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Monitoring of environmental contaminants in air and precipitation

Annual report 2021

Pernilla Bohlin-Nizzetto, Wenche Aas, Helene Lunder Halvorsen,
Vladimir Nikiforov and Katrine Aspmo Pfaffhuber

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PROJECT LEADER
Pernilla Bohlin-Nizzetto

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AUTHOR(S)
Pernilla Bohlin-Nizzetto, Wenche Aas, Helene Lunder Halvorsen,
Vladimir Nikiforov and Katrine Aspmo Pfaffhuber

QUALITY CONTROLLER
Hilde Uggerud

REPORT PREPARED FOR
Norwegian Environment Agency
Postboks 5672 Sluppen, 7485 Trondheim

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ABSTRACT

This report presents data from 2021 and time-trends for the Norwegian monitoring programme "Atmospheric contaminants". The results cover 200 organic compounds (regulated and non-regulated), 11 heavy metals, and a selection of organic chemicals of concern.

NORWEGIAN TITLE
Overvåking av langtransporterte atmosfæriske miljøgifter i luft og nedbør, årsrapport 2021.

KEYWORDS

Environmental chemistry/	Long-range transport of air pollutants/	Environmental monitoring/
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ABSTRACT (in Norwegian)

Denne rapporten inkluderer miljøovervåkningsdata fra 2021 og tidstrender for programmet Atmosfæriske miljøgifter. Resultatene omfatter 200 organiske miljøgifter (regulerte og ennå ikke regulerte), 11 tungmetaller og et utvalg organiske kjemikalier av bekymring for miljøet.

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Contents

Summary of main findings

This report presents environmental monitoring data for in total 200 organic compounds and 14 heavy metals in air and precipitation for 2021. The organic compounds include regulated persistent organic pollutants (POPs) and non-regulated organic chemicals of concern. The heavy metals include mercury (Hg) in both gas and particulate phase as gaseous elemental mercury (GEM), particulate bound mercury (PBM) and gaseous oxidized mercury (GOM). The data is collected at background monitoring stations on mainland Norway and Svalbard in the Arctic using active sampling technologies for contaminants in air and bulk sampler for contaminants in precipitation.

The monitoring is performed on behalf of the Norwegian Environment Agency and is part of the authorities' environmental monitoring in Norway. This report covers findings from two monitoring programmes *"Atmospheric contaminants"* and "*the Norway-Russia measurements*". The overall purposes of the monitoring are to i) assess long-term temporal trends of atmospheric contaminants in Norway, ii) increase the knowledge on long-range transported contaminants in air and precipitation in Norway, iii) assess spatial variabilities of atmospheric contaminants in Norway, iv) provide data for international conventions, programmes and networks, and v) provide data on emerging contaminants for future regulations.

Organic contaminants – measured concentrations and spatial variability
In 2021, the concentrations of the targeted organic contaminants ranged over six orders of magnitude, from below the method detection limits (<MDL) of 0.001 pg/m^3 to detected concentrations of thousands of pg/m^3. As in previous years, the highest concentrations in air were found for the cyclic volatile methyl siloxanes (cVMS), the climate relevant volatile fluorinated and chlorinated substances (vol. F+Cl substances), some polycyclic aromatic hydrocarbons (PAHs), short chain chlorinated paraffins (SCCPs) and some of the organophosphorous flame retardants (OPFRs) (Figure 1, Appendix A). In detail, at Birkenes the highest concentrations were measured for D5 (0.48-8.3 ng/m^3), D4 (0.50-3.0 ng/m^3), D6 (<0.19-2.0 ng/m^3) followed by 2-4 ring PAHs; phenanthrene, dibenzofuran, fluorene, fluoranthene, naphthalene and pyrene (individually ranging between 0.01-2.7 ng/m^3). At Zeppelin, the highest concentrations were measured for D5 (0.06-10 ng/m^3), D4 (0.05-18 ng/m^3), D6 (0.11-3.4 ng/m^3), six of the volatile fluorinated and chlorinated substances (i.e., PFTBA, HCBD, TCPFB, HCcBen and PFTPeA, individually ranging between 0.07-2.3 ng/m^3) and three of the OPFR compounds (i.e., TCPP, TCEP and TEP individual ranging between 0.02-4.2 ng/m^3). Weather the high concentrations at Zeppelin are solely a result of long-range transport or also influenced by local sources are still not fully understood. The lowest concentrations and lowest detection frequencies were found for the regulated POPs; polybrominated diphenyl ethers (PBDEs), hexabromocyclododecanes (HBCDDs), chlordanes (CHL), DDTs, polychlorinated biphenyls (PCBs), ionic per- and polyfluorinated alkylsubstances (PFAS) as well as some particle-associated PAHs (Figure 1, Appendix A). Low detection frequency was also found for medium-chain chlorinated paraffins (MCCPs), many of the targeted ionic PFAS and dechloranes, including the new PFAS and dechloranes included in 2021. One reason for low detection frequency for these compounds is their higher method detection limits (MDLs). For example, the ionic PFAS and dechloranes have MDLs that are one to two orders of magnitude higher than the MDLs for the POPs (i.e., 0.01-0.1 pg/m^3).

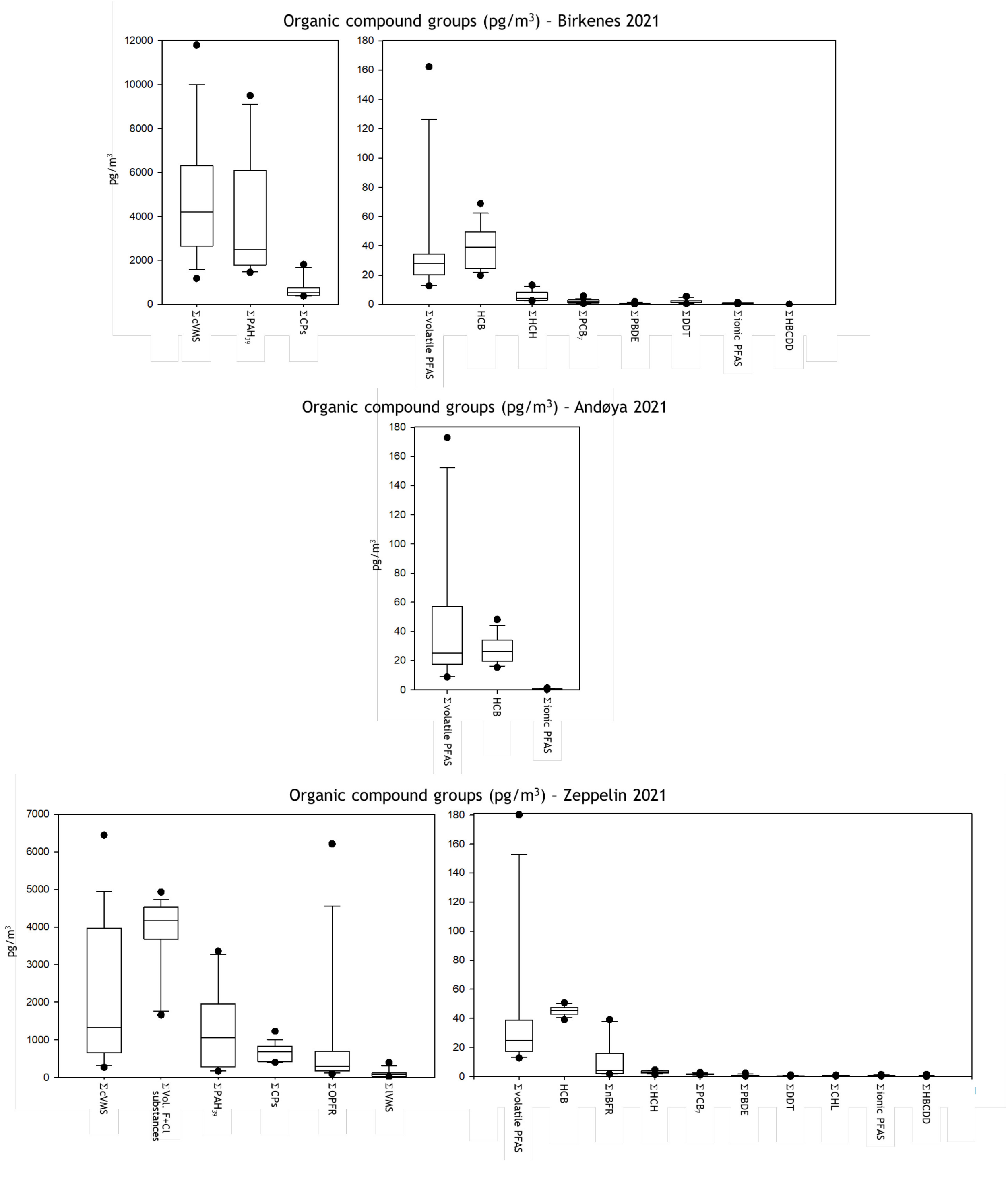


Figure 1: Box-plot of measured concentrations of organic contaminants (as sum of individual compounds when more than one) in air at Birkenes, Andøya and Zeppelin in 2021. The boxes represent the range from 25 to 75 percentile with the center line representing the median value. The bars represent the 10 and 90 percentiles.

Of the targeted volatile PFAS only 6:2-12:2 FTOH were detected in all or most of the samples at all three sites. The other six volatile PFAS were only detected occasionally. Of the targeted fifteen nBFRs (Table 2.4), only seven were detected in more than 50% of the active air samples at Zeppelin in 2021 (PBT, HBB, DPTE, EHTBB, TBPH/BEH-TBP, DBDPE and TBBPA). DBDPE is influenced by contamination and results for DBDPE are therefore uncertain. The highest concentrations were observed for HBB and

PBT. The analysis of OPFRs included 19 compounds in 2021 (Table 2.4). Of these, nine were detected in more than 50% of samples from Zeppelin. This is a higher number of detected compounds compared to 2020. The reason for more detection in 2021 is lower method detection limits for many of the OPFRs in 2021 compared to earlier years. A set of seven new siloxanes was included in monthly samples from Zeppelin in 2021, in addition to the three cyclic siloxanes measured since 2013 (Table 2.4). The three linear siloxanes L3, L4 and L5 were detected in most samples at concentrations 10-100 times lower than the cyclic siloxanes. The other new siloxanes were not above the detection limit in any of the samples. Nine of the volatile fluorinated and chlorinated substances were detected in more than 80% of the samples from Zeppelin (PFTBA, HCBD, TCPFB, HCcBen, PFTPeA, PFPHP, PcTol, DCTFP, and HCBcB) (Table 2.6). The other four substances were not detected in any sample.

The measured concentrations in air were significantly higher at Birkenes than Zeppelin for sums of cVMS, PAHs, DDTs, and HCHs. The higher concentrations of cVMS, PAHs, DDTs and HCHs at Birkenes likely reflect that Birkenes is located in Southern Norway and thereby is closer to and more influenced by source regions in central and east Europe, whereas Zeppelin is a remote Arctic location that is more influenced by long-range transport than specific local source regions in Europe. In contrast, for HCB the concentrations were significantly higher at Zeppelin than at Andøya and Birkenes (see Figure 8 under Key findings). However, the differences observed for HCB between the three sites are becoming smaller as the concentrations of HCB at Zeppelin has been reduced during the last years. The significantly higher concentrations at Zeppelin for HCB is now mainly due to smaller seasonal variations and thereby higher summer concentrations at Zeppelin than at Birkenes and Andøya. No spatial variation was observed for PCBs, CPs, PBDEs and PFAS (Figure 8).

Organic contaminants - time-trends from long-term monitoring data

Most of the targeted POPs were measured at similar or slightly lower concentrations in 2021 compared to 2020. This is consistent with the last years of the monitoring programme. For most of the POPs, the monitoring results over the last five years show small 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.

Concentrations measured in 2021 were higher compared to what was measured in 2020 for PBDEs at Birkenes and Zeppelin, for HCB at Birkenes, and Andøya and for PAHs at Birkenes. Whether this is a continuous increase or fluctuations will be seen over the next years.

As a number of the targeted POPs have been monitored in air since the beginning of 1990s, even before the Stockholm Convention came into force, long-term trend analysis can be performed. These POPs are: Hexachlorobenzene (HCB) at Birkenes and Zeppelin, hexachlorohexanes (HCHs) at Birkenes and Zeppelin, dichlorodiphenyltrichloroethane (DDTs) and chlordanes at Zeppelin, polychlorinated biphenyls (PCBs) and 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, i.e., short estimated half-lives around 5-10 years during the whole monitoring period, for HCHs at Birkenes and Zeppelin, DDTs and PCBs at Zeppelin and benzo(a)pyrene at Birkenes (Table 1.1, Figure 14-15). A slower decrease or no significant trends are seen for other PAHs at Birkenes and Zeppelin, and PCBs and DDTs at Birkenes with half-lives of more than 15 years or no significant trend.

For HCB at Zeppelin, no significant trend is observed for the whole monitoring period (1993-2021) nor for the period after the Stockholm Convention entered into force (2004-2021). This is caused by decreasing concentrations between 1994 and 2002, increasing concentrations between 2003 and 2016, and again decreasing concentrations after 2016 (Figure 13 in Key Findings). The concentrations of HCB at Zeppelin are now the lowest ever measured and as a result, the time-trend for 2016-2021 indicate short estimated half-lives.

Table 1.1. Long-term time trends for individual POPs and two different time periods: 1) the whole monitoring period (as described Table 2); and 2) from the year global regulation was taken into force for the individual compounds until the end of 2021 (After EoF). The trends are expressed as apparent first order half-lives (t1/2, y). Positive values indicate decreasing trends and negative values indicate increasing trends. The lower the value, the bigger the decrease or increase. Colour codes and arrows help to interpret the data: green (big decrease),and yellow-orange (minimal change-steady-state). The empty white cells mean that no data is available for this time period.

POP	Birkenes		Andøya		Zeppelin	
	Whole period	After EoF	Whole period	After EoF	Whole period	After EoF
	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$
HCB	34* ↘	23* ↘	NST →	NST →	NST →	NST →
α-HCH	5.6 ↓	11 ↘			5.6 ↓	7.1 ↓
γ-HCH	4.8 ↓	NST →			4.7 ↓	7.3 ↓
cis-CD					13 ↘	11 ↘
p,p'-DDE	NST →	NST →			8.9 ↓	8.1 ↓
p,p'-DDT	NST →	NST →			5.9 ↓	7.7 ↓
o,p'-DDT	15* ↘	15* ↘			6.8 ↓	9.3 ↓
p,p'-DDE	NST	NST			8.9 ↓	8.1 ↓
PCB-28	11 ↘	11 ↘			9.2 ↓	8.9 ↓
PCB-52	14* ↘	14* ↘			11 ↘	11 ↘
PCB-118	9.5 ↓	9.5 ↓			9.7 ↓	15 ↘
PCB-153	10* ↓	10* ↓			9.5* ↓	12* ↘
Fluorene	NST →				14 ↘	
Fluoranthene	NST →				12 ↘	
Benzo(a)pyrene	6.8 ↓					
BDE-47	10 ↓				22 ↘	
BDE-99	5.9 ↓				8.0 ↓	
PFOA	5.2* ↓	5.2* ↓	2.9* ↓	2.9* ↓	3.5 ↓	3.5 ↓

*R^2<0.7
NST: no significant trend

The targeted organic chemicals of concern (i.e., cVMS, CPs, nBFRs, OPFRs, dechloranes) have been monitored for less than ten years and a detailed long-term trend analyses is therefore less accurate. The measured concentrations of these chemicals in 2021 are similar to previous years and no clear trends are yet observed (see section 2.3, Key findings).

Heavy metals and mercury – measured concentrations and spatial variability

For heavy metals (HM) in precipitation, all the targeted HMs (Al, As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn and Hg) are detected at all stations. The observed concentrations and deposition levels of Pb, Cd and Zn are highest at Birkenes and Hurdal followed by Kårvatn, reflecting the increasing distances to the main emission sources in continental Europe (EMEP, 2021). High concentrations and deposition levels are also observed at Svanvik and Karpdalen in eastern Finnmark. These locations are part of the Russian-Norwegian ambient air monitoring in the border areas. The influence from the Russian smelters on the environment in eastern Finnmark has been repeatedly demonstrated through the national moss surveys (Steinnes et al. 2016). At the end of 2020, the smelter in Nikel was closed down, and the results from the monitoring in 2021 show a 2 to 10-fold decrease in the concentration of heavy metals in precipitation, compared to 2020 (Bohlin-Nizzetto et al., 2021).

From 2021, the sample collection frequency of Hg in precipitation increased from monthly to weekly sampling at Birkenes. In addition, weekly samples from Hurdal and Kårvatn were also included in the monitoring program. The annual concentrations of Hg in precipitation are highest at Hurdal, followed by Birkenes and Kårvatn. The precipitation amount was largest at Kårvatn, followed by Birkenes and Hurdal, which resulted in deposition being highest at Hurdal which was mostly controlled by consistently high concentrations in the precipitation through May. The concentration gradient is likely a result of the distance to emission sources on the European continent. No clear seasonal variation in concentration nor wet deposition is observed at any of the stations.

For HMs in air, the concentrations are mostly comparable to 2020 and well below the air quality criteria for metals as set by NIPH (National Institute for Public Health). In 2021, the concentrations of HM in air at Birkenes are two-three times higher than those observed at Andøya and Zeppelin. This is because Birkenes is closer to the emission sources on the European continent (EMEP, 2020). Historically, the concentrations in air at Svanvik and Karpdalen are about ten times higher than those observed at Birkenes depending on element (Berglen et al., 2021). However, since the close-down of the smelter in Nikel close to the Norwegian border, the concentrations of heavy metals in air are dramatically reduced, and in 2021 the concentrations are almost at the same level as at Birkenes. The annual mean concentration of gaseous elemental mercury (GEM) is similar at the three sites in the northern hemisphere while the concentration is lower at Trollhaugen in Antarctica. This is due to less emission of mercury in the southern hemisphere compared to the more industrialized and populated northern hemisphere and slow inter-hemispheric mixing. In 2021, measurements of mercury species (measured as gaseous oxidized mercury (GOM) and particulate bound mercury (PBM)) in air was introduced to the monitoring program at Zeppelin. At remote sites like the Norwegian monitoring stations, most of the mercury in air is present as GEM, while the concentrations of GOM and PBM are rather low, comprising <1% of the total mercury in air. This is due to GOM's and PBM's relatively short residence time and reduced potential for long range-transport from emission sources compared to GEM. GOM is less volatile and more water-soluble than GEM and is more likely to be removed by rain, adsorbed to surfaces and adhered to particulate matter.

Heavy metals and mercury - time-trends from long-term monitoring data

In a long-term perspective, the concentrations of most HMs in precipitation have been largely reduced. Exceptions are Pb at Kårvatn, where there has been no significant trend since 1990, and positive trend for Cu at Birkenes since 2000 and Zn at Kårvatn since 1990. For mercury, the declining trend has stabilized and since 2010 there is no significant concentration decrease observed at Birkenes (Figure 2). The decline in Hg-concentration and -deposition have been attributed to increasing precipitation and reductions in anthropogenic emissions. The temporal wet deposition trend at Lista/Birkenes, is heterogeneous and is driven by larger decreases earlier in the monitoring record.

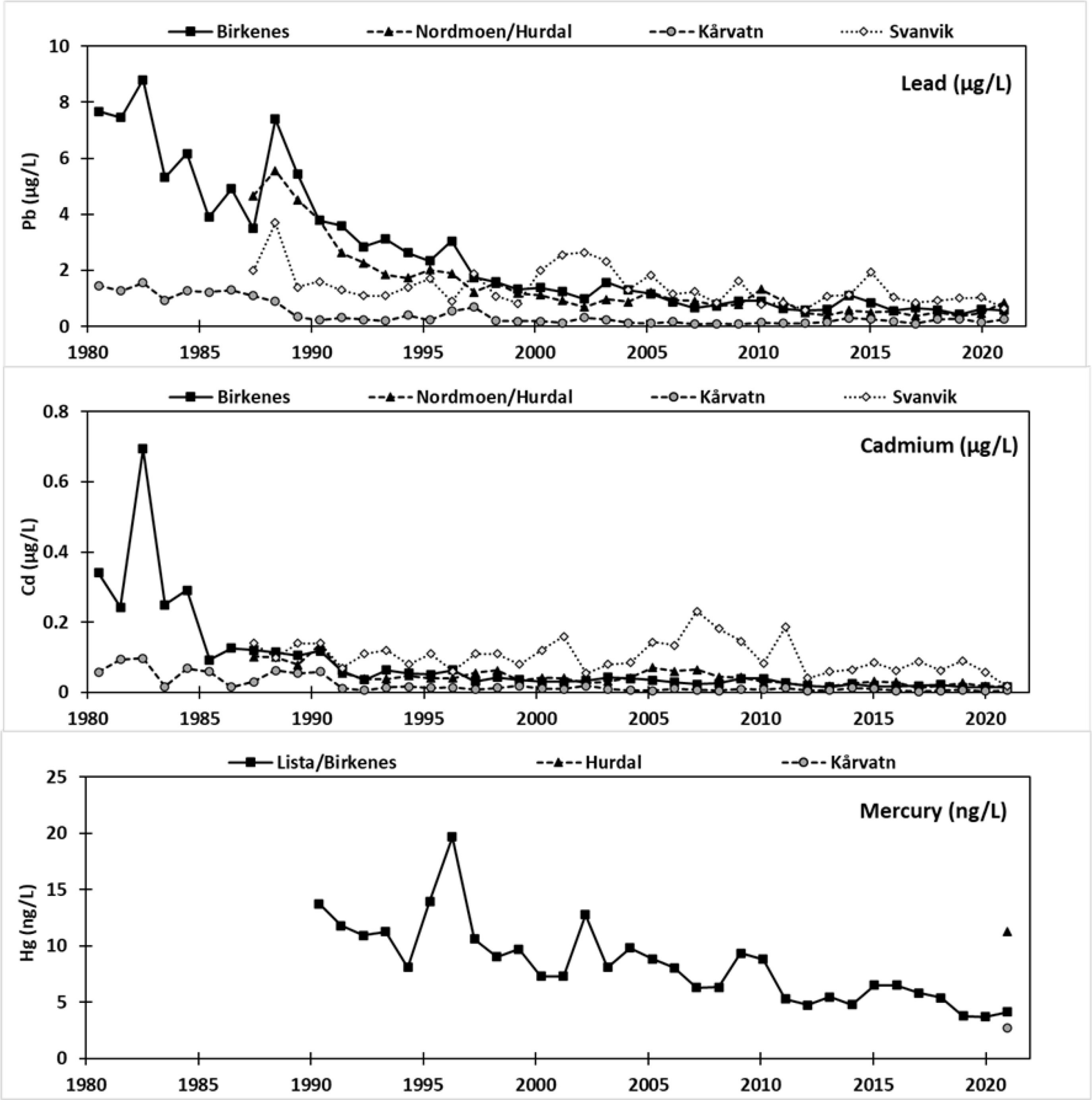


Figure 2: *Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.*

The monitoring show significant reduction in air concentrations for all measured elements at Lista/Birkenes for the period 1991 to 2021, while at Zeppelin a significant reduction is observed since 1994 for some elements (As, Pb, V and Hg). At Zeppelin, increasing trends are observed for Cr, Ni and Mn, while no trend is observed for Zn, Cd, Cu and Co. According to the European Environment Agency, European emissions of Ni, Zn, and Cr to air have steadily decreased since 2007 by more than 50 % in total, which may indicate that the Ni, Zn and Cr observed at Zeppelin have sources of more local origin (Platt et al., 2022), probably both geogenic and anthropogenic (ship emissions and mining) sources (Conca et al., 2019). Following the reduced Hg emissions in Europe, Norwegian monitoring data demonstrates that Hg concentrations in air are declining since year 2000 at all three stations in Norway (Figure 3). However, the decreasing trend is more significant at Birkenes in the south, likely reflecting the closeness to the decreased emissions in Europe. This finding is supported by back-trajectory models of air-masses originating in Europe and co-correlations of Hg variation with anthropogenic emissions tracers, as well as mechanistic chemical transportation models based on emissions inventories (National Mercury Assessment, 2022). GEM concentrations in air are not decreasing at the same rate as the European Hg emissions, which is due to legacy Hg emissions and the biogeochemical Hg cycle which complicates the relationship between Hg emission and concentration.

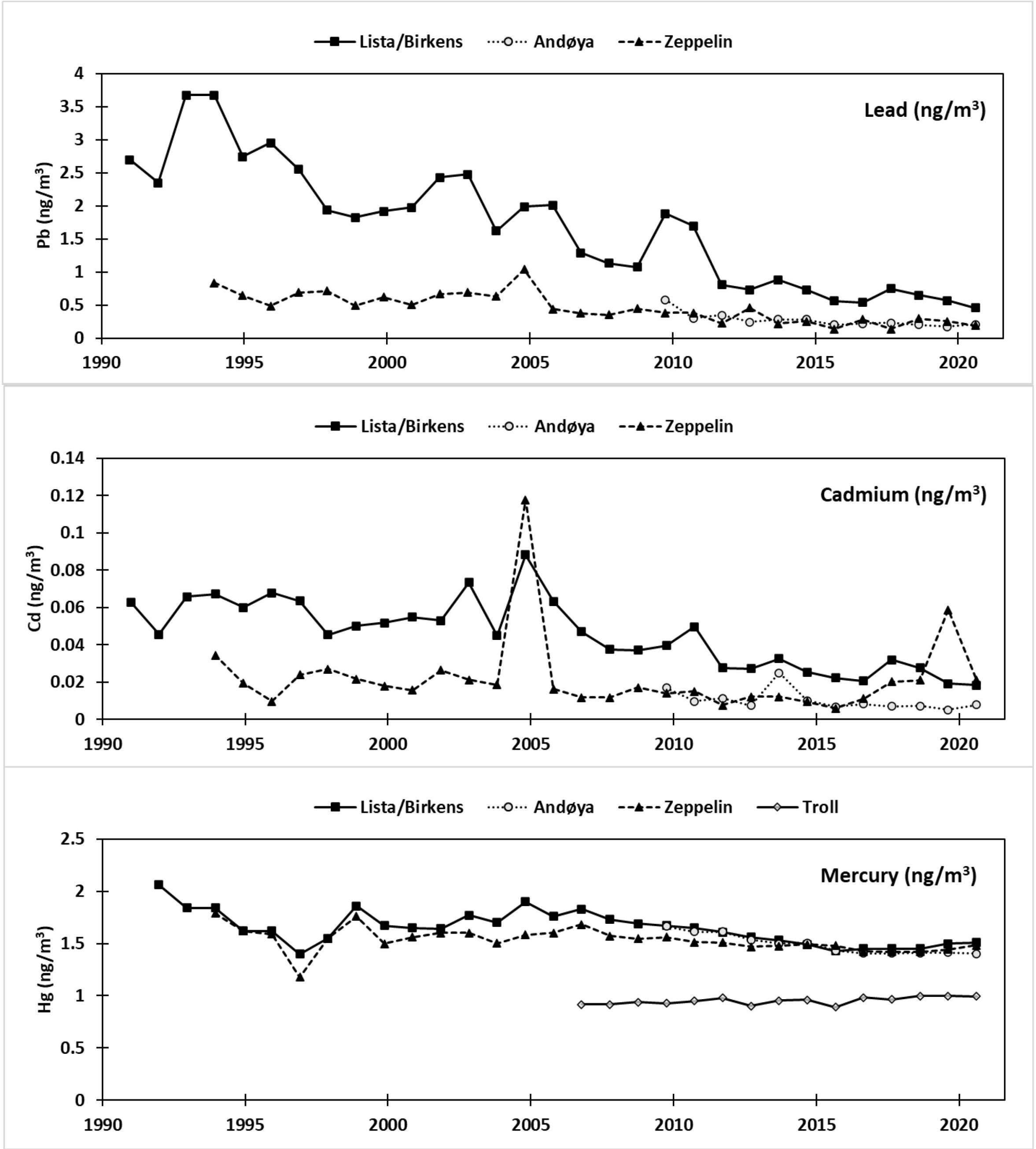


Figure 3: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2021, Unit: ng/m^3.

Sammendrag

Denne rapporten presenterer norske miljøovervåkningsdata for totalt 200 organiske forbindelser og 14 tungmetaller i luft og nedbør i 2021. De organiske forbindelsene inkluderer regulerte persistente organiske miljøgifter (POPer) og ikke-regulerte organiske forbindelser som er av mulig bekymring. Tungmetallene inkluderer kvikksølv (Hg) i både gass- og partikkelfase som gassformig elementært kvikksølv (GEM), gassformig oksidert kvikksølv (GOM) og partikkelbundet kvikksølv (PBM). Dataene ble samlet inn fra bakgrunnsstasjoner på fastlands-Norge og Svalbard i Arktis ved bruk av aktiv luftprøvetaking samt bulk nedbørsprøvetaking.

Overvåkningen utføres på oppdrag fra Miljødirektoratet og er en del av myndighetenes miljøovervåkning i Norge. Rapporten omfatter funn fra to overvåkningsprogrammer; «Atmosfæriske miljøgifter» og «Norge-Russland overvåkning». Hovedformålet med overvåkningen er å i) evaluere lange tidstrender for miljøgifter i luft i Norge, ii) øke kunnskapen om langtransport av miljøgifter via luft og nedbør i Norge, iii) evaluere romlig fordeling av atmosfæriske miljøgiftnivåer i Norge, iv) fremskaffe data til internasjonale konvensjoner, programmer og nettverk, og v) fremskaffe luftdata om nye miljøgifter for å støtte fremtidige tiltak.

Organiske miljøgifter – målte konsentrasjoner og romlig fordeling

Luftkonsentrasjonene av de organiske forbindelsene i overvåkningsprogrammet i 2021 ble målt over et stort konsentrasjonsområde; fra under den analytiske deteksjonsgrensen (< MDL) på 0.001 pg/m^3 til detekterte konsentrasjoner på tusenvis av pg/m^3. Som i de siste årene, ble de høyeste konsentrasjonene i luft funnet for siloksaner (cVMS), klimarelevante fluor- og klororganiske forbindelser (Vol. F+Cl forbindelser)), noen polysykliske aromatiske hydrokarboner (PAH), kortkjedet klorparafiner (SCCPs) og noen fosfororganiske flammehemmere (OPFR) (Figure 4, Appendix A). I detalj; de høyeste konsentrasjonene på Birkenes ble målt for D5 (0.48-8.3 ng/m^3), D4 (0.50-3.0 ng/m^3), D6 (<0.19-2.0 ng/m^3) etterfølgt av 2-4 ringet PAHer; fenantren, dibensofuran, fluoren, fluoranthen, naftalen og pyren (konsentrasjoner mellom 0.01-2.7 ng/m^3). På Zeppelin ble de høyeste nivåene målt for D5 (0.06-10 ng/m^3), D4 (0.05-18 ng/m^3), D6 (0.11-3.4 ng/m^3), seks av de flyktige fluor- og klororganiske forbindelsene (i.e. PFTBA, HCBD, TCPFB, HCcBen og PFTPeA, konsentrasjoner mellom 0.07-2.3 ng/m^3) og tre av OPFR-forbindelsene (i.e TCPP, TCEP og TEP, konsentrasjoner mellom 0.02-4.2 ng/m^3). Laveste konsentrasjon og lavest deteksjonsfrekvens er funnet for polybrommerte difenyletere (PBDE), hexabrom syklododekan (HBCDD), klordaner, DDT og noen partikkelbundne PAH-er (Figure 4, Appendix A). Det ble også gjort få funn av mellomkjedede klorparafiner (MCCPs) og flere av de målte per- og polyfluorerte alkylstoffene (PFAS) og dekloraner. Det samme gjelder for de nye PFAS og dekloraner som ble inkludert i måleprogrammet i 2021. En årsak til lav deteksjon av disse stoffene er at de har analytiske deteksjonsgrenser (MDL) som er en faktor 10-100 høyere enn for POP-ene (0.01-0.1 pg/m^3).

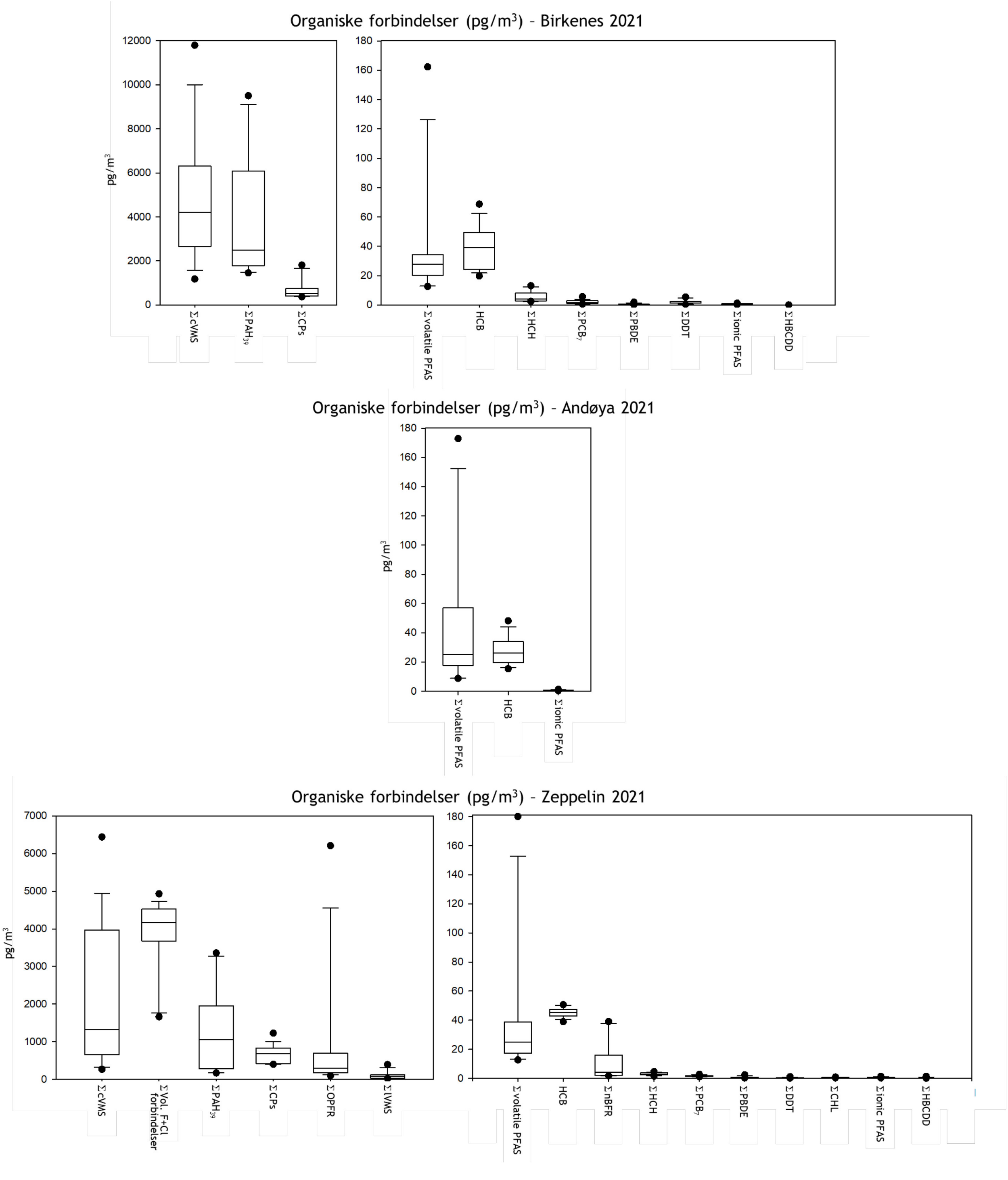


Figure 4: Box-plot over de målte konsentrasjonene av de organiske forbindelsene (som sum av enkeltforbindelser når mer enn én) i luft ved Birkenes, Andøya og Zeppelin i 2021. Boksene representerer området fra 25- til 75 persentil med midtlinjen som representerer medianverdien. Søylene representerer 10- og 90-persentilene.

I detalj for ikke-regulerte organiske forbindelser som er av mulig bekymring: Av de ti flyktige PFAS som ble målt i 2021 var det kun 6:2-12:2 FTOH som ble detektert i de fleste prøvene fra Birkenes, Andøya og Zeppelin. De andre seks flyktige PFAS ble kun detektert i få prøver. Av de 15 nye bromerte flammehemmere (nBFRs), ble kun syv detektert i mer enn 50% av prøvene fra Zeppelin i 2021 (PBT, HBB, DPTE, EHTBB, TBPH/BEH-TBP, DBDPE and TBBPA). DBDPE er påvirket av høye blindnivåer og data for DBDPE er derfor usikre. Høyest konsentrasjoner av nBFRs ble målt for HBB og PBT. For OPFRs ble ni av 19 forbindelser detektert i mer enn 50% av prøvene fra Zeppelin. Flere OPFRs ble detektert i 2021 enn 2020. Dette skyldes lavere deteksjonsgrense for flere OPFRs i 2021 enn i 2020. Et sett med syv nye siloksaner ble i 2021 lagt til måleprogrammet på Zeppelin, i tillegg til de tre sykliske siloksanene, som er målt siden 2013. Av de nye siloksanene var deteksjonsfrekvensen for de tre lineære oligomerene (L3, L4, L5) høy. De målte konsentrasjonene var 10-100 ganger lavere enn konsentrasjoner for de sykliske D4-D6. De andre nye siloksanene ble ikke detektert i noen prøver på Zeppelin. Ni av de flyktige fluor- og klororganiske forbindelsene ble detektert i mer enn 80% av prøvene fra Zeppelin (PFTBA, HCBD, TCPFB, HCcBen, PFTPeA, PFPHP, PcTol, DCTFP, and HCBcB) (Tabell 2.6). De andre fire forbindelser var lavere enn deteksjonsnivået i alle prøver fra Zeppelin.

Konsentrasjonene av sum cVMS, sum PAH, sum DDT og sum HCH var signifikant høyere på Birkenes enn på Zeppelin (se Figur 8 under Key findings). Årsaken til høyere konsentrasjoner på Birkenes, er nærheten til kildeområder i sentral- og øst-Europa, som medfører en større påvirkning. I motsetning er Zeppelin i Arktis mer påvirket av langtransport enn spesifikke kildeområder. For HCB derimot, var konsentrasjonene signifikant høyere på Zeppelin enn på Andøya og Birkenes. Forskjellen mellom Zeppelin og de to andre stasjonene har minsket i løpet av de siste årene, som et resultat av lavere konsentrasjoner av HCB på Zeppelin. Høyere konsentrasjoner på Zeppelin beror nå på mindre sesongvariasjon (dvs. høyere konsentrasjoner på sommeren) ved denne stasjonen, enn ved de andre to stasjonene, der nivåene på sommeren er mye lavere enn på vinteren. Ingen romlig variasjon ble observert for sum PCB-7, sum CP, sum PBDE eller sum PFAS (Figur 8).

Organiske miljøgifter – Tidstrender fra lange tidsserier

De fleste regulerte POPene ble målt i lignende eller noe lavere konsentrasjoner i 2021 enn i 2020. Dette stemmer med resultat fra de siste årene av overvåkningsprogrammet. For flesteparten av POP-ene viser overvåkningsprogrammet små reduksjoner de siste fem årene eller svingende konsentrasjoner fra år til år. Dette tyder på at de har oppnådd temporal bakgrunnstilstand der de primære utslippene i stor grad har stanset og den globale konsentrasjonen i stedet kontrolleres av utslipp fra sekundære kilder.

Høyere konsentrasjoner i 2021 enn i 2020 ble målt for PBDE på Birkenes og Zeppelin, HCB på Birkenes og Andøya, og PAHer på Birkenes. Om dette er en økning over tid eller svingende konsentrasjoner, vil avklares over tid.

Flere regulerte POP-er og POP-liknende forbindelser har vært en del av overvåkningsprogrammet siden begynnelsen av 1990-tallet, før Stockholm konvensjonen trådte i kraft. Dette gjelder: Heksaklorbenzen (HCB) ved Birkenes og Zeppelin, heksaklorheksaner (HCH) ved Birkenes og Zeppelin, diklordifenyltrikloretaner (DDT), klordaner, polyklorerte bifenyler (PCB) og PAH-er ved Zeppelin. Lange tidsserier er også tilgjengelig for HCH-er og HCB i nedbør ved Birkenes. Data fra lange tidsserier og resultater fra trendanalyser viser synkende konsentrasjoner over tid, med halveringstider rundt 5-10 år i hele overvåkningsperioden for HCH-er ved Birkenes og Zeppelin, DDT-er og PCB-er ved Zeppelin og Benzo(a)pyren ved Birkenes (Tabell 1.1, Figur 14-15). Mindre nedgang med halveringstider over 15 år, eller ingen signifikant trend ses for andre PAH-er ved Birkenes eller Zeppelin, og PCBer og DDT ved Birkenes.

For HCB har overvåkningen vist økende nivåer i 2004-2016, etterfulgt av en nedadgående trend etter 2016 med korte halveringstider etter 2016 (Figur 13 under Key Findings). Konsentrasjonene av HCB er nå blant de laveste noensinne på alle stasjonene.

Table 1.2. Lange tidstrender for individuelle POPer, delt opp i to tidsperioder: 1) hele overvåkningsperioden (I henhold til Table 2); og 2) fra året da global regulering tredde i kraft for de individuelle POPene og frem til slutten av 2021 (Etter EoF). Trender vises som halveringstider (t1/2, y) der positive verdier indikerer nedadgående trender og negative verdier indikerer oppadgående trender. Jo lavere verdi, jo større er nedadgående eller oppadgående trend. Fargekoding og piler skal gi enklere tolking av verdier: Grønn (stor minking), gul-oransje (minimal endring-steady-state). Tomme hvite celler betyr at data mangler for stasjonen eller tidsperioden.

	Birkenes		Andøya		Zeppelin	
POP	**Hele måle-period**	**Etter EoF**	**Hele måle-period**	**Etter EoF**	**Hele måle-period**	**Etter EoF**
	$t_{1/2}$	**$t_{1/2}$**	**$t_{1/2}$**	**$t_{1/2}$**	**$t_{1/2}$**	**$t_{1/2}$**
HCB	34* ↘	23* ↘	NST →	NST →	NST →	NST →
α-HCH	5.6 ↓	11 ↘			5.6 ↓	7.1 ↓
γ-HCH	4.8 ↓	NST →			4.7 ↓	7.3 ↓
cis-CD					13 ↘	11 ↘
p,p'-DDE	NST →	NST →			8.9 ↓	8.1 ↓
p,p'-DDT	NST →	NST →			5.9 ↓	7.7 ↓
o,p'-DDT	15* ↘	15* ↘			6.8 ↓	9.3 ↓
p,p'-DDE	NST	NST			8.9 ↓	8.1 ↓
PCB-28	11 ↘	11 ↘			9.2 ↓	8.9 ↓
PCB-52	14* ↘	14* ↘			11 ↘	11 ↘
PCB-118	9.5 ↓	9.5 ↓			9.7 ↓	15 ↘
PCB-153	10* ↓	10* ↓			9.5* ↓	12* ↘
Fluorene	NST →				14 ↘	
Fluoranthene	NST →				12 ↘	
Benzo(a)pyrene	6.8 ↓					
BDE-47	10 ↓				22 ↘	
BDE-99	5.9 ↓				8.0 ↓	
PFOA	5.2* ↓	5.2* ↓	2.9* ↓	2.9* ↓	3.5 ↓	3.5 ↓

*R^2<0.7

NST: ikke noe signifikant trend

For forbindelser av bekymring, der overvåkningen har pågått i mindre enn ti år (dvs. cVMS, CP-er, nBFR-er, OPFR-er og dekloraner), er tidstrendsanalyser mindre nøyaktige. De målte konsentrasjonene av disse forbindelsene i 2021 er på samme nivåer som tidligere år og det er ikke observert noen synkende/stigende trend (se Key Findings).

Tungmetaller og kvikksølv – målte konsentrasjoner og romlig fordeling

Alle tungmetaller er detektert i nedbør på alle stasjoner. Observerte konsentrasjoner og nivåer av våtavsetting for Pb, Cd og Zn i 2021 er høyest ved Birkenes og Hurdal, etterfulgt av Kårvatn, som gjenspeiler økende avstand til de største utslippskildene på det europeiske kontinent (EMEP, 2021). Høye konsentrasjoner og avsetting er også observert ved Svanvik og Karpdalen. Miljøet i Øst-Finnmark er påvirket av utslipp fra det russiske smelteverket i Nikel. Denne påvirkningen er gjentatte ganger vist gjennom de nasjonale moseundersøkelsene (Steinnes et al., 2016). På slutten av 2020 ble smelteverket i Nikel nedlagt, og resultatene fra måleprogrammet i 2021 viser en 2 til 10gangers nedgang i konsentrasjonen av tungmetaller i nedbør, sammenliknet med 2020 (Bohlin-Nizzetto et al., 2021). Fra 2021 ble det igangsatt ukentlig prøveinnsamling av Hg i nedbør på Birkenes, samt at det i tillegg ble innført innsamling av nedbør ved Hurdal og Kårvatn. Den årlige gjennomsnittskonsentrasjonen av Hg i nedbør var høyest ved Hurdal, etterfulgt av Birkenes og Kårvatn, mens nedbørmengden var høyest ved Kårvatn etterfulgt av Birkenes og Hurdal. Dette resulterte i at våtavsettingen var høyest ved Hurdal og i stor grad var bestemt av høye konsentrasjoner i nedbørprøvene gjennom hele mai. Den observerte konsentrasjonsgradienten er et resultat av økende avstand til utslippskildene på det europeiske kontinentet. Det er ikke observert noen sesongvariasjon i hverken konsentrasjon eller våtavsetting for Hg ved noen av stasjonene.

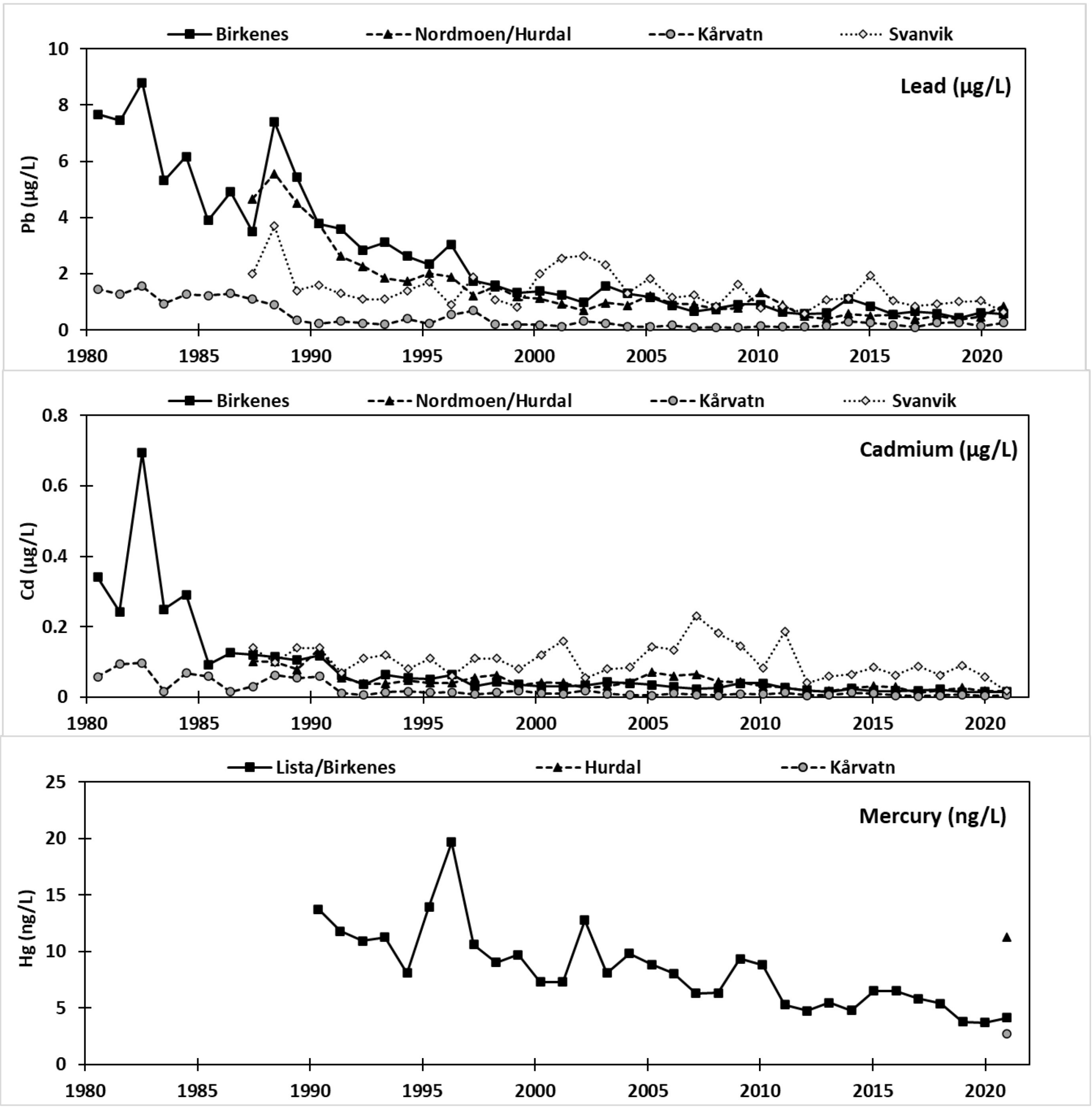


Figure 5: *Tidsserier av volumvektede årlige gjennomsnittskonsentrasjoner av bly, kadmium og kvikksølv i nedbør ved norske bakgrunnsstasjoner.*

For HM i luft er de observerte konsentrasjonene tilsvarende som i 2020 og godt under luftkvalitetskriteriene for metaller satt av FHI (Folkehelseinsituttet). I 2021 var konsentrasjonen av HM i luft ved Birkenes omtrent 2-3 ganger høyere enn ved Andøya og Zeppelin, som skyldes at Birkenes er nærmere utslippskildene på det europeiske kontinentet (EMEP, 2021). Historisk er konsentrasjonen av

HM i luft ved Svanvik og Karpdalen ca. 10 ganger høyere enn ved Birkenes (Berglen et al., 2021), men siden smelteverket i Nikel nær den norske grensen til Russland ble stengt, er konsentrasjonene av HM i luft kraftig redusert og i 2021 var de observerte konsentrasjonene omtrent på samme nivå som ved Birkenes. Gjennomsnittskonsentrasjonen av GEM i luft er omtrent den samme ved alle de norske stasjoner på den nordlige halvkule, mens konsentrasjonen av GEM ved Troll i Antarktis er lavere. Dette skyldes at det er færre utslippskilder til kvikksølv på den sørlige halvkule sammenliknet med den mer industrialiserte og befolkningstette nordlige halvkule, samt at det er langsom blanding av luftmasser mellom de to halvkulene. I 2021 ble det innført måling av kvikksølvspesier i luft ved Zeppelin. Disse omfatter det såkalte gassfase oksidert kvikksølv (GOM) og kvikksølv bundet til partikler (PBM). Ved bakgrunnsstasjoner er mesteparten av kvikksølv i luft til stede som GEM, mens konsentrasjonen av GOM og PBM er lav. Av det totale kvikksølvinnholdet i luft er normalt <1% GOM og PBM. Det skyldes at GOM og PBM har relativt kort levetid i atmosfæren sammenliknet med GEM og dermed har redusert potensial for langtransport fra utslippskildene. GOM er mindre flyktig og mer vannløselig enn GEM og blir derfor lettere fjernet fra atmosfæren med regn, adsorbert til overflater eller partikler i luften.

Tungmetaller og kvikksølv – tidstrender fra langtids overvåkingsdata
Konsentrasjonen av de fleste tungmetaller i nedbør er kraftig redusert siden målingene startet på 1990-tallet, bortsett fra for Pb ved Kårvatn og Co ved Birkenes hvor ingen signifikant trend er observert siden 1990. De største reduksjonene skjedde tidlig i måleserien, og siden 2010 er det ingen signifikant nedgang for de fleste tungmetaller. For Hg har den nedadgående trenden stabilisert seg og siden 2010 er det ikke observert noen signifikant nedgang ved Birkenes. Nedgang i Hg konsentrasjon og våtavsetting er begrunnet med økende mengde nedbør som et resultat av klimaforandringer, samt reduksjoner i antropogene utslipp. Den nedadgående trenden er svært varierende fra år til år og nedgangen var størst i begynnelsen av måleserien.

Luftovervåkingen viser signifikante reduksjoner for alle elementer ved Lista/Birkenes for perioden 1991 til 2021, mens på Zeppelin er det signifikante reduksjoner fra 1994 for noen elementer (As, Pb og Hg). Økende trender er observert for Cr, Ni og Mn på Zeppelin, mens ingen trend er observert for Zn, Cd, Cu og Co. I følge det europeiske miljøbyrået (EEA) er europeiske utslipp av Ni, Zn og Cr redusert med mer enn 50% siden 2007, noe som kan indikere at Ni, Zn og Cr observert ved Zeppelin har kilder av mer lokal opprinnelse (Platt et al., 2022), og stammer sannsynligvis fra både geogene og antropogene (skipstrafikk og gruvedrift) kilder (Conca et al., 2019). Utslippene av Hg i Europa er kraftig redusert, noe også luftovervåkingen i Norge viser. Konsentrasjonsreduksjonen er kraftigst ved Birkenes i sør på grunn av nærhet til de reduserte utslipp i Europa. Dette støttes også av trajektorie-modeller av luftmasser fra Europa, samt samvariasjonsstudier mellom Hg og antropogene utslipps-«tracere», i tillegg til mekanistiske kjemiske transport modeller som baserer seg på utslippsoversikter (NMA, 2022). GEM-konsentrasjoner i luft minker ikke like raskt som Hg-utslippene i Europa. Dette skyldes såkalte «legacy» Hg utslipp og en svært komplisert biogeokjemisk kvikksølvsyklus som er med på å komplisere forholdet mellom utslipp og konsentrasjon.

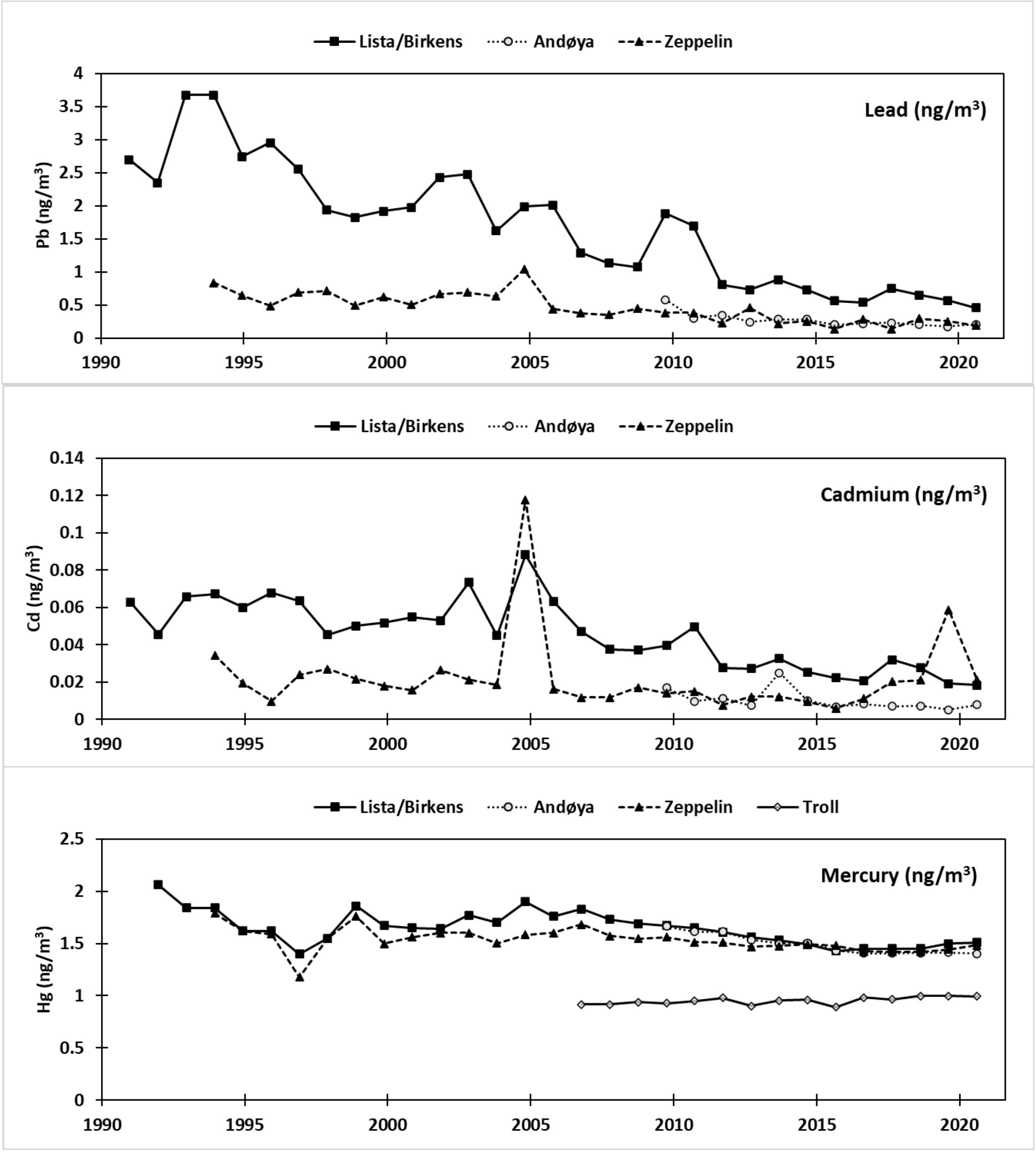


Figure 6: *Tidsserier av årlig middelkonsentrasjon i luft og aerosoler av bly, kadmium og kvikksølv mellom 1991 og 2021. Enhet: ng/m^3.*

Monitoring of environmental contaminants in air and precipitation

Annual report 2021

1 Background

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

2 Monitoring 2021

2.1 Introduction

The data from 2021, presented in this report, are a compilation of data from two monitoring programs:

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

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

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

POPs and heavy metals can undergo long-range environmental transport, are toxic, bioaccumulative and persistent in the environment. Continuous monitoring is a high priority for Norwegian authorities due to the contaminants' harmful impacts on human health and/or on the environment together with their transboundary nature. For many of these contaminants, long-range transport via air is the most important source to pollution in remote areas where there are few or no local sources. Recognition of long-range atmospheric transport of environmental contaminants to remote areas, such as the Arctic, has been vital in our understanding of the presence and environmental behaviour of POPs and Hg. This in turn has contributed to the regulation of the use and emission of several POPs and heavy metals both on a regional and global scale (Rottem et al., 2017; Downie & Fenge, 2003; AMAP, 2018). 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). With the Minamata convention entering into force in 2017, there is increased focus on monitoring of Hg. Additions to the monitoring program for long-range transported atmospheric contaminants were made in 2021 to improve our understanding of the long-range transport of atmospheric mercury to the Norwegian environment. POPs are regulated on a global scale by the Stockholm Convention on POPs (Stockholm Convention, 2007) and on a European scale by the 1998 Aarhus Protocol on POPs; "the POP-protocol", under LRTAP (UN/ECE, 1998b). The two POP conventions today include 30 and 23 substances/substance groups respectively and the number of chemicals included in the regulations are continuously expanded (UN/ECE, 2010, Stockholm Convention, 2019a).

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

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

The findings from this monitoring are also important for monitoring the effectiveness of and compliance with existing abatement strategies. Data and results from the national monitoring program are reported and used in several international fora including: The Global Monitoring Programme (GMP) of the Stockholm Convention on POPs, the European Monitoring and Evaluation Programme (EMEP) under the Convention on Long-range Transboundary Air Pollution, the Comprehensive Atmospheric Monitoring Programme (CAMP) under the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR) and the Arctic Monitoring and Assessment Program (AMAP) (AMAP, 2016). A subset of the data 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.

2.2 Overview of plan for sampling and analysis

2.2.1 Monitoring sites

To document the long-range transport of the environmental contaminants, the monitoring stations/observatories in this report have been placed, as far as possible, in areas that are not influenced by local sources for the regulated and long-term monitored contaminants. For example, the occurrence of organic pollutants in the Arctic region has mostly been attributed to long-range transport from distantly located, industrial and agricultural areas. However, for the organic contaminants of emerging concern, it is important to continuously evaluate possible influences of local sources in comparison to long-range transport since these contaminants still are in use and present in materials and products. Consequently, measures to remove specific material and products are taken both at sampling stations and in the analytical laboratories when such are identified and can be replaced. 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). An assessment of the influence and importance of local sources on measurements must be taken through international collaboration (e.g. via AMAP).

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 (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: i.e. Birkenes in southern Norway, and Andøya in northern Norway, and one, is located on Svalbard, an archipelago in the Arctic Ocean: i.e. Zeppelin (Figure 7, Table 2.1). POPs in precipitation is only monitored at Birkenes while heavy metals in precipitation is monitored at four sites: Birkenes, Hurdal and Kårvatn in the southern-central parts of Norway, and Svanvik in northern Norway (Figure 7, Table 2.1). This report also includes heavy metals in precipitation and air from Karpdalen in Sør-Varanger and heavy metals in air at Svanvik (Berglen et al., 2019). Further information of the sampling sites is available at: http://www.nilu.no/projects/ccc/sitedescriptions/.

Table 2.1: Information about the monitoring stations and list of measured contaminants at each station in 2021.

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, HBCDDs, PAHs, PFAS (ionic + volatile), cVMS, S/MCCPs	HCB, PFAS (ionic + volatile)	HCB, HCH, DDTs, chlordanes, PCBs, PBDEs, HBCDDs, PAHs, PFAS (ionic + volatile), cVMS, lVMS, S/MCCPs, nBFRs, OPFRs, dechloranes, volatile fluorinated and chlorinated substances				
Organic contaminants - Precipitation	**HCB, HCHs, PCBs**						
Heavy metals - Air	**As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn, Hg**	**As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn, Hg**	**As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn, Hg + Hg-species**			**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**			**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, Mn, Ni, V, Zn**	**Al, As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn**

Figure 7: Norwegian background stations measuring environmental contaminants in 2021.

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

Air samples for organic contaminants and heavy metals (excluding mercury) are collected using active air samplers at all three sites. The number of samples per year and the sampling length per sample are compound and site specific (i.e. 12 to 52 sampler per year, Table A.3.4). The sampling methodologies have been optimized to achieve maximum detection while minimizing the influence of possible sampling artefacts, such as breakthrough and degradation. Mercury in air 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 (details in Annex B). 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). Details about the sampling and analytical methodologies are given in Annex B. All POP and heavy metal data presented in this report are available at http://ebas.nilu.no/.

2.2.2 Organic contaminants

The monitoring programme for organic contaminants in 2021 included eight classes and one individual compound classified as POPs. Most of the regulated pollutants are measured once per week at Birkenes and Zeppelin with some exceptions. Air samples for PBDEs, HBCDDs 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 approach is to improve detection of these compounds that previous years often have been below detection limit. At Birkenes, the measurements of HCHs and DDTs are done once per month. 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 2.2). Exceptions are the ionic PFAS which are covering only the particle phase.

Table 2.2: Monitoring programme for regulated organic pollutants (e.g. POPs) in 2021.

		Birkenes		**Andøya**		**Zeppelin**	
POP class/ compound	**Matrix**	**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
HBCDDs	Gas+particle phase	2006	monthly*	-	-	2006	monthly*
PAHs	Gas+particle phase	2009	weekly	2009-2012**	-	1994	weekly
PFAS (ionic)	Particle phase	2006	monthly*	2009	monthly*	2006	monthly*

*New sampling frequency from 2017

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

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

Organic contaminants that are not yet regulated, but have been identified as contaminants of emerging concern in, for example, environmental screening programmes in Norway (van Bavel et al., 2016; Schlabach et al., 2017a+b), are also included in the monitoring programme. The purpose of the monitoring of these emerging contaminants is to obtain data in air that can be used for possible future regulations at national, EU- and/ or global level. Another aspect is that if monitoring is initiated before a regulation/measure enters into force it may also be possible to get a more complete picture of the time trends, and the effect of the regulations.

Two of the organic contaminants of emerging concern; cVMS and S/MCCPs, have been monitored in air as part of this programme since 2013. Similarly, another three contaminant classes have been included in monitored programme since 2017; i.e. volatile PFAS, novel brominated flame retardants (nBFRs),and OPFRs. In 2020 and 2021, also climate relevant volatile fluorinated and chlorinated substances were included. Most of the target ionic PFAS are non-regulated and therefore fall under the category of chemicals of 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 B.

The volatile fluorinated and chlorinated substances were collected on weekly basis starting from mid-May 2021.

Table 2.3: Organic contaminants of emerging concern included in the monitoring programme "Long-range transported atmospheric contaminants" in 2021, year of first monitoring, sampling frequency and sample matrix at the different observatories.

		Zeppelin		**Birkenes**		**Andøya**	
Organic contaminants of emerging concern	**Matrix**	**Start year**	**Sampling frequency**	**Start year**	**Sampling frequency**	**Start year**	**Sampling frequency**
S/MCCPs	Gas+particle phase	2013	weekly	2017	monthly	-	-
cVMS	Gas phase	2013	weekly*	2017	monthly	-	-
PFAS (volatile)	Gas phase	2017	monthly	2017	monthly	2017	monthly
Other PFAS	Particle phase	2021	monthly				
nBFRs	Gas+particle phase	2017	monthly**			-	-
OPFRs	Gas+particle phase	2017	monthly**			-	-
Dechloranes	Gas+particle phase	2019	monthly				
Volatile fluorinated and chlorinated substances	Gas phase	2020	campaign				

*New sampling frequency from 2017.

**Two samples per months

Table 2.4: Full names and abbreviations of the organic contaminants of emerging concern included in the monitoring programme in 2021.

Full name	Abbreviation	CAS
Chlorinated paraffins		
Short-chain chlorinated paraffins (C10-C13)	SCCPs	85535-84-8
Medium-chain chlorinated paraffins (C14-C17)	MCCPs	85535-85-9
Siloxanes		
Octamethylcyclotetrasiloxane	D4	556-67-2
Decamethylcyclopentasiloxane	D5	541-02-6
Dodecamethylcyclohexasiloxane	D6	540-97-6
Octamethyltrisiloxane	L3	107-51-7
Decamethyltetrasiloxane	L4	141-62-8
Dodecamethylpentasiloxane	L5	141-63-9
Tris(trimethylsiloxy)phenylsilane	M3T(Ph)	2116-84-9
2,4,6,8-tetramethyl-2,4,6,8-tetrakis (3,3,3-trifluoropropyl)-cyclotetrasiloxane	F3-Sil	429-67-4
2,4,6-trimethyl-2,4,6-tris(3,3,3-trifluoropropyl)cyclotrisiloxane	F4-Sil	2374-14-3
Heptamethylphenylcyclotetra-siloxane	Ph-D4	84-61-7
Volatile PFAS		
4:2 fluorotelomer alcohol	4:2 FTOH	2043-47-2
6:2 fluorotelomer alcohol	6:2 FTOH	647-42-7
8:2 fluorotelomer alcohol	8:2 FTOH	678-39-7
10:2 fluorotelomer alcohol	10:2 FTOH	865-86-1
12:2 fluorotelomer alcohol	12:2 FTOH	39239-77-5
N-ethyl perfluorooctanesulfonamide	N-EtFOSA	4151-50-2
N-ethyl perfluorooctane sulfonamido-ethanol	N-EtFOSE	1691-99-2
N-methylperfluoro-1-octansulfonamide	N-MeFOSA	31506-32-8
N-Methylperfluorooctanesulfon-amido-ethanol	N-MeFOSE	24448-09-7
Other PFAS		
Perfluorinated octane sulfonated, branched	brPFOS	
10:2 Fluorotelomer sulfonic acid	10:2 FTS	120226-60-0
12:2 Fluorotelomer sulfonic acid	12:2 FTS	149246-64-0
Perfluoro-3,7-dimethyloctanoic acid	PF-3,7-DMOA	172155-07-6
Perfluorooctane sulfonamidoacetic acid	FOSAA	2806-24-8
N-Methyl Perfluorooctane sulfonamido-acetic acid	MeFOSAA	2355-31-9
N-ethyl-N-[(heptadecafluorooctyl)-sulfonyl]glycine	EtFOSAA	2991-50-6
Perfluorobutane sulfonamide	FBSA	
N-Methyl perfluorobutane-sulfonamide	MeFBSA	68298-12-4

Full name	Abbreviation	CAS
N-Ethylperfluorobutane-sulfonamide	EtFBSA	
7H-dodecafluoroheptanoic acid	HPFHpA	1546-95-8
7:3 Fluorotelomer acrylate	7:3 FTCA	812-70-4
Potassium 1,1,2,2-tetrafluoro-2-(perfluorohexyloxy)ethane sulfonate	F53	754925-54-7
Sodium 8-chloroperfluoro-1-octane-sulfonate	8Cl-PFOS	777011-38-8
Potassium 9-chlorohexadeca-fluoro-3-oxanonane-1-sulfonate	6:2 F53B	73606-19-6
Novel brominated flame retardants - nBFRs		
Allyl 2,4,6-tribromophenyl ether	ATE (TBP-AE)*	3278-89-5
α-Tetrabromoethylcyclohexane	α-TBECH (DBE-DBCH)	1232836-48-4, 3322-93-8
β-Tetrabromoethylcyclohexane	β-TBECH (DBE-DBCH)	1232836-49-5, 3322-93-8
γ/δ-Tetrabromoethylcyclohexane	γ/δ-TBECH (DBE-DBCH)	
2-Bromoallyl-2,4,6-tribromophenyl ether	BATE (TBP-BAE)*	99717-56-3
Pentabromotoluene	PBT	87-83-2
Pentabromoethylbenzene	PBEB	85-22-3
1,2,3,4,5-pentabromobenzene	PBBZ	608-90-2
Hexabromobenzene	HBB	87-82-1
2,3-dibromopropyl-2,4,6-tribromophenyl ether	DPTE (TBP-DBPE)	35109-60-5
2-ethylhexyl-2,3,4,5-tetrabromobenzoate	EHTBB	183658-27-7
1,2-bis(2,4,6-tribromophenoxy)ethane	BTBPE	37853-59-1
Bis(2-ethylhexyl)tetrabromophthalate	TBPH (BEH-TBP)	26040-51-7
Decabromodiphenylethane	DBDPE	84852-53-9
Tetrabromobisphenol A	TBBPA	79-94-7
Organophosphorous flame retardants - OPFRs		
Triethyl phosphate	TEP	78-40-0
Tri(2-chloroethyl)phosphate	TCEP	115-96-8
Tripropyl phosphate	TPrP (TPP)	513-08-6
Tris(2-chloroisopropyl)phosphate	TCPP (TCIPP)	13674-84-5
Triisobutyl phosphate	TBP (TiBP)	126-71-6
Butyl diphenyl phosphate	BdPhP	2752-95-6
Triphenyl phosphate	TPP (TPhP)	115-86-6
Dibutylphenyl phosphate	DBPhP	2528-36-1
Tri-n-butylphosphate	TnBP	126-73-8
Tris(1,3-dichloro-2-propyl)phosphate	TDCPP (TDCIPP)	13674-87-8
Tris(2-butoxyethyl)phosphate	TBEP (TBOEP)	78-51-3
Tricresyl phosphate	TCP	1330-78-5
2-ethylhexyldiphenyl phosphate	EHDP (EHDPP)	1241-94-7
Trixylyl phosphate	TXP	25155-23-1
Tris(4-isopropylphenyl)phosphate	TIPPP	68937-41-7
Tris(2-ethylhexyl)phosphate	TEHP	78-42-2

Full name	Abbreviation	CAS
2-isopropylphenyl diphenyl phosphate	2-IPPDPP	64532-94-1 28108-99-8
4-isopropylphenyl diphenyl phosphate	4-IPPDPP	55864-04-5
Bis(4-isopropylphenyl) phenyl phosphate	B4IPPPP	55864-07-8
Dechloranes		
Dechlorane plus syn	syn-DP	135821-03-3
Dechlorane plus anti	anti-DP	135821-74-8
Dechlorane 601	Dec-601	13560-90-2
Dechlorane 602	Dec-602	31107-44-5
Dechlorane 603	Dec-603	13560-92-4
Dechlorane 604	Dec-604	34571-16-9
Dibromoaldrin	Dba	20389-65-5
Chlordene plus		1356-91-3
Dechlorane plus Cl10		
Dechlorane plus axx Cl10		
Dechlorane plus ax Cl11		
Dechlorane plus Cl11		
Volatile fluorinated and chlorinated substances		
Perfluorotributylamine	PFTBA	311-89-7
Tetrachlorohexafluorobutane	TCPFB	375-45-1
Perfluorotripentylamine	PFTPeA	338-84-1
Hexachlorobutadiene	HCBD	87-68-3
Perfluoroperhydrophenanthrene	PFPHP	306-91-2
Dichlorotrifluoropyridene	DCTFP	1737-93-5
Dichlorobenzotrichloride, 2,3- **Dichlorobenzotrichloride, 3,4-**	DCBTC	13014-24-9 84613-97-8
Dichloroperfluorocyclohexene	DCPFcH	336-19-6
Pentafluorobromobenzene	PFBB	344-04-7
3,5-bis-(trifluoromethyl)-bromobenzene	bisTFMBB	328-70-1
Pentachlorotoluene	PCTol	877-11-2
Hexachlorocyclobutene	HCcBen	6130-82-1
	HCBcB	-

*Possible degradation during analytical clean-up steps. Results uncertain.

2.2.3 *Heavy metals and mercury*

Heavy metals in precipitation have been monitored at Norwegian observatories as part of government funded monitoring programmes since 1980.

With the Minamata convention entering into force in 2017, there is a need for increased focus on Hg monitoring. At the end of the previous program period, it was decided to expand the monitoring programme for Hg from 2021 by including Hg in precipitation at Hurdal and Kårvatn in addition to Birkenes, and to increase the sampling frequency from monthly to weekly sampling. Further, it was decided to include Hg speciation measurements at Zeppelin. Atmospheric Hg speciation measurements, in concert with trajectory modelling and chemical profiling, will help us to better understand the contribution from different source categories in different source regions. This is a relevant contribution to Article 22 of the Minamata Convention (the Effectiveness Evaluation), that require an estimation of the influence of different regulatory measures to the observed mercury concentrations.

Mercury species were previously measured at Zeppelin since 2007 (not funded by the Norwegian Environment Agency). Data are published in Platt et al., 2022 and references therein, and data are available at http://ebas.nilu.no/.

Table 2.5: Monitoring of heavy metals in 2021.

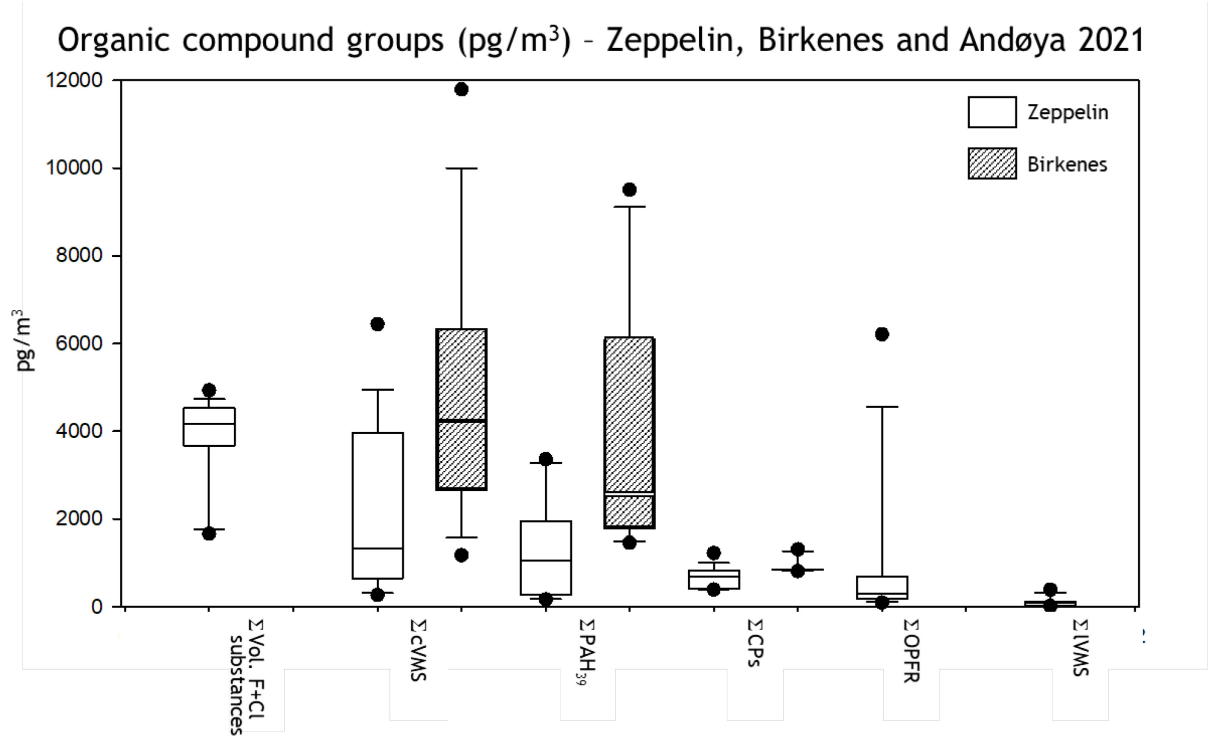
	Matrix	Birkenes	Andøya	Zeppelin	Hurdal	Kårvatn	Svanvik	Karpdalen
Heavy metals - air	Particle phase	weekly	weekly	weekly	-	-	weekly	weekly
Heavy metals - precipitation	Precipitation	weekly	-	-	weekly	weekly	weekly	weekly
Hg - air	Gas phase	continuously	-	continuously	-	-	-	-
Hg species - air	Gas and particles	-	-	semi-continuously				
Hg - precipitation	Precipitation	weekly	-	-	weekly	weekly	-	-

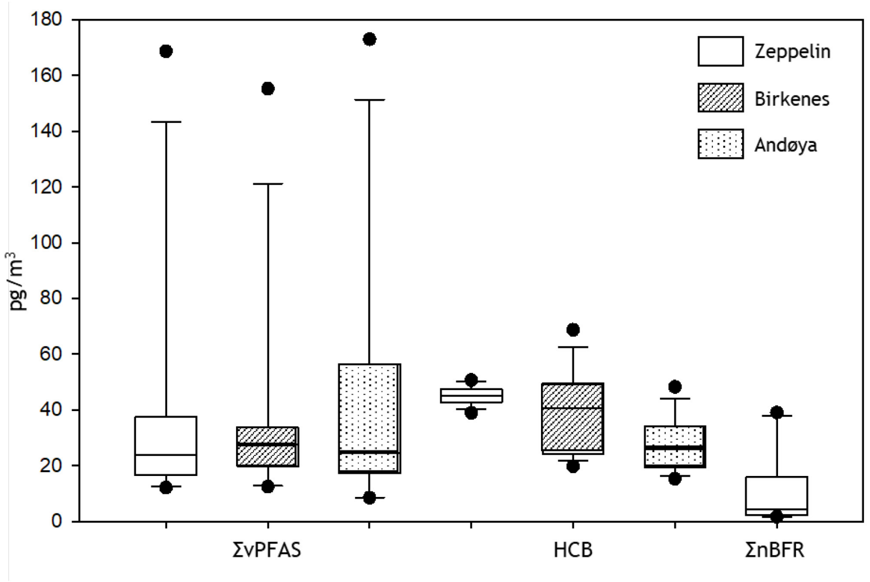
2.3 Key findings

2.3.1 Organic contaminants

2.3.1.1 Measured concentrations

The measured concentrations of the targeted organic contaminants at Birkenes, Andøya and Zeppelin are presented in Annex A, Figure 1 and Figure 8-12.





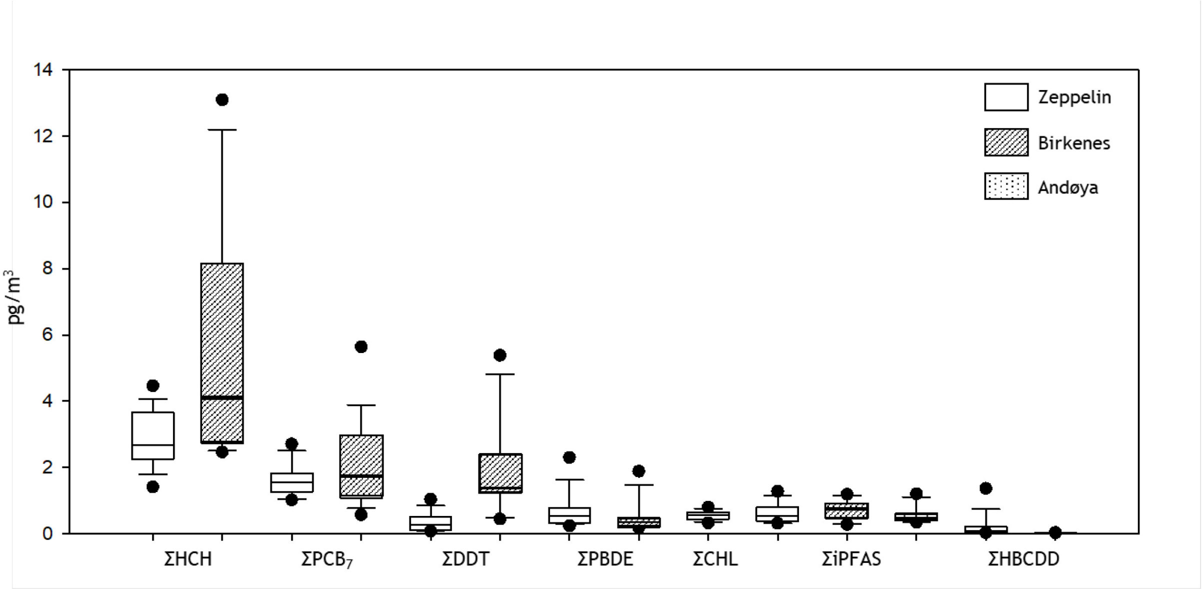


Figure 8: Box-plot of measured concentrations of the targeted organic compound groups in air at the respective monitoring station in 2021. The highest concentrations are presented in the upper figure and the lowest concentrations in the lower figure. The boxes represent the range from 25 to 75 percentile with the center line representing the median value. The bars represent the 10 and 90 percentiles.

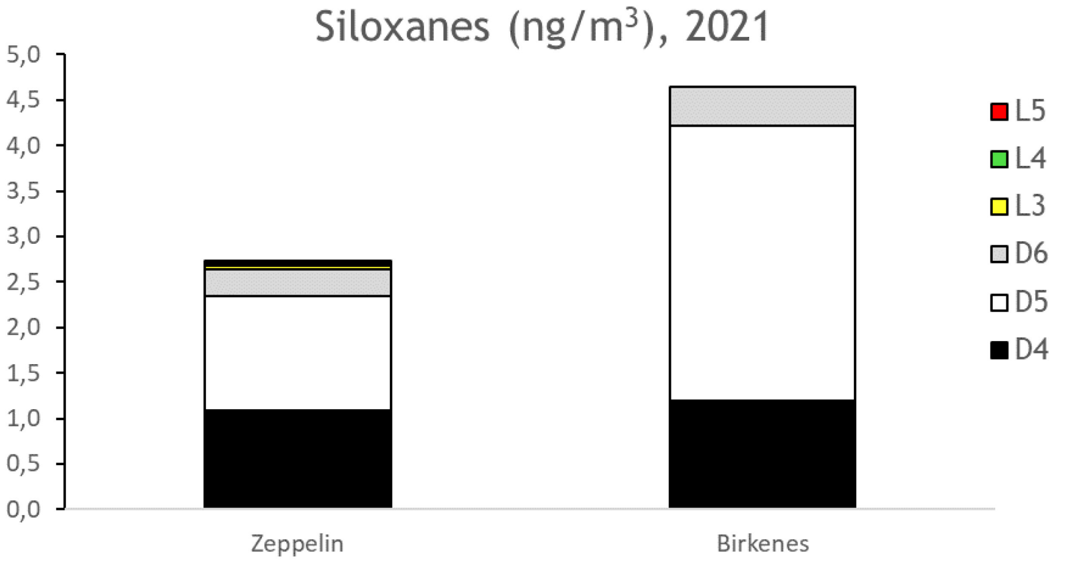


Figure 9: Annual mean concentrations of cyclic and linear volatile methyl siloxanes in air (ng/m^3) at Zeppelin and Birkenes in 2021. The annual mean concentrations for the cyclic oligomers D4-D5 are based on weekly samples at Zeppelin and monthly samples at Birkenes. Linear oligomers L3-L5 were only measured at Zeppelin and the annual mean concentration is based on monthly samples.

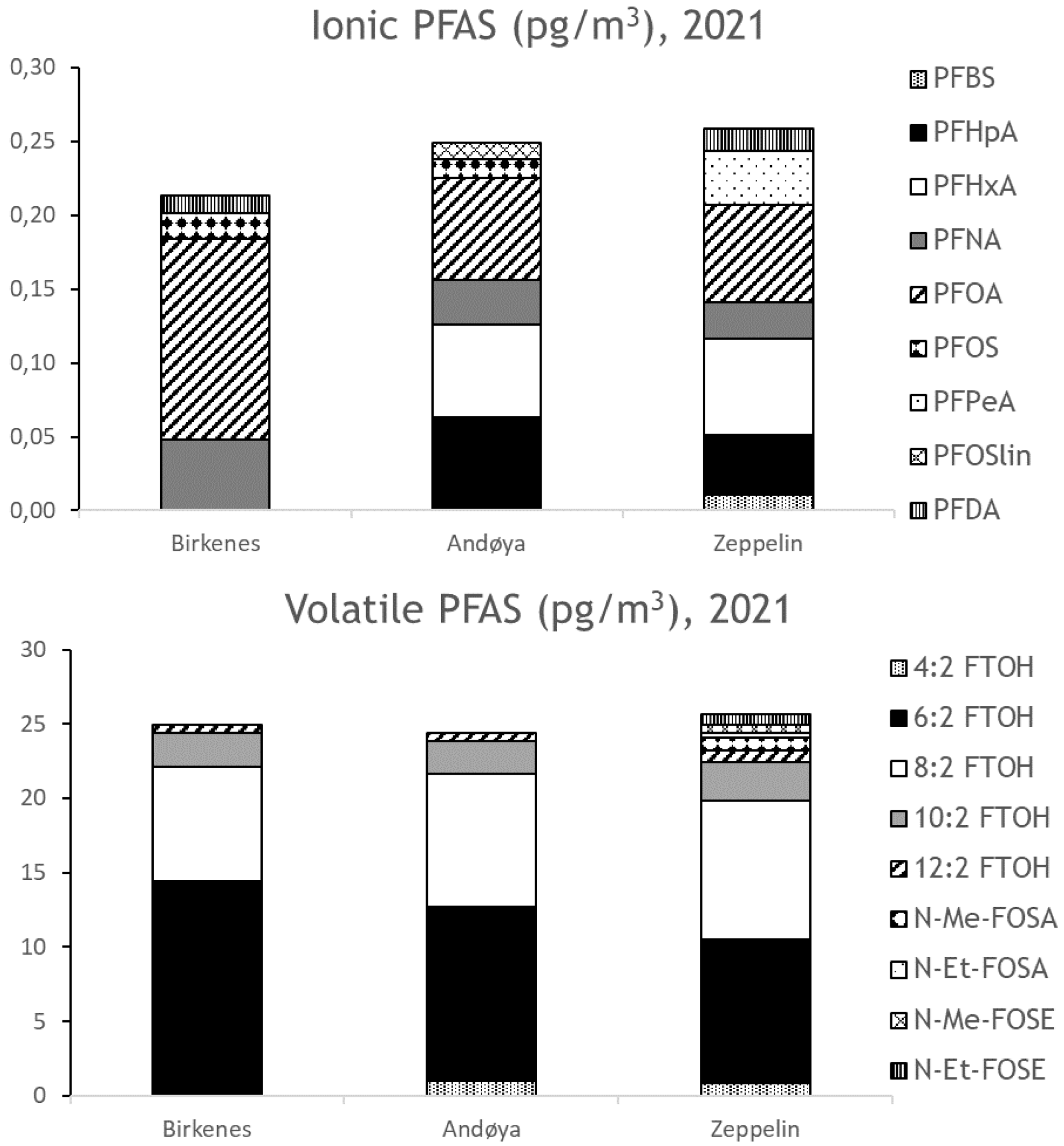


Figure 10: Annual median concentrations of ionic and volatile PFAS in air (pg/m^3) at Birkenes, Andøya and Zeppelin in 2021. The annual median concentrations for all sites are based on monthly samples, ionic PFAS for particle phase only and volatile PFAS for gas phase only.

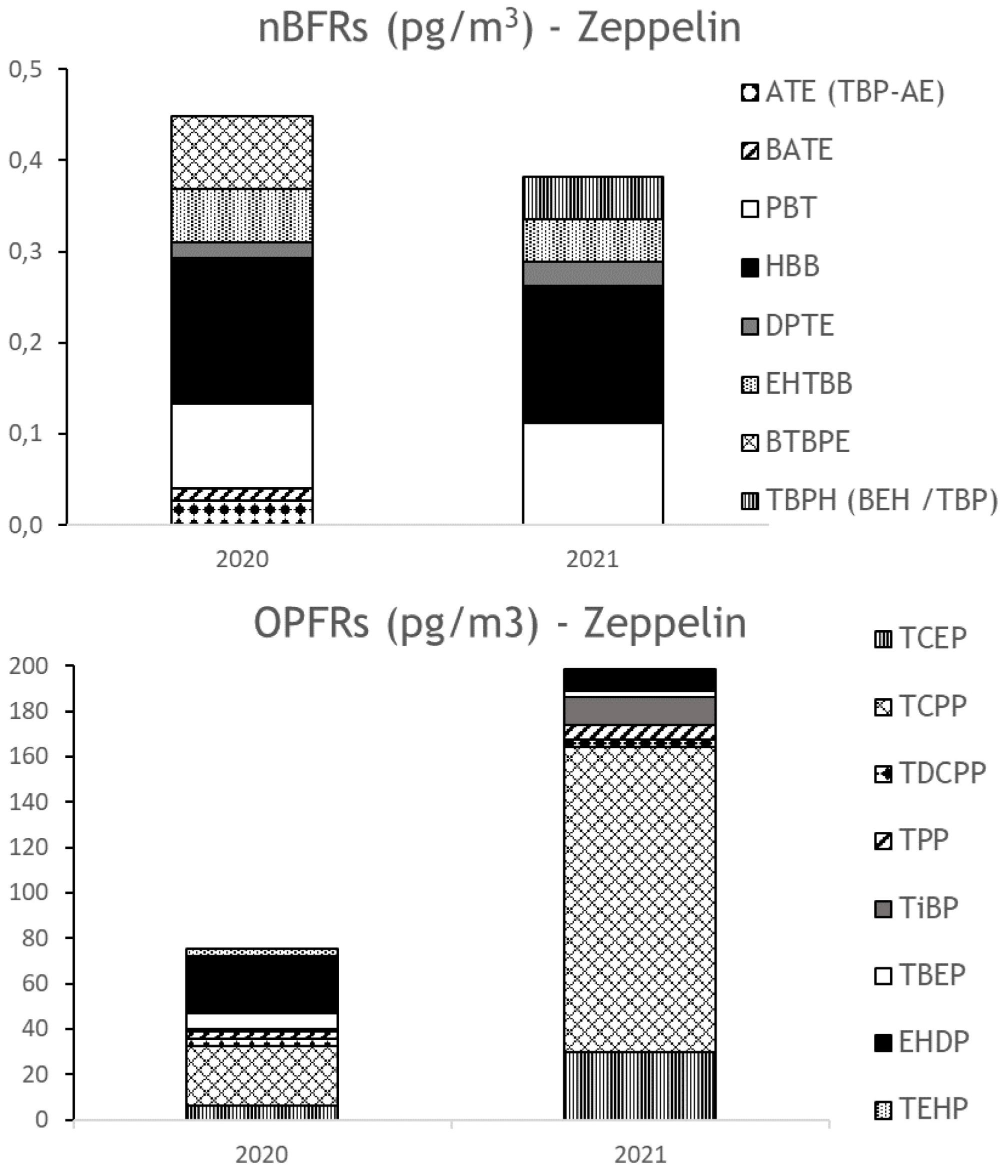


Figure 11: Annual median concentrations of the detected nBFRs and OPFRs in air (pg/m^3) at Zeppelin in 2020 and 2021. The annual median concentrations are based on monthly samples in 2021 while only on summer and winter samples in 2020.

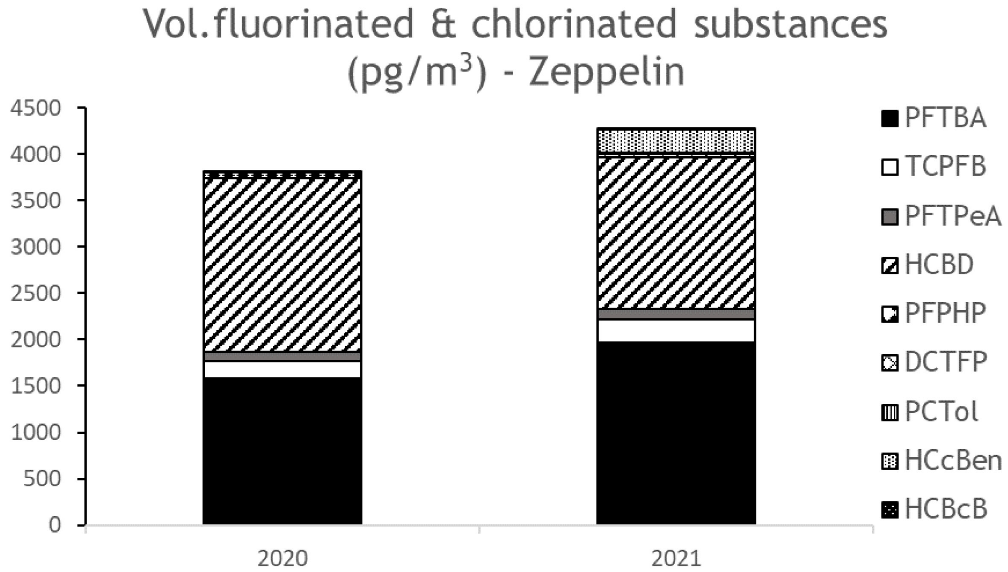


Figure 12: Annual mean concentrations of the detected volatile fluorinated and chlorinated substances in air (pg/m^3) at Zeppelin in 2020 and 2021. The annual mean concentration for 2021 is based on weekly samples from May to December while 2020 is based on eight summer and eight winter samples.

2.3.1.2 Detection frequencies

Table 2.6: Detection frequency (expressed as %) for regulated organic pollutants in air at the three monitoring stations in 2021. Presented are contaminants included in the routine monitoring programme. The colour codes indicate highest detection in red and lowest detection in green. For details on levels and method detection limits (MDLs) of contaminants see Appendix A table A1-A3.

		Birkenes	**Andøya**	**Zeppelin**
Compound	**Matrix**	**Detection frequency (%)**		
HCB	Gas+particle	100	100	100
α-HCH	Gas+particle	100	n.a.	100
γ-HCH	Gas+particle	100	n.a.	100
p,p'-DDT	Gas+particle	82	n.a.	62
o,p'-DDT	Gas+particle	100	n.a.	89
p,p'-DDE	Gas+particle	100	n.a.	100
o,p'-DDE	Gas+particle	100	n.a.	94
p,p'-DDD	Gas+particle	44	n.a.	21
o,p'-DDD	Gas+particle	67	n.a.	52
cis-CD	Gas+particle	n.a.	n.a.	100
cis-NO	Gas+particle	n.a.	n.a.	93
trans-CD	Gas+particle	n.a.	n.a.	100
trans-NO	Gas+particle	n.a.	n.a.	100
PCB-28	Gas+particle	100	n.a.	100
PCB-52	Gas+particle	100	n.a.	100
PCB-101	Gas+particle	98	n.a.	100
PCB-118	Gas+particle	94	n.a.	100
PCB-138	Gas+particle	92	n.a.	100

		Birkenes	Andøya	Zeppelin
Compound	**Matrix**	**Detection frequency (%)**		
PCB-153	Gas+particle	92	n.a.	100
PCB-180	Gas+particle	50	n.a.	39
BDE-47	Gas+particle	100	n.a.	100
BDE-49	Gas+particle	100	n.a.	100
BDE-66	Gas+particle	100	n.a.	73
BDE-71	Gas+particle	54	n.a.	35
BDE-99	Gas+particle	92	n.a.	100
BDE-100	Gas+particle	92	n.a.	100
BDE-153	Gas+particle	75	n.a.	40
BDE-154	Gas+particle	69	n.a.	33
BDE-183	Gas+particle	83	n.a.	51
BDE-196	Gas+particle	15	n.a.	20
BDE-206	Gas+particle	46	n.a.	68
BDE-209	Gas+particle	46	n.a.	90
α-HBCDD	Gas+particle	18	n.a.	77
β-HBCDD	Gas+particle	0	n.a.	42
γ-HBCDD	Gas+particle	0	n.a.	23
1-Methylnaphthalene	Gas+particle	83	n.a.	95
1-Methylphenanthrene	Gas+particle	100	n.a.	39
2-Methylanthracene	Gas+particle	2	n.a.	5
2-Methylnaphthalene	Gas+particle	69	n.a.	93
2-Methylphenanthrene	Gas+particle	100	n.a.	36
3-Methylphenanthrene	Gas+particle	100	n.a.	36
9-Methylphenanthrene	Gas+particle	100	n.a.	36
Acenaphthene	Gas+particle	98	n.a.	9
Acenaphthylene	Gas+particle	74	n.a.	16
Anthanthrene	Gas+particle	31	n.a.	4
Anthracene	Gas+particle	90	n.a.	4
Benz(a)anthracene	Gas+particle	89	n.a.	14
Benzo(a)fluoranthene	Gas+particle	45	n.a.	4
Benzo(a)fluorene	Gas+particle	91	n.a.	16
Benzo(a)pyrene	Gas+particle	94	n.a.	16
Benzo(b)fluoranthene	Gas+particle	100	n.a.	37
Benzo(b)fluorene	Gas+particle	81	n.a.	5
Benzo(e)pyrene	Gas+particle	98	n.a.	27
Benzo(ghi)fluoranthen	Gas+particle	n.a.	n.a.	0
Benzo(ghi)perylene	Gas+particle	98	n.a.	25
Benzo(k)fluoranthene	Gas+particle	94	n.a.	21
Biphenyl	Gas+particle	89	n.a.	80
Chrysene	Gas+particle	100	n.a.	37
Coronene	Gas+particle	83	n.a.	12
Cyclopenta(cd)pyrene	Gas+particle	0	n.a.	0

		Birkenes	Andøya	Zeppelin
Compound	**Matrix**	**Detection frequency (%)**		
Dibenzo(ae)pyrene	Gas+particle	57	n.a.	5
Dibenzo(ah)anthracen	Gas+particle	65	n.a.	4
Dibenzo(ah)pyrene	Gas+particle	6	n.a.	0
Dibenzo(ai)pyrene	Gas+particle	9	n.a.	0
Dibenzofuran	Gas+particle	100	n.a.	96
Dibenzothiophene	Gas+particle	100	n.a.	59
Fluoranthene	Gas+particle	100	n.a.	52
Fluorene	Gas+particle	100	n.a.	82
Inden(123-cd)pyrene	Gas+particle	98	n.a.	25
Naphthalene	Gas+particle	67	n.a.	100
Perylene	Gas+particle	44	n.a.	4
Phenanthrene	Gas+particle	100	n.a.	30
Pyrene	Gas+particle	100	n.a.	48
Retene	Gas+particle	100	n.a.	34
FTS 4:2	Particle phase	0	0	0
FTS 6:2	Particle phase	42	8	0
FTS 8:2	Particle phase	0	0	0
PFBS	Particle phase	25	8	50
PFDoDA	Particle phase	17	0	8
PFHpA	Particle phase	42	100	75
PFHxA	Particle phase	33	92	100
PFHxS	Particle phase	0	8	0
PFNA	Particle phase	92	92	67
PFOA	Particle phase	100	100	100
PFOS	Particle phase	58	50	8
PFOSA	Particle phase	17	0	25
PFUnA	Particle phase	42	42	25
PFPS	Particle phase	0	0	0
PFHpS	Particle phase	0	0	0
PFNS	Particle phase	0	0	0
PFPeA	Particle phase	n.a.	n.a.	92
PFTrDA	Particle phase	0	0	0
PFTeDA	Particle phase	0	0	0
PFHxDA	Particle phase	0	0	0
PFODcA	Particle phase	0	0	0
PFDS	Particle phase	0	0	0
PFOSlin	Particle phase	33	42	8
PFDA	Particle phase	67	33	58
PFUnS	Particle phase	0	0	0
PFDoS	Particle phase	0	0	0
PFTrS	Particle phase	n.a.	n.a.	100
PFTS	Particle phase	n.a.	n.a.	100

Table 2.7. Detection frequency (expressed as %) for regulated organic pollutants in precipitation at the monitoring station in 2021. Presented are contaminants included in the routine monitoring programme. The colour codes indicate highest detection in red and lowest detection in green. For details on levels and method detection limits (MDLs) of contaminants see Appendix A table A1.

		Birkenes
Compound	**Matrix**	**Detection frequency (%)**
HCB	Precip	44
α-HCH	Precip	38
γ-HCH	Precip	72
PCB-28	Precip	5
PCB-52	Precip	23
PCB-101	Precip	13
PCB-118	Precip	18
PCB-138	Precip	18
PCB-153	Precip	15
PCB-180	Precip	35

Table 2.8: Detection frequency (expressed as %) for organic contaminants of emerging concern in air at the representative monitoring stations in 2021. The colour codes indicate highest detection in red and lowest detection in green. For details on levels and method detection limits (MDLs) of contaminants see Appendix A table A1-A3.

		Birkenes	Andøya	Zeppelin
Compound	**Matrix**	**Detection frequency (%)**		
SCCP	Gas+particle	17	n.a.	61
MCCP	Gas+particle	0	n.a.	16
D4	Gas phase	100	n.a.	95
D5	Gas phase	100	n.a.	91
D6	Gas phase	65	n.a.	55
L3	Gas phase	n.a.	n.a.	75
L4	Gas phase	n.a.	n.a.	67
L5	Gas phase	n.a.	n.a.	67
M3T(Ph)	Gas phase	n.a.	n.a.	0
F3-Sil	Gas phase	n.a.	n.a.	0
F4-Sil	Gas phase	n.a.	n.a.	0
Ph-D4	Gas phase	n.a.	n.a.	0
4:2 FTOH	Gas phase	17	8	18
6:2 FTOH	Gas phase	100	92	100
8:2 FTOH	Gas phase	100	100	100
10:2 FTOH	Gas phase	92	38	82
12:2 FTOH	Gas phase	75	30	91
N-Me-FOSA	Gas phase	8	0	9
N-Et-FOSA	Gas phase	17	42	55
N-Me-FOSE	Gas phase	8	0	9
N-Et-FOSE	Gas phase	0	0	9
brPFOS	Particle phase	n.a.	n.a.	8
10:2 FTS	Particle phase	n.a.	n.a.	0
12:2 FTS	Particle phase	n.a.	n.a.	0
PF-3,7-DMOA	Particle phase	n.a.	n.a.	0
FOSAA	Particle phase	n.a.	n.a.	0
MeFOSAA	Particle phase	n.a.	n.a.	0
EtFOSAA	Particle phase	n.a.	n.a.	0
FBSA	Particle phase	n.a.	n.a.	0
MeFBSA	Particle phase	n.a.	n.a.	0
EtFBSA	Particle phase	n.a.	n.a.	0
HPFHpA	Particle phase	n.a.	n.a.	0
7:3 FTCA	Particle phase	n.a.	n.a.	0
F53	Particle phase	n.a.	n.a.	0
8Cl-PFOS	Particle phase	n.a.	n.a.	0
6:2 F53B	Particle phase	n.a.	n.a.	0
TEP	Gas+particle	n.a.	n.a.	100
TCEP	Gas+particle	n.a.	n.a.	100

		Birkenes	Andøya	Zeppelin
Compound	**Matrix**	**Detection frequency (%)**		
TCPP (TCIPP)	Gas+particle	n.a.	n.a.	92
TPrP	Gas+particle	n.a.	n.a.	0
TDCPP	Gas+particle	n.a.	n.a.	85
TPP	Gas+particle	n.a.	n.a.	86
TiBP/TnBP	Gas+particle	n.a.	n.a.	91
TBEP (TBOEP)	Gas+particle	n.a.	n.a.	79
DBPhP	Gas+particle	n.a.	n.a.	7
2-IPPDPP	Gas+particle	n.a.	n.a.	75
4-IPPDPP	Gas+particle	n.a.	n.a.	0
TCP	Gas+particle	n.a.	n.a.	0
BdPhP	Gas+particle	n.a.	n.a.	0
EHDP	Gas+particle	n.a.	n.a.	79
B4IPPPP	Gas+particle	n.a.	n.a.	0
TXP	Gas+particle	n.a.	n.a.	0
TIPPP	Gas+particle	n.a.	n.a.	0
TTBPP	Gas+particle	n.a.	n.a.	0
TEHP	Gas+particle	n.a.	n.a.	29
ATE (TBP-AE)*	Gas+particle	n.a.	n.a.	30
a-TBECH	Gas+particle	n.a.	n.a.	40
b-TBECH	Gas+particle	n.a.	n.a.	40
g/d-TBECH	Gas+particle	n.a.	n.a.	20
BATE*	Gas+particle	n.a.	n.a.	20
PBT	Gas+particle	n.a.	n.a.	100
PBEB	Gas+particle	n.a.	n.a.	40
PBBZ	Gas+particle	n.a.	n.a.	40
HBB	Gas+particle	n.a.	n.a.	100
DPTE	Gas+particle	n.a.	n.a.	100
EHTBB	Gas+particle	n.a.	n.a.	100
BTBPE	Gas+particle	n.a.	n.a.	30
TBPH (BEH /TBP)	Gas+particle	n.a.	n.a.	60
DBDPE	Gas+particle	n.a.	n.a.	100
TBBPA	Gas+particle	n.a.	n.a.	71
syn-DP	Gas+particle	n.a.	n.a.	8
anti-DP	Gas+particle	n.a.	n.a.	23
Dec 601	Gas+particle	n.a.	n.a.	0
Dec 602	Gas+particle	n.a.	n.a.	0
Dec 603	Gas+particle	n.a.	n.a.	0
Dec 604	Gas+particle	n.a.	n.a.	0
Dec 604B	Gas+particle	n.a.	n.a.	0
Dibromoaldrin	Gas+particle	n.a.	n.a.	0
Chlordene plus	Gas+particle	n.a.	n.a.	0
Dechlorane plus Cl10	Gas+particle	n.a.	n.a.	0

		Birkenes	Andøya	Zeppelin
Compound	**Matrix**	**Detection frequency (%)**		
Dechlorane plus axx	Gas+particle	n.a.	n.a.	69
Dechlorane plus ax	Gas+particle	n.a.	n.a.	0
Dechlorane plus Cl11	Gas+particle	n.a.	n.a.	0
PFTBA	Gas phase	n.a.	n.a.	82
TCPFB	Gas phase	n.a.	n.a.	82
PFTPeA	Gas phase	n.a.	n.a.	82
HCBD	Gas phase	n.a.	n.a.	100
PFPHP	Gas phase	n.a.	n.a.	82
DCTFP	Gas phase	n.a.	n.a.	93
PCTol	Gas phase	n.a.	n.a.	100
DCPFcH	Gas phase	n.a.	n.a.	0
PFBB	Gas phase	n.a.	n.a.	0
bTFMBB	Gas phase	n.a.	n.a.	0
DCBTC	Gas phase	n.a.	n.a.	0
HCcBen	Gas phase	n.a.	n.a.	100
HCBcB	Gas phase	n.a.	n.a.	93

*Possible degradation of ATE and BATE during clean-up with sulphuric acid. Results uncertain.

2.3.1.3 Temporal trends

Trend analyses of organic contaminants are done using the Digital Filtration Technique (DF). This technique is limited to data series covering minimum 10 years of continuous monitoring and data series with a majority of measurements being above the method detection limit (MDL). Results are presented as half-lives in Table 1.1 and in Figure 13-15. The figures presents i) HCB separately due to its specific trends; ii) long-term decreasing temporal trends that have flattened out, and iii) long-term decreasing temporal trends that still continue to decrease.

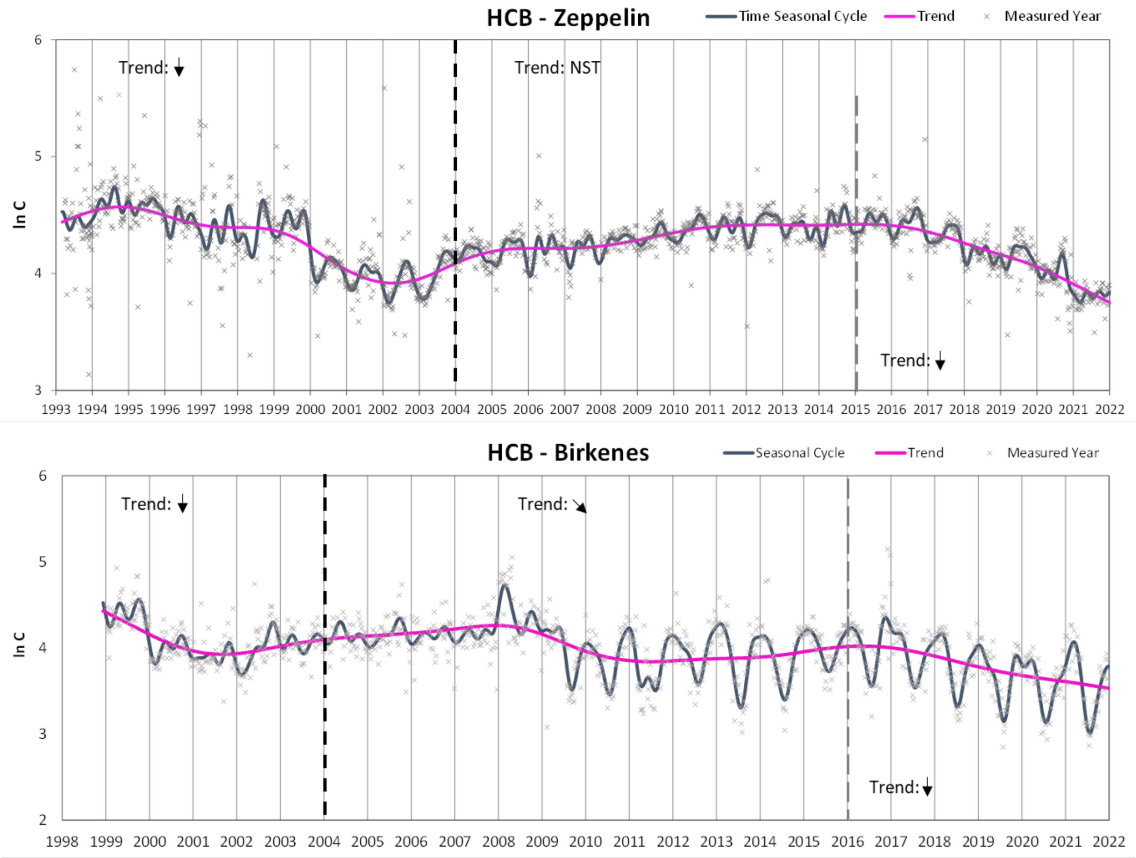


Figure 13: Temporal trends of HCB at Zeppelin and Birkenes. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line in black indicates the year when Stockholm Convention was taken into force for HCB (2004). The results of trend analyses: before and after 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. The dashed line in grey indicates the year in which a trend shift was initiated and a trend analysis from then to today is indicated in the lower part.

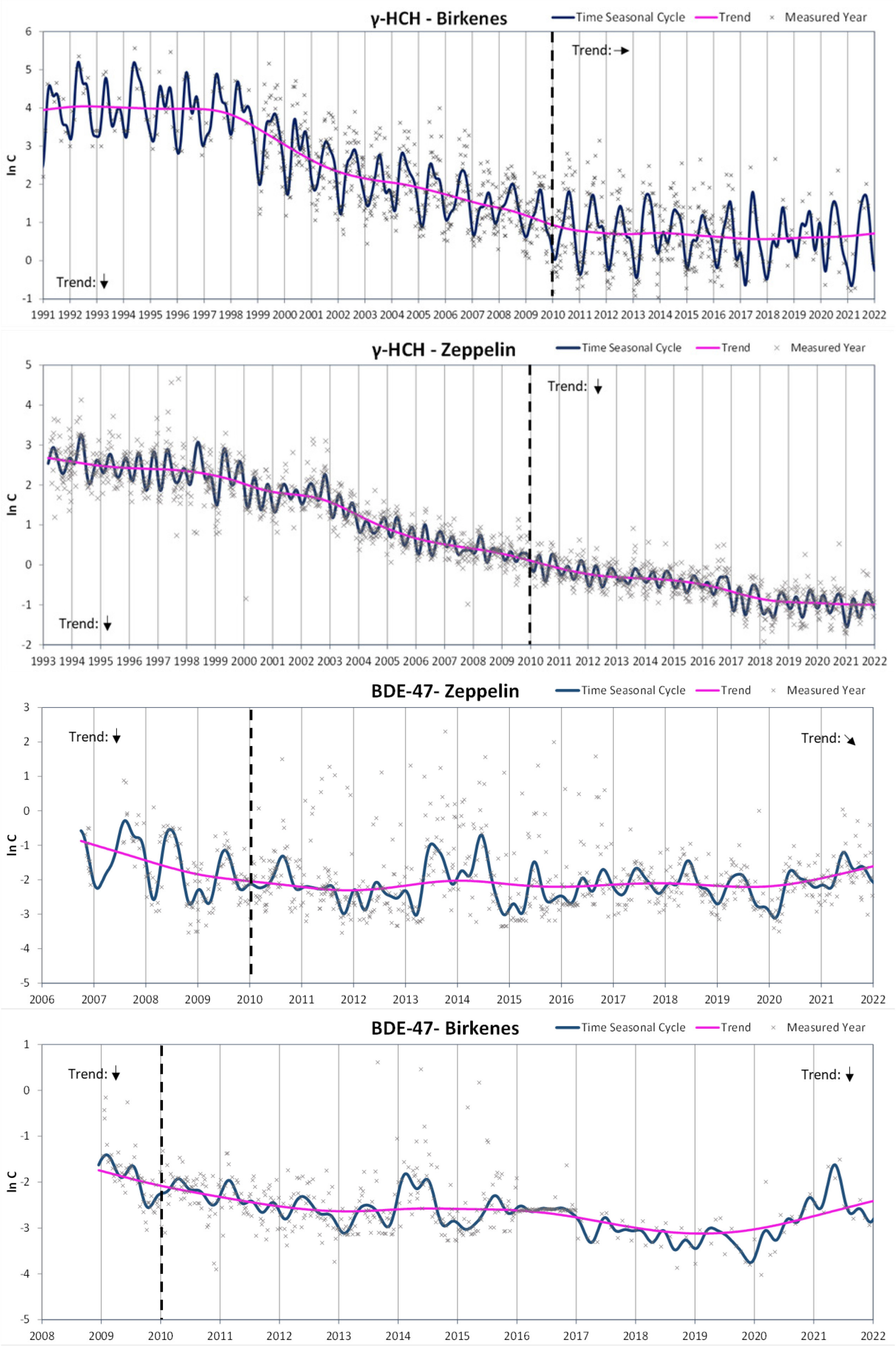


Figure 14: Examples of decreasing temporal trends where the concentrations are flattening out over the last years: γ-HCH and BDE-47 at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for the individual compounds. The results of trend analyses: before and after 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.

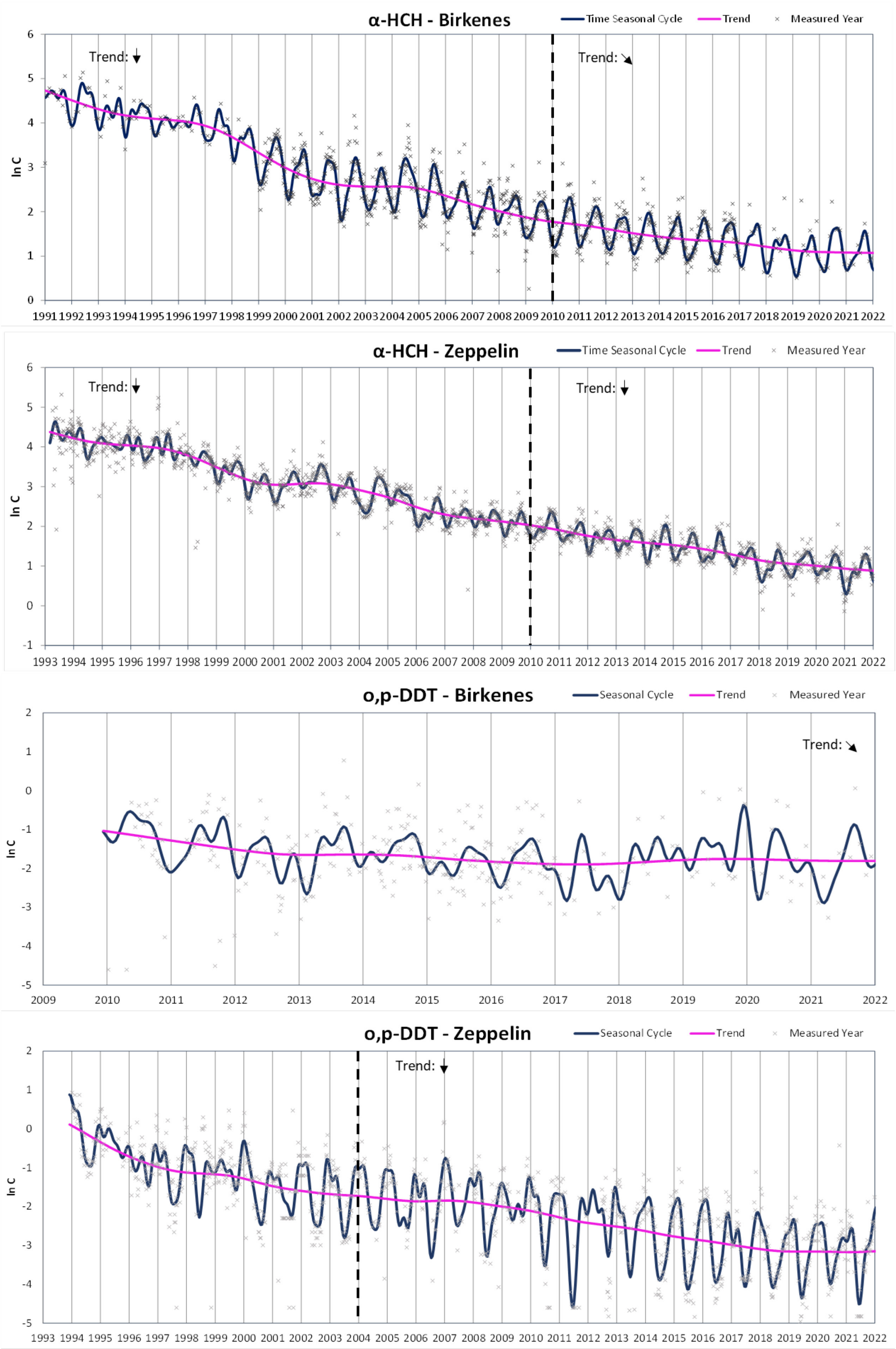


Figure 15: Examples of continuous decreasing temporal trends over the whole period: α-HCH and o,p'-DDT at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for the individual compounds. The results of trend analyses: before and after listed in the Stockholm Convention, are indicated by four types of arrows (⬇: decrease, ↘: small decrease, ↗ small increase and ⬆ increase).

For organic contaminants of concern that all have shorter monitoring period than ten years, the time trends are presented with box-plots (Figure 16-18).

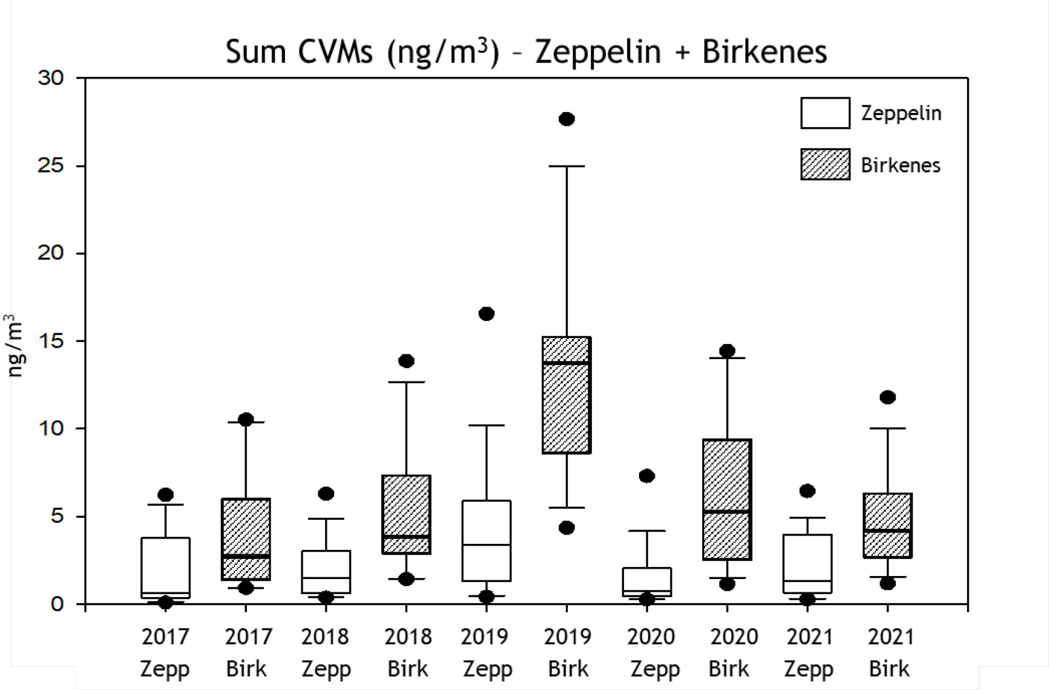


Figure 16: Box plots of measured concentrations of sum cVMS in air at Zeppelin and Birkenes from 2017 to 2021. The box represents the range from 25 to 75 percentile with the centre line representing the median value. The bars represent the 10 and 90 percentiles. Data for Zeppelin covers weekly measurements while date for Birkenes covers monthly measurements.

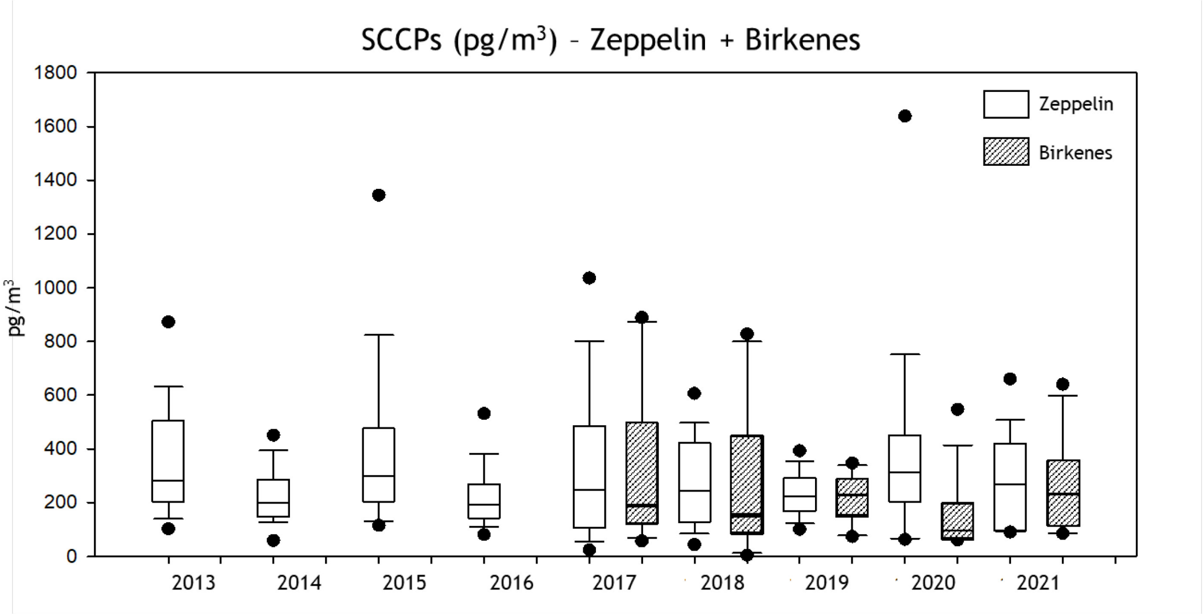


Figure 17: Box plots of measured concentrations of SCCPs in air at Zeppelin (2013-2021) and Birkenes (2017-2021). The box represents the range from 25 to 75 percentile with the centre line representing the median value. The bars represent the 10 and 90 percentiles. Data for Zeppelin covers weekly measurements while date for Birkenes covers monthly measurements.

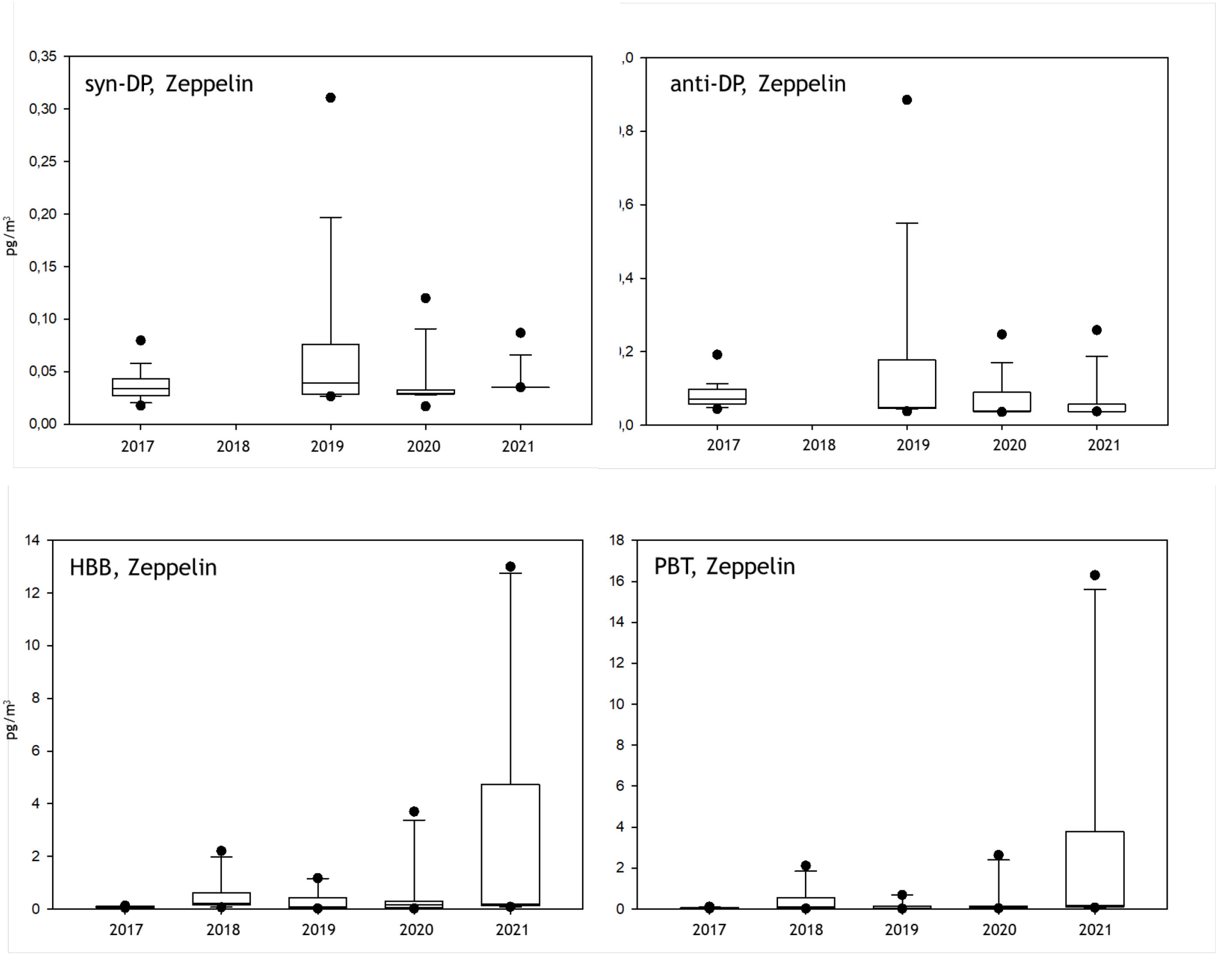


Figure 18: Box plots of measured concentrations of two dechloranes (syn-DP and anti-DP) and two nBFRs (HBB and PBT) in air at Zeppelin from 2017 to 2021. The box represents the range from 25 to 75 percentile with the centre line representing the median value. The bars represent the 10 and 90 percentiles.

2.3.2 Heavy metals and Hg

2.3.2.1 Measured concentrations

Table 2.9: Annual mean concentrations of all heavy metals measured in air (ng/m^3) at the Norwegian monitoring stations, compared to target values in regulations related to pollution control (Forurensingsforskriften kap 7) and air quality criteria (FHI's luftkvalitetskriterier).

	Forurensings forskriften, kap 7, ng/m^3	FHIs luftkvalitets kriterier, ng/m^3	Birkenes, ng/m^3	Andøya, ng/m^3	Zeppelin, ng/m^3	Svanvik, ng/m^3	Karpdalen, ng/m^3
Al	n.a.	n.a.	19.3	35.6	69.8	35.8	31.8
As	6	2	0.106	0.042	0.039	0.099	0.096
Cd	5	2.5	0.018	0.008	0.021	0.022	0.022
Cr	n.a.	n.a.	0.216	0.100	0.159	0.219	0.191
Co	n.a.	n.a.	0.016	0.012	0.012	0.034	0.039
Cu	n.a.	n.a.	0.297	0.250	0.125	0.588	0.861
Fe	n.a.	n.a.	18.8	24.4	24.4	39.2	30.9
Pb	500	100	0.459	0.210	0.190	0.598	0.686
Mn	n.a.	150	0.712	0.509	0.593	0.767	0.590
Ni	20	10	0.175	0.102	0.097	0.987	1.24
Ti	n.a.	n.a.	1.27	1.52	1.84	na	na
V	n.a.	200	0.294	0.125	0.080	2.53	2.97
Zn	n.a.	n.a.	3.42	0.913	1.56	2.22	1.74
Hg	n.a.	200	1.51	1.40	1.48	na	na

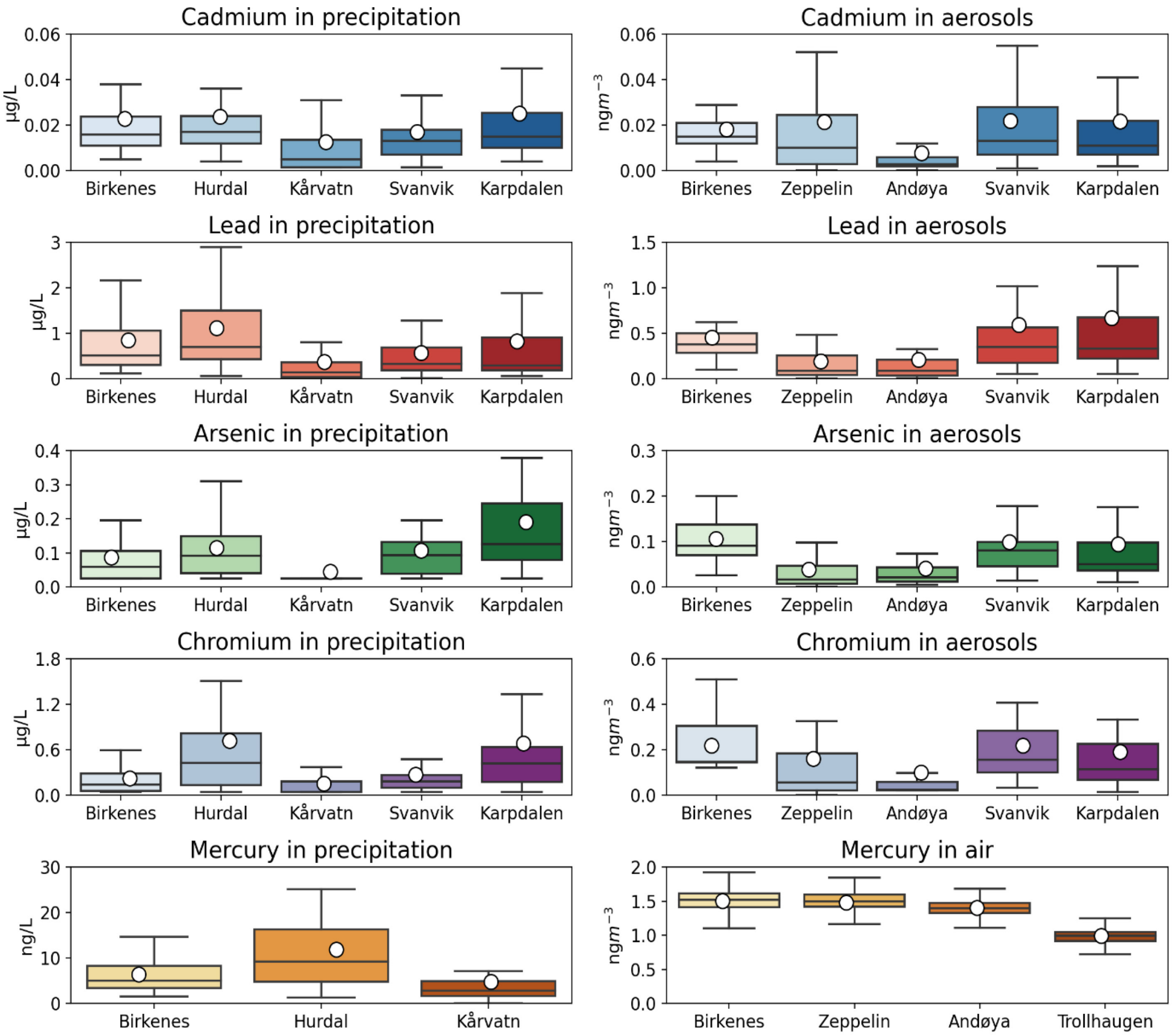


Figure 19: Box plots of measured concentrations of cadmium, lead, arsenic, chromium and mercury in precipitation and aerosols in 2021. The box represents the 50th, 25th, and 75th percentiles and the whiskers lie within the 1.5 inter-quartile ranges of the weekly observations.

Table 2.10: Annual mean concentration of mercury in precipitation and wet deposition, together with precipitation amount at Birkenes, Kårvatn and Hurdal in 2021.

Concentration, Hg (ng/L)			Wet deposition, Hg (ng/m^2)			Precipitation amount, mm		
Birkenes	**Kårvatn**	**Hurdal**	**Birkenes**	**Kårvatn**	**Hurdal**	**Birkenes**	**Kårvatn**	**Hurdal**
4.1	2.8	11.3	6128	4948	9455	1477	1793	839

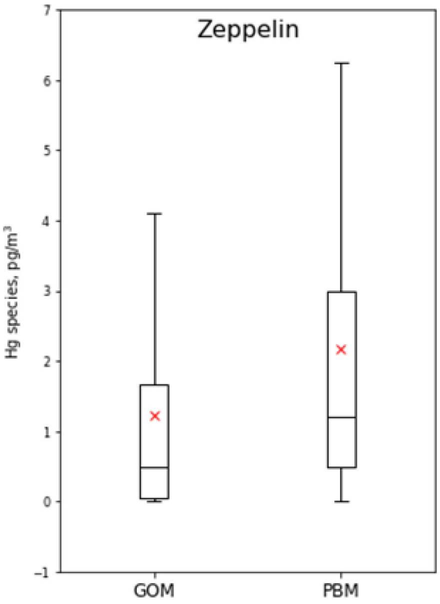


Figure 20: Box plots of Hg species measured in air at Zeppelin from July to December in 2021. The box represents the range from 25 to 75 percentile with the center line representing the median value. The bars represent the 10 and 90 percentiles, while the red cross represents the mean value.

2.3.2.2 Detection frequencies

Table 2.11: Detection frequency (expressed as %) for heavy metals in air at the representative monitoring stations in 2021. The colour codes indicate highest detection in red and lowest detection in green. For details on levels and method detection limits (MDLs) of contaminants see Appendix A table A5-A6.

	Matrix	Birkenes	Andøya	Zeppelin	Svanvik	Karpdalen
Al	Particle phase	82	96	94	100	100
As	Particle phase	96	100	92	100	100
Cd	Particle phase	98	90	98	100	100
Cr	Particle phase	27	27	37	100	82
Co	Particle phase	45	79	81	100	100
Cu	Particle phase	92	90	75	92	100
Fe	Particle phase	88	100	87	100	100
Pb	Particle phase	96	100	83	100	100
Mn	Particle phase	92	94	90	100	100
Ni	Particle phase	67	29	52	100	100
Ti	Particle phase	90	92	65	n.a.	n.a.
V	Particle phase	88	100	90	100	100
Zn	Particle phase	96	56	81	100	100
Hg-GEM	Gas phase	100	100	100	n.a.	n.a.
Hg-GOM	Gas phase	n.a.	n.a.	35	n.a.	n.a.
Hg-PBM	Particle phase	n.a.	n.a.	65	n.a.	n.a.

Table 2.12: Detection frequency (expressed as %) for heavy metals in precipitation at the representative monitoring stations in 2021. The colour codes indicate highest detection in red and lowest detection in green. For details on levels and method detection limits (MDLs) of contaminants see Appendix A table A5-A6.

	Matrix	Birkenes	Hurdal	Kårvatn	Svanvik	Karpdalen
Al	Precip	n.a.	n.a.	n.a.	100	97
As	Precip	63	74	23	74	81
Cd	Precip	100	100	64	90	95
Cr	Precip	74	79	45	77	86
Co	Precip	83	86	70	97	100
Cu	Precip	100	100	100	100	100
Pb	Precip	100	100	77	95	95
Mn	Precip	100	98	87	n.a.	n.a.
Ni	Precip	98	98	23	100	97
V	Precip	100	100	83	100	97
Zn	Precip	100	100	96	97	95
Hg	Precip	100	100	100	n.a.	n.a.

2.3.2.3 *Temporal trends*

Trend analysis for HMs in aerosols and precipitations are performed by applying the non-parametric Mann-Kendall test for trend and Sen's slope estimate for the magnitude of the trend. Results are presented in table 2.13.

Table 2.13: Trends in heavy metal concentrations in air and precipitation, only significant (p=0.05) trends are presented. Negative trends are marked in green and positive trends are marked in red.

		Trends in aerosols and air, %/year										
Site	**Period**	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Pb**	**Mn**	**Ni**	**V**	**Zn**	**Hg (GEM)**
Zeppelin	1994-2021	-3.34	-	-	-	-	-2.90	3.25	-	-2.44	-	-0.54
Zeppelin	2000-2021	-3.96	-	18.4	-	-	-3.68	7.11	7.12	-	-	-0.54
Birkenes	1991-2021	-2.16	-2.05	-2.74	-2.01	-1.39	-2.60		-2.38	-3.40	-0.85	-0.59
Birkenes	2000-2021	-3.20	-3.95	-3.53	-2.51	-3.22	-4.69		-3.87	-5.14	-2.38	-0.74
		Trends in precipitation, %/year										
		As	**Cd**	**Cr**	**Co**	**Cu**	**Pb**	**Mn**	**Ni**	**V**	**Zn**	**Hg**
Birkenes[1)]	1990-2021	-3.46	-2.89	-3.37	-	-	-3.64		-2.66	-3.50	-2.42	-2.29
	2000-2021	-4.97	-3.45	-2.98	-	15.6	-3.70		-	-5.24	-	-2.68
Hurdal[2)]	1990-2021		-2.01				-3.11				-	
	2000-2021		-2.94				-2.82				-	
Kårvatn	1990-2021		-2.24				-				5.66	
	2000-2021		-2.47				-				6.34	

1) Observations of Hg at Lista from 1990-2004.

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

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Appendix A
Summary of results for individual compounds

Table A.1: Summary of measured concentrations (pg/m³ or ng/m³), detection frequencies (%) and method detection limits (MDL, pg/m³ or ng/m³) of targeted organic contaminants in air at Birkenes in 2021. The colour codes indicate highest detection/concentrations in red and lowest detection/ concentrations in green.

BIRKENES - Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
POPs (pg/m^3) **Class of uncertainty:1-2 (specification for individual compounds below)**							
HCB[1]	Gas+particle	52	1.1	100	17.6-71.5	39.3	39.1
α-HCH[1]	Gas+particle	12	0.042	100	1.97-5.65	3.1	2.6
γ-HCH[1]	Gas+particle	12	0.109	100	0.46-7.45	2.7	1.7
p,p'-DDT[1]	Gas+particle	12	0.021	82	<0.020-1.18	0.252	0.169
o,p'-DDT[1]	Gas+particle	12	0.017	100	0.038-1.06	0.229	0.179
p,p'-DDE[1]	Gas+particle	12	0.053	100	0.330-2.87	1.21	1.02
o,p'-DDE[1]	Gas+particle	12	0.006	100	0.038-0.191	0.083	0.069
p,p'-DDD[1]	Gas+particle	12	0.007	44	<0.007-0.034	0.015	0.007
o,p'-DDD[1]	Gas+particle	12	0.007	67	<0.007-0.046	0.022	0.019
Sum DDT[1]	Gas+particle	12			0.443-5.38	1.81	1.37
PCB-28[1]	Gas+particle	52	0.089	100	0.134-2.28	0.597	0.524
PCB-52[1]	Gas+particle	52	0.100	100	0.158-2.82	0.681	0.566
PCB-101[1]	Gas+particle	52	0.062	98	<0.060-1.81	0.407	0.288
PCB-118[1]	Gas+particle	52	0.021	94	<0.020-0.41	0.102	0.069
PCB-138[1]	Gas+particle	52	0.034	92	<0.032-0.611	0.147	0.096
PCB-153[1]	Gas+particle	52	0.055	92	<0.052-1.08	0.237	0.158
PCB-180[1]	Gas+particle	52	0.028	50	<0.026-0.164	0.047	0.03
Sum PCB-7[1]	Gas+particle	52			0.5-9.20	2.22	1.73
Sum PCB[1]	Gas+particle	52			1.04-36.1	8.74	7.56
BDE-47[2]	Gas+particle	12	0.016	100	0.053-0.221	0.103	0.079
BDE-49[2]	Gas+particle	12	0.002	100	0.004-0.129	0.020	0.008
BDE-66[2]	Gas+particle	12	0.001	100	0.002-0.133	0.017	0.005
BDE-71[2]	Gas+particle	12	0.001	54	<0.001-0.126	0.012	<0.001
BDE-99[2]	Gas+particle	12	0.006	92	0.014-0.106	0.041	0.028
BDE-100[2]	Gas+particle	12	0.002	92	0.005-0.076	0.015	0.007
BDE-153[2]	Gas+particle	12	0.002	75	<0.002-0.242	0.026	0.003
BDE-154[2]	Gas+particle	12	0.002	69	<0.002-0.171	0.020	0.003
BDE-183[2]	Gas+particle	12	0.002	83	<0.002-0.062	0.016	0.009
BDE-196[2]	Gas+particle	12	0.004	15	<0.004-0.044	0.010	<0.004
BDE-206[2]	Gas+particle	12	0.053	46	<0.053-0.237	0.089	<0.053
BDE-209[2]	Gas+particle	12	0.558	46	<0.56-4.85	1.362	<0.563
Sum BDE[2]	Gas+particle	12			0.724-4.955	1.798	0.78

BIRKENES - Air							
Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
Sum BDE$_{excl\ -209}^2$	Gas+particle	12			0.168-1.882	0.436	0.30
TBA^2	Gas+particle	12	0.023	100	2.4-12.3	5.06	4.21
α-HBCDD^2	Gas+particle	12	0.009	18	<0.009-0.016	0.010	<0.009
β-HBCDD^2	Gas+particle	12	0.007	0	<0.007-<0.007	<0.007	<0.007
γ-HBCDD^2	Gas+particle	12	0.009	0	<0.009-<0.009	<0.009	<0.007
PAHs (ng/m^3) Class of uncertainty:1							
1-Methylnaphthalene	Gas+particle	52	0.0114	83	<0.011-0.44	0.076	0.027
1-Methylphenanthrene	Gas+particle	52	0.0029	100	0.007-0.321	0.053	0.028
2-Methylanthracene	Gas+particle	52	0.0044	2	<0.004-0.014	0.005	0.002
2-Methylnaphthalene	Gas+particle	52	0.0205	69	<0.02-0.45	0.092	0.037
2-Methylphenanthrene	Gas+particle	52	0.0055	100	0.009-0.267	0.069	0.042
3-Methylphenanthrene	Gas+particle	52	0.0044	100	0.007-0.224	0.058	0.036
9-Methylphenanthrene	Gas+particle	52	0.0030	100	0.003-0.082	0.021	0.014
Acenaphthene	Gas+particle	52	0.0121	98	0.018-0.391	0.082	0.042
Acenaphthylene	Gas+particle	52	0.0012	74	<0.001-0.536	0.052	0.005
Anthanthrene	Gas+particle	52	0.0006	31	<0.001-0.045	0.003	0.001
Anthracene	Gas+particle	52	0.0008	90	0.001-0.16	0.024	0.005
Benz(a)anthracene	Gas+particle	52	0.0003	89	<0.001-0.255	0.018	0.006
Benzo(a)fluoranthene	Gas+particle	52	0.0004	45	<0.001-0.075	0.005	0.001
Benzo(a)fluorene	Gas+particle	52	0.0006	91	<0.001-0.121	0.013	0.006
Benzo(a)pyrene	Gas+particle	52	0.0004	94	<0.001-0.28	0.019	0.005
Benzo(b)fluoranthene	Gas+particle	52	0.0011	100	0.002-0.482	0.055	0.023
Benzo(b)fluorene	Gas+particle	52	0.0004	81	0.001-0.068	0.008	0.003
Benzo(e)pyrene	Gas+particle	52	0.0005	98	0.001-0.248	0.037	0.015
Benzo(ghi)fluoranthene	Gas+particle	52	0.0009	n.a	NaN-NaN	NaN	NaN
Benzo(ghi)perylene	Gas+particle	52	0.0005	98	0.001-0.296	0.033	0.015
Benzo(k)fluoranthene	Gas+particle	52	0.0004	94	<0.001-0.203	0.018	0.007
Biphenyl	Gas+particle	52	0.0216	89	<0.022-1.21	0.233	0.075
Chrysene	Gas+particle	52	0.0007	100	0.002-0.427	0.062	0.024
Coronene	Gas+particle	52	0.0012	83	<0.001-0.137	0.013	0.005
Cyclopenta(cd)pyrene	Gas+particle	52	0.0018	0	<0.002-0.002	<0.002	0.001
Dibenzo(ae)pyrene	Gas+particle	52	0.0015	57	<0.002-0.049	0.007	0.003
Dibenzo(ah)anthracene	Gas+particle	52	0.0007	65	<0.001-0.047	0.005	0.002
Dibenzo(ah)pyrene	Gas+particle	52	0.0015	6	<0.002-0.02	0.003	0.001
Dibenzo(ai)pyrene	Gas+particle	52	0.0014	9	<0.001-0.019	0.003	0.001
Dibenzofuran	Gas+particle	52	0.0306	100	0.07-3.42	0.74	0.356
Dibenzothiophene	Gas+particle	52	0.0015	100	0.002-0.159	0.024	0.022
Fluoranthene	Gas+particle	52	0.0134	100	0.03-1.46	0.23	0.123
Fluorene	Gas+particle	52	0.0237	100	0.088-2.66	0.54	0.292
Inden(123-cd)pyrene	Gas+particle	52	0.0006	98	0.001-0.352	0.033	0.012

BIRKENES - Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Naphthalene	Gas+particle	52	0.0289	67	<0.029-1.38	0.189	0.050
Perylene	Gas+particle	52	0.0003	44	<0.001-0.035	0.003	0.001
Phenanthrene	Gas+particle	52	0.0551	100	0.132-2.51	0.953	0.623
Pyrene	Gas+particle	52	0.0089	100	0.01-0.913	0.128	0.059
Retene	Gas+particle	52	0.0022	100	0.005-0.482	0.063	0.037
Sum PAH$_{16}$	Gas+particle	52			1.07-5.898	2.440	1.540
Sum PAH$_{39}$	Gas+particle	52			1.45-9.506	3.980	2.290
Ionic and volatile PFAS (pg/m^3) Class of uncertainty:2							
FTS 4:2	Particle phase	12	0.04	0	<0.04-0.04	<0.04	<0.04
FTS 6:2	Particle phase	12	0.04	42	<0.04-0.24	0.08	<0.04
FTS 8:2	Particle phase	12	0.04	0	<0.04-0.04	<0.04	<0.04
PFBS	Particle phase	12	0.01	25	<0.01-0.22	0.03	<0.01
PFDoDA	Particle phase	12	0.02	17	<0.02-0.04	0.02	<0.02
PFHpA	Particle phase	12	0.02	42	<0.02-0.12	0.05	<0.02
PFHxA	Particle phase	12	0.02	33	<0.02-0.28	0.08	<0.02
PFHxS	Particle phase	12	0.01	0	<0.01-0.01	<0.01	<0.01
PFNA	Particle phase	12	0.01	92	<0.01-0.17	0.07	0.05
PFOA	Particle phase	12	0.01	100	0.02-0.24	0.13	0.14
PFOS	Particle phase	12	0.01	58	<0.01-0.09	0.03	0.02
PFOSA	Particle phase	12	0.01	17	<0.01-0.01	0.01	<0.01
PFUnA	Particle phase	12	0.01	42	<0.01-0.06	0.02	<0.01
PFPS	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFHpS	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFNS	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFPeA	Particle phase	12		n.a			
PFTrDA	Particle phase	12	0.05	0	<0.05-0.05	<0.05	<0.05
PFTeDA	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFHxDA	Particle phase	12	0.05	0	<0.05-0.05	<0.05	<0.05
PFODcA	Particle phase	12	0.05	0	<0.05-0.05	<0.05	<0.05
PFDS	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFOSlin	Particle phase	12	0.01	33	<0.01-0.035	0.01	<0.01
PFDA	Particle phase	12	0.01	67	<0.01-0.107	0.04	0.01
PFUnS	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFDoS	Particle phase	12	0.02	0	<0.02-0.02	<0.02	<0.02
PFTrS	Particle phase	12		n.a			
PFTS	Particle phase	12		n.a			
Sum ionic PFAS	Particle phase	12			0.27-1.19	0.73	0.76
4:2 FTOH	Gas phase	12	0.59	17	<0.54-1.47	0.73	<0.57
6:2 FTOH	Gas phase	12	1.97	100	6.89-63.9	19.0	14.5
8:2 FTOH	Gas phase	12	1.05	100	3.27-60.7	11.4	7.64

BIRKENES - Air							
Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
10:2 FTOH	Gas phase	12	1.23	92	<1.13-25.7	4.16	2.33
12:2 FTOH	Gas phase	12	0.40	75	<0.37-7.1	1.13	0.55
N-Me-FOSA	Gas phase	12	0.84	8	<0.766-1.05	0.81	<0.79
N-Et-FOSA	Gas phase	12	0.35	17	<0.319-1.65	0.44	<0.33
N-Me-FOSE	Gas phase	12	0.50	8	<0.46-0.61	0.49	<0.48
N-Et-FOSE	Gas phase	12	0.74	0	<0.676-<0.888	<0.71	<0.70
Sum volatile PFAS	Gas phase	12			12.6-162	37.4	27.9
Chlorinated paraffins (pg/m^3) **Class of uncertainty:3**							
SCCP	Gas+particle	12	388	17	<370-640	260	<390
MCCP	Gas+particle	12	1310	0	<1252-<1336	655	<1317
Siloxanes (ng/m3) **Class of uncertainty:3**							
D4	Gas phase	12	0.058	100	0.503-3.04	1.20	0.89
D5	Gas phase	12	0.071	100	0.476-8.32	3.01	2.49
D6	Gas phase	12	0.150	65	0.192-2.04	0.44	0.24
sum cVMS	Gas phase	12			1.174-11.79	4.65	4.20

*MDLs are presented as a guidance based on average sample volume per compound group. The MDL is however variable over the year due to variable sample volume and analytical conditions.

Table A.2: Summary of measured concentrations (pg/m^3), detection frequencies (%) and method detection limits (MDL, pg/m^3) of targeted organic contaminants in air at Andøya in 2021. The colour codes indicate highest detection/concentrations in red and lowest detection/ concentrations in green.

ANDØYA - Air							
Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
POPs (pg/m^3) **Class of uncertainty:1**							
HCB[1]	Gas+particle	52	0.31	100	15.3-48.2	27.5	26.2
Ionic and volatile PFAS (pg/m^3) **Class of uncertainty:2**							
FTS 4:2	Particle phase	12	0.04	0	<0.04-<0.04	<0.04	<0.04
FTS 6:2	Particle phase	12	0.04	42	<0.04-0.09	0.04	<0.04
FTS 8:2	Particle phase	12	0.04	0	<0.04-<0.04	<0.04	<0.04
PFBS	Particle phase	12	0.01	25	<0.01-0.01	0.02	<0.01
PFDoDA	Particle phase	12	0.02	17	<0.02-<0.02	<0.02	<0.02
PFHpA	Particle phase	12	0.02	42	0.03-0.23	0.08	0.06
PFHxA	Particle phase	12	0.02	33	<0.02-0.24	0.09	0.06
PFHxS	Particle phase	12	0.01	0	<0.01-0.01	0.01	<0.01
PFNA	Particle phase	12	0.01	92	<0.01-0.13	0.04	0.03

ANDØYA - Air

Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
PFOA	Particle phase	12	0.01	100	0.035-0.23	0.08	0.07
PFOS	Particle phase	12	0.01	58	<0.01-0.04	0.02	0.01
PFOSA	Particle phase	12	0.01	17	<0.01-<0.01	<0.01	<0.01
PFUnA	Particle phase	12	0.01	42	<0.01-0.03	0.01	<0.01
PFPS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFHpS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFNS	Particle phase	12	0.02	0	<0.02-<0.02	<0.07	<0.02
PFPeA	Particle phase	12		n.a.			
PFTrDA	Particle phase	12	0.05	0	<0.05-<0.05	<0.05	<0.05
PFTeDA	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFHxDA	Particle phase	12	0.05	0	<0.05-<0.05	<0.05	<0.05
PFODcA	Particle phase	12	0.05	0	<0.05-<0.05	<0.05	<0.05
PFDS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFOSlin	Particle phase	12	0.01	33	<0.01-0.02	0.01	0.01
PFDA	Particle phase	12	0.01	67	<0.01-0.07	0.02	<0.01
PFUnS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFDoS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFTrS	Particle phase	12		n.a.			
PFTS	Particle phase	12		n.a.			
Sum ionic PFAS	Particle phase	12			0.34-1.2	0.56	0.48
4:2 FTOH	Gas phase	12	0.59	17	<0.58-2.57	1.24	0.97
6:2 FTOH	Gas phase	12	1.97	100	<1.93-63.6	16.3	11.7
8:2 FTOH	Gas phase	12	1.05	100	2.32-1420	139.3	8.94
10:2 FTOH	Gas phase	12	1.23	92	<1.19-367	35.3	2.25
12:2 FTOH	Gas phase	12	0.40	30	<0.38-10.3	1.89	0.52
N-Me-FOSA	Gas phase	12	0.84	8	<0.80-<1.06	<0.84	<0.82
N-Et-FOSA	Gas phase	12	0.35	17	<0.33-0.75	0.44	<0.34
N-Me-FOSE	Gas phase	12	0.50	8	<0.48-<0.64	<0.50	<0.49
N-Et-FOSE	Gas phase	12	0.74	0	<0.71-<0.94	<0.74	<0.72
Sum volatile	Gas phase	12			8.71-1853	193.0	27.8

*MDLs are presented as a guidance based on average sample volume per compound group. The MDL is however variable over the year due to variable sample volume and analytical conditions.

Table A.3: Summary of measured concentrations (pg/m³ or ng/m³), detection frequencies (%) and method detection limits (MDL, pg/m³ or ng/m³) of targeted organic contaminants at Zeppelin in 2021. The colour codes indicate highest detection/concentrations in red and lowest detection/concentrations in green.

ZEPPELIN - Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
POPs (pg/m³) **Class of uncertainty: 1-2 (specification for individual compounds below)**							
HCB[1]	Gas+particle	52	0.56	100	33-51.3	44.5	45.2
α-HCH[1]	Gas+particle	52	0.02	100	1.12-4.28	2.50	2.33
γ-HCH[1]	Gas+particle	52	0.05	100	0.13-0.86	0.38	0.36
p,p'-DDT[1]	Gas+particle	52	0.010	62	<0.007-0.127	0.029	0.022
o,p'-DDT[1]	Gas+particle	52	0.009	89	<0.008-0.172	0.056	0.047
p,p'-DDE[1]	Gas+particle	52	0.026	100	0.028-1.50	0.246	0.162
o,p'-DDE[1]	Gas+particle	52	0.003	94	<0.002-0.097	0.030	0.020
p,p'-DDD[1]	Gas+particle	52	0.004	21	<0.002-0.009	0.004	0.003
o,p'-DDD[1]	Gas+particle	52	0.004	52	<0.003-0.019	0.006	0.005
Sum DDT[1]	Gas+particle	52			0.058-1.91	0.359	0.258
cis-CD[1]	Gas+particle	52	0.011	100	0.125-0.340	0.236	0.224
cis-NO[1]	Gas+particle	52	0.006	93	0.005-0.038	0.022	0.022
trans-CD[1]	Gas+particle	52	0.008	100	0.027-0.200	0.088	0.081
trans-NO[1]	Gas+particle	52	0.010	100	0.104-0.326	0.213	0.210
Sum Chlordane[1]	Gas+particle	52			0.302-0.874	0.559	0.537
PCB-28[1]	Gas+particle	52	0.044	100	0.39-1.84	0.747	0.667
PCB-52[1]	Gas+particle	52	0.050	100	0.215-0.694	0.419	0.401
PCB-101[1]	Gas+particle	52	0.031	100	0.117-0.377	0.220	0.198
PCB-118[1]	Gas+particle	52	0.011	100	0.033-0.174	0.072	0.061
PCB-138[1]	Gas+particle	52	0.017	100	0.03-0.141	0.063	0.055
PCB-153[1]	Gas+particle	52	0.027	100	0.04-0.174	0.090	0.078
PCB-180[1]	Gas+particle	52	0.014	39	<0.009-0.031	0.016	0.014
Sum PCB-7[1]	Gas+particle	52			0.84-3	1.63	1.47
Sum PCB[1]	Gas+particle	52			3.65-14.28	7.20	6.75
BDE-47[2]	Gas+particle	52	0.021	100	0.049-1.04	0.221	0.154
BDE-49[2]	Gas+particle	52	0.002	100	0.003-0.039	0.009	0.007
BDE-66[2]	Gas+particle	52	0.002	73	0.002-0.123	0.007	0.004
BDE-71[2]	Gas+particle	52	0.001	35	<0.001-0.008	0.002	0.001
BDE-99[2]	Gas+particle	52	0.009	100	0.009-0.125	0.042	0.035
BDE-100[2]	Gas+particle	52	0.003	100	0.003-0.069	0.016	0.013
BDE-153[2]	Gas+particle	52	0.003	40	<0.003-0.016	0.004	0.003
BDE-154[2]	Gas+particle	52	0.003	33	<0.002-0.015	0.004	0.003
BDE-183[2]	Gas+particle	52	0.003	51	<0.002-0.017	0.005	0.003
BDE-196[2]	Gas+particle	52	0.005	20	<0.004-0.061	0.010	0.005
BDE-206[2]	Gas+particle	52	0.071	68	0.065-3.02	0.32	0.17

ZEPPELIN - Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
BDE-209[3]	Gas+particle	52	0.744	90	(0.69-137)	(14.2)	(5.86)
Sum BDE[3]	Gas+particle	52			3.41-60.9	14.8	6.27
Sum BDE$_{\text{excl -209}}$[2]	Gas+particle	52			0.38-1.61	0.67	0.60
TBA[2]	Gas+particle	52	0.03	100	0.905-29.2	6.58	5.94
α-HBCDD[2]	Gas+particle	12	0.012	77	<0.014-1.29	0.163	0.051
β-HBCDD[2]	Gas+particle	12	0.010	42	<0.009-0.266	0.034	0.011
γ-HBCDD[2]	Gas+particle	12	0.012	23	<0.012-0.142	0.023	<0.012
PAHs (ng/m^3) **Class of uncertainty: 1**							
1-Methylnaphthalene	Gas+particle	52	0.006	95	<0.005-0.301	0.048	0.030
1-Methylphenanthrene	Gas+particle	52	0.001	39	<0.001-0.014	0.002	0.001
2-Methylanthracene	Gas+particle	52	0.002	5	<0.001-0.005	0.002	<0.001
2-Methylnaphthalene	Gas+particle	52	0.010	93	<0.009-0.336	0.057	0.043
2-Methylphenanthrene	Gas+particle	52	0.003	36	<0.002-0.021	0.004	0.002
3-Methylphenanthrene	Gas+particle	52	0.002	36	<0.001-0.016	0.003	0.002
9-Methylphenanthrene	Gas+particle	52	0.002	36	<0.001-0.008	0.002	0.001
Acenaphthene	Gas+particle	52	0.006	9	<0.003-0.023	0.007	<0.003
Acenaphthylene	Gas+particle	52	0.001	16	<0.001-0.012	0.002	<0.001
Anthanthrene	Gas+particle	52	0.0003	4	<0.001-0.004	0.001	<0.001
Anthracene	Gas+particle	52	0.0004	4	<0.001-0.004	0.001	<0.001
Benz(a)anthracene	Gas+particle	52	0.0002	14	<0.001-0.021	0.002	<0.001
Benzo(a)fluoranthene	Gas+particle	52	0.0002	4	<0.001-0.004	0.001	<0.001
Benzo(a)fluorene	Gas+particle	52	0.0003	16	<0.001-0.013	0.001	<0.001
Benzo(a)pyrene	Gas+particle	52	0.0002	16	<0.001-0.026	0.002	<0.001
Benzo(b)fluoranthene	Gas+particle	52	0.001	37	<0.001-0.093	0.004	0.001
Benzo(b)fluorene	Gas+particle	52	0.0002	5	<0.001-0.008	0.001	<0.001
Benzo(e)pyrene	Gas+particle	52	0.0002	27	<0.001-0.049	0.003	0.001
Benzo(ghi)fluoranthene	Gas+particle	52	0.0005	0	<0.001-<0.001	<0.001	<0.001
Benzo(ghi)perylene	Gas+particle	52	0.0003	25	<0.001-0.035	0.002	0.001
Benzo(k)fluoranthene	Gas+particle	52	0.0002	21	<0.001-0.033	0.002	0.001
Biphenyl	Gas+particle	52	0.011	80	0.007-1.25	0.248	0.116
Chrysene	Gas+particle	52	0.0003	37	<0.001-0.076	0.004	0.001
Coronene	Gas+particle	52	0.001	12	<0.001-0.012	0.002	<0.001
Cyclopenta(cd)pyrene	Gas+particle	52	0.001	0	<0.001-0.002	<0.001	<0.001
Dibenzo(ae)pyrene	Gas+particle	52	0.001	5	<0.001-0.011	0.002	<0.001
Dibenzo(ah)anthracene	Gas+particle	52	0.000	4	<0.001-0.005	0.001	<0.001
Dibenzo(ah)pyrene	Gas+particle	52	0.001	0	<0.001-0.012	<0.002	<0.001
Dibenzo(ai)pyrene	Gas+particle	52	0.001	0	<0.001-0.011	<0.001	<0.001
Dibenzofuran	Gas+particle	52	0.015	96	<0.014-1.57	0.369	0.220
Dibenzothiophene	Gas+particle	52	0.001	59	0.001-0.017	0.003	0.001
Fluoranthene	Gas+particle	52	0.007	52	<0.004-0.241	0.020	0.005

ZEPPELIN - Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Fluorene	Gas+particle	52	0.012	82	0.01-0.882	0.133	0.032
Inden(123-cd)pyrene	Gas+particle	52	0.000	25	<0.001-0.039	0.003	0.001
Naphthalene	Gas+particle	52	0.014	100	0.016-1.61	0.233	0.133
Perylene	Gas+particle	52	0.0002	4	<0.001-0.003	0.001	<0.001
Phenanthrene	Gas+particle	52	0.028	30	0.016-0.202	0.038	0.014
Pyrene	Gas+particle	52	0.004	48	0.002-0.134	0.011	0.003
Retene	Gas+particle	52	0.001	34	<0.001-0.025	0.002	0.002
Sum PAH$_{16}$	Gas+particle	52			0.165-3.36	1.22	0.725
Sum PAH$_{39}$	Gas+particle	52			0.09-1.39	0.466	0.195
Ionic and volatile PFAS (pg/m^3) **Class of uncertainty: 2**							
FTS 4:2	Particle phase	12	0.04	0	<0.04-<0.04	<0.04	<0.04
FTS 6:2	Particle phase	12	0.04	0	<0.04-<0.04	<0.04	<0.04
FTS 8:2	Particle phase	12	0.04	0	<0.04-<0.04	<0.04	<0.04
PFBS	Particle phase	12	0.01	50	<0.01-0.02	0.01	0.01
PFDoDA	Particle phase	12	0.02	8	<0.01-0.01	0.01	<0.01
PFHpA	Particle phase	12	0.02	75	0.02-0.22	0.07	0.04
PFHxA	Particle phase	12	0.02	100	0.02-0.3	0.09	0.07
PFHxS	Particle phase	12	0.01	0	<0.01-<0.01	<0.01	<0.01
PFNA	Particle phase	12	0.01	67	<0.01-0.112	0.04	0.02
PFOA	Particle phase	12	0.01	100	0.01-0.20	0.07	0.07
PFOS	Particle phase	12	0.01	8	<0.01-0.03	0.01	<0.01
PFOSA	Particle phase	12	0.01	25	<0.01-0.02	0.01	<0.01
PFUnA	Particle phase	12	0.01	25	<0.01-0.38	0.04	<0.01
PFPS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFHpS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFNS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFPeA	Particle phase	12		92	0.02-0.18	0.05	0.04
PFTrDA	Particle phase	12	0.05	0	<0.05-<0.05	<0.05	<0.05
PFTeDA	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFHxDA	Particle phase	12	0.05	0	<0.05-<0.05	<0.05	<0.05
PFODcA	Particle phase	12	0.05	0	<0.05-<0.05	<0.05	<0.05
PFDS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFOSlin	Particle phase	12	0.01	8	<0.01-0.02	0.01	<0.01
PFDA	Particle phase	12	0.01	58	<0.01-0.05	0.02	0.02
PFUnS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFDoS	Particle phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
PFTrS	Particle phase	12		0	<0.05-<0.05	<0.05	<0.05
PFTS	Particle phase	12		0	<0.05-<0.05	<0.05	<0.05
Sum ionic PFAS	Particle phase	12			0.31-1.28	0.59	0.54
4:2 FTOH	Gas phase	12	0.59	18	<0.57-2.23	1.04	0.84

ZEPPELIN - Air

Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
6:2 FTOH	Gas phase	12	1.97	100	4.09-41.9	13.8	9.68
8:2 FTOH	Gas phase	12	1.05	100	4.18-88.2	16.1	9.33
10:2 FTOH	Gas phase	12	1.23	82	<1.21-29.5	5.15	2.61
12:2 FTOH	Gas phase	12	0.40	91	<0.38-11.5	1.90	0.75
N-Me-FOSA	Gas phase	12	0.84	9	<0.67-1.77	1.00	0.84
N-Et-FOSA	Gas phase	12	0.35	55	<0.33-1.95	0.55	0.38
N-Me-FOSE	Gas phase	12	0.50	9	<0.40-2.18	0.71	0.51
N-Et-FOSE	Gas phase	12	0.74	9	<0.59-2.32	0.96	0.74
Sum volatile PFAS	Gas phase	12			12.6-180	39.5	25.0
brPFOS	Particle phase	12	0.01	8	<0.01-0.014	0.01	<0.01
10:2 FTS	Particle phase	12	0.04	0	<0.04-<0.04	<0.04	<0.04
12:2 FTS	Particle phase	12	0.06	0	<0.06-<0.06	<0.06	<0.06
PF-3,7-DMOA	Particle phase	12	0.01	0	<0.01-<0.01	<0.01	<0.01
FOSAA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
MeFOSAA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
EtFOSAA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
FBSA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
MeFBSA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
EtFBSA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
HPFHpA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
7:3 FTCA	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
F53	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
8Cl-PFOS	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
6:2 F53B	Particle phase	12	0.1	0	<0.1-<0.1	<0.1	<0.1
Chlorinated paraffins (pg/m^3) **Class of uncertainty: 3**							
SCCP	Gas+particle	52	184	61	<170-698	280	267
MCCP	Gas+particle	52	622	16	<310-1140	394	317
Siloxanes (ng/m^3) **Class of uncertainty: 3**							
D4	Gas phase	52	0.06	95	0.05-18.1	1.08	0.40
D5	Gas phase	52	0.07	91	0.06-9.99	1.26	0.60
D6	Gas phase	52	0.150	55	0.11-3.38	0.30	0.15
sum cVMS	Gas phase	52			0.26-31.5	2.56	2.64
L3	Gas phase	12	0.005	75	<0.005-0.188	0.037	0.029
L4	Gas phase	12	0.015	67	<0.015-0.138	0.035	0.032
L5	Gas phase	12	0.10	67	<0.010-0.063	0.026	0.030
M3T(Ph)	Gas phase	12	0.030	0	<0.030-<0.030	<0.030	<0.030
F3-Sil	Gas phase	12	0.030	0	<0.030-<0.030	<0.030	<0.030
F4-Sil	Gas phase	12	0.030	0	<0.030-<0.030	<0.030	<0.030
Ph-D4	Gas phase	12	0.030	0	<0.030-<0.030	<0.030	<0.030

ZEPPELIN - Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
OPFRs (pg/m^3) **Class of uncertainty: 3**							
TEP	Gas+particle	12	11.7	100	18.1-177	53.7	35.4
TCEP	Gas+particle	12	3.58	100	7.39-2020	315	30.1
TCPP (TCIPP)	Gas+particle	12	7.45	92	<40-4150	480	134
TPrP	Gas+particle	12	0.38	0	<0.04-<0.57	0.25	<0.18
TDCPP	Gas+particle	12	0.57	85	<0.86-7.77	3.57	3.12
TPP	Gas+particle	12	1.23	86	<1.83-247	32.4	6.7
TiBP/TnBP	Gas+particle	12	0.40	91	<4.36-348	43.7	12.1
TBEP (TBOEP)	Gas+particle	12	0.95	79	<1.16-8.02	3.15	2.56
DBPhP	Gas+particle	12	0.38	7	<0.15-3.36	0.50	<0.21
2-IPPDPP	Gas+particle	12	0.97	75	<0.46-4.89	2.16	1.76
4-IPPDPP	Gas+particle	12	0.38	0	<0.18-<0.57	0.29	<0.21
TCP	Gas+particle	12	0.38	0	<0.18-<0.7	0.32	<0.30
BdPhP	Gas+particle	12	0.38	0	<0.18-<0.7	0.32	<0.30
EHDP	Gas+particle	12	2.22	79	<1.05-195	28.0	9.2
B4IPPPP	Gas+particle	12	0.38	0	<0.18-<0.57	0.29	<0.21
TXP	Gas+particle	12	0.38	0	<0.18-<0.7	0.32	<0.30
TIPPP	Gas+particle	12	0.38	0	<0.18-<0.91	0.34	<0.30
TTBPP	Gas+particle	12	0.38	0	<0.18-<0.57	0.29	<0.21
TEHP	Gas+particle	12	0.38	29	<0.18-5.96	1.19	<0.47
nBFRs (pg/m^3) **Class of uncertainty: 2**							
ATE (TBP-AE)	Gas+particle	12	0.009	30	<0.008-0.044	0.017	<0.009
a-TBECH	Gas+particle	12	0.052	40	<0.049-0.934	0.232	<0.054
b-TBECH	Gas+particle	12	0.034	40	<0.032-0.501	0.123	<0.036
g/d-TBECH	Gas+particle	12	0.025	20	<0.023-0.072	0.034	<0.024
BATE	Gas+particle	12	0.010	20	<0.01-0.049	0.017	<0.010
PBT	Gas+particle	12	0.019	100	0.067-16.3	2.92	0.112
PBEB	Gas+particle	12	0.009	40	<0.009-0.19	0.041	<0.009
PBBZ	Gas+particle	12	0.076	40	<0.071-2.16	0.507	<0.091
HBB	Gas+particle	12	0.032	100	0.082-13	2.83	0.151
DPTE	Gas+particle	12	0.008	100	0.017-2.82	0.624	0.026
EHTBB	Gas+particle	12	0.008	100	0.013-0.308	0.088	0.046
BTBPE	Gas+particle	12	0.016	30	<0.015-0.195	0.039	<0.016
TBPH (BEH /TBP)	Gas+particle	12	0.035	60	<0.033-0.139	0.068	0.048
DBDPE	Gas+particle	12	0.694	100	0.801-10.9	3.22	1.46
Sum nBFR	Gas+particle	12			1.65-39.0	10.7	4.22
TBBPA	Gas+particle	12	0.052	71	<0.018-0.182	0.090	0.090

ZEPPELIN - Air							
Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
Dechloranes (pg/m^3) Class of uncertainty: 2							
syn-DP	Gas+particle	12	0.070	8	<0.070-0.087	0.039	<0.070
anti-DP	Gas+particle	12	0.074	23	<0.074-0.258	0.060	<0.074
Dec 601	Gas+particle	12	0.010	0	<0.010-<0.015	<0.010	<0.010
Dec 602	Gas+particle	12	0.006	0	<0.006-<0.008	<0.006	<0.006
Dec 603	Gas+particle	12	0.006	0	<0.006-<0.009	<0.006	<0.006
Dec 604	Gas+particle	12	0.105	0	<0.105-<0.136	<0.105	<0.105
Dec 604B	Gas+particle	12	0.077	0	<0.077-<0.113	<0.080	<0.077
Dibromoaldrin	Gas+particle	12	0.037	0	<0.037-<0.052	<0.037	<0.037
Chlordene plus	Gas+particle	12	0.009	0	<0.009-<0.013	<0.009	<0.009
Dechlorane plus Cl10	Gas+particle	12	0.006	0	<0.006-<0.009	<0.006	<0.006
Dechlorane plus axx	Gas+particle	12	0.006	69	<0.006-0.029	0.011	0.010
Dechlorane plus ax	Gas+particle	12	0.008	0	<0.008-<0.012	<0.008	<0.008
Dechlorane plus Cl11	Gas+particle	12	0.011	0	<0.011-<0.016	<0.011	<0.011
Volatile fluorinated and chlorinated substances (pg/m^3) Class of uncertainty:2							
PFTBA	Gas phase	32	5	82	1503-2342	1962	1999
TCPFB	Gas phase	32	1	82	170-328	255	266
PFTPeA	Gas phase	32	5	82	65-140	110	112
HCBD	Gas phase	32	5	100	1355-2103	1631	1659
PFPHP	Gas phase	32	5	82	41-68	47	46
DCTFP	Gas phase	32	0.5	93	3.7-9	5.6	5.6
PCTol	Gas phase	32	0.5	100	0.7-2.4	1.3	1.2
DCPFcH	Gas phase	32	1	0	<1.0-<1.0	<1.0	<1.0
PFBB	Gas phase	32	5	0	<5.0-<5.0	<5.0	<5.0
bTFMBB	Gas phase	32	1	0	<1.0-<1.0	<1.0	<1.0
DCBTC	Gas phase	32	0.5	0	<0.5-<0.5	<0.5	<0.5
HCcBen	Gas phase	32	1	100	215-349	250	242
HCBcB	Gas phase	32	1	93	6.3-11.5	7.7	7.7

*MDLs are presented as a guidance based on average sample volume per compound group. The MDL is however variable over the year due to variable sample volume and analytical conditions.

Table A.4: Summary of measured concentrations (ng/L), detection frequencies (%) and method detection limits (MDL, ng/L) of POPs in precipitation at Birkenes in 2021. The colour codes indicate highest detection/concentrations in red and lowest detection/concentrations in green.

BIRKENES - Precipitation							
Compound	**Matrix**	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
POPs (ng/L) **Class of uncertainty:1**							
HCB[1]	Precip	49	0.065	44	<0.014-0.411	0.070	0.06
α-HCH[1]	Precip	49	0.116	38	<0.026-0.516	0.077	0.09
γ-HCH[1]	Precip	49	0.072	72	<0.016-0.321	0.153	0.16
PCB-28[1]	Precip	49	0.024	5	<0.003-0.108	0.014	<0.019
PCB-52[1]	Precip	49	0.010	23	<0.001-0.046	0.006	0.008
PCB-101[1]	Precip	49	0.010	13	<0.001-0.043	0.005	<0.006
PCB-118[1]	Precip	49	0.005	18	<0.001-0.022	0.003	<0.003
PCB-138[1]	Precip	49	0.007	18	<0.001-0.03	0.004	<0.005
PCB-153[1]	Precip	49	0.009	15	<0.002-0.041	0.005	<0.007
PCB-180[1]	Precip	49	0.003	35	<0.001-0.123	0.008	0.003
Sum PCB-7[1]	Precip	49		8	0.02-0.63	0.053	

*MDLs are presented as a guidance based on average sample volume per compound group. The MDL is however variable over the year due to variable sample volume and analytical conditions.

Table A.5: Summary of measured concentrations (ng/m^3) and detection frequencies (%) of heavy metals in air at Birkenes, Zeppelin, Svanvik, Andøya and Karpdalen in 2021. The colour codes indicate highest detection/concentrations in red and lowest detection/concentrations in green.

HEAVY METALS - Air						
Compound	**Matrix**	**No. of samples**	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Birkenes - Air (ng/m^3) **Class of uncertainty: 1**						
Al	Particle phase	49	82	1.505-62.8	19.3	15.2
As	Particle phase	49	96	0.026-0.317	0.106	0.091
Cd	Particle phase	49	98	0.004-0.067	0.018	0.015
Cr	Particle phase	49	27	0.123-0.603	0.216	0.147
Co	Particle phase	49	45	0.002-0.059	0.016	0.010
Cu	Particle phase	49	92	0.057-1.61	0.297	0.262
Fe	Particle phase	49	88	1.047-62.8	18.8	13.4
Pb	Particle phase	49	96	0.104-1.48	0.459	0.380
Mn	Particle phase	49	92	0.174-1.8	0.712	0.629
Ni	Particle phase	49	67	0.031-0.423	0.175	0.143
Ti	Particle phase	49	90	0.118-5.55	1.27	0.709
V	Particle phase	49	88	0.018-0.912	0.294	0.216
Zn	Particle phase	49	96	0.625-23.3	3.42	2.12
Hg	Gas phase	360	100	0.966-1.899	1.51	1.52
Zeppelin - Air (ng/m^3) **Class of uncertainty: 1 and 3 (specification for individual compounds below)**						
Al[1]	Particle phase	52	94	0.1-725	69.8	30.7
As[1]	Particle phase	52	92	0-0.414	0.039	0.017
Cd[1]	Particle phase	52	98	0-0.179	0.021	0.010
Cr[1]	Particle phase	52	37	0-2.27	0.159	0.056
Co[1]	Particle phase	52	81	0-0.134	0.012	0.006
Cu[1]	Particle phase	52	75	0-1.37	0.125	0.059
Fe[1]	Particle phase	52	87	0.04-297	24.4	12.2
Pb[1]	Particle phase	52	83	0-1.56	0.190	0.089
Mn[1]	Particle phase	52	90	0.001-6.91	0.593	0.262
Ni[1]	Particle phase	52	52	0-1.08	0.097	0.038
Ti[1]	Particle phase	52	65	0.009-22.6	1.84	1.03
V[1]	Particle phase	52	90	0-0.796	0.080	0.043
Zn[1]	Particle phase	52	81	0.002-16.3	1.56	0.730
Hg-GEM[1]	Gas phase	348	100	0.751-1.928	1.48	1.50
Hg-GOM[3]	Gas phase	172	35	0-9.94	1.22	0.500
Hg-PBM[3]	Particle phase	172	62	0-47.54	2.17	1.21
Svanvik - Air (ng/m^3) **Class of uncertainty: 1**						
Al	Particle phase	49	100	2.57-168	35.8	21.2
As	Particle phase	49	100	0.014-0.536	0.099	0.081

HEAVY METALS - Air						
Compound	**Matrix**	**No. of samples**	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Cd	Particle phase	49	100	0.001-0.125	0.022	0.013
Cr	Particle phase	49	100	0.033-1.01	0.219	0.156
Co	Particle phase	49	100	0.003-0.132	0.034	0.028
Cu	Particle phase	49	92	0.0835-5.99	0.588	0.366
Fe	Particle phase	49	100	3.91-184	39.2	22.0
Pb	Particle phase	49	100	0.055-3.83	0.598	0.353
Mn	Particle phase	49	100	0.069-3.14	0.767	0.460
Ni	Particle phase	49	100	0.029-10.3	0.987	0.594
V	Particle phase	49	100	0.015-33.9	2.53	0.885
Zn	Gas phase	49	100	0.407-10.4	2.22	1.49
Andøya- Air (ng/m^3) **Class of uncertainty: 1**						
Al	Particle phase	52	96	1.019-261	35.6	22.4
As	Particle phase	52	100	0.005-0.26	0.042	0.022
Cd	Particle phase	52	90	0-0.094	0.008	0.003
Cr	Particle phase	52	27	0.022-2.27	0.100	0.024
Co	Particle phase	52	79	0.001-0.071	0.012	0.007
Cu	Particle phase	52	90	0.007-1.59	0.250	0.200
Fe	Particle phase	52	100	0.808-170	24.4	14.4
Pb	Particle phase	52	100	0.006-1.41	0.210	0.090
Mn	Particle phase	52	94	0.017-3.23	0.509	0.269
Ni	Particle phase	52	29	0.029-1.75	0.102	0.030
Ti	Particle phase	52	92	0.062-8.82	1.52	0.942
V	Particle phase	52	100	0.009-0.716	0.125	0.064
Zn	Particle phase	52	56	0.180-5.92	0.913	0.553
Hg-GEM	Gas phase	357	100	1.167-1.588	1.40	1.39
Karpdalen- Air (ng/m^3) **Class of uncertainty: 1**						
Al	Particle phase	50	100	2.14-409	31.8	14.4
As	Particle phase	50	100	0.011-0.428	0.096	0.051
Cd	Particle phase	50	100	0.002-0.147	0.022	0.011
Cr	Particle phase	50	82	0.015-1.1	0.191	0.120
Co	Particle phase	50	100	0.003-0.347	0.039	0.016
Cu	Particle phase	50	100	0.063-15.9	0.861	0.264
Fe	Particle phase	50	100	2.9-327	30.9	14.7
Pb	Particle phase	50	100	0.057-4	0.686	0.351
Mn	Particle phase	50	100	0.069-5.37	0.590	0.353
Ni	Particle phase	50	100	0.049-7.73	1.24	0.661
V	Particle phase	50	100	0.015-17.3	2.97	1.43
Zn	Particle phase	50	100	0.274-12.9	1.74	0.921

Table A.6: Summary of measured concentrations (µg/L) and detection frequencies (%) of heavy metals in precipitation at Birkenes, Kårvatn, Svanvik, Hurdal and Karpdalen in 2021. The colour codes indicate highest detection/concentrations in red and lowest detection/concentrations in green.

HEAVY METALS - Precipitation						
Compound	**Matrix**	**No. of samples**	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Birkenes (µg/l) **Class of uncertainty: 1**						
As	Precip	46	63	0.025-0.393	0.056	0.060
Cd	Precip	46	100	0.005-0.099	0.015	0.016
Cr	Precip	46	74	0.045-0.851	0.114	0.141
Co	Precip	46	83	0.004-0.469	0.017	0.021
Cu	Precip	46	100	0.17-51.6	1.95	2.12
Pb	Precip	46	100	0.116-3.59	0.583	0.514
Mn	Precip	46	100	0.257-20.3	1.54	1.65
Ni	Precip	46	98	0.03-11.3	0.199	0.247
V	Precip	46	100	0.048-1.65	0.188	0.191
Zn	Precip	46	100	1.28-69.1	5.26	5.22
Hg (ng/L)	Precip	38	100	1.60-22.0	4.15	5.04
Kårvatn (µg/L) **Class of uncertainty: 1**						
As	Precip	47	23	0.025-0.209	0.036	0.025
Cd	Precip	48	65	0.002-0.186	0.006	0.005
Cr	Precip	47	45	0.045-1.05	0.084	0.045
Co	Precip	47	70	0.004-0.273	0.014	0.012
Cu	Precip	47	100	0.052-8.40	1.07	1.01
Mn	Precip	47	87	0.100-14.9	1.10	1.05
Pb	Precip	48	77	0.02-4.86	0.265	0.141
Ni	Precip	47	23	0.100-1.09	0.127	0.100
V	Precip	47	83	0.01-0.66	0.055	0.051
Zn	Precip	48	96	0.3-16.6	2.29	2.05
Hg (ng/L)	Precip	37	100	0.02-36.7	2.76	2.86
Svanvik (µg/L) **Class of uncertainty: 1**						
Al	Precip	39	100	1.72-125	21.6	21.2
As	Precip	39	74	0.025-0.354	0.080	0.094
Cd	Precip	39	90	0.002-0.066	0.018	0.013
Cr	Precip	39	77	0.045-2.23	0.183	0.182
Co	Precip	39	97	0.004-0.664	0.078	0.126
Cu	Precip	39	100	0.505-34.6	5.00	5.49
Pb	Precip	39	95	0.02-3.79	0.650	0.325
Ni	Precip	39	100	0.145-20.4	1.64	1.99
V	Precip	39	100	0.06-12	0.469	0.465
Zn	Precip	39	97	0.3-78.4	8.91	3.35

HEAVY METALS - Precipitation

Compound	Matrix	No. of samples	DF (%)	Concentration range	Annual mean	Annual median
Hurdal (µg/L) Class of uncertainty: 1						
As	Precip	43	74	0.025-0.355	0.087	0.092
Cd	Precip	44	100	0.004-0.133	0.017	0.017
Cr	Precip	43	79	0.045-3.94	0.266	0.426
Co	Precip	43	86	0.004-0.241	0.029	0.035
Cu	Precip	43	100	0.308-35.8	3.26	4.14
Mn	Precip	43	98	0.100-70.4	2.70	3.08
Pb	Precip	44	100	0.069-4.16	0.857	0.690
Ni	Precip	43	98	0.03-4.33	0.327	0.399
V	Precip	43	100	0.033-1.03	0.217	0.218
Zn	Precip	44	100	1.11-86.2	6.41	7.26
Hg (ng/L)	Precip	24	100	1.34-37.3	11.3	9.22
Karpdalen (µg/L) Class of uncertainty: 1						
Al	Precip	36	97	5-1010	50.4	45.9
As	Precip	37	81	0.025-0.997	0.121	0.127
Cd	Precip	37	95	0.004-0.251	0.015	0.015
Cr	Precip	37	86	0.045-3.99	0.346	0.422
Co	Precip	37	100	0.031-2.02	0.192	0.209
Cu	Precip	37	100	0.81-103	5.34	5.69
Pb	Precip	37	95	0.061-4.99	0.537	0.297
Ni	Precip	37	97	0.3-58.5	3.72	4.00
V	Precip	37	97	0.037-8.03	0.448	0.549
Zn	Precip	37	95	0.628-318	5.64	4.00

Appendix B

Material and methods for sampling, chemical analysis and quality assurance and control

B1. Heavy metals

Sampling and analytical methods

Collection of precipitation, for analysis of heavy metals, is done using a bulk sampler (funnel+collector) from Innovation NILU. Precipitation amount is determined by weighing. The sample is sent to NILUs laboratory at Kjeller where it is preserved to 1% HNO_3 for analyses of heavy metals. Identification and quantification is performed by inductively coupled plasma mass spectrometry (ICP-MS), and indium is used as internal standard. The ion optic is optimized for 115 In (Table B.6).

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.

Table B.1: Quantification limits for heavy metals in precipitation.

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

Air sampling for the analysis of heavy metals in particles at Birkenes is done using a Kleinfiltergerät with a PM_{10}-impactor and an airflow of 2.3 m^3/hour. Weekly samples (7 days) on Whatman quartz 47 mm filter are collected. This is the same sampler and filter as is used to collect EC/OC. At Andøya and the Zeppelin Observatory, sampling of heavy metals on particles are done using a Digitel high volume air sampler without any defined size cut off. Samples are collected on weekly basis, using Whatman 41 filter papers for 48 hours with an airflow rate of 20-25 m^3/hour. The filters are digested with nitric acid by Ultraclave, a microwave based decomposition technique. Identification and quantification is performed by ICP-MS, and indium is used as internal standard. The ion optic is optimized for 115 In (Table B.6).

Table B.2: Quantification limit for heavy metals in aerosols.

	Lower quantification limit (ng/m³)		
	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

B2. Mercury

Sampling and analytical methods

Collection of precipitation, for analysis of Hg, is done 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 (Table B.6). 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. Field operators collect samples weekly using clean techniques and replace the collection bottles.

Precipitation samples are returned to NILUs laboratory and analysed for total mercury using accredited methods based on 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) in air is monitored using a Tekran 2537 Hg vapour analyzer (Table B.6). 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. The detection limit is 0.01 ng/m^3.

Mercury species, Gaseous Oxidized Mercury (GOM) and Particulate Bound Mercury (PBM), are collected in the following way: air is pulled into the analyzer through a Teflon-coated elutriator and an impactor designed to remove particles > 2.5 µm at flow rates of 10 L min−1. The sample air flows over a KCl-coated quartz denuder to trap gaseous organic mercury (GOM) and then over a quartz particulate filter to trap particulate-bound mercury (PBM). GOM and PBM accumulate for 1 to 2 h followed by consecutive thermal desorption and AFS detection by the Tekran 2537, as with gaseous elemental mercury. The detection limit depends on sample volume and blank level and is typically 1 pg/m^3.

B3. POPs and organic contaminants of emerging concern

Sampling and analytical methods

Air sampling of HCB, OCPs, PCBs, PAHs, PBDEs, HBCDDs, TBA, ionic and volatile PFASs, S/MCCPs, nBFRs, OPFRs, dechloranes and volatile fluorinated and chlorinated substances

Air samples are 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, the data are reported for sum gas- and particle phase (i.e. bulk concentrations). For ionic PFAS, only a GFF is used for analysis and data are reported for particle phase only. For volatile PFAS, only the PUF/XAD/PUF sandwich is used and data are reported for gas phase only. Specification on each sampler type is given in Table B.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 B.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, (Zeppelin) HCB, ionic and volatile PFAS (Andøya) HCB, OCPs, PCBs, PBDEs, HBCDDs, TBA, PAHs, M/SCCPs, ionic and volatile PFAS (Birkenes)	HCB, OCPs, PCBs, PAHs, PBDEs, HBCDDs, S/MCCPs, dechloranes (Zeppelin)

Sampling is done on a weekly or monthly basis for individual compounds and observatory according to Table 2.2-2.3. The sampling duration for each observatory and POP class varies according to Table B.4. The variable sampling lengths result in total air volumes of 600-2000 m^3 (as reported on sampling protocols).

Table B.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
HBCDDs	48 h*	-	72 h
PFAS*	48 h	48 h	48 h
S/MCCPs	24 h	-	48 h
Siloxanes**	72 h	-	72 h
nBFRs	-	-	48-72 h
OPFRs	-	-	48-72 h
Dechloranes	-	-	48 h
Volatile fluorinated and chlorinated substances	-	-	72 hr

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

After sampling, the exposed samples (GFF, PUFs, PUF/XAD/PUF) are 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 follow the yearly sample batch in order to control potential contamination risks during storage and transportation (as a part of the extensive control procedures of the accredited quality system). All exposed samples are registered and stored cold (6˚C) prior to analysis and quantification. The GFF and PUFs are extracted in the same solvent to obtain the bulk concentration (gas+particle phase) of the individual target compounds (below). Exceptions are samples for PFAS, for which only GFFs are used for ionic PFAS representing the particle phase concentrations only and PUF/XAD/PUF is used for volatile PFAS representing concentrations in the gas phase only.

Sampling and analysis of volatile methyl siloxanes (cVMS and lVMS), and volatile fluorinated and chlorinated substances

Sampling of siloxanes and the volatile fluorinated and chlorinated substances differ from the rest of the organic compounds. Sampling is 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 (Warner, 2020) . Sampling for siloxanes is done every week at Zeppelin and once per month at Birkenes. At both stations, all the siloxane samples are collected from Friday-Monday (~70 h), 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 local siloxane inputs. In addition, the sampling technicians are ordered not to use any personal-care products on the days of starting and stopping the siloxane samples.

The volatile fluorinated and chlorinated substances were in 2021 sampled at Zeppelin on weekly basis, 72 hrs per week, from May-December. All samples were taken during weekdays.

Each sample for siloxanes and volatile fluorinated and chlorinated substances, respectively, consisted of 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.

In 2021, cyclic VMS were analysed on all samples while linear and other VMS were analysed on one sample per month from Zeppelin only.

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, 20 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 (Warner, 2020).

Extracts were analyzed for cVMS 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 and 35°C min^{-1} to 300°C 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.

Extracts were analyzed for other siloxanes on a Thermo Trace 1310 GC connected to an Thermo GC Q Exactive MS detector and a TriPlus RSH autosampler. Helium (purity 5.0) was used as carrier gas (constant flow rate 1.2 mL min-1). The GC injector was split/splitless with a 5.0 mm I.D. gooseneck splitless liner (Restek, USA), connected to a 30 m TG-5SilMS column with 5m guard column (Thermo, 0.25 mm I.D., 0.25 µm film thickness). A 10 µl syringe was used to inject 2 µL sample at an injector temperature of 250 °C. The GC oven started at 40 °C for 1.5 min, followed by 10 °C min-1 up to 210°C and 30 °C min-1 to 300 °C for a final hold time of 1.5 min. The MS ion source was operated at 250 °C. Mass-spectral resolution was set at 120000, full scan range was m/z 50-750, electron energy was 40 eV. 3-point calibration curves (5 ng/ml to 20 ng/ml) were used for quantification. There was no standard available for Phenylheptamethylcyclotetrasiloxane. This substance was searched using spectral data from the literature and predicted retention time.

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

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

Identification and quantification of HCB, PCBs, OCPs and nBFRs was carried out using a high-resolution gas chromatography coupled to a high-resolution mass spectrometer as detector (HRGC/HRMS). The analyses were performed in Electron Impact ionization (EI) mode for PCBs, HCB, HCHs, DDTs and nBFRs using selected ion monitoring (SIM) for the respective compounds groups. Identification and quantification of chlordanes, SCCP, MCCP, and dechloranes was carried out using GC coupled to an Agilent HR qToF (time of flight) in Electron Capture Negative Ion (ECNI) mode. A mass window of ± 20 ppm were used for extraction of the ions for quantification. In total, 32 PCB congeners, 13 OCPs and 14 nBFRs were quantified.

Analysis and quantification of PAHs

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

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

Analysis and quantification PBDEs, TBA, HBCDDs, TBBPA

Samples were spiked with 20 µL of IS containing ^{13}C-labelled PBDE congeners (~270-2500 pg/µL) and 20 µL IS containing ^{13}C-labelled HBCDD congeners (α-, β-, γ-HBCDD, ~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 HBCDD analysis. The extract for PBDE/TBA was spiked with 20 µL of unlabelled TCN (100 pg/µL) as recovery standard, and the extract for HBCDD analysis was spiked with 20 µL RS containing deuterated (d18-α,β,γ) HBCDD (~130 pg/µL).

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

For identification and quantification of HBCDDs, 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 HBCDDs (α, β, γ) were quantified. TBBPA was also quantified on the HBCDD extract, by using ^{13}C-labelled β-HBCDD as internal standard and compensating for approximately 82% loss during acid treatment.

Analysis and quantification OPFRs

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

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

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

Analysis and quantification of ionic PFAS

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

Analysis and quantification of volatile PFAS

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

Sampling, analysis and quantification of POPs in precipitation

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

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

Identification and quantification of the PCBs, HCB and HCHs was carried out using a HRGC/HRMS, as described above. In total, seven PCB congeners, HCB and two HCHs were quantified.

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

B4. Quality assurance/Quality control (QA/QC)

Detailed information about the QA/QC routines at NILU's laboratories is presented in the Technical report for monitoring programmes (NILU, 2022). In short; the organic and inorganic chemical analyses, are accredited in accordance to NS-EN ISO/IEC 17025. The accredited analytical methods are to be found under accreditation number TEST 008 and includes P12 chemical analysis and P3002 air sampling. The accredited chemical analyses include heavy metals, mercury, PCBs, organochlorine pesticides (HCB, HCHs, chlordanes, and DDTs), and PAHs. The EMEP Manual (2001) describes the recommended procedures for the sampling and chemical analysis of air and precipitation of all these analytes within the EMEP region. These are in-house methods that are based on the EMEP manual (EMEP, 2014), and were the reference methods when the manual was developed. Methods for e.g. PBDEs and HBCDDs are not included in the manual, but the methods correspond to the POP-method. Table B.5-B.6 shows an overview of the methods used for all analytes included in the monitoring programme, together with relevant references where the methods have been utilized. Numerous analytical methods for POPs have been published over the past 30-40 years, and Muir and Sverko (2006) summarized the commonly used analytical methods. They concluded that methods best suited for the situation in a given lab should be adapted, and that participation in interlaboratory comparisons are more important, rather than to standardize the methodology.

Table B.5 also summarizes the methods used for the organic contaminants of emerging concern and lists the references where the most common analytical methods are described. NILU strives to use the methods that is expected to currently give the best results, and the methods are under continuously development. For example is ABN under testing as a replacement sampling material for the determination of S/MCCP and OPFR, which is expected to lower the blank contributions.

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

The analytical procedure is accompanied by a comprehensive quality control program based on the requirements of NILU's accreditation.

Field blank samples (n=3-4 per year) and method 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 method 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.

Based upon the method blanks, the method detection limit (MDL) is calculated for all compounds, given as the average plus 3 times the standard deviation of the concentrations of target analytes in the blank. When no target compound is detected in the blank samples, the instrumental detection limit (IDL), defined as 3 times the noise level, is used in the calculation of MDL. Concentrations below MDL are set to MDL/2 in further statistical treatment.

Table B.5: Overview of methods used for organic contaminants in the monitoring programme, performed by NILU.

	Sampling material:	Sampling reference:	Extraction method:	Clean-up method:	Instrumental method:	Analytical method reference:
HCB	PUF/GFF	EMEP, 2014; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP 2014; Muir, Sverko 2006; Halse et al. 2011
HCHs	PUF/GFF	EMEP, 2014; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP, 2014; Halse et al. 2011
DDTs	PUF/GFF	EMEP, 2014; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP 2014; Muir, Sverko 2006; Halse et al. 2011
Chlordanes/Nonachlors	PUF/GFF	EMEP, 2014; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-QTOF ECNI	EMEP 2014; Muir, Sverko 2006; Halse et al. 2011
PCBs	PUF/GFF	EMEP, 2014; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP 2014; Muir, Sverko 2006; Halse et al. 2011
POPs in precipitation (PCB, HCB, HCH)	Bulk (wet+dry deposition)	EMEP, 2014	Liquid extraction, cyclohexane	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP, 2014
PAH	PUF/GFF	EMEP 2014; Yu et al. 2019	Soxhlet extraction, cyclohexane	Silica fractionation	GC-LRMS EI	EMEP, 2014; Halse et al. 2011
S/MCCP	PUF/GFF	EMEP, 2014*	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-QTOF ECNI	EMEP, 2014*; Yuan, Muir, MacLoed 2019; Nipen et al. 2022
Dechloranes	PUF/GFF	EMEP, 2014*	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-QTOF ECNI	EMEP, 2014*; Sverko et al. 2011
PBDEs	PUF/GFF	EMEP 2014*; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP, 2014*; de Wit 2002
HBCD	PUF/GFF	EMEP 2014*; Hung et al. 2016	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	LC-MS-TOF ESI	EMEP, 2014*; de Wit 2002
TBA	PUF/GFF	EMEP, 2014*	Soxhlet extraction, diethylether/n-hexane (10:90, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP, 2014*
nBFRs	PUF/GFF	EMEP, 2014*	Soxhlet extraction, acetone/hexane (1:1, v:v)	Sulphuric acid+silica fractionation	GC-HRMS EI	EMEP, 2014*; Covaci et al. 2011
OPFRs	PUF/GFF	EMEP, 2014*	Soxhlet extraction, acetone/hexane (1:1, v:v)	SPE Z-sep/C18 silica/ Florisil (EZ-POP)	LC-MS-MS ESI	SPE from Stenerson et al. 2015
PFAS ionic	GFF	Hung et al. 2016	Sonication bath, methanol	Acidified Envi-Carb	LC-MS-MS ESI	Amin et al. 2020
PFAS volatile	PUF/XAD/PUF	Hung et al. 2016	Cold-extraction	Envi-Carb	GC-MS EI	Dreyer et al. 2008
Volatile methyl siloxanes (VMS)	ABN	Warner et al. 2020	On column	None	GC-MS EI	Warner et al. 2020
Volatile fluorinated and chlorinated substances	ABN	Warner et al. 2020*	On column	None	GC-MS EI	Warner et al. 2020*

*Substance not included in the publication, but is based on the same method.

Table B.6: Overview of methods used for heavy metals and mercury in the monitoring programme, performed by NILU.

	Sampling material:	**Sampling reference:**	**Sample preparation**	**Extraction method:**	**Instrumental method:**	**Analytical method reference:**
Elements in particles: V, Cr, Mn, Co, Ni, Cu, Zn, As, Cd and Pb	Quartz fibre filter (Birkenes)	Based on EN 12341:2014; EMEP, 2014; Groot Zwaaftink et al. 2022	1/2 filter, HNO_3/H_2O 1:2	UltraClave, max temp of 250 °C in 15 min	ICP-MS	Groot Zwaaftink et al. 2022
	Whatman 41 filter paper (Zeppelin, Andøya)		1/4 filter, HNO_3/H_2O 1:2	UltraClave, max temp of 250 °C in 15 min	ICP-MS	Groot Zwaaftink et al. 2022
Elements in precipitation: V, Cr, Mn, Co, Ni, Cu, Zn, As, Cd and Pb	Acid washed container	Based on NS 4864:1983; EMEP, 2014; Berg et al. 1997	Conservation 1% HNO_3	Not applicable	ICP-MS	Berg et al. 1997
Mercury in air	Gold traps	EN 15852:2010 and SOPs from NADP-AMNet and GMOS	Not applicable	Not applicable	Tekran monitor	EN 15852:2010 and SOPs from NADP-AMNet and GMOS
Mercury in precipitation	Borosilicate glass container	EN 15853:2010; Iverfeldt, 1991a+b; Jensen and Iverfeldt, 1993	Pre-sampling conservation with HCl	Not applicable	CV-AFS	US-EPA 1631-5

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).

All raw data for POPs and heavy metals are openly accessible from the NILU database (http://ebas.nilu.no) for thorough examinations.

Sampling and analysis of the organic contaminants of emerging concern (i.e. volatile siloxanes/fluorinated/chlorinated substances, S/MCCPs, nBFRs, OPFRs, dechloranes and PFAS) are associated with a bigger uncertainty than the well-established POPs. This is due to more diffuse sources in laboratories and sampling facilities (e.g., the use of CPs has increased again in a lot of different industrial, household products and consumer goods during the last years) that results in a larger risk for contamination. NILU is continuously taking actions to minimize this influence. Examples of such measures are improved pre-cleaning of analytical equipment, isolated work in clean cabinet facilities and removal of some materials and products where the chemicals are in use. However, samples cannot be sampled, stored, extracted and prepared for analysis without any physical contact with a lot of different materials and instruments. This causes a raising number of blank samples exceeding the acceptance level, which in consequence raises the method detection limit (MDL) for samples analysed in parallel with those blank samples. Therefore, for most of the emerging contaminants we adopt a sample blank treatment commonly used for non-regulated contaminants. The mass of the target compounds in each sample is compared to the average mass in the field blanks (on a site specific basis) and treated as follows: If the blank level is <20% of the measured level, no correction is done. If the blank level is 20–100% of the measured level, the blank level is subtracted from the measured level. In this case, the MDL is calculated as 3 times the standard deviation only.

The quality and uncertainty of the analysis of the different compound classes is classified in three categories:
Category 1: The methods are accredited according to EN ISO/IEC 17025 or could easily be included into this system. The analysis is well proven with available relevant interlaboratory studies and/or certified reference material.
Category 2: The methods are not accredited according to EN ISO/IEC 17025. Either reference material or interlaboratory studies are available and the methods are well proven.
Category 3: Non or few reference material or satisfying interlaboratory studies available. The methods are less reproducible and the results have higher uncertainty.

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NILU – Norwegian Institute for Air Research
P.O. Box 100, NO-2027 KJELLER, Norway

E-mail: nilu@nilu.no
http://www.nilu.no

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