002	<0.003	<0.002	<0.003	<0.002	<0.002	<0.002	<0.005	<0.002	<0.002	*0.002*
2-Methylnaphthalene	0.091	0.065	0.088	0.061	0.035	0.022	0.022	0.017	0.024	0.683	0.228	0.082	0.144
2-Methylphenanthrene	0.038	0.062	0.061	0.054	0.050	0.047	0.033	0.035	0.024	0.049	0.078	0.070	0.050
3-Methylphenanthrene	0.033	0.051	0.053	0.044	0.044	0.040	0.030	0.031	0.022	0.045	0.068	0.063	0.044
9-Methylphenanthrene	0.012	0.019	0.015	0.020	0.017	0.015	0.012	0.012	0.009	0.017	0.021	0.022	0.016
Acenaphthene	0.050	0.071	0.254	0.055	0.062	0.045	0.048	0.044	0.043	0.087	0.071	0.095	0.076
Acenaphthylene	0.028	0.598	0.049	0.049	0.092	0.007	0.004	0.003	0.004	0.010	0.024	0.040	0.038
Anthanthrene	*0.002*	0.003	<0.001	0.006	*0.002*	<0.002	<0.002	<0.002	*0.001*	*0.001*	0.002	<0.001	*0.002*
Anthracene	0.008	0.047	<0.001	0.022	0.052	0.006	0.137	0.004	0.004	0.017	0.010	0.014	0.029
Benz(a)anthracene	0.013	0.017	0.010	0.026	0.008	0.003	0.002	0.003	0.003	0.012	0.014	0.011	0.010
Benzo(a)fluoranthene	0.004	0.004	*0.001*	0.006	*0.002*	<0.002	<0.001	*0.001*	*0.001*	0.003	0.004	*0.001*	0.003
Benzo(a)fluorene	0.010	0.013	0.008	0.014	0.009	0.005	0.002	0.004	0.003	0.010	0.012	0.011	0.009
Benzo(a)pyrene	0.015	0.017	0.004	0.035	0.014	0.004	0.002	0.005	0.004	0.010	0.015	0.003	0.011
Benzo(b)fluoranthene	0.050	0.043	0.053	0.078	0.074	0.024	0.015	0.026	0.012	0.049	0.035	0.037	0.042
Benzo(b)fluorene	0.004	0.007	0.004	0.007	0.005	0.003	0.001	0.002	0.002	0.006	0.006	0.008	0.005
Benzo(e)pyrene	0.030	0.029	0.035	0.050	0.046	0.015	0.010	0.015	0.007	0.027	0.023	0.023	0.026
Benzo(ghi)fluoranthene	NaN	NaN	<0.001	NaN	NaN	NaN	<0.001	<0.001	NaN	NaN	NaN	NaN	*0.001*
Benzo(ghi)perylene	0.036	0.033	0.028	0.053	0.036	0.012	0.009	0.012	0.007	0.025	0.027	0.020	0.025
Benzo(k)fluoranthene	0.017	0.015	0.011	0.031	0.020	0.006	0.004	0.007	0.004	0.014	0.013	0.010	0.013
Biphenyl	0.249	0.232	0.163	0.168	0.055	0.028	0.028	0.022	0.042	1.455	0.534	0.216	0.320
Chrysene	0.047	0.049	0.055	0.117	0.049	0.032	0.013	0.024	0.011	0.037	0.038	0.039	0.043
Coronene	*0.004*	0.012	0.005	0.044	0.011	0.004	*0.004*	0.004	*0.004*	0.008	0.010	0.008	0.010
Cyclopenta(cd)pyrene	<0.001	NaN	<0.001	NaN	<0.001	NaN	<0.001	<0.001	<0.001	<0.001	NaN	NaN	*0.001*

Table A.1.5. cont.

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
Dibenzo(ae)pyrene	0.005	0.005	0.005	0.012	0.008	<0.005	<0.005	<0.005	*0.003*	*0.005*	0.005	*0.004*	0.006
Dibenzo(ah)anthracene	0.005	0.004	0.004	0.008	0.005	*0.003*	<0.004	<0.004	*0.002*	0.003	0.004	0.002	0.004
Dibenzo(ah)pyrene	<0.003	<0.003	<0.003	<0.006	<0.003	<0.005	<0.006	<0.006	<0.003	<0.002	<0.003	<0.004	*0.004*
Dibenzo(ai)pyrene	<0.003	<0.003	<0.003	*0.006*	<0.003	<0.005	<0.006	<0.005	<0.003	<0.002	<0.003	<0.004	*0.004*
Dibenzofuran	0.770	0.809	0.656	0.635	0.381	0.219	0.171	0.130	0.175	0.284	1.178	0.878	0.519
Dibenzothiophene	0.011	0.021	0.048	0.036	0.034	0.043	0.024	0.020	0.014	0.012	0.030	0.026	0.025
Fluoranthene	0.184	0.275	0.158	0.286	0.177	0.124	0.093	0.116	0.078	0.151	0.274	0.267	0.182
Fluorene	0.493	0.579	0.535	0.391	0.336	0.151	0.195	0.109	0.154	0.307	0.962	0.762	0.413
Inden(123-cd)pyrene	0.030	0.026	0.018	0.049	0.032	0.009	0.007	0.010	0.007	0.024	0.024	0.016	0.021
Naphthalene	0.227	0.136	0.115	0.078	*0.045*	<0.031	<0.031	<0.031	*0.038*	1.186	0.513	0.228	0.266
Perylene	0.003	0.004	*0.002*	0.004	*0.002*	<0.002	<0.001	*0.001*	*0.001*	*0.002*	0.002	*0.001*	*0.002*
Phenanthrene	0.620	1.054	0.717	0.787	0.787	0.583	0.583	0.537	0.400	0.624	1.157	1.024	0.735
Pyrene	0.097	0.157	<0.004	0.154	0.097	0.056	0.036	0.038	0.042	0.098	0.133	0.133	0.095
Retene	0.035	0.069	0.030	0.043	0.027	0.021	0.018	0.052	0.033	0.069	0.065	0.051	0.044
Sum PAH	3.345	4.651	3.301	3.532	2.682	1.62	1.593	1.366	1.223	5.882	5.826	4.306	3.385
Sum PAH16	1.92	3.12	2.017	2.218	1.885	1.095	1.18	0.971	0.812	2.654	3.313	2.701	2.003

Table A.1.6: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
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	0.339	0.08	0.057	0.083	<0.04	0.066	<0.04	0.042	0.017	<0.04	0.046	0.05	0.08
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFHpA	<0.05	0.128	0.117	<0.05	0.113	0.198	0.147	0.154	<0.05	0.055	<0.05	<0.05	0.10
PFHxA	<0.05	0.074	<0.05	NaN	0.148	0.29	0.244	0.208	0.084	0.076	<0.05	0.061	0.12
PFHxS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	*0.02*
PFNA	<0.07	0.088	0.125	<0.07	0.122	0.133	0.123	0.139	<0.07	<0.07	<0.07	<0.07	0.10
PFOA	<0.05	0.13	0.137	0.123	0.157	0.242	0.232	0.28	0.082	0.071	0.069	0.114	0.14
PFOS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFOSA	<0.05	<0.05	<0.05	NaN	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFUnA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFNS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	*0.07*
PFPeA													
PFTrDA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	*0.07*
PFTeDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFHxDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFODcA	<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*
PFDS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	*0.1*
PFOSlin	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFDA	<0.05	<0.05	<0.05	<0.05	<0.05	0.059	<0.05	0.056	<0.05	<0.05	<0.05	<0.05	*0.05*
sum PFAS	*1.10*	*1.04*	*1.03*	*0.87*	*1.12*	*1.48*	*1.33*	*1.37*	*0.84*	*0.85*	*0.83*	*0.89*	*1.08*
sum PFAS$_{det}$	*0.34*	*0.50*	*0.44*	*0.21*	*0.54*	*0.93*	*0.75*	*0.82*	*0.18*	*0.20*	*0.12*	*0.23*	*0.44*

Table A.1.7: Monthly and annual mean concentrations (pg/m^3) for cVMSs in air at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
SCCP	203	83	165	245	283	273	347	160	224	149	327	295	216
MCCP	267	<190	<190	<190	<190	287	1507	336	<190	414	460	<190	327

Table A.1.8: Monthly and annual mean concentrations (ng/l) for HCB, HCHs and PCBs in precipitation at Birkenes, 2019

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
HCB	*0.11*	0.06	*0.03*	*0.13*	*0.26*	0.15	0.07	*0.05*	0.09	*0.05*	0.08	0.06	*0.08*
α-HCH	0.05	0.07	0.06	0.23	0.18	0.08	0.05	0.06	0.08	0.08	0.11	0.08	0.08
γ-HCH	0.06	0.12	0.04	0.06	0.24	0.30	0.16	0.18	0.12	0.11	0.12	0.13	0.14
sum HCH	0.12	0.17	0.07	0.22	0.41	0.35	0.20	0.21	0.19	0.18	0.19	0.21	0.21
PCB-28	0.012	0.007	*0.006*	*0.014*	*0.011*	*0.013*	0.007	0.005	*0.004*	*0.004*	0.005	0.005	*0.006*
PCB-52	0.011	0.007	0.006	*0.012*	0.010	0.008	*0.011*	*0.006*	*0.005*	0.005	0.005	0.006	*0.007*
PCB-101	*0.016*	*0.012*	*0.010*	*0.020*	*0.019*	*0.010*	*0.012*	*0.005*	*0.007*	*0.007*	*0.008*	*0.008*	*0.009*
PCB-118	0.009	*0.006*	*0.006*	*0.012*	0.008	*0.005*	*0.005*	0.002	*0.003*	0.003	0.005	0.006	*0.005*
PCB-138	*0.016*	*0.012*	*0.008*	*0.019*	*0.014*	*0.008*	*0.009*	*0.004*	*0.005*	*0.005*	0.008	0.010	*0.008*
PCB-153	*0.022*	*0.016*	*0.013*	*0.028*	*0.021*	*0.012*	*0.014*	*0.006*	*0.007*	*0.008*	*0.009*	*0.011*	*0.012*
PCB-180	0.010	0.006	*0.003*	*0.009*	*0.008*	*0.005*	*0.005*	*0.002*	*0.003*	*0.003*	0.004	*0.006*	*0.005*
sum PCB-7	0.096	0.065	0.051	0.115	0.091	0.061	0.063	0.030	0.034	0.035	0.045	0.051	0.052

Table A.1.9: Monthly and annual mean concentrations (pg/m^3) for hexachlorobenzene (HCB) in air at Andøya, 2019

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
HCB	41.9	36.8	44.2	39.9	40.0	18.9	14.8	17.4	29.4	30.2	24.9	36.1	30.3

Table A.1.10: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Andøya, 2019

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFHpA	0.067	0.058	0.054	0.083	0.108	0.212	0.186	0.106	<0.05	0.088	<0.05	<0.05	*0.09*
PFHxA	<0.05	<0.05	<0.05	<0.05	0.122	0.211	0.187	<0.05	<0.05	0.071	<0.05	<0.05	*0.08*
PFHxS	0.02	0.035	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	*0.02*
PFNA	0.079	<0.07	<0.07	<0.07	<0.07	0.124	0.087	<0.07	<0.07	<0.07	<0.07	<0.05	*0.08*
PFOA	0.146	0.148	0.08	0.095	0.132	0.195	0.171	0.118	0.082	0.095	0.062	0.068	*0.12*
PFOS	0.086	0.083	0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	*0.06*
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFNS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	*0.07*
PFPeA													
PFTrDA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	*0.07*
PFTeDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFHxDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFODcA	<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*
PFDS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	*0.1*
PFOSlin	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
PFDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
sum PFAS	*0.92*	*0.92*	*0.83*	*0.88*	*1.01*	*1.32*	*1.21*	*0.93*	*0.83*	*0.90*	*0.81*	*0.80*	*0.95*
sum PFAS$_{det}$	*0.40*	*0.32*	*0.18*	*0.18*	*0.36*	*0.74*	*0.63*	*0.27*	*0.08*	*0.25*	*0.06*	*0.07*	*0.45*

Table A.1.11: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
HCB	61.2	57.3	48.6	63.4	69.1	66.5	63.8	74.7	65.8	63.5	65.0	58.4	63.4
α-HCH	2.19	2.11	2.11	2.76	2.91	2.89	3.48	3.92	3.50	4.09	3.12	2.55	2.98
γ-HCH	0.32	0.39	0.39	0.53	0.34	0.24	0.55	0.35	0.52	0.52	0.44	0.39	0.41
sum HCHs	2.52	2.50	2.49	3.30	3.24	3.13	4.03	4.27	4.03	4.61	3.56	2.94	3.39
cis-CD	0.23	0.19	0.26	0.29	0.23	0.22	0.24	0.22	0.30	0.29	0.32	0.30	0.26
cis-NO	0.01	0.01	*0.01*	0.02	0.03	0.04	0.04	0.03	0.05	0.03	0.02	*0.02*	0.03
trans-CD	0.12	0.10	0.14	0.13	0.05	0.04	0.04	0.04	0.05	0.07	0.13	0.14	0.08
trans-NO	0.21	0.17	0.25	0.28	0.22	0.20	0.20	0.18	0.25	0.24	0.29	0.27	0.23
sum CHLs	0.57	0.48	0.66	0.72	0.53	0.50	0.52	0.47	0.65	0.63	0.77	0.73	0.60
pp-DDT	0.049	0.048	0.032	0.028	*0.011*	*0.008*	0.012	0.009	0.028	0.041	0.051	0.057	0.030
op-DDT	0.086	0.083	0.094	0.067	0.021	0.011	0.029	0.018	0.043	0.063	0.069	0.100	0.055
pp-DDE	0.449	0.436	0.320	0.160	0.030	0.024	0.044	0.032	0.094	0.204	0.296	0.596	0.218
op-DDE	0.063	0.070	0.060	0.039	0.009	*0.005*	0.012	0.008	0.012	0.025	0.032	0.065	0.032
pp-DDD	0.005	0.004	<0.005	<0.005	<0.005	<0.004	<0.004	<0.005	<0.005	<0.005	0.006	*0.004*	*0.005*
op-DDD	0.008	0.007	*0.006*	0.007	<0.004	<0.003	*0.007*	<0.004	0.006	0.005	0.009	0.008	0.006
sum DDTs	0.660	0.644	0.517	0.305	0.076	0.055	0.108	0.076	0.187	0.343	0.465	0.831	0.346

Table A.1.12: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
PCB-18	1.519	1.100	1.175	1.070	0.451	0.430	0.844	0.677	0.616	0.705	0.839	0.949	0.855
PCB-28	0.887	0.778	0.711	0.809	0.596	0.881	1.243	0.967	0.712	0.624	0.660	0.627	0.808
PCB-31	0.793	0.616	0.603	0.698	0.507	0.767	1.128	0.872	0.646	0.552	0.605	0.580	0.713
PCB-33	0.535	0.413	0.400	0.478	0.389	0.635	0.889	0.683	0.471	0.330	0.411	0.388	0.518
PCB-37	0.100	0.089	0.073	0.091	0.092	0.163	0.230	0.165	0.128	0.048	0.097	0.082	0.118
PCB-47	0.278	0.251	0.212	0.254	0.157	0.201	0.286	0.234	0.204	0.083	0.228	0.210	0.220
PCB-52	0.566	0.551	0.495	0.536	0.291	0.302	0.505	0.414	0.397	0.315	0.529	0.432	0.443
PCB-66	0.151	0.151	0.133	0.144	0.095	0.127	0.180	0.139	0.134	0.051	0.152	0.130	0.134
PCB-74	0.118	0.131	0.106	0.116	0.067	0.080	0.120	0.094	0.095	*0.034*	0.111	0.098	0.098
PCB-99	0.125	0.132	0.127	0.116	0.051	0.043	0.072	0.057	0.071	*0.031*	0.091	0.094	0.083
PCB-101	0.290	0.299	0.269	0.279	0.148	0.144	0.226	0.173	0.205	0.096	0.227	0.211	0.213
PCB-105	0.042	0.048	0.039	0.030	0.012	0.011	0.018	0.013	0.017	*0.007*	0.023	0.027	0.023
PCB-114	0.004	0.003	0.004	*0.003*	<0.002	*0.001*	*0.003*	0.002	0.003	*0.002*	*0.004*	<0.002	*0.003*
PCB-118	0.121	0.133	0.117	0.091	0.040	0.037	0.061	0.045	0.056	*0.025*	0.075	0.081	0.072
PCB-122	0.003	*0.002*	0.004	<0.002	*0.001*	*0.001*	*0.001*	0.002	0.002	*0.001*	*0.004*	*0.002*	*0.002*
PCB-123	0.003	0.004	0.004	*0.003*	<0.001	<0.001	0.003	0.002	0.002	*0.001*	0.004	*0.002*	*0.002*
PCB-128	0.019	0.022	0.007	0.015	0.005	0.004	0.007	0.005	0.007	*0.004*	0.009	0.008	0.009
PCB-138	0.102	0.108	0.097	0.083	0.036	0.027	0.045	0.035	0.052	*0.026*	0.062	0.067	0.060
PCB-141	0.021	0.024	0.021	0.019	0.008	0.007	0.012	0.009	0.014	*0.008*	0.015	0.008	0.013
PCB-149	0.128	0.127	0.116	0.126	0.070	0.059	0.096	0.075	0.104	0.058	0.110	0.102	0.097
PCB-153	0.125	0.170	0.146	0.141	0.057	0.040	0.068	0.053	0.074	0.043	0.095	0.094	0.090
PCB-156	0.009	0.010	0.006	0.004	0.002	0.001	0.002	0.002	0.002	*0.002*	0.003	*0.003*	0.004
PCB-157	*0.002*	*0.002*	*0.003*	<0.002	<0.001	<0.001	*0.001*	<0.001	*0.001*	<0.001	*0.001*	<0.001	*0.001*
PCB-167	0.003	0.003	0.004	*0.003*	*0.001*	<0.001	0.001	0.001	0.001	*0.001*	*0.002*	0.002	*0.002*

Table A.1.12 (cont.)

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
PCB-170	0.008	0.007	0.006	0.006	*0.003*	*0.002*	0.003	0.002	0.003	*0.003*	0.004	0.005	0.004
PCB-180	0.021	0.018	0.009	0.016	0.007	0.004	0.008	0.006	0.011	*0.008*	0.013	0.013	0.011
PCB-183	0.008	0.008	0.008	0.009	0.003	0.002	0.004	0.004	0.007	*0.003*	0.006	0.005	0.006
PCB-187	0.020	0.020	0.017	0.024	0.010	0.007	0.014	0.010	0.017	*0.010*	0.020	0.019	0.016
PCB-189	*0.001*	*0.001*	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	*0.001*
PCB-194	*0.002*	*0.002*	<0.002	<0.003	<0.002	<0.001	*0.001*	<0.001	*0.001*	<0.001	<0.001	<0.002	*0.002*
PCB-206	*0.002*	<0.002	<0.005	<0.005	<0.002	<0.001	<0.002	<0.002	<0.002	<0.002	<0.002	<0.001	*0.002*
PCB-209	0.005	0.006	*0.004*	<0.003	0.002	0.002	0.002	0.001	0.002	*0.001*	0.003	0.004	*0.003*
sum-trichlor	5.23	4.21	4.17	4.34	2.66	3.71	5.74	4.50	3.54	3.96	3.69	3.83	4.17
sum-tetrachlor	2.35	2.26	1.97	2.13	1.29	1.49	2.39	1.90	1.78	2.28	2.02	1.94	1.98
sum-pentachlor	1.03	1.04	0.90	0.90	0.44	0.43	0.71	0.55	0.55	0.77	0.52	0.38	0.67
sum-hexachlor	0.60	0.63	0.50	0.52	0.26	0.22	0.37	0.29	0.37	0.37	0.37	0.35	0.40
sum-heptachlor	0.07	0.07	0.04	0.06	0.03	0.02	0.04	0.03	0.04	0.10	0.04	0.04	0.04
sum-PCB7	2.11	2.06	1.85	1.95	1.18	1.43	2.16	1.69	1.51	1.14	1.66	1.52	1.70
sum PCB	9.28	8.22	7.59	7.97	4.68	5.87	9.26	7.28	6.29	7.41	6.65	6.56	7.28

Table A.1.13:: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
BDE-28	0.007	0.006	0.007	0.009	0.005	0.008	0.014	0.012	0.006	0.006	0.003	NaN	0.008
BDE-47	0.090	0.077	0.126	0.193	0.123	0.189	0.149	0.104	0.075	0.163	0.065	NaN	0.125
BDE-49	0.004	0.004	0.005	0.007	0.005	0.005	0.008	0.008	0.007	0.026	0.074	NaN	0.012
BDE-66	0.003	0.003	0.003	0.004	0.003	0.004	0.006	0.007	*0.008*	*0.025*	*0.049*	NaN	0.010
BDE-71	<0.001	<0.001	*0.003*	*0.002*	<0.001	<0.001	*0.004*	*0.005*	*0.006*	*0.023*	0.071	NaN	*0.009*
BDE-77	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	*0.004*	*0.006*	*0.003*	<0.001	<0.001	NaN	*0.002*
BDE-85	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	*0.004*	*0.005*	*0.003*	<0.001	<0.001	NaN	*0.002*
BDE-99	0.015	0.015	0.026	0.041	0.035	0.052	0.048	0.026	0.017	0.018	0.012	NaN	0.029
BDE-100	0.006	0.006	0.009	0.016	0.012	0.016	0.016	0.012	0.007	0.009	0.004	NaN	0.011
BDE-119	*0.001*	<0.001	*0.007*	*0.004*	<0.001	<0.001	*0.005*	*0.008*	*0.003*	*0.003*	*0.004*	NaN	*0.003*
BDE-138	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	*0.009*	*0.010*	*0.005*	<0.003	<0.003	NaN	*0.004*
BDE-153	0.004	0.004	0.004	*0.004*	*0.003*	<0.003	*0.012*	0.012	*0.006*	<0.004	<0.003	NaN	*0.006*
BDE-154	0.003	*0.002*	0.003	*0.003*	*0.002*	0.003	0.011	0.011	*0.005*	<0.003	<0.002	NaN	*0.005*
BDE-183	0.006	*0.004*	0.004	*0.003*	*0.003*	*0.003*	*0.010*	*0.012*	*0.006*	<0.004	<0.003	NaN	*0.006*
BDE-196	<0.006	*0.008*	*0.013*	<0.010	<0.006	<0.005	*0.020*	*0.006*	*0.009*	*0.023*	<0.006	NaN	*0.010*
BDE-206	0.422	0.389	1.187	1.083	*0.155*	*0.106*	0.329	*0.104*	0.237	NaN	0.342	NaN	0.484
BDE-209	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
sum BDE													
sum BDE (excl. 209)	0.57	0.52	1.40	1.38	0.36	0.40	0.65	0.35	0.40	2.10	0.64	0.00	0.725
TBA	2.94	3.42	2.40	3.47	4.31	12.58	19.78	25.65	12.25	8.09	8.62	NaN	9.77

Table A.1.14: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
α-HBCD	NaN	0.011	1.140	0.131	0.084	0.027	0.027	0.056	0.197	0.031	0.049	0.043	0.121
β-HBCD	*0.009*	*0.003*	0.223	0.024	0.016	0.004	*0.009*	0.008	0.033	<0.004	*0.007*	*0.004*	*0.021*
γ-HBCD	<0.012	<0.015	0.131	*0.020*	<0.014	<0.015	<0.010	<0.015	0.026	<0.021	<0.015	<0.013	*0.021*
sum HBCD	*0.02*	*0.03*	*1.49*	*0.17*	*0.11*	*0.05*	*0.05*	*0.08*	*0.26*	*0.06*	*0.07*	*0.06*	*0.16*

Table A.1.15: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
1-Methylnaphthalene	0.172	0.102	0.043	0.019	0.018	0.021	0.018	0.009	0.017	0.044	0.053	0.164	0.057
1-Methylphenanthrene	0.003	0.002	0.001	*0.001*	*0.001*	0.002	0.002	0.002	0.001	0.001	*0.001*	0.002	0.002
2-Methylanthracene	<0.001	<0.001	<0.001	<0.001	<0.001	NaN	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
2-Methylnaphthalene	0.212	0.128	0.051	0.029	0.022	0.036	0.032	0.016	0.027	0.062	0.065	0.177	0.073
2-Methylphenanthrene	0.007	0.003	0.001	0.001	0.001	0.004	0.004	0.003	0.002	0.002	0.002	0.003	0.003
3-Methylphenanthrene	0.005	0.002	0.001	*0.001*	*0.001*	0.003	0.003	0.002	0.002	0.002	0.001	0.002	0.002
9-Methylphenanthrene	0.003	0.001	<0.001	<0.001	<0.001	0.002	0.002	0.002	0.001	0.001	<0.001	0.001	0.001
Acenaphthene	0.010	0.004	0.003	*0.002*	<0.005	<0.005	*0.007*	*0.004*	0.003	0.004	0.005	0.008	0.005
Acenaphthylene	<0.001	<0.001	<0.001	*0.001*	<0.007	<0.001	<0.002	*0.002*	0.001	0.002	0.002	0.002	*0.002*
Anthanthrene	*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*
Anthracene	0.001	*0.001*	<0.001	<0.001	*0.002*	<0.001	*0.004*	*0.003*	*0.003*	<0.001	<0.001	*0.001*	*0.002*
Benz(a)anthracene	0.010	0.004	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	<0.001	0.003	*0.002*
Benzo(a)fluoranthene	*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*
Benzo(a)fluorene	0.005	0.002	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	*0.002*
Benzo(a)pyrene	0.010	0.005	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	*0.002*	<0.001	<0.001	0.002	*0.002*
Benzo(b)fluoranthene	0.024	0.012	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.002*	0.002	0.008	*0.005*
Benzo(b)fluorene	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*
Benzo(e)pyrene	0.013	0.007	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.001*	*0.001*	0.005	*0.003*
Benzo(ghi)fluoranthene	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*
Benzo(ghi)perylene	0.013	0.007	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.001*	0.001	0.005	*0.003*
Benzo(k)fluoranthene	0.010	0.005	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	*0.001*	*0.001*	0.004	*0.002*
Biphenyl	0.855	0.813	0.581	0.084	0.015	0.012	0.016	0.034	0.045	0.150	0.268	0.576	0.279
Chrysene	0.023	0.011	0.004	*0.001*	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.001*	0.001	0.006	*0.005*
Coronene	0.006	0.003	0.001	<0.001	<0.002	<0.001	<0.001	<0.001	*0.001*	*0.001*	*0.002*	0.003	*0.002*
Cyclopenta(cd)pyrene	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*

Table A.1.15 cont.

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
Dibenzo(ae)pyrene	*0.002*	*0.001*	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	*0.002*	*0.002*
Dibenzo(ah)anthracene	*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*
Dibenzo(ah)pyrene	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.003	<0.003	<0.003	*0.002*
Dibenzo(ai)pyrene	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	0.003	<0.003	<0.003	*0.002*
Dibenzofuran	1.049	0.960	0.625	0.179	0.031	0.016	0.020	0.055	0.094	0.198	0.357	0.702	0.345
Dibenzothiophene	0.009	0.007	0.004	*0.001*	<0.001	<0.001	*0.001*	*0.001*	0.002	0.003	0.004	0.005	0.003
Fluoranthene	0.087	0.042	0.012	0.003	*0.003*	*0.003*	<0.002	<0.002	*0.004*	0.005	0.006	0.030	0.017
Fluorene	0.538	0.368	0.142	0.020	0.009	0.010	0.012	0.014	0.023	0.068	0.135	0.351	0.139
Inden(123-cd)pyrene	0.014	0.006	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	*0.003*
Naphthalene	0.766	0.727	0.300	0.080	0.065	0.090	0.090	0.048	0.094	0.182	0.251	0.682	0.273
Perylene	*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*
Phenanthrene	0.142	0.073	0.023	0.008	*0.006*	0.012	0.014	0.012	0.012	0.015	0.015	0.055	0.032
Pyrene	0.020	0.020	0.006	*0.002*	*0.002*	*0.002*	<0.002	*0.002*	*0.003*	*0.002*	0.002	0.013	0.006
Retene	0.005	0.002	<0.001	<0.001	*0.002*	<0.001	<0.002	<0.002	<0.001	*0.002*	<0.001	0.002	*0.002*
Sum PAH	4.029	3.329	1.829	0.456	0.215	0.24	0.256	0.233	0.361	0.771	1.198	2.834	1.285
Sum PAH16	1.671	1.287	0.505	0.125	0.106	0.132	0.142	0.094	0.154	0.288	0.426	1.176	0.499

Table A.1.16: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
FTS 4:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04		*0.04*
FTS 6:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NaN	NaN	*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	NaN	*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	NaN	*0.02*
PFDoDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.095	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFHpA	<0.05	<0.05	0.087	0.132	0.126	0.097	0.261	<0.05	<0.05	<0.05	0.112	NaN	*0.10*
PFHxA	<0.05	<0.05	0.109	<0.05	<0.05	0.123	0.433	<0.05	<0.05	<0.05	0.14	NaN	*0.10*
PFHxS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NaN	*0.02*
PFNA	<0.07	<0.07	0.073	0.103	<0.07	<0.07	0.158	<0.05	<0.07	<0.07	0.114	NaN	*0.08*
PFOA	0.072	<0.05	0.208	0.129	0.078	0.1	0.413	0.079	0.059	0.055	0.323	NaN	*0.14*
PFOS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFOSA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFUnA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFPS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NaN	*0.02*
PFHpS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFNS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	NaN	*0.07*
PFPeA													
PFTrDA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	NaN	*0.07*
PFTeDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFHxDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFODcA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFDS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NaN	*0.10*
PFOSlin	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NaN	*0.05*
PFDA	<0.05	<0.05	0.088	<0.05	<0.05	<0.05	0.188	0.056	<0.05	<0.05	0.14	NaN	*0.07*
sum PFAS	0.822	*0.8*	*1.10*	*0.99*	*0.90*	*0.97*	*2.03*	*0.82*	*0.81*	*0.805*	*1.32*	*0.00*	*1.03*
sum PFAS$_{det}$	0.072	*0.000*	*0.565*	*0.364*	*0.204*	*0.320*	*1.453*	*0.135*	*0.059*	*0.055*	*0.829*	*0.000*	*0.495*

Table A.1.17: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Zeppelin, 2019

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
SCCP	236	240	125	236	213	198	186	228	241	301	350	175	230
MCCP	197	324	208	159	169	44	50	73	130	187	271	331	241

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 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.66	0.61	0.20	1.56	0.61	0.54	0.73	0.21	0.39	0.34	0.29	0.45	0.44
Hurdal	0.47	0.41	0.12	2.03	0.67	0.46	0.24	0.33	0.44	0.24	0.22	0.24	0.38
Kårvatn	0.26	0.09	0.15	0.55	0.31	0.49	0.07	1.07	0.13	0.82	0.34	0.14	0.27
Svanvik	0.33	1.45	0.41	0.41	2.98	0.83	0.78	1.13	0.56	1.04	0.74	0.91	1.01
Karpbukt	0.38	0.63	1.09	0.72	0.88	0.55	1.33	1.41	2.13	0.75	1.75	2.62	1.06

Table A.2.2: Monthly and annual volume weighted mean concentrations of cadmium in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.021	0.009	0.006	0.057	0.022	0.013	0.012	0.007	0.016	0.011	0.014	0.016	0.014
Hurdal	0.015	0.014	0.004	0.089	0.026	0.014	0.228	0.011	0.018	0.007	0.014	0.018	0.027
Kårvatn	0.003	0.004	0.004	0.018	0.009	0.009	0.003	0.006	0.008	0.013	0.004	0.010	0.007
Svanvik	0.033	0.137	0.024	0.019	0.269	0.030	0.073	0.065	0.058	0.203	0.109	0.138	0.090
Karpbukt	0.027	0.035	0.041	0.023	0.045	0.021	0.024	0.057	0.118	0.018	0.049	0.066	0.038

Table A.2.3: Monthly and annual volume weighted mean concentrations of zinc in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DES	2019
Birkenes	8.2	3.7	1.4	8.7	4.0	3.7	3.8	1.6	3.5	2.3	1.9	2.4	3.1
Hurdal	2.5	3.7	2.1	13.2	5.4	3.6	8.4	2.7	2.9	2.1	3.9	3.8	3.8
Kårvatn	1.7	2.7	1.9	3.3	4.7	4.6	1.2	3.6	0.8	5.5	3.2	4.4	2.6
Svanvik	1.6	4.0	2.5	2.6	13.5	3.6	3.7	3.5	4.0	5.4	4.8	3.1	4.4
Karpbukt	10.0	8.8	12.7	5.7	7.8	4.8	3.5	3.5	7.5	2.9	6.3	10.0	6.5

Table A.2.4: Monthly and annual volume weighted mean concentrations of nickel in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.19	0.16	0.09	0.29	0.21	0.16	0.19	0.06	0.16	0.11	0.14	0.27	0.16
Svanvik	9.37	118.68	39.43	35.30	100.72	24.02	34.73	24.29	43.75	30.61	38.27	32.36	40.86
Karpbukt	8.08	11.67	13.14	11.68	18.63	6.53	13.02	37.98	85.52	3.91	10.72	10.99	14.86

Table A.2.5: Monthly and annual volume weighted mean concentrations of arsenic in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.11	0.04	0.03	0.25	0.07	0.03	0.04	0.04	0.11	0.06	0.05	0.06	0.06
Svanvik	0.19	1.02	0.30	0.39	2.09	0.36	0.75	0.73	0.65	0.31	0.55	0.38	0.65
Karpbukt	0.20	0.22	0.28	0.23	0.45	0.22	0.30	0.74	1.04	0.09	0.26	0.30	0.32

Table A.2.6: Monthly and annual volume weighted mean concentrations of copper in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	1.73	11.15	0.28	7.77	12.79	11.49	24.37	1.23	0.84	0.78	0.93	1.47	4.53
Svanvik	23.49	110.81	33.90	37.90	143.98	49.10	39.21	22.35	38.06	59.64	56.32	71.88	56.03
Karpbukt	9.18	17.56	21.74	26.49	30.67	28.33	12.66	27.11	65.01	6.56	15.58	18.12	21.85

Table A.2.7: Monthly and annual volume weighted mean concentrations of cobalt in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.01	0.01	0.01	0.09	0.02	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.02
Svanvik	0.31	3.21	0.93	0.88	2.97	0.71	0.96	0.72	1.21	1.12	0.91	1.06	1.18
Karpbukt	0.23	0.33	0.37	0.34	0.56	0.22	0.42	1.10	2.24	0.11	0.31	0.31	0.43

Table A.2.8: Monthly and annual volume weighted mean concentrations of chromium in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.06	0.11	0.06	0.21	0.11	0.18	0.15	0.06	0.12	0.06	0.08	0.07	0.09
Svanvik	0.11	0.73	0.29	0.24	1.07	0.34	0.34	0.38	0.42	0.21	0.30	0.15	0.39
Karpbukt	0.12	0.18	0.39	0.34	0.46	0.26	0.34	0.57	1.10	0.09	0.20	0.27	0.31

Table A.2.9: Monthly and annual volume weighted mean concentrations of manganese in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.57	0.40	0.30	14.08	2.53	2.19	2.29	0.69	1.46	0.60	0.55	0.53	1.38

Table A.2.10: Monthly and annual volume weighted mean concentrations of vanadium in precipitation at Norwegian background stations 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	0.14	0.13	0.09	0.43	0.17	0.25	0.19	0.09	0.17	0.12	0.11	0.15	0.15
Svanvik	0.46	1.66	0.25	0.25	1.73	0.35	0.30	0.37	0.37	0.33	1.70	2.31	0.77
Karpbukt	0.35	0.47	0.30	0.29	0.60	0.28	0.33	0.43	0.51	0.15	0.45	0.78	0.40

Table A.2.11: Monthly and annual volume weighted mean concentrations of aluminium in precipitation at Svanvik and Karpdalen. 2019. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Svanvik	14.77	34.95	18.42	13.48	62.70	38.46	22.54	211.17	409.96	61.10	26.13	11.46	88.86
Karpbukt	16.91	30.73	18.10	25.18	37.02	31.22	349.20	672.97	685.23	51.88	15.76	24.45	125.91

Table A.2.12: Monthly and annual average volume weighted mean concentrations of mercury in precipitation at Birkenes in 2019. Unit: ng/l

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	14.0	2.3	2.8	13.4	6.1	6,0	4.1	2.6	2.7	2.6	1.8	0.9	3.8

Table A.2.13: Annual and monthly total precipitation in 2019. 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**	**2019**
Birkenes	98.45	89.13	135.53	56.95	99.94	132.44	122.84	252.94	217.85	212.83	278.96	216.02	1913.87
Hurdal	46.36	75.62	109.46	20.61	139.37	148.10	75.67	166.06	167.08	124.74	175.98	116.56	1365.61
Kårvatn	214.26	91.31	120.03	27.64	147.27	116.60	94.24	39.82	346.99	107.94	47.44	96.67	1450.20
Svanvik	43.29	26.69	8.35	3.76	30.13	76.14	27.87	40.79	31.72	20.51	11.77	25.02	346.04
Karpbukt	46.81	39.07	18.03	9.14	45.63	111.57	46.10	28.66	20.18	40.24	39.29	36.78	481.51

Table A.2.14: Monthly- and annual wet deposition of lead at Norwegian background stations 2019. Unit: µg/m^2.

STATION	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
Birkenes	65	54	26	89	61	71	90	53	84	72	80	96	842
Hurdal	22	31	13	42	93	69	18	55	74	30	38	28	513
Kårvatn	56	9	18	15	46	57	6	43	45	88	16	14	393
Svanvik	14	39	3	2	90	63	22	46	18	21	9	23	350
Karpbukt	18	25	20	7	40	61	61	40	43	30	69	96	510

Table A.2.15: Monthly- and annual wet deposition of cadmium at Norwegian background stations 2019. Unit: µg/m^2.

STATION	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
Birkenes	2.1	0.8	0.8	3.2	2.2	1.7	1.5	1.7	3.5	2.5	3.8	3.5	27.2
Hurdal	0.7	1.0	0.5	1.8	3.6	2.1	17.2	1.8	3.0	0.9	2.5	2.1	36.9
Kårvatn	0.7	0.3	0.5	0.5	1.3	1.0	0.3	0.3	2.9	1.4	0.2	1.0	10.2
Svanvik	1.4	3.7	0.2	0.1	8.1	2.3	2.0	2.6	1.8	4.2	1.3	3.5	31.2
Karpbukt	1.3	1.3	0.7	0.2	2.1	2.4	1.1	1.6	2.4	0.7	1.9	2.4	18.2

Table A.2.16: Monthly- and annual wet deposition of zinc at Norwegian background stations 2019. Unit: µg/m^2.

STATION	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
Birkenes	803	333	184	494	395	492	465	405	758	479	538	514	5854
Hurdal	116	280	235	271	755	529	634	446	482	260	681	443	5125
Kårvatn	357	243	227	92	686	536	117	142	281	595	151	426	3753
Svanvik	68	106	21	10	405	277	103	145	126	112	57	77	1507
Karpbukt	468	343	228	52	358	532	163	99	152	116	246	366	3125

Table A.2.17: Monthly- and annual wet deposition of nickel at Norwegian background stations 2019. Unit: µg/m^2.

STATION	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2019**
Birkenes	18	14	12	17	21	21	23	15	36	24	38	59	297
Svanvik	405	3168	329	133	3035	1829	968	991	1388	628	451	809	14138
Karpbukt	378	456	237	107	850	729	600	1089	1726	157	421	404	7157

Table A.2.18: Monthly- and annual wet deposition of arsenic at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	10	3	4	14	7	4	5	10	24	12	14	13	121
Svanvik	8	27	3	1	63	28	21	30	21	6	6	9	224
Karpbukt	9	9	5	2	21	25	14	21	21	4	10	11	152

Table A.2.19: Monthly- and annual wet deposition of copper at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	170	994	37	442	1278	1522	2994	310	183	166	259	318	8674
Svanvik	1017	2958	283	143	4338	3738	1093	912	1207	1223	663	1798	19390
Karpbukt	430	686	392	242	1400	3161	584	777	1312	264	612	666	10523

Table A.2.20: Monthly- and annual wet deposition of cobalt at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	1	1	1	5	2	4	3	2	4	3	4	3	31
Svanvik	13	86	8	3	89	54	27	29	38	23	11	26	409
Karpbukt	11	13	7	3	26	25	19	32	45	5	12	11	208

Table A.2.21: Monthly- and annual wet deposition of chromium at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	6	10	8	12	11	23	19	14	26	13	22	15	178
Svanvik	5	19	2	1	32	26	9	16	13	4	4	4	136
Karpbukt	6	7	7	3	21	29	16	16	22	4	8	10	149

Table A.2.22: Monthly- and annual wet deposition of manganese at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	56	35	41	802	253	290	281	173	317	127	154	114	2633

Table A.2.23: Monthly- and annual wet deposition of vanadium at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	14	12	13	25	17	34	24	24	38	26	30	32	287
Svanvik	20	44	2	1	52	27	8	15	12	7	20	58	266
Karpbukt	16	18	5	3	27	31	15	12	10	6	18	29	191

Table A.2.24: Monthly- and annual wet deposition of aluminium at Norwegian background stations 2019. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Svanvik	639	933	154	51	1889	2928	628	8614	13003	1253	308	287	30751
Karpbukt	792	1200	326	230	1689	3483	16098	19290	13830	2088	619	899	60625

Table A.2.25: Monthly and annual wet deposition of mercury at Birkenes in 2019. Unit: ng/m^2

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	1731	260	491	733	651	859	388	697	589	571	491	200	7660

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), 1981-2019

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 indicates data from Lista	1980	7.9	0.34	15.7								
	1981	7.4	0.24	6.2								
	1982	8.8	0.69	7								
	1983	5.4	0.25	6.6								
	1984	6.2	0.29	12.1								
	1985	4.1	0.09	9.4								
	1986	4.8	0.12	9								
	1987	3.5	0.12	9.2								
	1988	7.4	0.12	14.1								
	1989	5.4	0.11	11.4								
	1990	3.8	0.12	9.5								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
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								
Kårvatn	1979	1.5	0.04	3								
	1980	1.4	0.06	4.2								
	1981	1.4	0.09	3								
	1982	1.5	0.10	3.1								
	1983	0.7	0.12	2.9								
	1984	1.3	0.07	3.6								
	1985	1.1	0.06	4								
	1986	1.4	0.01	3.2								
	1987	1.1	0.03	2.5								
	1988	0.9	0.06	4.2								
	1989	0.3	0.05	1.8								
	1990	0.2	0.06	1								
	1991	0.3	0.01	1								
	1992	0.2	<0.01	0.8								
	1993	0.2	0.01	0.6								
	1994	0.4	0.02	1.2								
	1995	0.2	0.01	1.2								
	1996	0.5	0.01	1.4								
	1997	0.7	0.01	1.6								
	1998	0.2	0.01	1.3	0.1	0.1	0.1	0.01	0.3		0.3	
	1999	0.2	0.02	2.1								
	2000	0.18	0.01	1								
	2001	0.13	0.01	1.4								
	2002	0.32	0.018	1.2								
	2003	0.25	0.009	1								
	2004	0.13	0.005	1.2								
	2005	0.12	0.005	0.9								
	2006	0.17	0.010	1.9								

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
Kårvant	2007	0.09	0.007	0.9								
(cont.)	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								
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	
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			

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	2015	1.14	0.061	7.4	24.2	1.04	26.1	0.79	0.44	0.53	47	
(cont.)	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	

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

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

Table A.2.27 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 2019. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Ni	V	Zn	Hg(g)
JAN	0.23	0.035	0.11	0.010	0.32	0.92	0.14	0.18	4.1	1.55
FEB	0.15	0.039	0.26	0.026	0.51	1.09	0.29	0.50	4.1	1.61
MAR	0.07	0.015	0.26	0.014	0.26	0.32	0.09	0.20	1.6	1.60
APR	0.32	0.101	0.82	0.076	1.22	1.93	0.39	0.74	9.7	1.63
MAY	0.11	0.017	0.15	0.017	0.43	0.43	0.11	0.23	1.9	1.54
JUN	0.19	0.020	0.31	0.025	0.46	0.54	0.24	0.51	2.3	1.50
JUL	0.10	0.014	0.29	0.021	0.37	0.43	0.21	0.47	2.0	1.63
AUG	0.10	0.020	0.47	0.024	0.41	0.61	0.27	0.47	3.3	1.31
SEP	0.09	0.015	0.46	0.015	0.29	0.39	0.15	0.20	2.9	1.25
OCT	0.15	0.019	0.15	0.005	0.22	0.38	0.08	0.12	1.9	1.14
NOV	0.11	0.020	0.13	0.007	0.20	0.44	0.08	0.10	2.2	1.26
DEC	0.09	0.018	0.13	0.006	0.29	0.35	0.11	0.11	15.1	1.38
2019	0.14	0.028	0.29	0.020	0.41	0.65	0.18	0.32	4.3	1.45

Table A.2.29: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Andøya in 2019. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.02	0.006	0.16	0.014	1.63	0.19	0.58	0.15	0.16	1.2	1.49
FEB	0.06	0.011	1.26	0.026	2.90	0.39	0.89	0.82	0.17	2.1	1.49
MAR	0.02	0.004	0.10	0.009	1.52	0.12	0.31	0.06	0.10	0.8	1.39
APR	0.11	0.026	0.36	0.030	0.87	0.64	1.38	0.33	0.25	3.1	1.46
MAY	0.08	0.013	0.11	0.022	0.51	0.26	0.41	0.40	0.35	1.1	1.31
JUN	0.03	0.003	0.04	0.013	0.27	0.10	0.48	0.09	0.24	0.5	1.48
JUL	0.03	0.003	0.04	0.009	0.29	0.10	0.25	0.25	0.70	0.5	1.35
AUG	0.06	0.007	0.09	0.014	0.38	0.22	0.41	0.12	0.25	1.0	1.39
SEP	0.07	0.005	0.07	0.025	1.69	0.11	0.64	0.12	0.16	1.0	1.27
OCT	0.02	0.004	0.07	0.010	1.51	0.09	0.26	0.05	0.07	0.5	1.31
NOV	0.02	0.003	0.07	0.009	1.61	0.09	0.21	0.09	0.13	0.4	1.42
DEC	0.01	0.002	0.04	0.004	0.41	0.08	0.15	0.04	0.06	0.2	1.51
2019	0.04	0.007	0.20	0.015	1.14	0.20	0.51	0.21	0.23	1.1	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 2019. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.13	0.019	0.17	0.007	1.15	0.48	0.26	0.09	0.07	1.3	1.38
FEB	0.09	0.014	0.20	0.007	0.86	0.47	0.31	0.10	0.09	1.1	1.17
MAR	0.09	0.015	0.21	0.008	0.77	0.46	0.37	0.08	0.07	1.5	0.92
APR	0.04	0.047	0.67	0.019	0.62	0.24	0.89	0.77	0.08	6.9	1.38
MAY	0.03	0.015	0.62	0.031	0.48	0.21	0.80	0.74	0.10	3.8	1.36
JUN	0.01	0.009	0.42	0.009	0.37	0.09	0.29	0.24	0.04	3.3	1.36
JUL	0.02	0.053	0.45	0.023	0.69	0.08	0.27	0.32	0.05	1.2	1.38
AUG	0.01	0.032	0.22	0.013	0.41	0.08	0.62	0.12	0.06	3.5	1.56
SEP	0.01	0.005	0.16	0.008	0.08	0.02	0.25	0.08	0.04	0.4	1.64
OCT	0.04	0.019	0.38	0.023	0.15	0.13	0.82	0.19	0.12	0.9	1.59
NOV	0.02	0.023	0.19	0.013	0.17	0.11	0.52	0.12	0.08	1.1	1.61
DEC	0.13	0.025	0.33	0.022	0.19	0.77	1.03	0.15	0.14	1.2	1.66
2019	0.05	0.021	0.32	0.015	0.46	0.29	0.56	0.23	0.08	2.1	1.42

Table A.2.31: Monthly and annual average mean concentrations of heavy metals in aerosols at Svanvik in 2019. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn
JAN	16	2.32	0.319	0.26	0.51	11.6	52	3.90	0.57	12.4	4.7	14.0
FEB	15	2.18	0.221	0.39	0.57	12.1	53	4.61	0.61	15.4	6.0	11.1
MAR	10	0.15	0.024	0.12	0.07	1.0	11	0.54	0.20	1.4	0.1	2.0
APR	71	0.28	0.051	0.23	0.14	2.2	65	0.83	1.08	2.7	0.6	3.2
MAY	54	0.85	0.141	0.31	0.52	10.1	82	2.46	0.90	12.3	2.3	6.1
JUN	33	0.34	0.053	0.24	0.25	4.6	51	0.72	0.58	6.0	0.9	2.3
JUL	40	0.34	0.046	0.18	0.19	3.5	58	0.96	0.80	4.3	0.6	2.3
AUG	17	0.79	0.068	0.16	0.29	4.5	39	2.47	0.53	6.3	0.5	3.3
SEP	19	0.17	0.039	0.11	0.06	1.0	25	0.63	0.45	1.2	0.2	2.5
OCT	11	0.40	0.045	0.06	0.10	1.8	18	0.66	0.23	2.0	1.0	2.8
NOV	16	1.12	0.163	0.16	0.39	7.5	38	2.07	0.29	9.1	2.5	6.9
DEC	7	0.49	0.124	0.12	0.19	8.0	23	1.89	0.27	5.9	4.5	5.4
2019	26	0.79	0.108	0.20	0.28	5.7	44	1.82	0.55	6.6	2.0	5.2

Table A.2.32: Monthly and annual average mean concentrations of heavy metals in aerosols at Karpdalen in 2019. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn
JAN	9	2.43	0.280	0.23	0.29	7.4	32	4.57	0.41	7.7	5.8	11.2
FEB	16	2.29	0.227	0.35	0.40	8.7	41	3.47	0.55	10.8	6.2	10.4
MAR	10	1.43	0.136	0.16	0.22	4.2	25	1.96	0.28	5.0	0.9	6.8
APR	24	0.66	0.076	0.16	0.17	3.1	31	1.65	0.46	4.1	0.7	3.4
MAY	26	0.46	0.067	0.28	0.19	4.2	32	1.77	0.41	5.0	1.7	3.0
JUN	38	0.30	0.047	0.15	0.17	3.8	42	0.71	0.58	4.4	0.7	2.2
JUL	29	0.31	0.040	0.15	0.15	3.4	36	0.60	0.59	4.1	0.5	1.8
AUG	15	2.03	0.287	0.26	0.58	10.5	57	3.98	0.56	14.7	0.7	9.5
SEP	19	1.63	0.244	0.24	0.53	8.8	54	2.71	0.52	13.3	0.5	9.1
OCT	6	0.64	0.094	0.19	0.11	2.7	13	1.13	0.14	2.7	1.6	7.2
NOV	6	2.13	0.323	0.09	0.28	8.4	25	3.43	0.19	7.1	5.4	13.1
DEC	10	1.29	0.235	0.13	0.24	12.1	26	3.81	0.31	7.4	7.2	11.5
2019	17	1.29	0.171	0.20	0.28	6.4	34	2.47	0.41	7.2	2.6	7.4

Table A.2. 33: Monthly and annual concentration of Mercury at Trollhaugen in 2019. Unit: ng/m^3

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2019
Trollhaugen	1.073	1.020	1.017	0.968	1.076	1.084	1.042	1.000	1.023	0.914	0.853	0.899	0.997

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		

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		
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		

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			
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			
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		

Annex 3

Description of methods for sampling, chemical analysis and quality control

Heavy metals

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

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

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

Table A.3.1: Quantification limits for heavy metals in precipitation.

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

Air sampling for the analysis of heavy metals in particles at Birkenes is done using a Kleinfiltergerät with a PM_{10}-impactor. Weekly samples (7 days) on Whatman quartz 47 mm filter are collected. This is the same sampler and filter as is used to collect EC/OC. The airflow is 2.3 m^3/hour. At Andøya and the Zeppelin Observatory, sampling of heavy metals in particles are done using a Digitel high volume air sampler without any defined size cut off. The airflow rate is 20-25 m^3/hour and Whatman 41 filters are used and samples are collected for 48 h. The filters are digested with nitric acid by Ultraclave, a microwave based decomposition technique.

Table A.3.2: Quantification limit for heavy metals in aerosols.

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

Mercury

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

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

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

POPs and organic contaminants of emerging concern

Air sampling of HCB, OCPs, PCBs, PAHs, PBDEs, HBCDs, TBA, ionic and volatile PFASs, S/MCCPs, nBFRs, OPFRs, phthalates, and 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 quality control procedure of the NILU monitoring program). All exposed samples were registered and stored cold (2ºC) prior to analysis and quantification. The GFF and PUFs were extracted in the same solvent to obtain the bulk concentration (gas+particle phase) of the individual target compounds (below). Exceptions were ionic PFAS for which only GFFs were used for ionic PFAS representing the particle phase concentrations only and PUF/XAD/PUF was used for volatile PFAS representing concentrations in the gas phase only.

Sampling of Cyclic volatile methyl siloxanes (cVMS)

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

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

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

All samples were spiked to the upper frit of a cartridge with 20 µL of internal standard (IS) containing 13C-labelled D4, D5 and D6 in acetone (1 ng/µl). Then the cartridge was eluted slowly with ca 5 ml of hexane, so that 3.5-4 ml of eluate was collected into a 4 ml screw-cap vial. Before quantitative analysis, 50 µl of a recovery standard containing M4T in hexane (0.2 ng/µl) was added to the vial and the vial was sealed immediately with a crimp cap. An aliquot was taken and transferred to a crimped cap GC vial prior to instrumental analysis.

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

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

Samples were spiked with 20 µL of internal standards (IS) containing 13C-labelled PCB congeners (~230 pg/µL), 20 µL IS containing 13C-labelled OCP congeners (~100-2500 pg/µL), 50 µL IS containing ^{13}C-labelled hexachlorodecane (~1000 pg/µL) for SCCP, 20 µL IS containing ^{13}C-labelled trans-CD (~500 pg/µL) for MCCP, 20 µL 13C-labelled Dechlorane plus syn for Dechloranes, before being Soxhlet extracted for 8 h in diethylether/*n*-hexan (10:90, v:v). The filters and the corresponding PUF plugs were extracted separately, but in the same solvent in order to aggregate the sample. The samples for nBFRs were spiked with 20 uL of IS containing 13C-labelled nBFR congeners (~1000 pg/µL), and extracted in acetone/hexane (1:1, v:v). The extracts were concentrated and cleaned by acid treatment and silica fractionation. Before quantitative analysis, 20 µL of unlabelled tetrachloronaphthalene (TCN, 100 pg/µL) was added as recovery standard (RS).

Identification and quantification of HCB, PCBs, OCPs and nBFRs was carried out using a high-resolution gas chromatography coupled to a high-resolution mass spectrometer as detector (HRGC/HRMS). The analyses were performed in Electron Impact ionization (EI) mode for PCBs, HCB, HCHs, DDTs and nBFRs using selected ion monitoring (SIM) for the respective compounds groups. Identification and quantification of chlordanes, SCCP, 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 13C-labelled PBDE congeners (~270-2500 pg/µL) and 20 µL IS containing 13C-labelled HBCD congeners (α-, β-, γ-HBCD, ~100 pg/µL), and then Soxhlet extracted for 8 h in in diethylether/*n*-hexan (10:90, v:v). The filters and the corresponding PUF plugs were extracted separately, but in the same solvent in order to aggregate the sample. The extract was then concentrated and cleaned by acid treatment and silica fractionation. Before quantitative analysis, the extract was split in two; one for PBDE/TBA and one for HBCD analysis. The extract for PBDE/TBA was spiked with 20 µL of unlabelled TCN (100 pg/µL) as recovery standard, and the extract for HBCD analysis was spiked with 20 µL RS containing deuterated (d18-α,β,γ) HBCD (~130 pg/µL).

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

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

Analysis and quantification OPFRs

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

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

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

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

Analysis and quantification of ionic PFAS

The two filters (sampled during the same month) were combined and spiked with 20 µL of IS containing ^{13}C-labelled PFAS congeners (0.1 ng/µL) and then extracted using sonication bath for 3x10 min in methanol. The extract was then concentrated and cleaned with acidified Envi-Carb. Before quantitative analysis, 10 µL of unlabelled 3.7-dimethyl PFOA (0.1 ng/µL) was added as recovery standard.

Identification and quantification of the PFASs was carried out using UHPLC/MS-MS with ESI in negative ion mode using selected-reaction monitoring (SRM). In total, 12 PFASs were quantified.

Analysis and quantification of volatile PFAS

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

Analysis and quantification of phthalates

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

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

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

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

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

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

Sampling, analysis and quantification of POPs in precipitation

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

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

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

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

Quality assurance/Quality control (QA/QC)

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

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

Field blank samples (n=3-4 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, according to EU standard EN 45001. The instrument limit of detection is determined by calculating the signal-to-noise ratio (S/N) > 3 for solvent blanks (using n-hexane). Based upon average concentrations in laboratory blanks, the limit of detection (LOD) and limit of quantification (LOQ) is calculated for all compounds. LOD = average blank concentrations plus 3 times standard deviations (STD) of the blank concentrations. LOQ = average blank concentrations plus 10 times STD. All samples within the range LOQ>×>LOD are considered to have higher uncertainties. All raw data for POPs and heavy metals are openly accessible from the NILU database (http://ebas.nilu.no) for thorough examinations. Values below LOD were used as LOD/2 in further statistical treatment.

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

Sampling and analysis of the organic contaminants of emerging concern (i.e. cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, 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. 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. 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 20–50% of the measured level, the blank level is subtracted from the measured level. If the blank level is >50%of the measured level, the value is considered as“non-detect” (<LOD).

NILU – Norwegian Institute for Air Research

NILU – Norwegian Institute for Air Research is an independent, nonprofit institution established in 1969. Through its research NILU increases the understanding of climate change, of the composition of the atmosphere, of air quality and of hazardous substances. Based on its research, NILU markets integrated services and products within analyzing, monitoring and consulting. NILU is concerned with increasing public awareness about climate change and environmental pollution.

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