Monitoring of environmental contaminants in air and precipitation

Annual report 2022

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ABSTRACT

This report presents air monitoring data from 2022 for the Norwegian monitoring programme "Atmospheric contaminants". The results cover 260 organic compounds (regulated and non-regulated) and 16 compound groups, 14 heavy metals, and a selection of organic chemicals of concern.

NORWEGIAN TITLE

Overvåking av langtransporterte atmosfæriske miljøgifter i luft og nedbør, årsrapport 2022.

KEYWORDS

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

ABSTRACT (in Norwegian)

Denne rapporten inkluderer miljøovervåkningsdata fra 2022 for overvåkningsprogrammet Atmosfæriske miljøgifter. Resultatene omfatter 260 organiske miljøgifter (regulerte og ennå ikke regulerte), 14 tungmetaller og et utvalg organiske forbindelser som er av mulig bekymring for miljøet.

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Contents

Summary

This report presents environmental monitoring data for in total 260 organic compounds and 16 compound groups, and 14 heavy metals, in air and precipitation for 2022. The organic compounds include regulated persistent organic pollutants (POPs) and non-regulated organic chemicals of emerging concern (CECs). The heavy metals (HMs) 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. From 2022, monitoring data is also collected at a newly established urban monitoring station located in Sofienbergparken in Oslo.

The monitoring is performed on behalf of the Norwegian Environment Agency and is part of the Government's environmental monitoring in Norway. This report covers findings from the monitoring programme "*Atmospheric contaminants".* In 2022, the programme covered POPs, HMs and CECs in air at Zeppelin (in the Arctic), Birkenes (southern Norway) and Sofienbergparken (Oslo) (Figure 1). PAHs in air at Zeppelin was also covered, while PAHs in air at Birkenes was funded internally by NILU. In 2022, HMs in air at Svanvik (eastern Finnmark in northern Norway) was included in the monitoring programme, with measurements funded by the Ministry of Foreign Affairs. The programme also covered POPs and HMs in precipitation at Birkenes and HMs in precipitation at Hurdal, Kårvatn and Svanvik.

In 2022, the concentrations of the organic contaminants ranged over eight orders of magnitude, from below the method detection limits (<MDL) of 0.001 pg/m^3 to detected concentrations of several hundred thousand pg/m^3. At all stations, the highest concentrations 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) and short chain chlorinated paraffins (SCCPs) (see Figure 2 below and Appendix A for details). The lowest concentrations were generally found for the regulated compounds. All concentrations of the organic contaminants measured in Sofienbergparken were higher than the concentrations measured at the two background stations (i.e. Birkenes and Zeppelin), except for the vol. F+Cl substances. The concentrations of linear volatile methyl siloxanes (lVMS) and the UV compounds, measured in Sofienbergparken only, were also significant.

For the HMs, the highest concentrations in air were detected at the new urban station Sofienbergparken in Oslo, where the presence of local sources is likely. Still, the concentrations are below the air quality criteria for metals as set by the National Institute for Public Health (NIPH). The lowest concentrations of HMs in air were measured at Zeppelin in the Arctic, followed by Birkenes. The higher concentrations at Birkenes than Zeppelin is due to Birkenes being closer to the emission sources at the European continent (EMEP, 2021). In precipitation, all the targeted HMs were detected at all stations. For Pb, Cd, Cu, V and Hg, the concentrations are highest at Birkenes and Hurdal followed by Kårvatn, reflecting the decreasing distances to the main emission sources in continental Europe (EMEP, 2021). Elevated concentrations and deposition levels were also observed at Svanvik, in particular for Ni, V, Cr, Cu and Co. The results are in line with 2021 and show a 2 to 10-fold decrease in HM in precipitation compared to 2020 when the smelter in Nikel (Russia) was still in operation.

Sammendrag

Denne rapporten presenterer norske miljøovervåkningsdata for totalt 260 organiske forbindelser og 16 grupper, samt 14 tungmetaller, i luft og nedbør i 2022. De organiske forbindelsene inkluderer regulerte persistente organiske miljøgifter (POP-er) og ikke-regulerte organiske forbindelser som er av mulig bekymring (CEC-er). 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. I 2022 er det også inkludert data for en nyetablert urban overvåkningsstasjon i Oslo, Sofienbergparken.

Overvåkningen utføres på oppdrag fra Miljødirektoratet og er en del av regjeringens miljøovervåkning i Norge. Rapporten omfatter funn fra overvåkningsprogrammet «Atmosfæriske miljøgifter». I 2022 inkluderte programmet POP-er, tungmetaller og CEC-er i luft ved Zeppelin (Arktis), Birkenes (sør-Norge) og Sofienbergparken (Oslo) (Figure 1). PAH i luft ved Zeppelin var også dekket, mens PAH i luft ved Birkenes var dekket av NILUs «interne overvåkningsprogram». I 2022, ble tungmetaller ved Svanvik (øst-Finnmark i nord-Norge) inkludert i overvåkningsprogrammet, med finansiering fra utenriksdepartementet. POP-er og tungmetaller i nedbør fra Birkenes, samt tungmetaller i nedbør fra Hurdal, Kårvatn og Svanvik, inngår også i programmet.

Luftkonsentrasjonene av de organiske forbindelsene i overvåkningsprogrammet i 2022 ble målt over et stort konsentrasjonsområde; fra under metodens deteksjonsgrense (< MDL) på 0,001 pg/m^3 til detekterte konsentrasjoner på hundretusenvis av pg/m^3. Som i de siste årene så ble de høyeste konsentrasjonene i luft funnet for siloksaner (cVMS), klimarelevante fluor- og klororganiske forbindelser (Vol. F+Cl forbindelser), noen polysykliske aromatiske hydrokarboner (PAH) og kortkjedete klorparafiner (SCCP) (se figur 2 nedenfor og Appendix A for detaljer). Lavest konsentrasjoner ble målt for de regulerte forbindelsene. Konsentrasjonene for alle de organiske forbindelsene var høyere ved Sofienbergparken enn de to bakgrunnsstasjonene (Zeppelin og Birkenes), med unntak av vol. F+Cl forbindelsene. For CEC-er målt i tillegg ved Sofienbergparken, var konsentrasjonene av de lineære siloksanene (lVMS) og UV stoffene spesielt signifikante.

Tilsvarende som for de organiske forbindelsene, ble de høyeste konsentrasjonene for tungmetaller i luft observert ved den urbane bakgrunnstasjonen i Sofienbergparken. Dette antas å skyldes lokale kilder, men konsentrasjonene var likevel innenfor luftkvalitetskriteriene som er fastsatt av Folkehelseinstituttet (FHI). De laveste konsentrasjonene i luft ble funnet ved Zeppelin i Arktis, etterfulgt av Birkenes. Høyere konsentrasjoner ved Birkenes enn ved Zeppelin skyldes at Birkenes er nærmere utslippskildene på det europeiske kontinentet (EMEP, 2021). De observerte konsentrasjonene av Pb, Cd, Cu, V og Hg i nedbør var høyest ved Birkenes og Hurdal, etterfulgt av Kårvatn, som følge av økende avstand til det europeiske kontinentet. Høye konsentrasjoner i nedbør ble også observert på Svanvik, spesielt for Ni, V, Cr, Cu og Co. Konsentrasjonene målt i 2022 samsvarer med 2021 og har blitt redusert 2 til 10 ganger sammenliknet med 2020 da smelteverket i Nikel (Russland) fortsatt var i drift.

1 Background

Persistent organic pollutants (POPs) and heavy metals (HMs) can undergo long-range environmental transport, are toxic, bioaccumulative and persistent in the environment. Long-range transport via air is the most important source to pollution in remote areas, such as the Arctic. The presence of environmental contaminants in Arctic air has contributed to the regulation of the use and emission of several POPs and heavy metals both on a regional and global scale. Norway implements obligations under the UNECE Convention on Long-range Transboundary Air Pollution (UN/ECE, 1998a; UN/ECE, 1998b), the Stockholm- and Minamata Conventions (UNEP, 2013; Stockholm Convention, 2007) and associated EU regulations.

The monitoring programme *"Atmospheric contaminants"* supports policy makers with information on the contaminants' concentrations in air at background sites across Norway, including the Arctic. The programme is performed on behalf of the Norwegian Environment Agency and is part of the Government's environmental monitoring in Norway. The overall purposes of the monitoring are to i) assess long-term temporal trends of atmospheric contaminants in Norway and evaluate the effectiveness of regulatory actions, ii) increase the understanding of occurrence and distribution of organic contaminants of emerging concern (CECs) in background and urban air for future regulations, iii) increase the understanding of the contaminants' potential for long-range transport, iv) assess spatial variabilities of atmospheric contaminants in Norway, and v) provide data for international conventions, programmes and networks, e.g. The Global Monitoring Programme (GMP) of the Stockholm Convention on POPs and the European Monitoring and Evaluation Programme (EMEP) under the Convention on Long-range Transboundary Air Pollution (LRTAP).

The monitoring in 2022 included in total 260 organic compounds and 16 compound groups, and 14 heavy metals, measured in air and precipitation at background monitoring stations on mainland Norway and Svalbard in the Arctic, and at a newly established urban monitoring station. The organic compounds include POPs, PAHs and non-regulated CECs. 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). Data was collected using active sampling technologies for contaminants in air and bulk sampler for contaminants in precipitation.

2 Overview of monitoring sites

To document the long-range transport of the environmental contaminants, the background monitoring stations/observatories included in this monitoring programme have been placed, as far as possible, in areas that are not influenced by local sources. For example, the occurrence of organic anthropogenic contaminants in the Arctic region has been attributed to long-range transport from industrial, agricultural, and populated areas.

In contrast, the newly established urban monitoring station (Sofienbergparken, Oslo) is expected to be more influenced by local sources, especially for the CECs that are still in use and present in materials and products. This station will enable us to compare the atmospheric concentrations of environmental contaminants in background areas with concentrations in an urban area.

The number of observatories and the geographical distribution of the background stations have been selected to represent different parts of Norway, as well as locations which receives air masses from different source regions globally. The observatories included in this monitoring programme are to a large extent coordinated and thereby the same observatories as those within the national monitoring programme for "*long-range transboundary air pollutants",* which like this monitoring programme, is conducted by NILU on behalf of the Norwegian Environment Agency (Aas et al., 2023). Two observatories are currently used for the monitoring of POPs, CECs and heavy metals in background air;

one is located on the mainland of Norway; -Birkenes in southern Norway, and the other is located on Svalbard, an archipelago in the Arctic Ocean; -Zeppelin (Figure 1, Table 1). The programme also covers PAHs in air at Zeppelin, while PAHs in air at Birkenes is funded internally by NILU. In 2022, HMs in air at Svanvik (eastern Finnmark in northern Norway) was included in the monitoring programme[1], with measurements funded by the Ministry of Foreign Affairs. The monitoring station at Sofienbergparken, located in the city of Oslo, is used for monitoring POPs, CECs and heavy metals in urban air. POPs in precipitation are only monitored at Birkenes, while heavy metals in precipitation is monitored at four stations; Birkenes, Hurdal, Kårvatn and Svanvik (Figure 1, Table 1). Further information about the sampling sites is available at: https://projects.nilu.no/ccc/sitedescriptions/

Table 1: Information about the monitoring stations and list of contaminants measured at each station in 2022.

Monitoring station	Birkenes	Zeppelin	Hurdal	Kårvatn	Svanvik	Sofienberg-parken
Station code (EBAS)	NO0001R NO0002R	NO0042G	NO0056R	NO0039R	NO0047R	NO0073U
Lat	58° 23' N	78° 54' N	60° 22' N	62° 47' N	69° 27' N	59° 55' N
Lon	08° 15' E	11° 53' E	11° 5' E	08° 53' E	30° 02' E	10° 46' E
m.a.s.l.	190/219	475	300	210	27	24
Organic contaminants - Air	HCB, HCH, DDTs, PCBs, PBDEs, HBCDDs, PAHs, PFAS (ionic + volatile), cVMS, S/MCCPs	HCB, HCH, DDTs, chlordanes, PCBs, PBDEs, HBCDDs, PAHs, PFAS (ionic + volatile), cVMS, S/MCCPs, nBFRs, OPFRs, dechloranes, volatile fluorinated and chlorinated substances				PBDEs, HBCDDs, PAHs, PFAS (ionic + volatile), cVMS, lVMS, S/MCCPs, nBFRs, OPFRs, dechloranes, PCP/PCA, UV-substances, volatile fluorinated and chlorinated substances
Organic contaminants - Precipitation	**HCB, HCHs, PCBs**					
Heavy metals - Air	**Al, As, Cd, Cr, Co, Cu, Pb, Fe, Mn, Ni, V, Ti, Zn, Hg**	**Al, As, Cd, Cr, Co, Cu, Pb, Fe, Mn, Ni, V, Ti, Zn, Hg + Hg-species**			**Al, As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, Ti, V, Zn**	**As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn, Ag, Hg**
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**	

[1] Previously this report also included results from "The Norway-Russia measurement programme", covering heavy metals in air and precipitation at Karpdalen in eastern Finnmark. The smelter in Nikel (Russia) ceased operation in December 2020. In 2022, the monitoring station in Karpdalen was closed, and the monitoring of heavy metals was moved to Svanvik and included in the present programme "Atmospheric contaminants".

Figure 1: Norwegian background stations measuring environmental contaminants in 2022.

Air measurements of heavy metals and POPs started in 1991 at Lista observatory in southern Norway as part of a government programme on environmental monitoring and were reported to the Comprehensive Atmospheric Monitoring Programme (CAMP) under the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR) (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 Arctic Monitoring and Assessment Programme (AMAP) (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). From 2009-2021 a monitoring station for heavy metals and POPs was located at Andøya as part of the national Marine Pollution Monitoring Programme for the Norwegian Environment Agency (Green et al., 2011). This monitoring station is now closed.

3 Overview of sampling and analysis

Air samples for organic contaminants and heavy metals (excluding mercury) are collected using active air samplers at Birkenes, Zeppelin, Svanvik and Sofienbergparken. The number of samples per year and the sampling times are compound and site specific (i.e. 12 to 52 samples 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, analyzed and quantified at NILU under strict quality control using accredited methods (details in Annex B). For the CECs, 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. POPs, CECs and heavy metal data presented in this report are available at http://ebas.nilu.no/.

3.1 Organic contaminants

The monitoring programme for 2022 included eight regulated classes of organic contaminants and one individually regulated compound (Table 2). All of these, except PAHs, are classified as POPs according to the Stockholm Convention. Most of the regulated organic contaminants are measured once per week at Birkenes and Zeppelin with some exceptions. Since 2017, the measurements of HCHs and DDTs at Birkenes have been done once per month. Air samples for the ionic PFAS (iPFAS) at both Birkenes and Zeppelin have been collected two times per month (every second week) since 2017. The two samples are combined in the lab to give an aggregated monthly concentration. Combining two samples in the lab improves the detection of compounds, which otherwise may have been below detection limit. While air samples for PBDEs are collected weekly at Zeppelin, air samples for PBDEs have been collected two times per month at Birkenes since 2017. HBCDDs are measured together with PBDEs. For Birkenes, the two samples are combined in the lab and measured for both PBDEs and HBCDDs (i.e. monthly aggregated concentration). For Zeppelin, HBCDDs are measured together with PBDEs every second week. For Sofienbergparken, air samples for PBDEs, HBCDDs and iPFAS are collected once per month.

Data from the air measurements are presented as bulk concentrations (i.e. sum of gas- and particle phase) for most of the regulated compounds (Table 2). Exceptions are the ionic PFAS which are covering only the particle phase.

Table 2: Monitoring programme for regulated organic contaminants (e.g. POPs) in 2022.

		Sofienbergparken		Birkenes		Zeppelin	
POP class/ compound	**Matrix**	**Start year**	**Sampling frequency**	**Start year**	**Sampling frequency**	**Start year**	**Sampling frequency**
HCB - air	Gas+particle phase			1993	weekly	1993	weekly
HCB - precipitation	Precipitation			1992	weekly	-	-
HCHs	Gas+particle phase			1991	monthly*	1993	weekly
HCHs - precipitation	Precipitation			1992	weekly	-	-
DDTs	Gas+particle phase			2010	monthly*	1994	weekly

		Sofienbergparken		Birkenes		Zeppelin	
POP class/ compound	**Matrix**	**Start year**	**Sampling frequency**	**Start year**	**Sampling frequency**	**Start year**	**Sampling frequency**
Chlordanes	Gas+particle phase			2010-2016**	-	1993	weekly
PCBs	Gas+particle phase			2004	weekly	2001***	weekly
PCB_7 - precipitation	Precipitation			2006	weekly	-	-
PBDEs	Gas+particle phase	2022	monthly	2008	monthly*	2006	weekly
HBCDDs	Gas+particle phase	2022	monthly	2006	monthly*	2006	monthly*
PAHs	Gas+particle phase			2009	weekly	1994	weekly
iPFAS**	Particle phase	2022	monthly	2006	monthly*	2006	monthly*

*Sampling frequency since 2017
**Not included in the new monitoring programme from 2017.
***Data available before 2001 are classified as uncertain due to possible local contamination.
**** Only PFHxS, PFOS and PFOA are internationally regulated

Organic contaminants that are not yet regulated but have been identified as contaminants of emerging concern (i.e CECs) 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 (Table 3). 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. Most of the target iPFAS are non-regulated and therefore fall under the category of CECs in this monitoring programme.

Due to CECs being ubiquitous, it is important to continuously evaluate possible influences of local sources at the background monitoring stations. For example, elevated levels of some CECs have been found near Arctic settlements (Warner et al., 2010; Carlsson et al., 2018). 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.

Two of the CECs; cVMS and S/MCCPs, have been monitored in air as part of this programme since 2013 at Zeppelin, and since 2017 at Birkenes. Another three contaminant classes have been included in the monitoring programme at Zeppelin since 2017; i.e. volatile PFAS (vPFAS), novel brominated flame retardants (nBFRs), and OPFRs. Dechloranes were included at Zeppelin in 2019. In 2020, 2021 and 2022 also climate relevant volatile fluorinated and chlorinated substances were measured.

At the monitoring station in Sofienbergparken, a number of CECs have been included in addition to the CECs included in the basis programme at Zeppelin (mentioned above); i.e. extra PFAS, extra siloxanes (e.g. lVMS), extra brominated- and chlorinated flame retardants, chlorophenols and UV compounds. A complete list of all organic contaminants of emerging concern included in the monitoring programme in 2022 is given in Table 4.

For vPFAS and OPFRs at Zeppelin, 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, at Sofienbergparken, the monthly samples for vPFAS and OPFRs only consist of one sample per month.

Further details on the sampling strategies (sampling times, sampler type, adsorbents etc.) are given in Annex B.

Table 3: Organic contaminants of emerging concern included in the monitoring programme "Long-range transported atmospheric contaminants" in 2022, year of first monitoring, sampling frequency and sample matrix at the different observatories.

		Zeppelin		Birkenes		Sofienbergparken	
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	2022	monthly
cVMS	Gas phase	2013	weekly*	2017	monthly	2022	monthly
lVMS	Gas phase	2021	campaign			2022	monthly
vPFAS	Gas phase	2017	monthly**	2017	Monthly**	2022	monthly
Other iPFAS	Particle phase	2021	monthly**			2022	monthly
nBFRs	Gas+particle phase	2017	monthly**			2022	monthly
Other brominated and chlorinated FR	Gas+particle phase					2022	monthly
OPFRs	Gas+particle phase	2017	monthly**			2022	monthly
Dechloranes	Gas+particle phase	2019	monthly			2022	monthly
Volatile fluorinated and chlorinated substances	Gas phase	2020	campaign			2022	monthly
Chlorophenols and UV substances	Gas+particle phase					2022	monthly

*New sampling frequency from 2017.
**Two samples per months

Table 4: Full names and abbreviations of the organic contaminants of emerging concern included in the monitoring programme in 2022.

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	F4-Sil	429-67-4
2,4,6-trimethyl-2,4,6-tris(3,3,3-trifluoropropyl)cyclotrisiloxane	F3-Sil	2374-14-3
Heptamethylphenylcyclotetra-siloxane	Ph-D4	10448-09-6
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
Perfluorohexadecanoic acid	PFHxDA	67905-19-5
Perfluorooctadecanoic acid	PFOcDA	16517-11-6
Pentafluoropropanoic acid	PFPA	422-64-0
Perfluoropropane-1-sulfonic acid	PFPrS	423-41-6
Trifluoroacetic acid	TFA	76-05-1
Perfluoro-3,7-dimethyloctanoic acid	PF-3,7-DMOA	172155-07-6
Perfluorooctane sulfonamidoacetic acid	FOSAA	2806-24-8

Full name	Abbreviation	CAS
N-Methyl Perfluorooctane sulfonamido-acetic acid	MeFOSAA	2355-31-9
N-Methylperfluorooctanesulfonamidoethyl acrylate	N-MeFOSEA	25268-77-3
N-ethyl-N-[(heptadecafluorooctyl)-sulfonyl]glycine	EtFOSAA	2991-50-6
Perfluorobutane sulfonamide	FBSA	30334-69-1
N-Methyl perfluorobutane-sulfonamide	MeFBSA	68298-12-4
N-Ethylperfluorobutane-sulfonamide	EtFBSA	40630-67-9
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
ß-Tetrabromoethylcyclohexane	ß-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
Tetrabromo-p-xylene	pTBX	23488-38-2
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
Other nBFRs		
2,2-dimethylpropan-1-ol, tribromo derivative		36483-57-5
2,3,4,5-Tetrabromo-6-chlorotoluene	TBCT	39569-21-6
2,3,5,6-Tetrabromo-p-xylene		23488-38-2
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

Full name	Abbreviation	CAS
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
Tris(4-tert-butylphenyl)phosphate	TTBPP	78-33-1
Tris(2,3-dibromopropyl) phosphate	TDBPP	126-72-7
Tris(2-bromo-4-methylphenyl) phosphate	T2B4MP	871320-61-5
Tris(4-bromo-3-methylphenyl) phosphate	T4B3MP	127580-00-1
Tris(3-bromo-4-methylphenyl) phosphate	T3B4MP	35656-01-0
2,2-bis(chloromethyl_propane-1,3-diyl tetrakis(2-chloroethyl)bis(phosphate)	V6	38051-10-4
Dechloranes and other chlorinated FRs		
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
Chlorendic anhydride		115-27-5
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

Full name	Abbreviation	CAS
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
HexaChlorobicyclobutane	HCBcB	-
PCP and PCA		
Pentachlorophenol	PCP	87-86-5
Pentachloroanisole	PCA	1825-21-4
UV - substances		
2-Ethylhexyl-3-methoxycinnamate		
octocrilene	Parsol 340	6197-30-4
2-(2H-benzotriazol-2-yl)-4-(1,1,3,3-tetramethylbutyl)phenol	Octrizole	3147-75-9
2-(2H-benzotriazol-2-yl)-4,6-ditertpentylphenol	UV-328	25973-55-1
N-Cyclohexyl-2-benzothiazolesulfenamide		95-33-0
methyl-1H-benzotriazole	Tolyltriazole	29385-43-1
oxybenzone		131-57-7
Phenol, 2-(2H-benzotriazol-2-yl)-4,6-bis(1,1-dimethylethyl)-	UV-320	3846-71-7
Phenol, 2-(5-chloro-2H-benzotriazol-2-yl)-4,6-bis(1,1-dimethylethyl)-	UV-327	3864-99-1
Bumetrizole	UV-326	3896-11-5

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

3.2 Heavy metals and mercury

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

The Minamata Convention entered into force in 2017. To support the evaluation of the effectiveness of the Minamata Convention, Norwegian monitoring follows the Guidance on monitoring of mercury and mercury compounds (UNEP, 2021) in order to maintain harmonized and comparable information on mercury levels in the environment. Therefore, 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. The same year, Hg speciation measurements were included at Zeppelin, on behalf of the Norwegian Environment Agency. The data series however dates back to 2007, when the Norwegian University of Science and Technology (NTNU) started to monitor Hg species at Zeppelin. Data obtained by NTNU are published in Platt et al. (2022) and references therein, and data are available at http://ebas.nilu.no/. 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 requires an estimation of the influence of different regulatory measures to the observed mercury concentrations.

Table 5: Monitoring of heavy metals in 2022.

	Matrix	Birkenes	Zeppelin	Hurdal	Kårvatn	Svanvik	Sofienberg parken
Heavy metals - air	Particle phase	weekly	weekly	-	-	weekly	monthly
Heavy metals - precipitation	Precipi-tation	weekly	-	weekly	weekly	weekly	-
Hg - air	Gas phase	continuously	continuously	-	-	-	continuously
Hg species - air	Gas and particles	-	semi-continuously				-
Hg - precipitation	Precipi-tation	weekly	-	weekly	weekly	-	-

4 Key findings

4.1 Measured concentrations and spatial variability

4.1.1 Organic contaminants

In 2022, the concentrations of the organic contaminants ranged over eight orders of magnitude, from below the method detection limits (<MDL) of 0.001 pg/m^3 to detected concentrations of several hundred thousand pg/m^3. At all stations, the highest concentrations were found for the cyclic- and linear volatile methyl siloxanes (cVMS/lVMS), the climate relevant volatile fluorinated and chlorinated substances (vol. F+Cl substances), some polycyclic aromatic hydrocarbons (PAHs) and short chain chlorinated paraffins (SCCPs) (see Figure 2 below and Appendix A for details). The lowest concentrations and lowest detection frequencies[2] were generally found for the regulated compounds, including hexabromocyclododecane (HBCDD), the polybrominated diphenyl ethers (PBDEs), chlordanes (CHL), DDTs, polychlorinated biphenyls (PCBs) and hexachlorcyclohexanes (HCHs).

All concentrations of the organic contaminants measured in Sofienbergparken, located in Oslo, were higher than the concentrations measured at the two background stations, except for the vol. F+Cl substances that were found in the same concentrations at both Sofienbergparken and Zepplin. The largest differences in concentrations between Sofienbergparken and Zeppelin, in the Arctic, were found for cVMS, nBFRs and CPs (Figure 2). This may suggest that there are existing sources of these contaminants in urban environments. Furthermore, the concentrations of cVMS, CPs and the regulated compounds (not measured at Sofienbergparken); PAHs, DDTs, and HCHs, were significantly higher at the background station at Birkenes, located in southern Norway, than at Zeppelin. The higher concentrations likely reflect that Birkenes may be more influenced by long-range transport from source regions in central and eastern Europe, than Zeppelin (Lunder Halvorsen et al. 2021). In contrast, the concentrations of HCB, PBDEs and HBCDD were higher at Zeppelin than at Birkenes.

a)

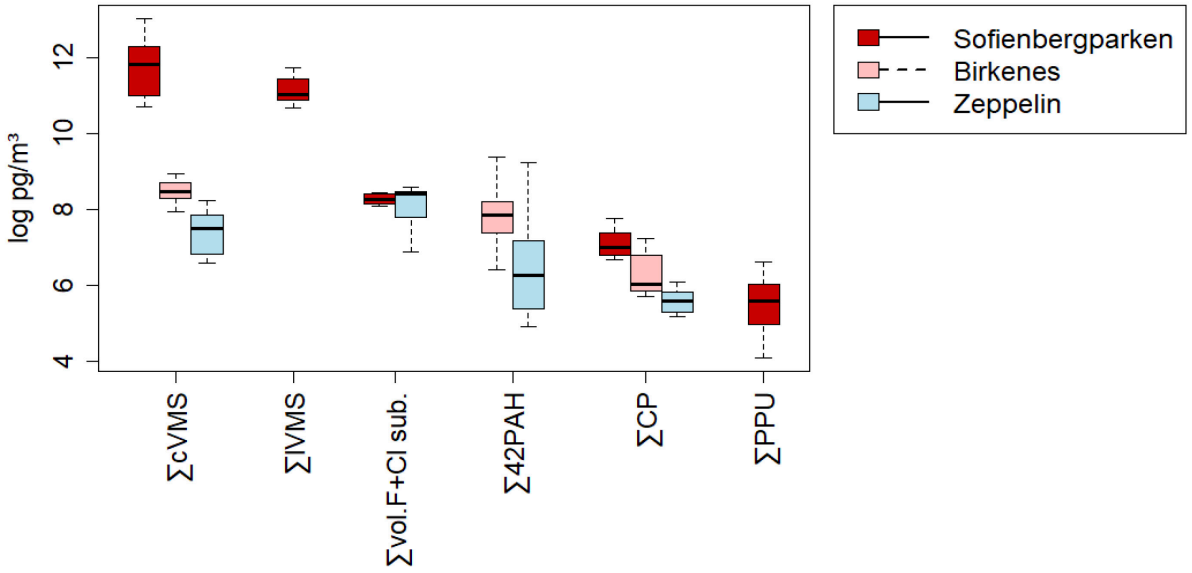
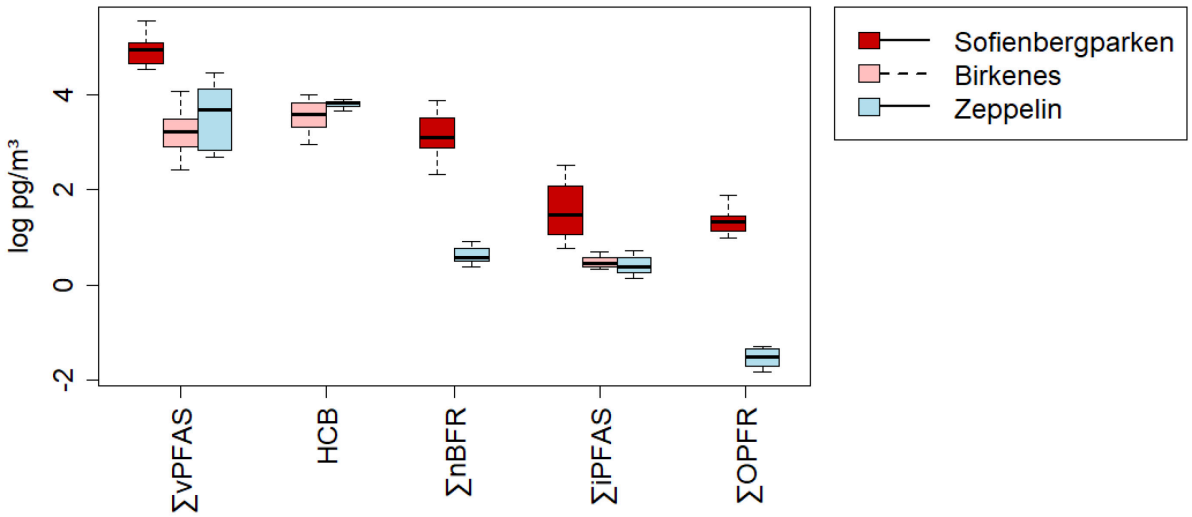


Figure 2a: Boxplot of the highest measured concentrations of the organic compound groups in air at the respective monitoring station in 2022. The boxes represent the range from 25 to 75 percentile with the center line representing the median value. The bars represent the 1 and 99 percentiles.

[2] Detection Frequency (DF) is the fraction of samples in percent higher than the method detection limits (MDL).

b)



c)

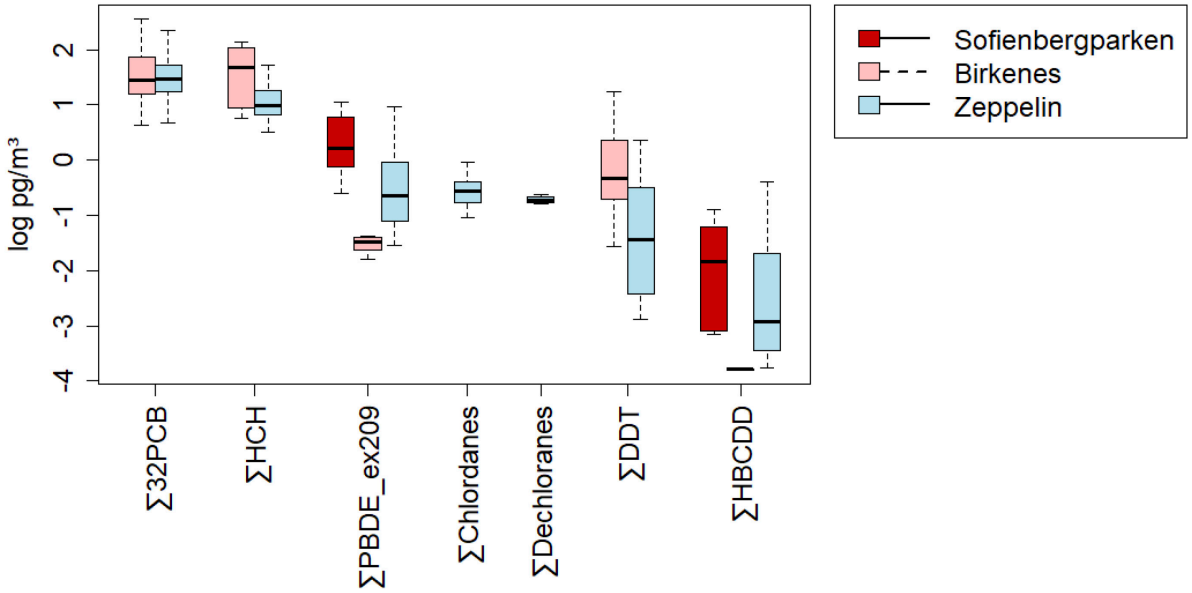


Figure 2b-c: Boxplot of measured concentrations of the targeted organic compound groups in air at the respective monitoring station in 2022. The medium concentrations are presented in the upper figure (b) and the lowest concentrations in the lower figure (c). The boxes represent the range from 25 to 75 percentile with the center line representing the median value. The bars represent the 1 and 99 percentiles.

Siloxanes

The median concentration of sum cVMS at Sofienbergparken was more than a factor of 100 higher than at Zeppelin. In comparison, the median concentration of sum cVMS at Birkenes were only four times higher than Zeppelin, which may suggest less influence from sources of cVMS at Birkenes, compared to Sofienbergparken. At both Sofienbergparken and Birkenes, the highest concentrations of cVMS were measured for D5, followed by D4 and D6. At Zeppelin, D4 was found in highest concentrations (Figure 3). Noticeably, the detection frequency of D4, D5 and D6 at Zeppelin were low compared to 2021 due to higher MDLs in 2022. The three linear siloxanes L3, L4 and L5 and M3T(Ph) measured additionally to the cVMS at Sofienbergparken, were detected in all samples, individually ranging between 4800-68 000 pg/m^3. Interestingly, the median concentration of L4 (15 100 pg/m^3) were in the same range as the cVMS; D4 (11 600 pg/m^3) (Figure 3). This contrasts with the results reported from Zeppelin in 2021, where the concentration of L4 (32 pg/m^3) was more than an order of magnitude lower than D4 (400 pg/m^3). Siloxanes are in uncertainty category 3 (Appendix B4) and more data is needed to elucidate the results for lVMS at Sofienbergparken. Also, introducing authentic internal standards in future measurements of lVMS may assure the reliability of e.g. L4.

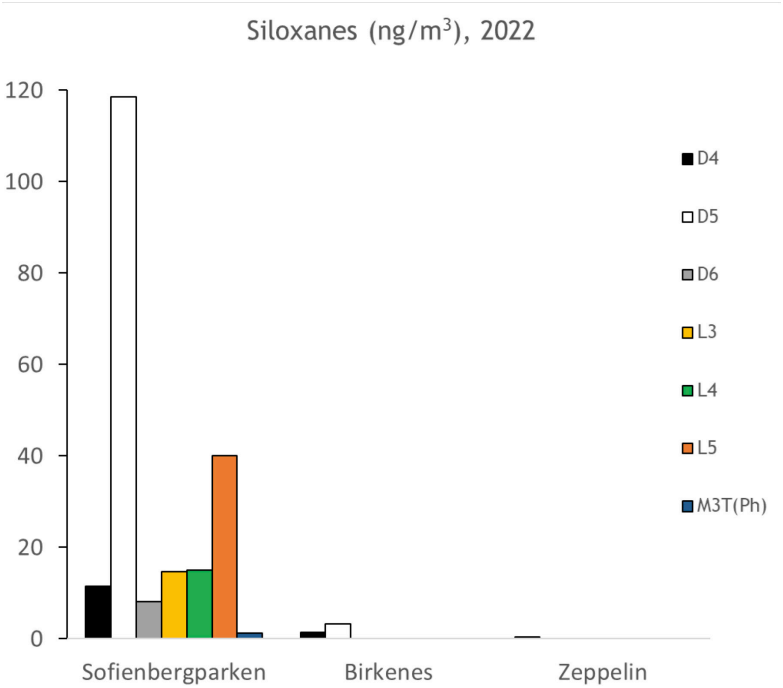


Figure 3: Annual median concentrations of detected siloxanes in air (ng/m^3) at Sofienbergparken, Birkenes and Zeppelin in 2022. The median concentrations for the cyclic oligomers D4-D6 are based on weekly samples at Zeppelin and monthly samples at Birkenes and Sofienbergparken. Linear oligomers L3-L5 and M3T(Ph) were only measured at Sofienbergparken.

Volatile fluorinated and chlorinated substances

The median of sum vol. F+Cl substances from Sofienbergparken was similar to the median at Zeppelin. This is, in contrast to the other organic contaminants measured at both stations. Nine of the volatile fluorinated and chlorinated substances were detected in more than 70% of the samples from both Zeppelin and Sofienbergparken. The highest concentrations were measured for PFTBA and HCBD at both stations (Figure 4), at concentrations larger than 1500 pg/m^3. At Zeppelin, the median concentrations of PFTBA and HCBD were comparable to the concentrations in 2021 (2000 pg/m^3 and 1700 pg/m^3 respectively). The concentrations of HCcBen (a tentatively identified suspected transformation product of HCBD) and PFTPeA were also relatively high and similar at both stations.

However, the median concentration of TCPFB was significantly higher at Zeppelin (261 pg/m^3), than at Sofienbergparken (25 pg/m^3).

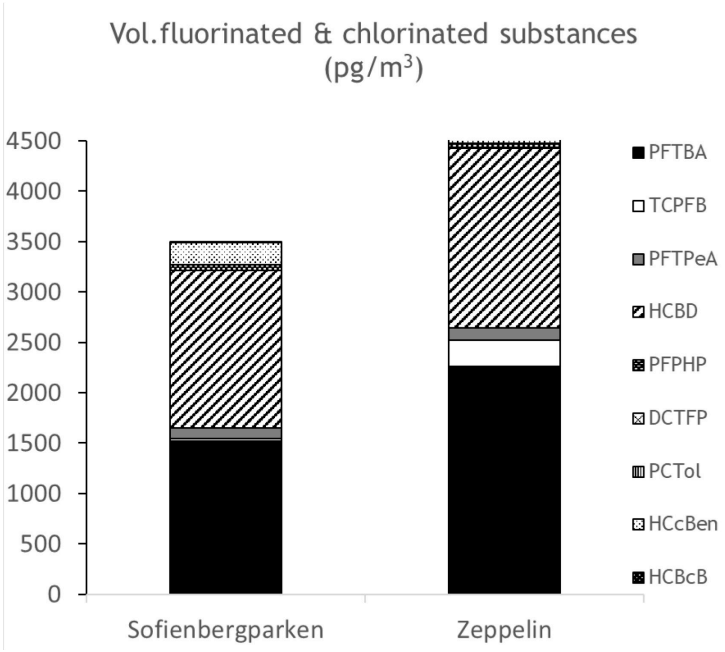


Figure 4: Annual median concentrations of the detected volatile fluorinated and chlorinated substances in air (pg/m^3) at Sofienbergparken and Zeppelin in 2022. The annual median concentration at Zeppelin is based on weekly samples, while Sofienbergparken is based on monthly samples.

Chlorinated paraffins

The median concentration of sum CPs at Sofienbergparken was a factor of four higher than at Zeppelin (Figure 2a). SCCP was found at higher concentrations than MCCPs at all three sites. While medium-chain chlorinated paraffins (MCCP) was detected in all samples at Sofienbergparken, the detection frequency of MCCP at Birkenes and Zeppelin were low. There are some uncertainties associated with the quantification of CPs (category 3, Appendix B4) due to the thousands of structurally similar isomers which are impossible to separate in the instrumental analysis. However, this should not affect comparability of results between the monitoring stations. Blank contamination is another source of uncertainty for CPs, but lower, less variable blank levels has led to lower MDLs for CPs in 2022 compared to 2021.

PCA and UV compounds

Air samples for PCA, PCP and UV compounds were originally collected at Sofienbergparken using filter/PUF/XAD/PUF sandwich (Appendix B3). However, due to matrix interferences, it was not possible to obtain results from these air extracts. Instead, PCA and UV compounds (except tolyltriazole) were measured on the same extract as HCBD (i.e. from ABN). This approach gives us uncertainties related to particle bound PCA and UV compounds as the amount of particles collected with ABN is smaller and less consistent than collection of particles on a separate filter. Internal standards are also lacking in the determination, and all data is therefore classified in uncertainty category 3.

Pentachloroanisole (PCA) was detected in all samples from Sofienbergparken (median 9.2 pg/m^3). Also, five of the UV compounds (i.e. UV-326, UV-328, 2-ethylhexyl-4-metoxy-cinnamate, octocrylene and oxybenzone) were detected in all samples. The highest concentrations were measured for octocrylene

(median 162 pg/m^3), which is found in sunscreens, and the levels were elevated during July-August (396-1049 pg/m^3). UV-328, recently approved for listing as POP under Stockholm Convention, was found in concentrations from 2 to 41 pg/m^3.

Flame retardants

The concentrations of PBDEs were higher at Sofienbergparken, compared to the background stations. As with previous years, the concentrations of sum PBDEs at Zeppelin were higher than at Birkenes. It should be noted that the numbers of BDEs included in the sum has increased from 17 BDEs in 2021, to 26 BDEs in 2022. Similar to previous years, BDE-209 was measured in much higher concentrations than the other BDEs and was excluded from the sum in Figure 2c. After BDE-209, BDE-47 is measured at highest concentrations at all sites. The blank contribution of BDE-209 is significant and BDE-209 is therefore the only PBDE in uncertainty category 3 (Appendix B4).

The concentrations of HCBDD measured at Zeppelin were also higher compared to Birkenes. An elevated field blank at the Zeppelin station suggested that local influence of HBCDD may be possible, and further investigations are therefore needed to explain the higher concentrations at Zeppelin.

Of the nBFRs (Table 2.4), 12 out of 15 was detected in more than 50% of the samples from Sofienbergparken, while only three (PBT, PBBZ and HBB) were detected in more than 50% of the samples from Zeppelin. At Sofienbergparken, a-TBECH, HBB and PBT were detected in highest concentrations. Furthermore, the concentrations of HBB and PBT were approximately 10-100 times higher at Sofienbergparken than at Zeppelin. DBDPE is measured in the same concentration range as a-TBECH. However, as for previous years, the concentrations of DBDPE are uncertain (category 3, Appendix B4) due to high influence by contamination. Furthermore, two of the additional nBFRs (2,2-dimethylpropan-1-ol, tribromo derivative and 2,3,5,6-Tetrabromo-p-xylene), included in the monitoring at Sofienbergparken only, were detected in 93% of the samples, at median concentrations 0.3 pg/m^3 and 0.2 pg/m^3, respectively.

Of the chlorinated FRs, only syn-DP and anti-DP were detected at Sofienbergparken and Zeppelin, with higher detection frequency and concentrations at Sofienbergparken than at Zeppelin.

Of the 16 OPFRs included in the basis programme (Table 2.4), seven OPFRs were detected in more than 50% of the samples from Sofienbergparken, with the highest concentration found for TCPP (2.4-5.7 pg/m^3). In comparison, five were detected in more than 50% of the samples from Zeppelin with concentrations close to MDL. Apparently, none of the five additional compounds investigated at Sofienbergparken were detected. However, while TDBPP and V6 are lacking internal standards and there is an uncertainty related to their detection (category 3, Appendix B4), no quantification standards are available to be purchased for T2B4MP, T2B3MP and T3B4MP. For these three latter compounds, it is only possible to investigate the m/z and a new uncertainty category was therefore introduced in this report (category 4).

PFAS

For both the volatile PFAS (vPFAS) and ionic PFAS (iPFAS), the median concentrations were higher at Sofienbergparken than both Birkenes and Zeppelin (Figure 5). Of the vPFAS, 6:2, 8:2, 10:2 and 12:2 FTOH were detected in all or most of the samples at all three sites. Furthermore, two of the additional volatile PFAS (FBSA and N-MeFBSA), included in the monitoring at Sofienbergparken only, were detected in all samples, at median concentrations of 0.33 pg/m^3 and 1.08 pg/m^3 respectively.

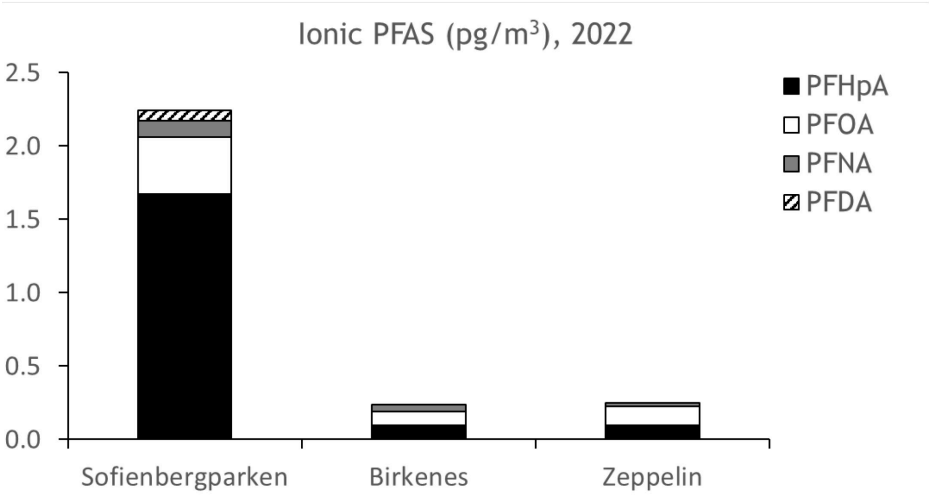
iPFAS, PFHpA, PFOA and PFNA were all detected at Sofienbergparken, Birkenes and Zeppelin. PFDA was detected additionally at Sofienbergparken. No other perfluorocarboxylic acids (PFCAs) were observed at any station (despite C_4 – C_{14} acids being targeted). This is in contrast to a recently drilled ice core on Svalbard, which reported continuous detection of C_2 – C_{11} PFCAs, with increasing atmospheric deposition towards shorter chain lengths (Hartz et al. 2023). TFA (the C_2 PFCA) was measured for the first time at Sofienbergparken. It had a high detection frequency (83%) in the particulate phase. However, it is likely that the TFA concentrations in air are underestimated, as it is expected to reside primarily in the gas phase (after atmospheric formation from CFC replacement products). No perfluorosulfonic acids (PFSAs) were observed at any station.

PAHs

The median sum 42PAHs was approximately five times higher at Birkenes than at Zeppelin. At Zeppelin, dibenzofuran, naphthalene, and biphenyl were found in highest concentrations (medians 0.125, 0.096 and 0.075 ng/m^3 respectively), constituting in total 40% of the median sum 42PAH concentration. At Birkenes, in Southern Norway, phenanthrene, dibenzofuran, fluorene, fluoranthene, naphthalene, pyrene and biphenyl (individually ranging between 0.01-3.8 ng/m^3).

HCB

In contrast to the other regulated organic contaminants, the median concentration of HCB on the other hand, was 25% higher at Zeppelin than at Birkenes. Higher concentrations at Zeppelin compared to Birkenes were also observed in 2021 and in our previous study of passive air samples across Norway (Lunder Halvorsen et al. 2021). Enhanced re-emissions from previously contaminated surface reservoirs (Ma et al., 2011) and increasing primary emissions have been put forward as possible explanations (Platt et al., 2022).



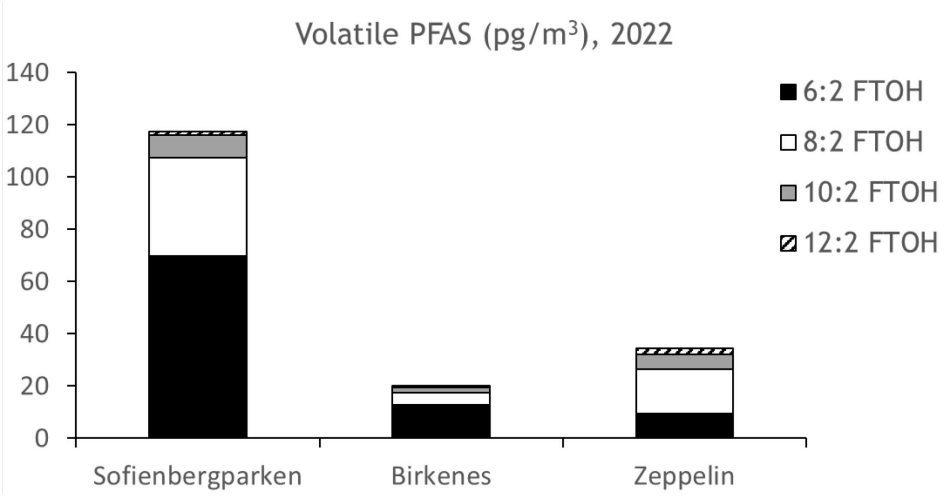


Figure 5: Annual median concentrations of detected ionic and volatile PFAS in air (pg/m³) at Sofienbergparken, Birkenes and Zeppelin in 2022, ionic PFAS for particle phase only and volatile PFAS for gas phase only. The annual median concentrations for Birkenes and Zeppelin are based on two samples per month that give an aggregated monthly concentration, while Sofienbergparken is based on monthly sampling.

4.1.2 Heavy metals and mercury

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, Cu, V and Hg are highest at Birkenes and Hurdal followed by Kårvatn reflecting the decreasing distances to the main emission sources in continental Europe (EMEP, 2021). Elevated concentrations and deposition levels are also observed at Svanvik in eastern Finnmark, in particular for Ni, V, Cr, Cu and Co. 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). The smelter in Nikel closed down in December 2020, but there is still production at the briquetting facility in Zapolyarny (Berglen et al. 2022). However, very little is known about the emissions from Zapolyarny and there is no contact with our former Russian colleagues. The results from Svanvik in 2022 are in line with 2021 and show a 2 to 10-fold decrease in HM in precipitation compared to 2020 when the smelters in Nikel were still in operation (Bohlin-Nizzetto et al., 2021).

For HMs in air, the concentrations are mostly comparable to 2021 and well below the air quality criteria for metals as set by NIPH (National Institute for Public Health), which also applies to the new urban background site Sofienbergparken.

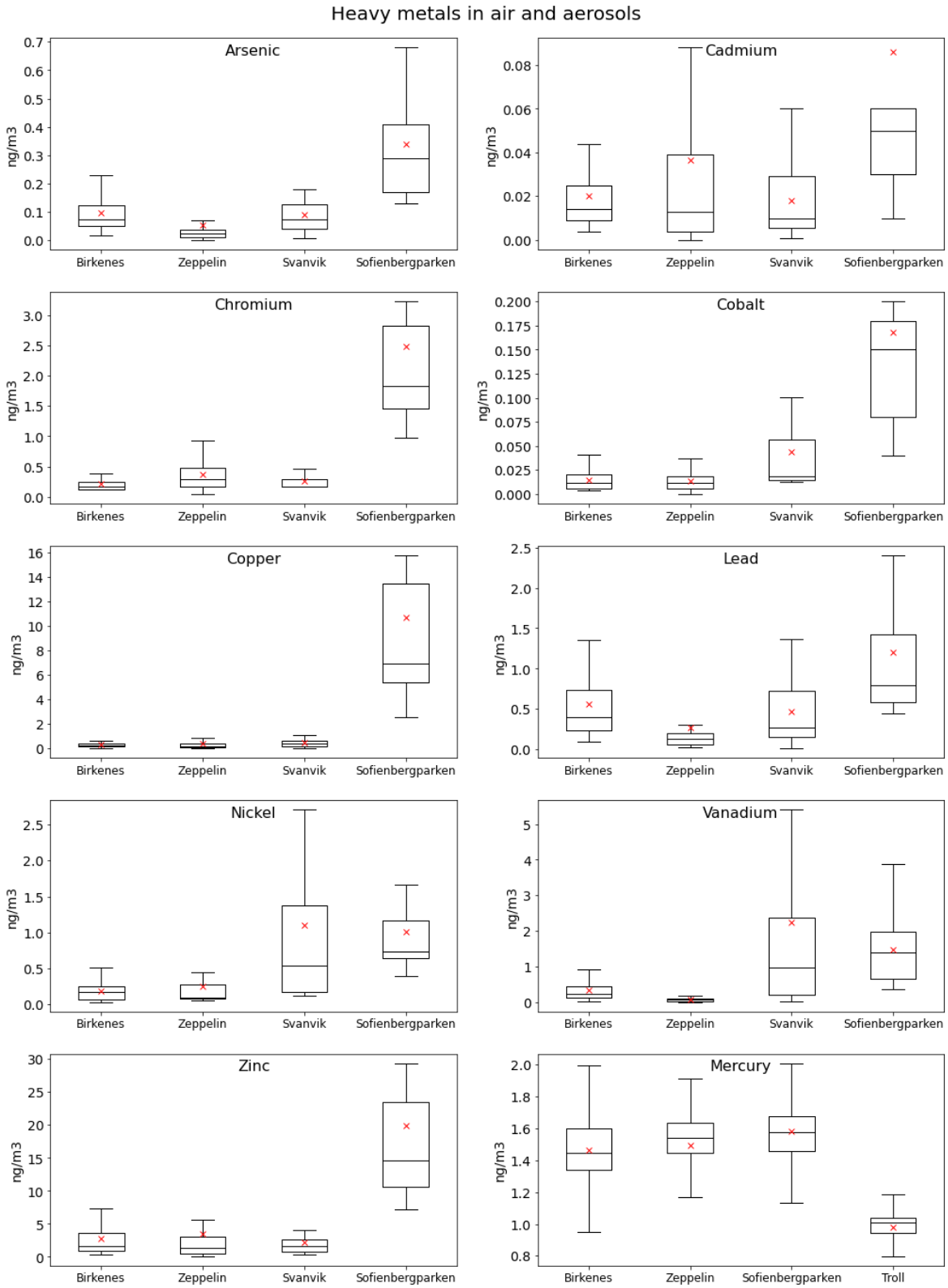
Overall, the lowest HM concentrations in air are measured at Zeppelin in the Arctic, while the highest concentrations for all HM's were observed at the new urban station in Sofienbergparken in Oslo. Birkenes experiences higher concentrations than Zeppelin, because Birkenes is closer to the emission sources at the European continent (EMEP, 2020), while in Sofienbergparken local sources, such as non-exhaust emissions from vehicles, road dust and wood burning, contribute considerably to the concentrations observed. Historically, and similar to the reported HM levels in precipitation, the concentrations in air samples at Svanvik were about ten times higher than those observed at Birkenes depending on element (Berglen et al., 2022). 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 2022 the concentrations are almost at the same level as at Birkenes (Figure 6). The annual mean

concentration of gaseous elemental mercury (GEM) is similar at Zeppelin, Birkenes and Sofienberparken, and at the same level as the northern hemispheric mean concentration (Sprovieri et al., 2016), while the concentration is lower at the Norwegian monitoring station Trollhaugen in Antarctica (Table A.4).

Mercury species (GOM and PHg) measured at Zeppelin in 2022 are higher than 2021 (Figure 7). This is because in 2021, only data from July-December were included, whereas in 2022 measurements were maintained the whole year. In spring, the concentration variability for mercury species is high, with concentrations ranging from below detection limit up to almost 300 pg/m^3.

Table 6: 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).

Compound	Forurensings-forskriften, kap 7, ng/m^3	FHIs luftkvalitets kriterier ng/m^3	Birkenes	Zeppelin	Svanvik	Sofienberg parken
			ng/m^3	ng/m^3	ng/m^3	ng/m^3
Al	n.a.	n.a.	22.6	57.6	35.6	n.a.
As	6	2	0.098	0.054	0.089	0.335
Cd	5	2.5	0.021	0.036	0.018	0.091
Cr	n.a.	n.a.	0.184	0.354	0.196	2.48
Co	n.a.	n.a.	0.014	0.013	0.040	0.162
Cu	n.a.	n.a.	0.307	0.367	0.452	11.0
Fe	n.a.	n.a.	22.9	22.4	38.1	n.a.
Pb	500	100	0.562	0.254	0.463	1.18
Mn	n.a.	150	0.712	0.775	0.672	10.6
Ni	20	10	0.181	0.189	1.089	0.980
Ag	n.a.	n.a.	n.a.	n.a.	n.a.	0.0136
Ti	n.a.	n.a.	1.41	1.86	1.99	n.a.
V	n.a.	200	0.326	0.074	2.25	1.40
Zn	n.a.	n.a.	2.85	3.39	2.22	20.1
Hg	n.a.	200	1.47	1.49	n.a.	1.58


Heavy metals in air and aerosols
Arsenic
Cadmium
Chromium
Cobalt
Copper
Lead
Nickel
Vanadium
Zinc
Mercury
ng/m3
Birkenes
Zeppelin
Svanvik
Sofienbergparken
Troll

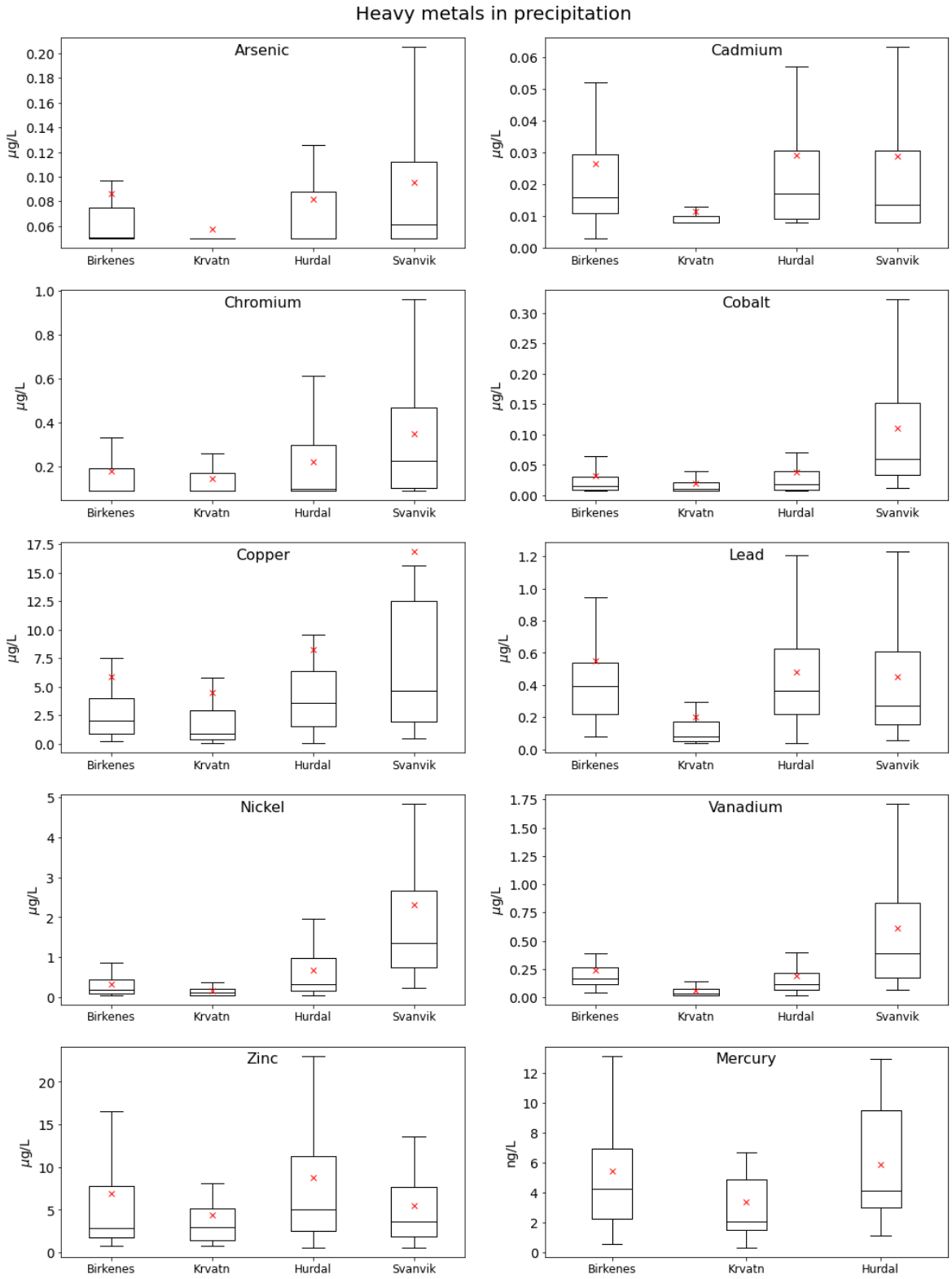


Figure 6: Box plots of measured concentrations of selected heavy metals in precipitation and aerosols in 2022. The box represents the 50th, 25th, and 75th percentiles and the whiskers lie within the 1.5 inter-quartile ranges of the weekly observations.

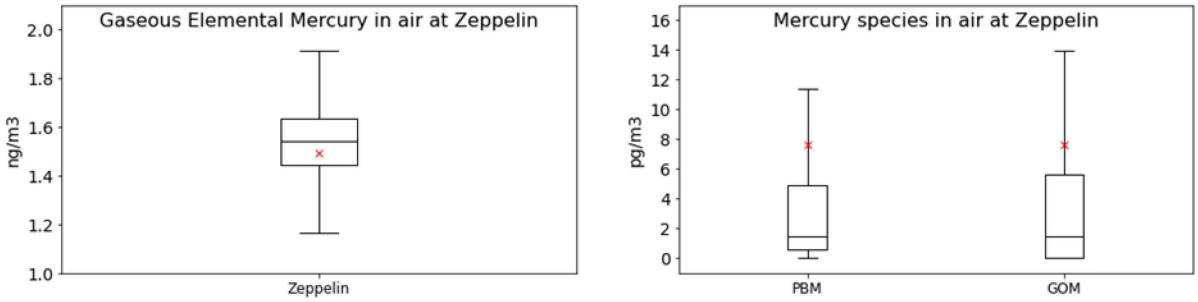
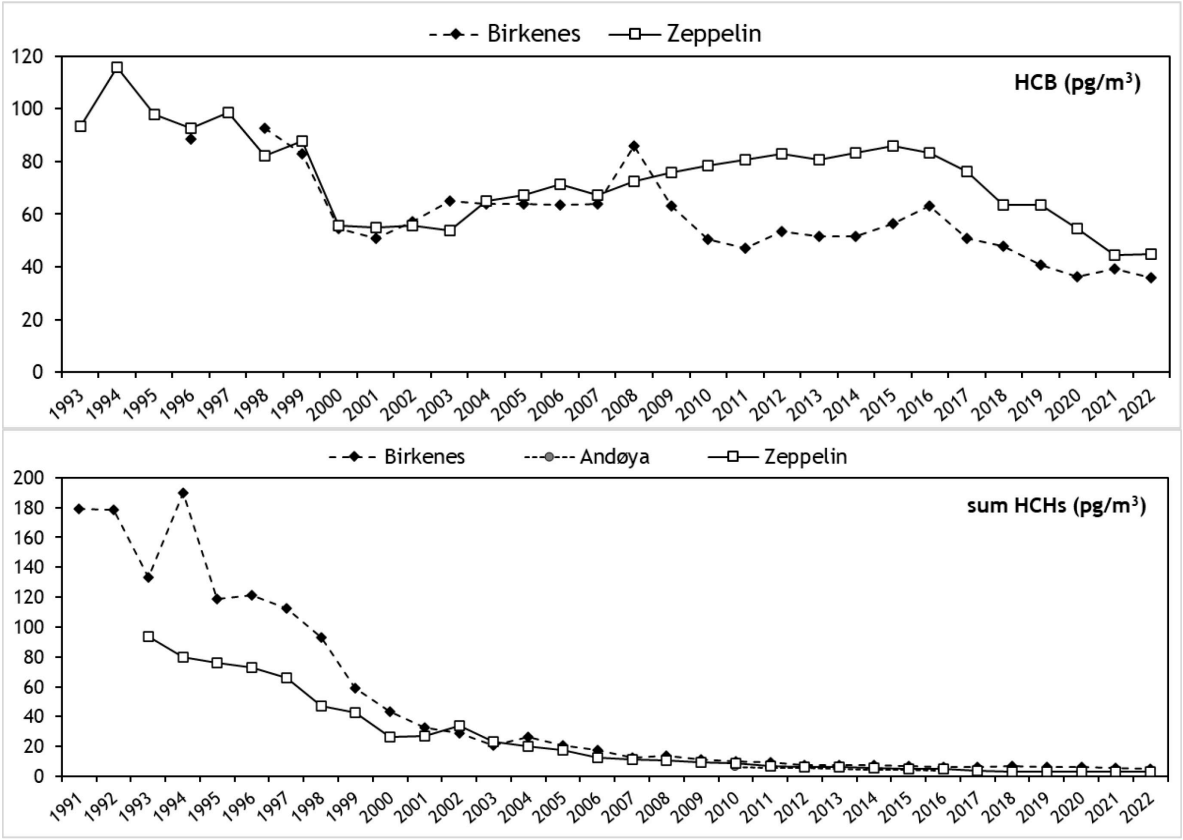


Figure 7: Box plots of Hg species measured in air at Zeppelin in 2022. The box represents the range from 25 to 75 percentile with the center line representing the median value. The bars represent the 10 and 90 percentiles, while the red cross represents the mean value.

4.2 Time-trends from long-term monitoring data

4.2.1 Organic contaminants

Most of the POPs measured in air were at similar or slightly lower concentrations in 2022 compared to 2021 (Figure 8). This is consistent with the last years of monitoring that have shown that the levels are declining or stabilizing at a low level. Small decreases in concentrations suggest that these POPs have entered a temporal remote state where the primary emissions have, to a large extent, stopped and the global concentrations now instead are controlled by emissions from secondary repositories.
For HCB at Zeppelin, no significant trend is observed for the whole monitoring period (1993-2021) due to increasing concentrations between 2003 and 2016.



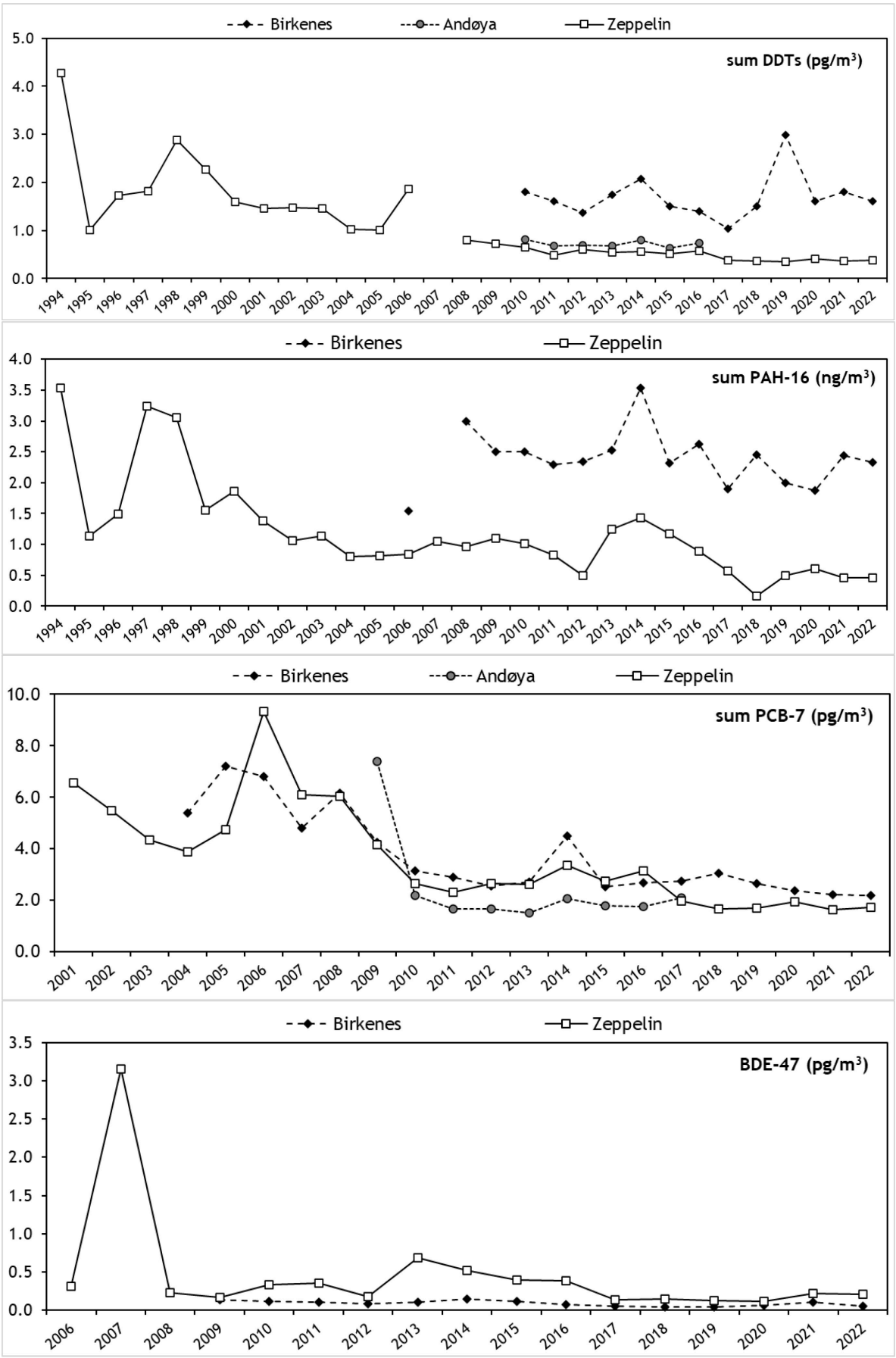


Figure 8: Time-trends of POPs measured in air.

4.2.2 Heavy metals and mercury

The monitoring show significant reduction in air concentrations for all measured HMs at Lista/Birkenes for the period 1991 to 2022, while at Zeppelin a significant reduction is observed since 1994 for some elements (As, Pb, V and Hg) (Figure 9). 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 %, which may indicate that the Ni, Zn and Cr observed at Zeppelin have sources of more local origin (Platt et al., 2022), probably originating from 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 the 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 proximity of the station to the ongoing decrease 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.

In a long-term perspective, the concentrations of most HMs in precipitation have been largely reduced (Figure 10).

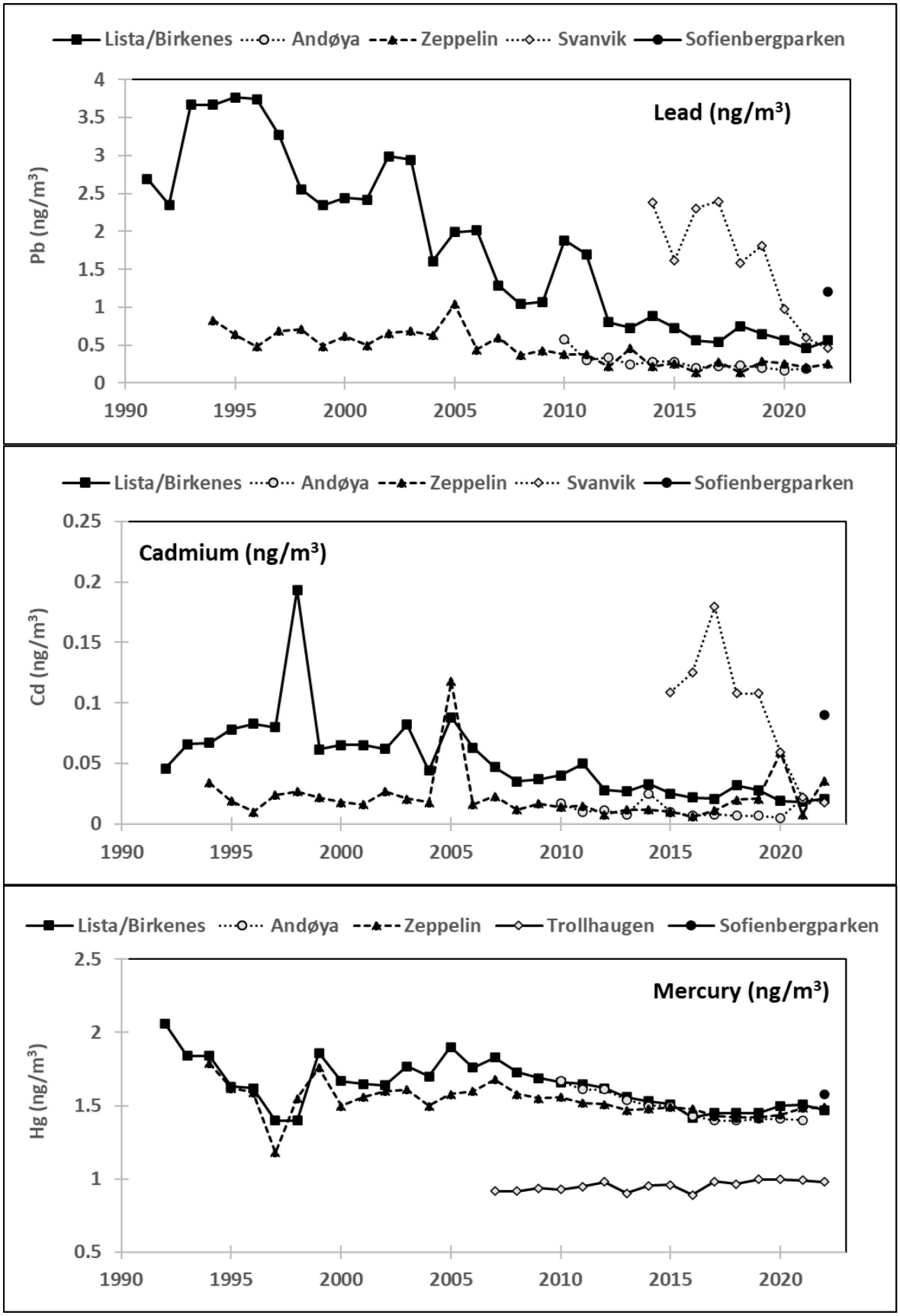


Figure 9: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2022, Unit: ng/m^3.

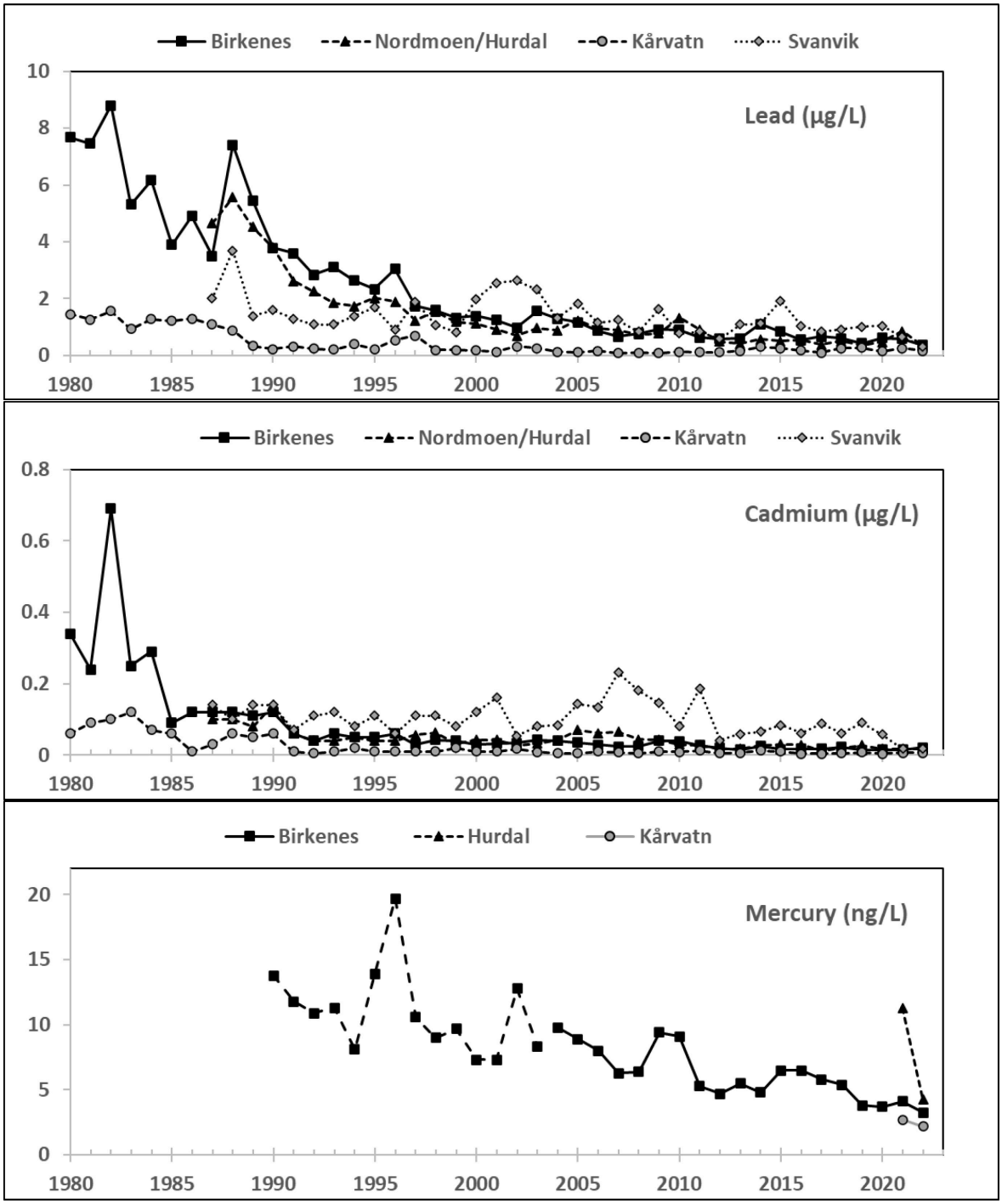


Figure 10: Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.

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Appendix A
Summary of results for individual compounds

Table A.1: Summary of measured concentrations (pg/m^3 or ng/m^3), detection frequencies (%) and method detection limits (MDL, pg/m^3 or ng/m^3) of targeted organic contaminants in air at Sofienbergparken in 2022. The colour codes indicate highest detection/concentrations in red, lowest detected concentrations in green and below MDL in white.

SOFIENBERGPARKEN – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
POPs (pg/m3) Class of uncertainty:1-3 (specification for individual compounds below)							
BDE-17[2]	Gas+particle	12	0.007	100	0.015-0.04	0.027	0.03
BDE-28[1]	Gas+particle	12	0.008	100	0.018-0.098	0.054	0.045
BDE-47[2]	Gas+particle	12	0.069	100	0.227-1.81	0.860	0.707
BDE-49[2]	Gas+particle	12	0.005	100	0.011-0.059	0.034	0.03
BDE-66[2]	Gas+particle	12	0.005	100	0.006-0.041	0.023	0.021
BDE-71[2]	Gas+particle	12	0.002	42	<0.002-0.012	0.005	<0.003
BDE-77[2]	Gas+particle	12	0.001	36	<0.001-0.003	0.002	<0.002
BDE-85[2]	Gas+particle	12	0.002	100	0.004-0.023	0.009	0.006
BDE-99[1]	Gas+particle	12	0.026	100	0.086-0.596	0.255	0.175
BDE-100[2]	Gas+particle	12	0.007	100	0.021-0.17	0.075	0.056
BDE-119[2]	Gas+particle	12	0.001	8	<0.001-0.054	0.006	<0.002
BDE-126[2]	Gas+particle	12	0.002	0	<0.002-<0.003	<0.002	<0.002
BDE-138[2]	Gas+particle	12	0.005	0	<0.005-<0.016	<0.009	<0.009
BDE-153[1]	Gas+particle	12	0.005	25	<0.005-0.023	0.011	0.011
BDE-154[2]	Gas+particle	12	0.003	91	<0.007-0.03	0.015	0.012
BDE-156[2]	Gas+particle	12	0.007	0	<0.007-<0.024	<0.015	<0.013
BDE-183[1]	Gas+particle	12	0.005	42	<0.010-0.04	0.014	0.01
BDE-184[2]	Gas+particle	12	0.002	0	<0.002-<0.005	<0.003	<0.002
BDE-190[2]	Gas+particle	12	0.004	0	<0.004-<0.014	<0.007	<0.006
BDE-191[2]	Gas+particle	12	0.004	0	<0.004-<0.009	<0.005	<0.004
BDE-196[2]	Gas+particle	12	0.007	0	<0.006-<0.014	<0.008	<0.007
BDE-197[2]	Gas+particle	12	0.006	17	<0.005-0.027	0.009	<0.006
BDE-202[2]	Gas+particle	12	0.008	0	<0.007-<0.019	<0.010	<0.009
BDE-206[2]	Gas+particle	12	0.061	0	<0.056-<0.063	<0.060	<0.061
BDE-207[2]	Gas+particle	12	0.034	8	<0.031-0.102	0.04	<0.034
BDE-209[3]	Gas+particle	12	0.508	75	<0.509-3.23	1.41	1.32
sum 17 BDE[3] (ref. 2021)		12			0.977-6.28	2.8474	2.4755
sum 26 BDE[3]		12			1.05-6.53	2.964	2.5826
sum 25 BDE (excl. 209)[2]		12			0.54-3.30	1.56	1.26
TBA[2]	Gas+particle	12	0.041	100	3.88-18.4	10.1	8.64
α-HBCDD[2]	Gas+particle	12	0.018	75	<0.018-0.376	0.114	0.098
β-HBCDD[2]	Gas+particle	12	0.007	42	<0.007-0.037	0.013	<0.007
γ-HBCDD[2]		12	0.018	50	<0.018-0.168	0.053	<0.018

SOFIENBERGPARKEN – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Ionic and volatile PFAS (pg/m3) Class of uncertainty:2							
FTS 4:2	Particle phase	12	0.073	0	<0.073-<0.073	<0.073	<0.073
FTS 6:2	Particle phase	12	1.54	0	<1.54-<1.54	<1.54	<1.54
FTS 8:2	Particle phase	12	0.036	8	<0.036-0.061	<0.036	<0.036
PFBA	Particle phase	12	0.25	0	<0.250-<0.250	<0.250	<0.250
PFPeA	Particle phase	12	0.073	42	<0.073-0.42	0.16	<0.73
PFHxA	Particle phase	12	0.145	33	<0.145-2.67	0.43	<0.145
PFHpA	Particle phase	12	0.054	92	<0.054-7.78	2.55	1.67
PFOA	Particle phase	12	0.036	100	0.15-1.14	0.45	0.39
PFNA	Particle phase	12	0.036	75	<0.036-0.3	0.12	0.11
PFDA	Particle phase	12	0.036	75	<0.036-0.25	0.1	0.076
PFUnA	Particle phase	12	0.054	42	<0.054-0.12	<0.054	<0.054
PFDoA	Particle phase	12	0.073	8	<0.073-0.1	<0.073	<0.073
PFTrA	Particle phase	12	0.145	0	<0.145-<0.145	<0.145	<0.145
PFTeA	Particle phase	12	0.036	0	<0.036-<0.036	<0.036	<0.036
PFBS	Particle phase	12	0.036	0	<0.036-<0.036	<0.036	<0.036
PFPS	Particle phase	12	0.073	0	<0.073-<0.073	<0.073	<0.073
PFHxS	Particle phase	12	0.036	0	<0.036-<0.036	<0.036	<0.036
PFHpS	Particle phase	12	0.073	0	<0.073-<0.073	<0.073	<0.073
PFOS	Particle phase	12	0.073	17	<0.073-0.15	<0.073	<0.073
PFNS	Particle phase	12	0.109	0	<0.109-<0.109	<0.109	<0.109
PFDS	Particle phase	12	0.109	0	<0.109-<0.109	<0.109	<0.109
PFUnS	Particle phase	12	0.145	0	<0.145-<0.145	<0.145	<0.145
PFDoS	Particle phase	12	0.145	0	<0.145-<0.145	<0.145	<0.145
PFTrS	Particle phase	12	0.145	0	<0.145-<0.145	<0.145	<0.145
PFTS	Particle phase	12	0.1	0	<0.100-<0.100	<0.100	<0.100
PFOSA	Particle phase	12	0.073	0	<0.073-<0.073	<0.073	<0.073
sum ionic PFAS	Particle phase	12			2.14-12.5	5.6	4.3
brPFOS	Particle phase	12			n.a-n.a	n.a.	n.a.
etFOSAA	Particle phase	12	0.74	0	<0.74-<0.74	<0.74	<0.74
PFHxDA	Particle phase	12	0.15	0	<0.15-<0.15	<0.15	<0.15
PFOcDA	Particle phase	12	0.15	0	<0.15-<0.15	<0.15	<0.15
PFPA	Particle phase	12			n.a-n.a	n.a.	n.a.
HPFHpA	Particle phase	12			n.a-n.a	n.a.	n.a.
7:3 FTCA	Particle phase	12	0.74	0	<0.74-<0.74	<0.74	<0.74
PF-3,7-DMOA	Particle phase	12			n.a-n.a	-	-
meFOSAA	Particle phase	12	0.74	0	<0.74-<0.74	<0.74	<0.74
FOSAA	Particle phase	12	0.74	0	<0.74-<0.74	<0.74	<0.74
6:2 F53B	Particle phase	12	0.74	0	<0.74-<0.74	<0.74	<0.74
F53	Particle phase	12			n.a-n.a	n.a.	n.a.
8Cl-PFOS	Particle phase	12	0.74	0	<0.74-<0.74	<0.74	<0.74
PFPrS	Particle phase	12			n.a-n.a	n.a.	n.a.
TFA	Particle phase	12	0.5	83	<0.5-24.1	4.9	2.0

SOFIENBERGPARKEN – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
4:2 FTOH	Gas phase	12	1.32	17	<1.32-63.2	7.25	<1.32
6:2 FTOH	Gas phase	12	3.77	100	20.6-125	71.0	69.6
8:2 FTOH	Gas phase	12	2.01	100	12.4-113	42.6	37.8
10:2 FTOH	Gas phase	12	1.51	100	3.08-30.2	10.4	8.62
12:2 FTOH	Gas phase	12	0.76	83	<0.76-5.89	2.11	1.48
N-Me-FOSA	Gas phase	12	1.51	0	<1.51-<1.51	<1.51	<1.51
N-Et-FOSA	Gas phase	12	0.84	0	<0.84-<0.84	<0.84	<0.84
N-Me-FOSE	Gas phase	12	0.54	0	<0.54-<0.54	<0.54	<0.54
N-Et-FOSE	Gas phase	12	0.66	0	<0.66-<0.66	<0.66	<0.66
Sum Vol PFAS	Gas phase	12			40.1-257.1	135	142
N-MeFOSEA[4]	Gas phase	12		0	<LOD-<LOD	<LOD	<LOD
FBSA	Gas phase	12	0.018	100	0.03-0.7	0.29	0.33
N-MeFBSA	Gas phase	12	0.073	100	0.1-1.84	0.97	1.08
10:2 FTS	Gas phase	12	0.36	0	<0.36-<0.36	<0.36	<0.36
12:2 FTS	Gas phase	12	0.36	0	<0.36-<0.36	<0.36	<0.36
N-EtFBSA	Gas phase	12	0.073	0	<0.07-<0.07	<0.07	<0.07
Chlorinated paraffins (pg/m3) Class of uncertainty: 3							
SCCP	Gas+particle	12	32	100	425-1519	761	631
MCCP	Gas+particle	12	174	100	356-879	527	431
Siloxanes (ng/m3) Class of uncertainty: 3							
D4	Gas phase	12	0.33	100	2.49-28.1	11.7	11.6
D5	Gas phase	12	0.43	100	39.1-417	140	119
D6	Gas phase	12	0.55	100	3.27-14.9	7.94	8.12
sum cVMS	Gas phase	12			45-459	160	140
L3	Gas phase	12	0.02	100	4.8-39.4	16.0	14.7
L4	Gas phase	12	0.02	100	7.4-33	15.8	15.1
L5	Gas phase	12	0.02	100	28.8-67.7	42.4	40.1
M3T(Ph)	Gas phase	12	0.02	100	0.93-2.2	1.4	1.3
F3-Sil	Gas phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
F4-Sil	Gas phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02
Ph-D4	Gas phase	12	0.02	0	<0.02-<0.02	<0.02	<0.02

SOFIENBERGPARKEN – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
OPFRs (ng/m3) Class of uncertainty: 3							
TEP	Gas+particle	11			n.a.-n.a.	n.a.	n.a.
TCEP	Gas+particle	11			n.a.-n.a.	n.a.	n.a.
TCPP (TCIPP)	Gas+particle	11	0.01	91	2.4-5.7	3.3	2.7
TPrP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TDCPP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TPP	Gas+particle	11	0.01	100	0.07-0.7	0.5	0.4
TiBP/TnBP	Gas+particle	11	0.01	100	0.11-2.4	0.5	0.2
TBEP (TBOEP)	Gas+particle	11	0.01	82	< 0.01-0.06	0.03	0.03
DBPhP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TCP	Gas+particle	11	0.01	100	0.01-0.04	0.02	0.01
BdPhP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
EHDP	Gas+particle	11	0.01	100	0.09-0.2	0.2	0.2
TXP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TIPPP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TTBPP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TEHP	Gas+particle	11	0.01	100	0.01-0.07	0.03	0.02
TDBPP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
T2B4MP[4]	Gas+particle	11		0	n.d.-n.d.	n.d.	n.d.
T4B3MP[4]	Gas+particle	11		0	n.d.-n.d.	n.d.	n.d.
T3B4MP[4]	Gas+particle	11		0	n.d.-n.d.	n.d.	n.d.
V6	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
nBFRs (pg/m3) Class of uncertainty: 2							
ATE (TBP-AE)*	Gas+particle	12	0.014	42	<0.014-0.0927	0.029	<0.014
a-TBECH	Gas+particle	12	0.067	100	1.99-16.1	4.98	3.72
b-TBECH	Gas+particle	12	0.050	100	0.973-8.73	2.68	1.98
g/d-TBECH	Gas+particle	12	0.028	100	0.0364-0.244	0.097	0.081
BATE*	Gas+particle	12	0.034	17	<0.034-0.067	0.024	<0.034
PBT	Gas+particle	12	0.042	100	0.39-7.42	2.72	2.17
PBEB	Gas+particle	12	0.036	75	<0.036-0.143	0.058	0.045
PBBZ	Gas+particle	12	0.047	100	0.0831-3.16	1.20	1.18
pTBX	Gas+particle	12	0.047	100	0.143-1.16	0.432	0.321
HBB	Gas+particle	12	0.060	100	0.788-9.38	4.17	3.53
DPTE	Gas+particle	12	0.028	100	0.205-2.73	1.07	0.864
EHTBB	Gas+particle	12	0.041	100	0.155-5.97	2.04	1.56
BTBPE	Gas+particle	12	0.067	58	<0.067-0.425	0.121	0.100
TBPH (BEH /TBP)	Gas+particle	12	0.111	92	<0.111-0.74	0.426	0.396
DBDPE	Gas+particle	12	1.35	42	<1.35-4.77	1.94	1.53
Sum nBFR	Gas+particle	12			7.85-47.9	22.0	18.8
TBBPA[3]	Gas+particle	12	2.14	58	<0.080-18.1	4.25	<1.43
2,2-dimethylpropan-1-ol, tribromo derivative	Gas phase	12	0.6	93	0.1-1.4	0.423	0.3
2,3,4,5-Tetrabromo-6-chlorotoluene	Gas phase	12	0.001	0	<0.001-<0.001	<0.001	<0.001
2,3,5,6-Tetrabromo-p-xylene	Gas phase	12	0.3	93	0.1-0.6	0.19	0.2

SOFIENBERGPARKEN – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Dechloranes (pg/m3) Class of uncertainty: 2							
syn-DP	Gas+particle	12	0.040	100	0.048-0.450	0.165	0.144
anti-DP	Gas+particle	12	0.072	92	<0.072-0.721	0.261	0.213
Dec 601	Gas+particle	12	0.024	0	<0.024-<0.025	<0.024	<0.024
Dec 602	Gas+particle	12	0.016	0	<0.016-<0.017	<0.016	<0.016
Dec 603	Gas+particle	12	0.017	0	<0.017-<0.017	<0.017	<0.017
Dec 604	Gas+particle	12	0.274	0	<0.267-<0.281	<0.274	<0.274
Dibromoaldrin	Gas+particle	12	0.149	0	<0.149-<0.153	<0.149	<0.149
Chlordene plus	Gas+particle	12	0.057	0	<0.056-<0.059	<0.057	<0.057
Dechlorane plus Cl10	Gas+particle	12	0.045	0	<0.044-<0.047	<0.045	<0.045
Dechlorane plus axx Cl10	Gas+particle	12	0.057	0	<0.055-<0.058	<0.057	<0.057
Dechlorane plus ax Cl11	Gas+particle	12	0.016	0	<0.016-<0.016	<0.016	<0.016
Dechlorane plus Cl11	Gas+particle	12	0.010	0	<0.010-<0.010	<0.010	<0.010
Chlorendic anhydride[3]	Gas+particle	12	0.001	0	<0.001-<0.001	<0.001	<0.001
Volatile fluorinated and chlorinated substances (pg/m3) Class of uncertainty:2							
PFTBA	Gas phase	7	50	100		1541	1521
TCPFB	Gas phase	7	1	100		42	25
PFTPeA	Gas phase	7	10	100		92	105
HCBD	Gas phase	12	5	100	930-1810	1523	1560
PFPHP	Gas phase	7	5	100		60	57
DCTFP	Gas phase	7	0.2	100		2.3	1.65
PCTol	Gas phase	7	0.2	79		0.9	0.5
DCPFcH	Gas phase	7	1	0	<1-<1	<1	<1
PFBB	Gas phase	7	5	0	<5-<5	<5	<5
bTFMBB	Gas phase	7	1	0	<1-<1	<1	<1
DCBTC	Gas phase	7	0.5	0	<0.5-<0.5	<0.5	<0.5
HCcBen	Gas phase	7	1	100	191-227	214	218
HCBcB	Gas phase	7	1	100	2.9-8.3	6	6.1
Chlorophenols, UV (pg/m3) Class of uncertainty: 3							
2-EthylHexyl-4-MethoxyCinnamate	Gas phase	12	2	100 %	6.4-83	28.9	25.1
Octocrylene	Gas phase	12	2	100 %	18-1266	238	162
OxyBenzone	Gas phase	12	1	100 %	17-732	129	61
Accelerator CZ	Gas phase	12	2	0 %	<1-<1	<1	<1
Tolyltriazole	Gas phase	12			n.a.-n.a.	n.a.	n.a.
UV-320(tBu2)	Gas phase	12	1	0 %	<0.5-0.5	<0.5	<0.5
UV-326(Me,tBu,Cl)	Gas phase	12	1	100 %	3.4-38	13.6	11.2
UV-327(tBu2,Cl)	Gas phase	12	0.5	42 %	0.3-1.6	0.5	<0.5
UV-328(tAm2)	Gas phase	12	1	100 %	2.2-41	14.0	10.5
UV-329(tOct)	Gas phase	12	1	21 %	0.3-12	1.3	<1
Pentachloroanisole	Gas phase	12	1	100 %	3.4-17	9.2	9.2
Pentachlorophenol	Gas phase	12			n.a.-n.a.	n.a.	n.a.

Table A.2: Summary of measured concentrations (pg/m^3 or ng/m^3), detection frequencies (%) and method detection limits (MDL, pg/m^3 or ng/m^3) of targeted organic contaminants in air at Birkenes in 2022. The colour codes indicate highest detection/concentrations in red, lowest detected concentrations in green and below MDL in white.

BIRKENES – 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	1.116	100	19.0-54.5	36.0	35.9
α-HCH[1]	Gas+particle	12	0.042	100	1.55-5.91	3.35	3.21
γ-HCH[1]	Gas+particle	12	0.109	100	0.311-5.00	1.94	1.44
p,p'-DDT[1]	Gas+particle	12	0.021	83	<0.021-0.901	0.203	0.106
o,p'-DDT[1]	Gas+particle	12	0.017	100	0.048-0.695	0.185	0.126
p,p'-DDE[1]	Gas+particle	12	0.053	100	0.107-6.13	1.13	0.498
o,p'-DDE[1]	Gas+particle	12	0.006	100	0.018-0.173	0.062	0.043
p,p'-DDD[1]	Gas+particle	12	0.007	40	<0.007-0.045	0.015	0.007
o,p'-DDD[1]	Gas+particle	12	0.007	55	<0.007-0.062	0.018	0.007
Sum DDT[1]	Gas+particle	12			0.209-8.006	1.62	0.757
PCB-18[1]	Gas+particle	52	0.136	100	0.179-2.26	0.880	0.754
PCB-28[1]	Gas+particle	52	0.088	100	0.123-1.24	0.577	0.461
PCB-31[1]	Gas+particle	52	0.084	100	0.119-1.17	0.533	0.412
PCB-33[1]	Gas+particle	52	0.058	100	0.061-0.645	0.299	0.233
PCB-37[1]	Gas+particle	52	0.017	100	0.018-0.127	0.054	0.043
PCB-47[1]	Gas+particle	52	0.167	100	0.175-1.54	0.567	0.489
PCB-52[1]	Gas+particle	52	0.099	100	0.208-1.61	0.659	0.506
PCB-66[1]	Gas+particle	52	0.030	100	0.049-0.446	0.155	0.121
PCB-74[1]	Gas+particle	52	0.022	100	0.035-0.307	0.117	0.09
PCB-99[1]	Gas+particle	52	0.017	100	0.045-0.331	0.133	0.106
PCB-101[1]	Gas+particle	52	0.061	100	0.133-1.08	0.401	0.304
PCB-105[1]	Gas+particle	52	0.007	100	0.008-0.069	0.028	0.022
PCB-114[1]	Gas+particle	52	0.002	47	<0.002-0.008	0.003	<0.002
PCB-118[1]	Gas+particle	52	0.021	100	0.032-0.244	0.099	0.08
PCB-122[1]	Gas+particle	52	0.002	51	<0.002-0.015	0.004	0.003
PCB-123[1]	Gas+particle	52	0.002	52	<0.002-0.007	0.003	0.002
PCB-128[1]	Gas+particle	52	0.004	100	0.005-0.054	0.018	0.014
PCB-138[1]	Gas+particle	52	0.034	100	0.039-0.448	0.147	0.105
PCB-141[1]	Gas+particle	52	0.014	83	<0.014-0.152	0.04	0.027
PCB-149[1]	Gas+particle	52	0.052	100	0.072-0.925	0.279	0.199
PCB-153[1]	Gas+particle	52	0.055	100	0.066-0.721	0.236	0.181
PCB-156[1]	Gas+particle	52	0.002	86	<0.002-0.02	0.006	0.005
PCB-157[1]	Gas+particle	52	0.001	21	<0.001-0.003	<0.001	<0.001
PCB-167[1]	Gas+particle	52	0.001	80	<0.001-0.013	0.004	0.003
PCB-170[1]	Gas+particle	52	0.010	52	<0.010-0.052	0.015	<0.010
PCB-180[1]	Gas+particle	52	0.028	62	<0.028-0.175	0.049	0.035

BIRKENES – Air							
Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
PCB-183[1]	Gas+particle	52	0.009	73	<0.009-0.064	0.020	0.014
PCB-187[1]	Gas+particle	52	0.019	88	<0.019-0.216	0.064	0.045
PCB-189[1]	Gas+particle	52	0.001	2	<0.001-0.002	<0.001	<0.001
PCB-194[1]	Gas+particle	52	0.003	34	<0.003-0.012	0.004	<0.003
PCB-206[1]	Gas+particle	52	0.003	8	<0.003-0.006	<0.003	<0.003
PCB-209[1]	Gas+particle	52	0.002	44	<0.002-0.004	<0.002	<0.002
sum 7 PCB[1]	Gas+particle	52			0.628-5.518	2.17	1.67
sum 32 PCB[1]	Gas+particle	52			1.463-13.966	5.40	4.28
sum PCB[1]	Gas+particle	52			2.521-20.121	8.36	6.55
BDE-17[2]	Gas+particle	12	0.003	83	<0.003-0.008	0.005	0.005
BDE-28[1]	Gas+particle	12	0.004	100	0.005-0.013	0.008	0.007
BDE-47[2]	Gas+particle	12	0.036	83	<0.036-0.077	0.051	0.044
BDE-49[2]	Gas+particle	12	0.003	100	0.004-0.013	0.008	0.008
BDE-66[2]	Gas+particle	12	0.002	100	0.002-0.007	0.005	0.005
BDE-71[2]	Gas+particle	12	0.001	58	<0.001-0.011	0.002	<0.001
BDE-77[2]	Gas+particle	12	0.001	33	<0.001-0.002	<0.001	<0.001
BDE-85[2]	Gas+particle	12	0.001	17	<0.001-0.002	<0.001	<0.001
BDE-99[1]	Gas+particle	12	0.014	67	<0.014-0.03	0.018	0.017
BDE-100[2]	Gas+particle	12	0.003	75	<0.003-0.008	0.005	0.004
BDE-119[2]	Gas+particle	12	0.001	36	<0.001-0.007	0.002	<0.001
BDE-126[2]	Gas+particle	12	0.001	8	<0.001-0.002	<0.001	<0.001
BDE-138[2]	Gas+particle	12	0.002	0	<0.002-<0.004	<0.003	<0.002
BDE-153[1]	Gas+particle	12	0.002	30	<0.002-0.011	0.004	<0.003
BDE-154[2]	Gas+particle	12	0.002	91	<0.002-0.014	0.006	0.005
BDE-156[2]	Gas+particle	12	0.004	0	<0.004-<0.006	<0.004	<0.004
BDE-183[1]	Gas+particle	12	0.003	92	<0.003-0.04	0.017	0.015
BDE-184[2]	Gas+particle	12	0.001	42	<0.001-0.008	0.002	<0.001
BDE-190[2]	Gas+particle	12	0.002	0	<0.002-<0.002	<0.002	<0.002
BDE-191[2]	Gas+particle	12	0.002	27	<0.002-0.011	0.003	<0.002
BDE-196[2]	Gas+particle	12	0.004	0	<0.004-<0.004	<0.004	<0.004
BDE-197[2]	Gas+particle	12	0.003	75	<0.003-0.046	0.014	0.009
BDE-202[2]	Gas+particle	12	0.004	45	<0.004-0.018	0.008	<0.004
BDE-206[2]	Gas+particle	12	0.032	17	<0.032-0.053	0.034	<0.032
BDE-207[2]	Gas+particle	12	0.018	33	<0.018-0.141	0.041	<0.018
BDE-209[3]	Gas+particle	12	0.265	58	<0.265-0.386	0.293	0.277
sum 17 BDE[3] (ref. 2021)	Gas+particle	12			0.3731-0.6815	0.46	0.43
sum 26 BDE[3]	Gas+particle	12			0.4107-0.9232	0.54	0.47
sum 25 BDE (excl. 209)[2]	Gas+particle	12			0.1477-0.5372	0.25	0.20
TBA[2]	Gas+particle	12	0.021	100		6.44	6.40
α-HBCDD[2]	Gas+particle	12	0.009	8		0.016	<0.009
β-HBCDD[2]	Gas+particle	12	0.004	8		0.006	<0.004
γ-HBCDD[2]	Gas+particle	12	0.009	8		0.010	<0.009

BIRKENES – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
PAHs (ng/m3) Class of uncertainty:1							
1-Methylnaphthalene	Gas+particle	52	0.008	83	<0.008-0.54	0.051	0.025
1-Methylphenanthrene	Gas+particle	52	0.003	100	0.008-0.226	0.055	0.046
2-Methylanthracene	Gas+particle	52	0.003	0	<0.004-<0.026	<0.008	<0.007
2-Methylnaphthalene	Gas+particle	52	0.012	77	<0.012-0.571	0.061	0.032
2-Methylphenanthrene	Gas+particle	52	0.003	100	0.013-0.234	0.063	0.053
3-Methylphenanthrene	Gas+particle	52	0.003	100	0.011-0.2	0.056	0.05
9-Methylphenanthrene	Gas+particle	52	0.002	100	0.006-0.096	0.024	0.021
Acenaphthene*	Gas+particle	52	0.010	98	<0.015-0.574	0.096	0.061
Acenaphthylene*	Gas+particle	52	0.003	54	<0.004-0.381	0.055	0.013
Anthanthrene	Gas+particle	52	0.002	27	<0.002-0.045	0.005	<0.003
Anthracene*	Gas+particle	52	0.002	44	<0.004-0.151	0.028	0.010
Benz(a)anthracene*	Gas+particle	52	0.001	83	<0.001-0.233	0.019	0.005
Benzo(a)fluoranthene	Gas+particle	52	0.001	37	<0.001-0.063	0.006	<0.003
Benzo(a)fluorene	Gas+particle	52	0.001	77	<0.001-0.097	0.012	0.006
Benzo(a)pyrene*	Gas+particle	52	0.001	85	<0.001-0.291	0.021	0.006
Benzo(b)fluoranthene*	Gas+particle	52	0.001	92	<0.001-0.526	0.058	0.024
Benzo(b)fluorene	Gas+particle	52	0.001	60	<0.002-0.104	0.008	0.004
Benzo(e)pyrene	Gas+particle	52	0.001	90	<0.001-0.325	0.038	0.017
Benzo(ghi)fluoranthene	Gas+particle	52	0.001	0	NaN-NaN	NaN	NaN
Benzo(ghi)perylene*	Gas+particle	52	0.002	90	<0.002-0.306	0.036	0.019
Benzo(j)fluoranthene	Gas+particle	52	0.001	85	<0.001-0.268	0.024	0.010
Benzo(k)fluoranthene*	Gas+particle	52	0.001	85	<0.001-0.234	0.020	0.007
Biphenyl	Gas+particle	52	0.009	85	0.014-1.26	0.159	0.071
Chrysene*	Gas+particle	52	0.001	96	<0.001-0.598	0.062	0.03
Coronene	Gas+particle	52	0.002	60	<0.002-0.171	0.017	0.009
Cyclopenta(cd)pyrene	Gas+particle	52	0.001	0	<0.001-<0.005	<0.002	<0.002
Dibenzo(ac)anthracene	Gas+particle	52	0.002	24	<0.002-0.027	0.005	<0.003
Dibenzo(ae)pyrene	Gas+particle	52	0.004	31	<0.004-0.073	0.011	<0.008
Dibenzo(ah)anthracene*	Gas+particle	52	0.002	40	<0.002-0.07	0.007	<0.003
Dibenzo(ah)pyrene	Gas+particle	52	0.004	0	<0.004-<0.014	<0.009	<0.009
Dibenzo(ai)pyrene	Gas+particle	52	0.004	2	<0.003-<0.017	<0.008	<0.008
Dibenzofuran	Gas+particle	52	0.014	100	0.043-3.8	0.654	0.368
Dibenzothiophene	Gas+particle	52	0.001	100	0.004-0.193	0.037	0.029
Fluoranthene*	Gas+particle	52	0.009	100	0.035-1.56	0.238	0.174
Fluorene*	Gas+particle	52	0.014	100	0.053-2.75	0.478	0.318
Indeno(123-cd)pyrene*	Gas+particle	52	0.002	90	<0.002-0.387	0.038	0.019
Naphthalene*	Gas+particle	52	0.032	60	<0.029-1.59	0.134	0.045
Perylene	Gas+particle	52	0.001	29	<0.001-0.035	0.004	<0.002
Phenanthrene*	Gas+particle	52	0.028	100	0.191-2.8	0.914	0.811
Pyrene*	Gas+particle	52	0.004	100	0.014-0.985	0.128	0.087
Retene	Gas+particle	52	0.002	100	0.007-0.119	0.039	0.029
triphenylene	Gas+particle	52	0.001	100	0.001-0.122	0.014	0.007
Sum 39 PAH (ref. 2021)	Gas+particle	52			0.508-21.65	3.66	2.43
Sum 42 PAH	Gas+particle	52			0.512-22.067	3.70	2.46
Sum 16 PAH(*)	Gas+particle	52			0.356-13.436	2.33	1.63

BIRKENES – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Ionic and volatile PFAS (pg/m3) Class of uncertainty:2							
FTS 4:2	Particle phase	12	0.041	0	<0.041-<0.041	<0.041	<0.041
FTS 6:2	Particle phase	12	0.860	17	<0.86-1.74	<0.86	<0.86
FTS 8:2	Particle phase	12	0.020	0	<0.020-<0.020	<0.020	<0.020
PFBA	Particle phase	12	0.250	0	<0.250-<0.250	<0.250	<0.250
PFPeA	Particle phase	12	0.041	0	<0.041-<0.041	<0.041	<0.041
PFHxA	Particle phase	12	0.081	25	<0.081-0.207	<0.081	<0.081
PFHpA	Particle phase	12	0.030	83	<0.030-0.452	0.125	0.097
PFOA	Particle phase	12	0.020	75	<0.020-0.422	0.111	0.096
PFNA	Particle phase	12	0.020	83	<0.020-0.146	0.054	0.046
PFDA	Particle phase	12	0.020	8	<0.020-0.0513	<0.020	<0.020
PFUnA	Particle phase	12	0.030	0	<0.030-<0.030	<0.030	<0.030
PFDoDA	Particle phase	12	0.041	0	<0.041-<0.041	<0.041	<0.041
PFTrDA	Particle phase	12	0.081	0	<0.081-<0.081	<0.081	<0.081
PFTeDA	Particle phase	12	0.020	0	<0.020-<0.020	<0.020	<0.020
PFBS	Particle phase	12	0.020	0	<0.020-<0.020	<0.020	<0.020
PFPS	Particle phase	12	0.041	0	<0.041-<0.041	<0.041	<0.041
PFHxS	Particle phase	12	0.020	8	<0.020-0.0316	<0.020	<0.020
PFHpS	Particle phase	12	0.041	0	<0.041-<0.041	<0.041	<0.041
PFOS	Particle phase	12	0.041	8	<0.041-0.0274	<0.041	<0.041
PFNS	Particle phase	12	0.061	0	<0.061-<0.061	<0.061	<0.061
PFDS	Particle phase	12	0.061	0	<0.061-<0.061	<0.061	<0.061
PFUnS	Particle phase	12	0.081	0	<0.081-<0.081	<0.081	<0.081
PFDoS	Particle phase	12	0.081	0	<0.081-<0.081	<0.081	<0.081
PFTrS	Particle phase	12	0.081	0	<0.081-<0.081	<0.081	<0.081
PFTS	Particle phase	12	0.100	0	<0.100-<0.100	<0.100	<0.100
PFOSA	Particle phase	12	0.041	0	<0.041-<0.041	<0.041	<0.041
sum ionic PFAS		12			1.40-3.67	1.78	1.58
4:2 FTOH	Gas phase	12	0.65	0	<0.65-<0.65	<0.65	<0.65
6:2 FTOH	Gas phase	12	1.87	100	5.65-28.4	13.3	12.7
8:2 FTOH	Gas phase	12	0.99	100	1.61-15.9	6.16	4.81
10:2 FTOH	Gas phase	12	0.75	83	<0.75-6.89	2.46	1.80
12:2 FTOH	Gas phase	12	0.37	83	<0.37-10.6	2.13	0.91
N-Me-FOSA	Gas phase	12	0.75	25	<0.75-2.8	0.77	<0.75
N-Et-FOSA	Gas phase	12	0.42	25	<0.42-2.8	0.64	<0.42
N-Me-FOSE	Gas phase	12	0.27	33	<0.27-3.27	0.74	<0.27
N-Et-FOSE	Gas phase	12	0.33	42	<0.33-3.89	1.04	<0.33
Sum Vol PFAS		12			11.3-58.9	27.5	25.2

BIRKENES – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Chlorinated paraffins (pg/m3) Class of uncertainty: 3							
SCCP	Gas+particle	12	67	100	108-279	177	171
	Gas+particle	12	369	33	<369-693	<369	<369
Siloxanes (ng/m3) Class of uncertainty: 3							
D4	Gas phase	12	0.33	100	0.47-3.18	1.56	1.5
D5	Gas phase	12	0.43	100	1.86-7.48	3.54	3.3
D6	Gas phase	12	0.55	17	<0.55-0.75	<0.55	<0.55
sum cVMS	Gas phase	12			2.81-11.95	5.44	4.83

*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 (ng/L), detection frequencies (%) and method detection limits (MDL, ng/L) of POPs in precipitation at Birkenes in 2022. The colour codes indicate highest concentrations in red, lowest detected concentrations in green and below MDL in white.

BIRKENES – Precipitation							
POPs (ng/L) Class of uncertainty:1							
HCB	Gas phase	50	0.052	24	<0.024-0.304	<0.055	<0.060
α-HCH	Gas phase	50	0.064	49	<0.044-0.559	0.087	0.087
γ-HCH	Gas phase	50	0.035	83	<0.034-0.367	0.147	0.141
PCB-28	Gas phase	50	0.009	9	<0.004-0.054	<0.009	<0.009
PCB-52	Gas phase	50	0.005	35	<0.002-0.031	<0.006	<0.006
PCB-101	Gas phase	50	0.010	24	<0.005-0.06	<0.010	<0.011
PCB-118	Gas phase	50	0.007	2	<0.003-0.042	<0.007	<0.007
PCB-138	Gas phase	50	0.010	26	<0.005-0.06	<0.010	<0.011
PCB-153	Gas phase	50	0.013	26	<0.007-0.076	<0.013	<0.013
PCB-180	Gas phase	50	0.005	11	<0.003-0.032	<0.006	<0.006
sum PCB-7	Gas phase	50			0.029-0.355	0.06	0.063

*MDLs are presented as a guidance based on median 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 (pg/m^3 or ng/m^3), detection frequencies (%) and method detection limits (MDL, pg/m^3 or ng/m^3) of targeted organic contaminants at Zeppelin in 2022. The colour codes indicate highest detection/concentrations in red, lowest detected concentrations in green and below MDL in white.

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	0.521	100	25.8-50.0	45.0	46.2
α-HCH[1]	Gas+particle	52	0.019	100	0.920-4.47	2.30	2.10
γ-HCH[1]	Gas+particle	52	0.051	100	0.174-2.11	0.600	0.500
p,p'-DDT[1]	Gas+particle	52	0.010	70	<0.010-0.117	0.032	0.021
o,p'-DDT[1]	Gas+particle	52	0.008	96	<0.008-0.15	0.054	0.042
p,p'-DDE[1]	Gas+particle	52	0.025	96	<0.025-1.01	0.250	0.145
o,p'-DDE[1]	Gas+particle	52	0.003	100	0.004-0.124	0.034	0.022
p,p'-DDD[1]	Gas+particle	52	0.003	20	<0.003-0.01	0.004	<0.003
o,p'-DDD[1]	Gas+particle	52	0.003	43	<0.003-0.018	0.006	0.005
Sum DDT[1]	Gas+particle	52			0.056-1.43	0.378	0.251
cis-CD[1]	Gas+particle	52	0.011	100	0.109-0.356	0.200	0.200
cis-NO[1]	Gas+particle	52	0.009	84	<0.009-0.048	0.000	0.000
trans-CD[1]	Gas+particle	52	0.012	100	0.023-0.226	0.100	0.100
trans-NO[1]	Gas+particle	52	0.010	100	0.100-0.391	0.200	0.200
Sum Chlordane[1]	Gas+particle	52			0.241-1.02	0.578	0.545
PCB-18[1]	Gas+particle	52	0.064	100	0.339-1.77	0.855	0.766
PCB-28[1]	Gas+particle	52	0.041	100	0.278-2.00	0.760	0.681
PCB-31[1]	Gas+particle	52	0.039	100	0.261-1.78	0.696	0.618
PCB-33[1]	Gas+particle	52	0.027	100	0.197-1.46	0.533	0.462
PCB-37[1]	Gas+particle	52	0.008	100	0.049-0.441	0.137	0.120
PCB-47[1]	Gas+particle	52	0.078	100	0.104-0.576	0.247	0.226
PCB-52[1]	Gas+particle	52	0.046	100	0.184-0.931	0.427	0.378
PCB-66[1]	Gas+particle	52	0.014	100	0.066-0.390	0.151	0.138
PCB-74[1]	Gas+particle	52	0.010	100	0.047-0.251	0.104	0.093
PCB-99[1]	Gas+particle	52	0.008	100	0.043-0.311	0.097	0.083
PCB-101[1]	Gas+particle	52	0.029	100	0.117-0.564	0.239	0.226
PCB-105[1]	Gas+particle	52	0.003	100	0.011-0.147	0.032	0.023
PCB-114[1]	Gas+particle	52	0.001	41	<0.001-0.009	0.002	<0.001
PCB-118[1]	Gas+particle	52	0.010	100	0.036-0.367	0.093	0.075
PCB-122[1]	Gas+particle	52	0.001	44	<0.001-0.011	0.002	0.002
PCB-123[1]	Gas+particle	52	0.001	47	<0.001-0.006	0.002	0.002
PCB-128[1]	Gas+particle	52	0.002	100	0.006-0.070	0.014	0.010
PCB-138[1]	Gas+particle	52	0.016	100	0.031-0.325	0.080	0.065
PCB-141[1]	Gas+particle	52	0.006	100	0.008-0.061	0.018	0.016
PCB-149[1]	Gas+particle	52	0.024	100	0.052-0.276	0.117	0.112
PCB-153[1]	Gas+particle	52	0.026	100	0.042-0.264	0.098	0.089
PCB-156[1]	Gas+particle	52	0.001	98	<0.001-0.036	0.005	0.004
PCB-157[1]	Gas+particle	52	0.001	24	<0.001-0.006	<0.001	<0.001
PCB-167[1]	Gas+particle	52	0.001	71	<0.001-0.009	0.002	0.001
PCB-170[1]	Gas+particle	52	0.005	45	<0.005-0.020	0.006	<0.005

ZEPPELIN – Air							
Compound	Matrix	No. of samples	MDL*	DF (%)	Concentration range	Annual mean	Annual median
PCB-180[1]	Gas+particle	52	0.013	55	<0.013-0.038	0.017	0.014
PCB-183[1]	Gas+particle	52	0.004	74	<0.004-0.011	0.006	0.006
PCB-187[1]	Gas+particle	52	0.009	96	<0.009-0.029	0.018	0.017
PCB-189[1]	Gas+particle	52	0.001	0	<0.001-<0.001	<0.001	<0.001
PCB-194[1]	Gas+particle	52	0.002	20	<0.002-0.003	<0.002	<0.002
PCB-206[1]	Gas+particle	52	0.002	10	<0.002-<0.002	<0.002	<0.002
PCB-209[1]	Gas+particle	52	0.001	73	<0.001-0.010	0.002	0.002
sum 7 PCB[1]	Gas+particle	52			0.719-3.59	1.72	1.55
sum 32 PCB[1]	Gas+particle	52			1.91-12.2	4.77	4.24
sum PCB[1]	Gas+particle	52			2.94-16.6	7.39	6.81
BDE-17[2]	Gas+particle	52	0.005	33	<0.005-0.033	0.006	<0.005
BDE-28[1]	Gas+particle	52	0.005	84	<0.005-0.064	0.010	0.008
BDE-47[2]	Gas+particle	52	0.047	100	0.057-1.81	0.203	0.142
BDE-49[2]	Gas+particle	52	0.003	79	<0.003-0.194	0.011	0.006
BDE-66[2]	Gas+particle	52	0.003	54	<0.003-0.127	0.007	0.003
BDE-71[2]	Gas+particle	52	0.001	18	<0.001-0.009	0.002	<0.001
BDE-77[2]	Gas+particle	52	0.001	2	<0.001-0.004	<0.001	<0.001
BDE-85[2]	Gas+particle	52	0.002	19	<0.002-0.021	0.003	<0.002
BDE-99[1]	Gas+particle	52	0.018	76	<0.018-0.281	0.052	0.031
BDE-100[2]	Gas+particle	52	0.005	90	<0.005-0.102	0.017	0.011
BDE-119[2]	Gas+particle	52	0.001	4	<0.001-0.02	0.002	<0.001
BDE-126[2]	Gas+particle	52	0.001	2	<0.001-0.013	0.002	<0.001
BDE-138[2]	Gas+particle	52	0.003	0	<0.003-<0.129	0.007	<0.003
BDE-153[1]	Gas+particle	52	0.003	18	<0.003-0.123	0.008	<0.003
BDE-154[2]	Gas+particle	52	0.002	51	<0.002-0.093	0.006	0.003
BDE-156[2]	Gas+particle	52	0.005	0	<0.005-<0.191	<0.011	<0.005
BDE-183[1]	Gas+particle	52	0.004	17	<0.004-<0.027	<0.005	<0.004
BDE-184[2]	Gas+particle	52	0.001	2	<0.001-0.022	0.002	0.002
BDE-190[2]	Gas+particle	52	0.002	0	<0.002-<0.053	<0.004	<0.003
BDE-191[2]	Gas+particle	52	0.002	0	<0.002-<0.04	<0.004	<0.003
BDE-196[2]	Gas+particle	52	0.005	4	<0.005-0.158	0.014	<0.006
BDE-197[2]	Gas+particle	52	0.004	14	<0.004-<0.116	<0.011	<0.006
BDE-202[2]	Gas+particle	52	0.005	14	<0.005-<0.193	<0.019	<0.006
BDE-206[2]	Gas+particle	52	0.042	50	<0.042-4.94	0.423	0.073
BDE-207[2]	Gas+particle	52	0.024	55	<0.024-6.4	0.386	0.056
BDE-209[3]	Gas+particle	52	0.350	94	<0.350-216	18.0	5.70
sum 17 BDE[3] (ref. 2021)	Gas+particle	52			0.486-224	18.8	6.00
sum 26 BDE[3]	Gas+particle	52			0.531-231	19.2	6.08
sum 25 BDE (excl. 209)[2]	Gas+particle	52			0.192-15.2	1.22	0.383
TBA[2]	Gas+particle	52	0.028	100	1.22-53.3	12.3	7.7
α-HBCDD[2]	Gas+particle	26	0.012	87	<0.012-0.559	0.114	0.043
β-HBCDD[2]	Gas+particle	26	0.005	43	<0.005-0.077	0.017	<0.005
γ-HBCDD[2]	Gas+particle	26	0.012	26	<0.012-0.066	0.018	<0.012

ZEPPELIN – Air							
PAHs (ng/m3) Class of uncertainty:1							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
1-Methylnaphthalene	Gas+particle	52	0.004	98	<0.004-0.599	0.052	0.019
1-Methylphenanthrene	Gas+particle	52	0.001	10	<0.002-0.013	<0.003	<0.003
2-Methylanthracene	Gas+particle	52	0.002	0	<0.002-<0.008	<0.003	<0.003
2-Methylnaphthalene	Gas+particle	52	0.006	98	<0.006-0.565	0.062	0.025
2-Methylphenanthrene	Gas+particle	52	0.002	27	<0.002-0.015	<0.003	<0.003
3-Methylphenanthrene	Gas+particle	52	0.001	14	<0.002-0.011	<0.003	<0.003
9-Methylphenanthrene	Gas+particle	52	0.001	8	<0.001-0.007	<0.003	<0.003
Acenaphthene*	Gas+particle	52	0.004	0	<0.004-<0.043	<0.013	<0.011
Acenaphthylene*	Gas+particle	52	0.001	2	<0.002-<0.018	<0.006	<0.005
Anthanthrene	Gas+particle	52	0.001	0	<0.001-<0.006	<0.002	<0.001
Anthracene*	Gas+particle	52	0.001	8	<0.001-0.048	<0.004	<0.003
Benz(a)anthracene*	Gas+particle	52	0.001	18	<0.001-0.020	<0.002	<0.001
Benzo(a)fluoranthene	Gas+particle	52	0.001	6	<0.001-0.005	<0.001	<0.001
Benzo(a)fluorene	Gas+particle	52	0.001	14	<0.001-0.010	<0.002	<0.001
Benzo(a)pyrene*	Gas+particle	52	0.001	20	<0.001-0.021	<0.002	<0.001
Benzo(b)fluoranthene*	Gas+particle	52	0.001	33	<0.001-0.049	<0.004	<0.001
Benzo(b)fluorene	Gas+particle	52	0.001	8	<0.001-0.005	<0.001	<0.001
Benzo(e)pyrene	Gas+particle	52	0.001	27	<0.001-0.029	<0.003	<0.001
Benzo(ghi)fluoranthene	Gas+particle	52	0.001	0	<0.001-<0.003	<0.001	<0.001
Benzo(ghi)perylene*	Gas+particle	52	0.001	27	<0.001-0.031	<0.003	<0.001
Benzo(j)fluoranthene	Gas+particle	52	0.001	20	<0.001-0.025	<0.002	<0.001
Benzo(k)fluoranthene*	Gas+particle	52	0.001	20	<0.001-0.020	<0.002	<0.001
Biphenyl	Gas+particle	52	0.004	98	<0.006-2.50	0.252	0.075
Chrysene*	Gas+particle	52	0.001	33	<0.001-0.047	<0.004	<0.001
Coronene	Gas+particle	52	0.001	10	<0.001-0.016	<0.004	<0.003
Cyclopenta(cd)pyrene	Gas+particle	52	0.001	0	<0.001-<0.003	<0.001	<0.001
Dibenzo(ac)anthracene	Gas+particle	52	0.001	0	<0.001-<0.009	<0.002	<0.002
Dibenzo(ae)pyrene	Gas+particle	52	0.002	0	<0.002-<0.016	<0.004	<0.004
Dibenzo(ah)anthracene*	Gas+particle	52	0.001	2	<0.001-<0.008	<0.002	<0.001
Dibenzo(ah)pyrene	Gas+particle	52	0.002	0	<0.002-<0.016	<0.005	<0.004
Dibenzo(ai)pyrene	Gas+particle	52	0.002	0	<0.002-<0.014	<0.004	<0.004
Dibenzofuran	Gas+particle	52	0.007	100	0.015-2.3	0.310	0.125
Dibenzothiophene	Gas+particle	52	0.001	50	<0.001-0.020	0.003	0.002
Fluoranthene*	Gas+particle	52	0.004	41	<0.003-0.171	0.015	0.006
Fluorene*	Gas+particle	52	0.007	96	<0.008-1.10	0.112	0.031
Indeno(123-cd)pyrene*	Gas+particle	52	0.001	27	<0.001-0.034	<0.003	<0.001
Naphthalene*	Gas+particle	52	0.015	100	0.014-2.35	0.253	0.096
Perylene	Gas+particle	52	0.001	2	<0.001-0.005	<0.001	<0.001
Phenanthrene*	Gas+particle	52	0.013	40	<0.013-0.214	0.032	0.018
Pyrene*	Gas+particle	52	0.002	35	<0.002-0.091	0.007	<0.002
Retene	Gas+particle	52	0.001	4	<0.001-0.008	<0.003	<0.002
triphenylene	Gas+particle	52	0.0004	22	<0.001-0.012	<0.002	<0.001
Sum 39 PAH (ref. 2021)	Gas+particle	52			0.107-10.4	1.19	0.467
Sum 42 PAH	Gas+particle	52			0.110-10.5	1.20	0.471
Sum 16 PAH(*)	Gas+particle	52			0.050-4.27	0.464	0.181

ZEPPELIN – Air							
Ionic and volatile PFAS (pg/m3) Class of uncertainty:2							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
FTS 4:2	Particle phase	12	0.044	0	<0.044-<0.044	<0.044	<0.044
FTS 6:2	Particle phase	12	0.940	8	<0.940-1.26	<0.940	<0.940
FTS 8:2	Particle phase	12	0.022	0	<0.022-<0.022	<0.022	<0.022
PFBA	Particle phase	12	0.250	0	<0.250-<0.250	<0.250	<0.250
PFPeA	Particle phase	12	0.044	50	<0.044-0.104	0.048	<0.044
PFHxA	Particle phase	12	0.088	42	<0.088-0.204	<0.088	<0.088
PFHpA	Particle phase	12	0.033	75	<0.033-0.298	0.116	0.099
PFOA	Particle phase	12	0.022	58	<0.011-0.297	0.124	0.130
PFNA	Particle phase	12	0.022	50	<0.022-0.165	0.0401	0.021
PFDA	Particle phase	12	0.022	33	<0.022-0.119	0.031	<0.022
PFUnA	Particle phase	12	0.033	0	<0.033-<0.033	<0.033	<0.033
PFDoA	Particle phase	12	0.044	0	<0.044-<0.044	<0.044	<0.044
PFTrA	Particle phase	12	0.088	0	<0.088-<0.088	<0.088	<0.088
PFTeA	Particle phase	12	0.022	0	<0.022-<0.022	<0.022	<0.022
PFBS	Particle phase	12	0.022	0	<0.022-<0.022	<0.022	<0.022
PFPS	Particle phase	12	0.044	0	<0.044-<0.044	<0.044	<0.044
PFHxS	Particle phase	12	0.022	0	<0.022-<0.022	<0.022	<0.022
PFHpS	Particle phase	12	0.044	0	<0.044-<0.044	<0.044	<0.044
PFOS	Particle phase	12	0.044	0	<0.044-<0.044	<0.044	<0.044
PFNS	Particle phase	12	0.066	0	<0.066-<0.066	<0.066	<0.066
PFDS	Particle phase	12	0.066	0	<0.066-<0.066	<0.066	<0.066
PFUnS	Particle phase	12	0.088	0	<0.088-<0.088	<0.088	<0.088
PFDoS	Particle phase	12	0.088	0	<0.088-<0.088	<0.088	<0.088
PFTrS	Particle phase	12	0.088	0	<0.088-<0.088	<0.088	<0.088
PFTS	Particle phase	12	0.100	0	<0.100-<0.100	<0.100	<0.100
PFOSA	Particle phase	12	0.044	0	<0.044-<0.044	<0.044	<0.044
sum ionic PFAS		12			1.145-2.036	1.54	1.46
4:2 FTOH	Gas phase	12	0.680	0	<0.68-<0.68	<0.68	<0.68
6:2 FTOH	Gas phase	12	1.96	100	5.30-42.1	14.0	9.53
8:2 FTOH	Gas phase	12	1.04	100	5.79-49.2	19.4	17.0
10:2 FTOH	Gas phase	12	0.780	100	1.12-17.6	6.20	5.38
12:2 FTOH	Gas phase	12	0.390	100	0.56-7.46	2.64	2.58
N-Me-FOSA	Gas phase	12	0.780	20	<0.78-0.86	<0.78	<0.78
N-Et-FOSA	Gas phase	12	0.440	30	<0.44-0.67	<0.44	<0.44
N-Me-FOSE	Gas phase	12	0.280	30	<0.28-0.85	0.29	<0.28
N-Et-FOSE	Gas phase	12	0.340	10	<0.34-0.52	<0.34	<0.34
Sum Vol PFAS		12			14.6-85.8	43.9	40.4

ZEPPELIN – Air							
Compound	**Matrix**	**No. of samples**	**MDL***	**DF (%)**	**Concentration range**	**Annual mean**	**Annual median**
Chlorinated paraffins (pg/m3) Class of uncertainty: 3							
SCCP	Gas+particle	51	31	100	39-363	138	125
MCCP	Gas+particle	51	172	35	<172-686	<172	<172
Siloxanes (ng/m3) Class of uncertainty: 3							
D4	Gas phase	52	0.33	60	<0.33-2.77	0.720	0.430
D5	Gas phase	52	0.43	56	<0.43-3.94	0.860	<0.43
D6	Gas phase	52	0.55	4	<0.55-<0.55	<0.55	<0.55
sum cVMS	Gas phase	52			0.65-6.57	1.86	1.13
OPFRs (ng/m3) Class of uncertainty: 3							
TEP	Gas+particle	11	n.a.	n.a.	n.a.-n.a.	n.a.	n.a.
TCEP	Gas+particle	11	n.a.	n.a.	n.a.-n.a.	n.a.	n.a.
TCPP (TCIPP)	Gas+particle	11	0.01	100	0.01-0.99	0.2	0.1
TPrP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TDCPP	Gas+particle	11	0.01		n.a.-n.a.	n.a.	n.a.
TPP	Gas+particle	11	0.01	55	<0.01-0.08	0.02	0.02
TiBP/TnBP	Gas+particle	11	0.01	73	< 0.01-0.010	< 0.01	< 0.01
TBEP (TBOEP)	Gas+particle	11	0.01	36	< 0.01-0.01	< 0.01	< 0.01
DBPhP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TCP	Gas+particle	11	0.01	64	<0.01-0.011	< 0.01	< 0.01
BdPhP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
EHDP	Gas+particle	11	0.01	82	< 0.01-0.02	< 0.01	< 0.01
TXP	Gas+particle	11	0.01	27	< 0.01-0.04	< 0.01	< 0.01
TIPPP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TTBPP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
TEHP	Gas+particle	11	0.01	0	< 0.01-< 0.01	< 0.01	< 0.01
nBFRs (pg/m3) Class of uncertainty: 2							
ATE (TBP-AE)	Gas+particle	26	0.010	4	<0.010-0.013	<0.010	<0.010
a-TBECH	Gas+particle	26	0.045	0	<0.045-<0.045	<0.045	<0.045
b-TBECH	Gas+particle	26	0.034	0	<0.034-<0.034	<0.034	<0.034
g/d-TBECH	Gas+particle	26	0.019	4	<0.019-0.037	<0.019	<0.019
BATE	Gas+particle	26	0.023	4	<0.023-0.026	<0.023	<0.023
PBT	Gas+particle	26	0.028	65	<0.028-0.129	0.045	0.034
PBEB	Gas+particle	26	0.024	4	<0.024-0.035	<0.024	<0.024
PBBZ	Gas+particle	26	0.032	74	<0.032-0.137	0.050	0.045
pTBX	Gas+particle	26	0.032	4	<0.032-0.033	<0.032	<0.032
HBB	Gas+particle	26	0.041	91	<0.041-0.234	0.095	0.092
DPTE	Gas+particle	26	0.019	35	<0.019-0.051	<0.019	<0.019
EHTBB	Gas+particle	26	0.028	17	<0.028-0.060	<0.028	<0.028
BTBPE	Gas+particle	26	0.045	0	<0.045-0.036	<0.045	<0.045
TBPH (BEH /TBP)	Gas+particle	26	0.076	17	<0.076-0.128	<0.076	<0.076
DBDPE	Gas+particle	26	0.918	17	<0.918-7.27	1.14	<0.918
Sum nBFR	Gas+particle	26			0.898-0.207	1.44	0.869
TBBPA[3]	Gas+particle	26	1.52	0	<0.046-<0.940	<0.238	<0.167

ZEPPELIN – Air							
Dechloranes (pg/m3) Class of uncertainty: 2							
syn-DP	Gas+particle	12	0.055	17	<0.055-0.432	<0.055	<0.055
anti-DP	Gas+particle	12	0.045	58	<0.045-1.53	0.150	0.058
Dec 601	Gas+particle	12	0.024	0	<0.024-<0.024	<0.024	<0.024
Dec 602	Gas+particle	12	0.011	0	<0.011-<0.011	<0.011	<0.011
Dec 603	Gas+particle	12	0.015	0	<0.015-<0.015	<0.015	<0.015
Dec 604	Gas+particle	12	0.258	0	<0.258-<0.258	<0.258	<0.258
Dibromoaldrin	Gas+particle	12	0.053	0	<0.053-<0.053	<0.053	<0.053
Volatile fluorinated and chlorinated substances (pg/m3) Class of uncertainty:2							
PFTBA	Gas phase	24	50	77	59-2529	2085	2264
TCPFB	Gas phase	24	1	100	36-299	221	260.5
PFTPeA	Gas phase	24	10	70	44-183	118	116
HCBD	Gas phase	24	5	100	851-2100	1745	1789
PFPHP	Gas phase	24	5	70	13-53	39	40
DCTFP	Gas phase	24	0.2	98	0.6-7.3	5.0	4.6
PCTol	Gas phase	24	0.2	84	0.4-3.3	1.0	1.2
DCPFcH	Gas phase	24	1	0	n.d.-n.d.	n.d.	n.d.
PFBB	Gas phase	24	5	0	n.d.-n.d.	n.d.	n.d.
bTFMBB	Gas phase	24	1	0	n.d.-n.d.	n.d.	n.d.
DCBTC	Gas phase	24	0.5	0	n.d.-n.d.	n.d.	n.d.
HCcBen	Gas phase	24	1	100	80-247	196	208
HCBcB	Gas phase	10	1	100	1.5-6.8	4.0	4.1

*MDLs are presented as a guidance based on median 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, and Sofienbergparken in 2022. The colour codes indicate highest detection/concentrations in red and lowest detection/concentrations in green.

HEAVY METALS - Air							
Compound	Matrix	No. of samples	MDL	DF (%)	Concentration range	Annual mean	Annual median
Birkenes - Air (ng/m^3) Class of uncertainty: 1							
Al	Particle phase	53	0.83	98	0.781 - 123	22.6	12.5
As	Particle phase	53	0.001	100	0.016 - 0.357	0.098	0.073
Cd	Particle phase	53	0.0001	100	0.004 - 0.121	0.021	0.014
Cr	Particle phase	53	0.03	60	0.061 - 0.813	0.184	0.160
Co	Particle phase	53	0.001	79	0.002 - 0.049	0.014	0.012
Cu	Particle phase	53	0.03	100	0.052 - 1.61	0.307	0.271
Fe	Particle phase	53	0.12	98	0.808 - 89.7	22.9	15.2
Pb	Particle phase	53	0.003	100	0.095 - 3.09	0.562	0.402
Mn	Particle phase	53	0.01	100	0.149 - 2.69	0.712	0.566
Ni	Particle phase	53	0.004	87	0.016 - 0.591	0.181	0.162
Ti	Particle phase	53	0.003	98	0.048 - 6.12	1.41	1.08
V	Particle phase	53	0.001	100	0.023 - 1.60	0.326	0.212
Zn	Particle phase	53	0.06	100	0.364 - 17.0	2.85	1.83
Hg	Gas phase	8330	0.01	100	0.695 - 2.18	1.47	1.44
Zeppelin - Air (ng/m^3) Class of uncertainty: 1 and 3 (specification for individual compounds below)							
Al[1]	Particle phase	44	0.023	95	0.577 - 214	57.6	47.4
As[1]	Particle phase	44	0.001	100	0.001 - 0.506	0.054	0.023
Cd[1]	Particle phase	44	0.0001	93	0.000 - 0.390	0.036	0.013
Cr[1]	Particle phase	44	0.03	89	0.022 - 1.16	0.354	0.289
Co[1]	Particle phase	44	0.001	95	0.000 - 0.058	0.013	0.011
Cu[1]	Particle phase	44	0.001	70	0.024 - 2.62	0.367	0.177
Fe[1]	Particle phase	44	0.05	93	0.826 - 75.4	22.4	17.8
Pb[1]	Particle phase	44	0.001	80	0.012 - 2.2	0.254	0.128
Mn[1]	Particle phase	44	0.001	100	0.014 - 6.15	0.775	0.470
Ni[1]	Particle phase	44	0.001	43	0.028 - 1.67	0.189	0.081
Ti[1]	Particle phase	44	0.001	98	0.064 - 6.89	1.86	1.55
V[1]	Particle phase	44	0.001	93	0.001 - 0.243	0.074	0.063
Zn[1]	Particle phase	44	0.002	91	0.065 - 31.3	3.39	1.37
Hg-GEM[1]	Gas phase	6403	0.01	100	0.011 - 1.97	1.49	1.54
Hg-GOM[3] (pg/m^3)	Gas phase	2335	1	70	0 - 181	7.6	1.5
Hg-PBM[3] (pg/m^3)	Particle phase	2344	1	80	0 - 276	7.6	1.4

HEAVY METALS - Air							
Compound	Matrix	No. of samples	MDL	DF (%)	Concentration range	Annual mean	Annual median
Svanvik - Air (ng/m^3) Class of uncertainty: 1							
Al	Particle phase	52	1.84	87	1.65 - 271	35.6	12.1
As	Particle phase	52	0.002	100	0.008 - 0.339	0.089	0.074
Cd	Particle phase	52	0.0003	98	0.001 - 0.075	0.018	0.010
Cr	Particle phase	52	0.09	38	0.08 - 0.912	0.196	0.084
Co	Particle phase	52	0.005	54	0.007- 0.26	0.040	0.018
Cu	Particle phase	52	0.03	100	0.038 - 2.05	0.452	0.367
Fe	Particle phase	52	2.67	98	2.38 - 310	38.1	15.8
Pb	Particle phase	52	0.003	98	0.018 - 1.62	0.463	0.293
Mn	Particle phase	52	0.03	98	0.061 - 4.57	0.672	0.347
Ni	Particle phase	52	0.06	75	0.058 - 8.87	1.09	0.642
Ti	Particle phase	51	0.003	75	0.14 - 16.6	1.99	0.601
V	Particle phase	52	0.002	98	0.006 - 25.3	2.25	0.964
Zn	Particle phase	52	0.31	94	0.154 - 13.3	2.22	1.68
Sofienbergparken - Air (ng/m^3) Class of uncertainty: 1							
As	Particle phase	13	0.001	100	0.13 - 0.87	0.335	0.29
Cd	Particle phase	13	0.0001	100	0.01 - 0.43	0.091	0.05
Cr	Particle phase	13	0.09	100	0.98 - 6.06	2.48	1.83
Co	Particle phase	13	0.001	100	0.04 - 0.47	0.162	0.15
Cu	Particle phase	13	0.001	100	2.56 - 40.9	11.0	6.97
Pb	Particle phase	13	0.001	100	0.45 - 2.86	1.18	0.8
Mn	Particle phase	13	0.001	100	2.44 - 23.1	10.6	10.1
Ni	Particle phase	13	0.001	100	0.39 - 2.95	0.980	0.74
Ag	Particle phase	13	0.0001	100	0.01 - 0.04	0.014	0.010
V	Particle phase	13	0.001	100	0.350 - 3.89	1.40	1.40
Zn	Particle phase	13	0.002	100	7.17 - 57.7	20.1	14.7
Hg	Gas phase	5847	0.01	100	1.03- 2.86	1.58	1.58
Troll - Air (ng/m^3) Class of uncertainty: 1							
Hg	Gas phase	8494	0.01	100	0.318 - 2.42	0.98	1.01

Table A.6: Summary of measured concentrations (µg/L) and detection frequencies (%) of heavy metals in precipitation at Birkenes, Kårvatn, Hurdal and Svanvik in 2022. The colour codes indicate highest detection/concentrations in red and lowest detection/concentrations in green.

HEAVY METALS - Precipitation							
Hurdal (µg/l) Class of uncertainty: 1							
Compound	Matrix	No. of samples	MDL	DF (%)	Concentration range	Annual mean	Annual median
As	Precip	44	0.07	50	0.025 - 0.263	0.062	0.038
Cd	Precip	44	0.001	82	0.004 - 0.208	0.018	0.017
Cr	Precip	44	0.08	55	0.045 - 0.943	0.111	0.099
Co	Precip	44	0.003	73	0.004 - 0.353	0.017	0.018
Cu	Precip	44	0.04	100	0.099 - 58.5	4.07	3.56
Pb	Precip	44	0.008	98	0.020 - 1.45	0.333	0.355
Mn	Precip	43	0.05	100	0.223 - 31.6	1.78	1.94
Ni	Precip	44	0.01	95	0.030 - 4.59	0.330	0.321
V	Precip	44	0.005	95	0.010 - 1.77	0.119	0.113
Zn	Precip	44	0.1	95	0.300 - 50.4	5.11	5.03
Hg (ng/L)	Precip	32	2	94	1.08 - 12.9	4.27	4.09

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 analysis of heavy metals. Identification and quantification are performed by inductively coupled plasma mass spectrometry (ICP-MS), and indium (In) 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 to avoid contamination, i.e. all sample preparation is done in a clean room and all equipment used is acid-washed.

Air sampling for the analysis of heavy metals in particles at Birkenes and Svanvik is done using a Kleinfiltergerät with a PM_{10}-impactor and an airflow of 2.3 m^3/hour. Weekly samples (7 days) are collected. At Birkenes, particles are collected on Whatman 47 mm quartz filters and at Svanvik, Pall Zefluor 47 mm filters. At the Zeppelin Observatory and Sofienbergparken, sampling of heavy metals on particles are done using a Digitel high volume air sampler. At Zeppelin the sampler is used with PM_3-cut-off, and samples are collected on weekly basis, using Whatman grade 41 filter papers for 48 hours with an airflow rate of 48 m^3/hour. In Sofienbergparken, the sampler is used with a PM_{10}-impactor, samples are collected once a month for 48 hours, using Whatman grade 41 filter papers at an airflow rate of 30 m^3/hour. The filters are digested with nitric acid by Ultraclave, a microwave-based decomposition technique. Identification and quantification are performed by ICP-MS, and In is used as internal standard. The ion optic is optimized for 115 In (Table B.6).

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 analyzed for total mercury using accredited methods based on the US-EPA-method 1631. Briefly, this method utilizes BrCl oxidation, followed by $SnCl_2$ reduction, dual gold trap amalgamation, thermal desorption and cold vapour atomic fluorescence spectrometry (CVAFS) (Iverfeldt, 1991b, Bloom and Fitzgerald, 1988, EMEP manual). The detection limit is 0.05 ng/L.

Gaseous elemental mercury (GEM) 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, TBBPA, ionic and volatile PFASs, PCA/PCP, UV compounds, S/MCCPs, nBFRs, OPFRs, dechloranes, and other chlorinated FRs

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 airflow 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 CECs, the data are reported for sum gas- and particle phase (i.e. bulk concentrations) from filter and PUFs. 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. PCA/PCP and UV compounds were originally sampled with filter and a PUF/XAD/PUF sandwich. Specification on each sampler type is given in Table B.3. Flowrate 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.1: Specification on air samplers for POPs and CECs.

	DIGITEL	DIGITEL (NILU custom)	NILU sampler
Flow rate	~30 m^3/hour	~30 m^3/hour	~25 m^3/hour
Filter	GFF: Whatman Type GF/C, diameter 150 mm, pore size 1.2 µm	GFF: Whatman Type GF/C, diameter 150 mm, pore size 1.2 µm	GFF: Gelman Type AE, diameter 142 mm, pore size 1 µm
PUF plugs	Diameter 110 mm, length 50 mm, density 25 kg/m^3	Diameter 75 mm, length 40 mm, density 25 kg/m^3	Diameter 110 mm, length 50 mm, density 25 kg/m^3
Usage	iPFAS/vPFAS (Zeppelin/Birkenes) iPFAS/vPFAS, PCA/PCP, UV compounds, M/SCCPs, dechloranes, PBDEs, HBCDDs, TBBPA, nBFRs, OPFRs, other chlorinated FRs (Sofienbergparken)	HCB, OCPs, PCBs, PBDEs, TBA, HBCDDs, PAHs, M/SCCPs (Birkenes)	HCB, OCPs, PCBs, PAHs, PBDEs, TBA, HBCDDs, TBBPA, nBFRs, S/MCCPs, dechloranes (Zeppelin)

Sampling is done on a weekly or monthly basis for individual compounds and observatory according to Table 2-3. The sampling duration for each observatory and POP class varies according to Table B. The variable sampling lengths result in total air volumes of 600-2000 m^3 (as reported on sampling protocols).

Table B.2: Sampling durations for individual POP and CEC classes at each sampling station.

	Sofienbergparken	Birkenes	Zeppelin
HCB	-	24 h	48 h
OCPs	-	24 h	48 h
PCBs	-	24 h	48 h
PAHs	-	24 h	48 h
PBDEs	48 h	48 h*	72 h
HBCDDs	48 h	48 h*	72 h
TBA	48 h	48 h*	72 h
TBBPA	48 h	-	72 h
nBFRs	48 h	-	72 h
OPFRs	48 h	-	72 h
PFAS	48 h	48 h*	48 h*
PCA/PCP+UV compounds	72 h	-	-
S/MCCPs	48 h	24 h	48 h
Dechloranes	48 h	-	48 h
Other chlorinated FRs	48 h	-	-
cVMS/lCMS	48 h	72 h	72 h
Volatile F+Cl substances	48-72 h	-	72 hr
Other brominated FRs	72 h	-	-

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

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), volatile fluorinated and chlorinated substances, other brominated FRs, and PCA and UV compounds

Sampling of siloxanes, the volatile fluorinated and chlorinated substances and some "other" brominated FRs (Sofienbergparken) 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 and Sofienbergparken. At Birkenes and Zeppelin, the siloxane samples are collected from Friday-Monday (~72 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 2022 sampled at Zeppelin every second week, 72 hrs per week. At Sofienbergparken, the volatile fluorinated and chlorinated substances were sampled once per month, starting from May 2022. At Sofienbergparken, also three "other" BFRs (2,2-dimethylpropan-1-ol, tribromo derivative, 2,3,4,5-Tetrabromo-6-chlorotoluene and 2,3,5,6-Tetrabromo-p-xylene) were sampled together with HCBD, monthly and for 72h.

Each sample for siloxanes, volatile fluorinated and chlorinated substances and the "other" BFRs, 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 2022, cyclic VMS were analyzed on the samples from all stations, while linear and other VMS were analyzed additionally on the samples from Sofienbergparken 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 with 20 µL of internal standard (IS) containing ^{13}C-labelled D4, D5 and D6 (1 ng/µL). Then the cartridge was eluted slowly with ca 5 mL of hexane, which was collected directly in a vial. Before quantitative analysis, 20 µL of a recovery standard containing tetrakis(trimethylsilyloxy)silane (0.2 ng/µL) was added to the vial and the vial was sealed immediately. An aliquot was taken and transferred to a GC vial prior to instrumental analysis (Warner, 2020).

Extracts were analyzed for cVMS on an Agilent 6890 GC connected to an Agilent 5973 MS detector. For separation, a 30 m DB-5 column (Agilent Technologies, 0.25 mm I.D., 0.25 µm film thickness) and a 10 m Rxi guard column (Restek, 0.25 mm I.D.) was used. Two ions were monitored for each compound (m/z 281 and 282 for D4, 285 and 286 for ^{13}C4-D4, 267 and 355 for D5, 364 and 365 for ^{13}C10-D5, 341 and 429 for D6, 434 and 435 for ^{13}C6-D6). 4 quantification standards (10 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. For separation, a 30 m TG-5SilMS column with 5 m guard column (Thermo, 0.25 mm I.D., 0.25 µm film thickness). 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. 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 quantification standard available for phenylheptamethylcyclotetrasiloxane (Ph-D4). However, a qualitative authentic specimen was prepared in house, and this year, for the first time, the substance was identified unequivocally, albeit semi-quantitatively.

For volatile fluorinated and chlorinated substances and "other" brominated FRs, the samples were spiked with internal standards containing ^{13}C-labelled HCBD and deuterated 2,2-dimethylpropan-1-ol, tribromo derivative and 2,3,5,6-Tetrabromo-p-xylene. Then the cartridge was eluted slowly with ca 4 mL of ethylacetate, which was concentrated to 100 µL prior to instrumental analysis. The extracts were analyzed on the same instrument as lVMS (i.e. Thermo). The GC oven started at 40 °C for 1 min, followed by 30 °C min^{-1} up to 300°C for a final hold time of 5.33 min. Mass-spectral resolution was set at 60000, mass range was optimized for different analytes (m/z 180-300, 300-500 or 205-225), electron energy was 40 eV. 4-point calibration curves (0.2 ng/ml to 25 ng/ml) were used for quantification.

Due to matrix interferences, PCA/PCP and the UV compounds originally sampled with filter/PUF/XAD/PUF, were instead measured on the same extract and same instrument (i.e. Thermo) as the volatile fluorinated and chlorinated substances. The GC oven started at 60 °C for 2 min, followed by 20 °C min^{-1} up to 300°C for a final hold time of 6 min. The MS ion source was operated at 250 °C. Mass-spectral resolution was set at 60000, mass range was m/z 200-500, electron energy was 40 eV. 3-point calibration curves (0.2 ng/ml to 5 ng/ml) were used for quantification. Tolytriazole and PCP were not able to detect with this instrument.

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

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 (~100 pg/µL) for dechloranes, before being Soxhlet extracted for 8h in diethylether/*n*-hexane (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. All the extracts were concentrated and treated with sulphuric acid followed by SPE clean-up with silica. Before quantitative analysis, 20 µL of unlabelled tetrachloronaphthalene (TCN, 100 pg/µL) was added as recovery standard (RS).

Identification and quantification of HCB, PCBs and OCP were carried out using a high-resolution gas chromatography coupled to a high-resolution mass spectrometer as detector (HRGC/HRMS). The analyses were performed in Electron Impact ionization (EI) mode for PCBs, HCB, HCHs and DDTs using selected ion monitoring (SIM) for the respective compound groups. Identification and quantification of chlordanes, SCCP, MCCP, dechloranes and some "other" chlorinated FRs (chlordene plus, dechlorane plus Cl10, dechlorane plus axx Cl10, dechlorane plus ax Cl11, dechlorane plus Cl11 and chlorendic anhydride) were 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. For chlorendic anhydride, only a native standard was available which resulted in a rather semi-quantitative determination.

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 8h 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 SPE with deactivated silica (8% water). 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.

Analysis and quantification PBDEs, TBA, HBCDDs, nBFRs and TBBPA

Samples were spiked with 20 µL of IS containing ^{13}C-labelled PBDE congeners (~270-2500 pg/µL), 20 µL IS containing ^{13}C-labelled HBCDD congeners (α-, β-, γ-HBCDD, ~100 pg/µL), 20 uL of IS containing ^{13}C-labelled nBFR congeners (~1000 pg/µL), and 20 uL of IS containing ^{13}C-labelled TBBPA. The samples were then Soxhlet extracted for 8h in diethylether/*n*-hexane (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, treated with acid, and cleaned by SPE with silica. The extract was spiked with 20 µL of unlabelled TCN (100 pg/µL) and 20 µL RS containing deuterated (d18-α,β,γ) HBCDD (~130 pg/µL). Before quantitative analysis, aliquots for PBDE/TBA and nBFRs were analyzed directly. Identification and quantification of the PBDEs, nBFRs and TBA was carried out using a HRGC/HRMS operating in EI mode using SIM for the respective compound groups. From 2022, the number of PBDEs analyzed were increased from 17 to 26 PBDEs.

For identification and quantification of HBCDDs and TBBPA, an aliquot of the final sample extract was solvent exchanged into methanol. The extract was then analyzed 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 88% loss during acid treatment.

Analysis and quantification OPFRs

All glass equipment were wrapped in aluminium foil and heated to 450°C for 8h and rinsed with solvent 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 8h in acetone/hexane (1:1, v:v). The extract was solvent exchanged to acetonitrile before clean-up.

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

Filters (two filters from the same month for Zeppelin and Birkenes) were 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).

Analysis and quantification of volatile PFAS

PUF/XAD/PUF (two sets from the same month for Zeppelin and Birkenes) were 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 v/v) 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 congeners (0.1 ng/ µL) and then liquid extracted in cyclohexane for 4h. After separation and removal of the water phase the solvent extract is solvent exchanged to hexane before acid treatment and clean-up by SPE with silica.

Identification and quantification of the PCBs, HCB and HCHs was carried out using a HRGC/HRMS, as described above.

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

Detailed information about the QA/QC routines at NILU's laboratories is presented in an internal technical report for monitoring programmes (Enge et al. 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. 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 and method blank samples are routinely included to control for unintended contamination during storage, transport, and analytical steps. The number of blank samples depends on the total number of samples per year, but typically there are 3-4 field blanks and 12 lab blanks. 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.3: 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.4: 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 ^oC 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 ^oC 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 described in the internal technical report for monitoring programmes (Enge et al. 2022). The report classifies the compound classes in three categories as given below. For practical reasons, one additional category has been introduced in this report.

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: None or few reference material or satisfying interlaboratory studies available. The methods are less reproducible, and the results have higher uncertainty.

Category 4 (extra): No standard available to be purchased and it is only possible to investigate the samples based on the m/z of the compounds. Resultingly, it is not possible to predict a concentration and these compounds are reported as detected/non-detected only.

NILU

The climate and environmental research institute NILU is an independent, non-profit research institution established in 1969. Through its research NILU increases the understanding of atmospheric composition, climate change, air quality, environmental contaminants, health effects, sustainable systems, circular economy, and digitalisation. Based on its research, NILU markets integrated services and products within analysing, monitoring and consulting. NILU is concerned with increasing public awareness about climate change and environmental pollution.

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NILU's vision: *Create sustainable development through internationally leading climate and environmental research*

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