Chapter 2
Research and Monitoring of Atmospheric Persistent Organic Pollutants (POPs) in the Polar Atmosphere

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Introduction

Research and monitoring of persistent organic pollutants (POPs) in the Arctic atmosphere has a relatively long history within modern interdisciplinary environmental pollutant research. The first evidence of adverse effects of POP-like substances on ecosystems and higher organisms was already provided in 1962, when Rachel Carson's book "Silent Spring" summarized the scientific evidence on organic pollutants and opened the public discussions on adverse effects of POPs distributed through atmospheric transport over large distances (Carson 1962). Data on the occurrence of POPs in the Arctic atmosphere, however, date back to 1968, when Singer reported the contamination of the world's oceans by POPs including the Arctic oceans. The first campaign-based monitoring of POPs is reported in 1981 (Billings and Bidleman 1980). The first evidence of atmospheric POP transport to the Arctic based upon POPs monitoring was also reported in 1981 by the same group (Billings et al. 1981) followed by a monitoring report from Norway in 1984

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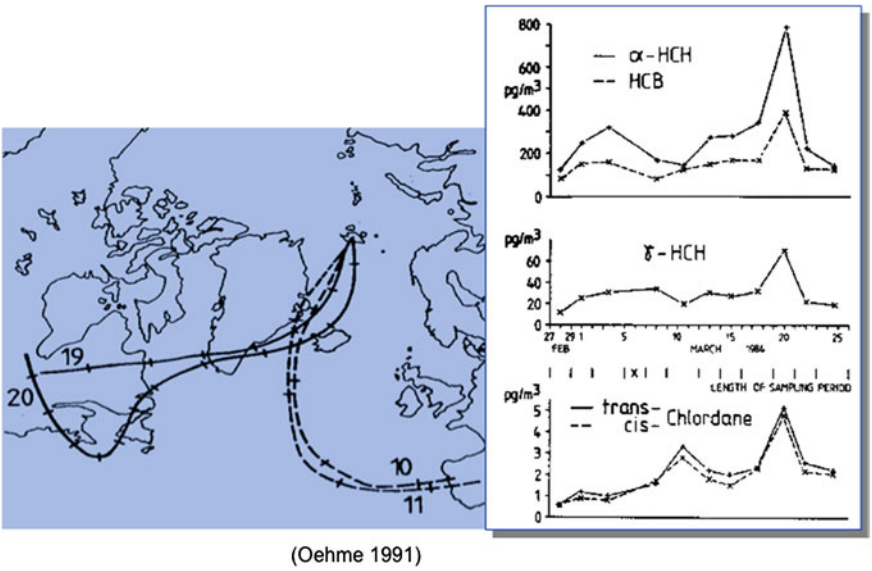

Fig. 2.1 Source region identification for air masses contaminated with elevated POPs. Figure modified according to Oehme and Ottar (1984), Oehme (1991) for compound abbreviation, see Table 2.1

(Oehme and Ottar 1984). For the first time, for this data set, meteorological modeling (back-trajectory calculations) was combined with POP monitoring date (Fig. 2.1).

Similarly, in 1981 and 1983, USA and Japanese research groups reported on the occurrence of POPs in the Antarctic atmosphere (Atlas and Giam 1981; Tanabe et al. 1983). In 1989, the first long-term monitoring programs provided the first convincing scientific evidence for the continuous hemispherical atmospheric long-range transport of POPs to the Arctic (Hung et al. 2010). These international research and monitoring activities were paving the way for today's international regulations on POPs usage and applications, documented in the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) and its Aarhus Protocol on POPs (www.unece.org/env/lrtap/pops_h1.html) and the United Nations Environment Programme (UNEP) Stockholm Convention on POPs (www.pops.int).

During the initial stage of IPY 2007–2009, the atmospheric POP monitoring was mainly focusing on the Northern Hemisphere and the Arctic. However, since only campaign-based surveys on POPs in background Antarctic locations are reported earlier (Gambaro et al. 2005; Kallenborn et al. 1998), the establishment of pollutant monitoring in Antarctica was considered an important priority for POPs research in the environmental science community, especially during the initiation of IPY 2007–2009. IPY was consequently considered by the environmental experts as important initiative and opportunity to coordinate and harmonize the current efforts on global

research and monitoring of atmospheric distribution processes for POPs, ultimately leading to accumulation and unwanted hazardous effects in the sensitive Arctic and Antarctic ecosystems. Therefore, a series of project initiatives were submitted and endorsed by IPY (ICSU and WMO) in order to establish an Antarctic–Arctic surveillance network based upon the already-established regional networks in the North (i.e., Arctic Monitoring and Assessment Programme, AMAP, and the European Monitoring and Evaluation Program, EMEP) and to identify knowledge gaps and future research priorities on coordinated POP monitoring in the polar atmosphere. Only one project initiative (*INterContinental Atmospheric Transport of Anthropogenic Pollutants to the Arctic* = INCATPA) was dedicated fully to atmospheric POP research in the Northern Hemisphere. This project was funded by Canada under IPY [initially considered as an important Canadian link into the ATMOPOL network (IPY Project No. 79)]. Although several IPY initiatives on atmospheric POP research were endorsed as relevant scientific contributions by IPYIPO, science projects dealing with international research on atmospheric POPs were unfortunately not considered as sufficiently important research priorities for involved national funding authorities. However, although not directly funded by IPY, a series of IPY associated and inspired research projects were carried out under the frame of IPY 2007–2009 despite of the lack of direct funding. All IPY projects as well as associated research activities linked to IPY projects are presented and considered in this general overview of IPY-associated research activities under the IPY scientific umbrella.

Modern POPs Monitoring and Research

Modern atmospheric POPs research and monitoring in Polar remote environments has developed from a loosely mainly campaign-based linked collaborative network of national measuring stations into a tightly connected international coordinated monitoring network following jointly developed sampling routines and quality control procedures. In polar POPs monitoring, currently, the focus is still on the long-term atmospheric POP surveillance in the Arctic. However, during the past decade, the Antarctic atmospheric POP monitoring is gaining a significant role in globally monitored polar atmospheric POP monitoring. This development leading hopefully into a global grit of POP monitoring stations is especially supported by UNEP and UNEPs international convention for the global regulation of POPs (i.e., Stockholm Convention). Currently, the Stockholm convention identified a list of 26 priority compounds (isomer/congener groups), subject for international monitoring, restrictions, and regulations (Table 2.1). The below priority list represents the core group for all official national and international atmospheric monitoring programs regardless location and regions, in which the monitoring program is performed.

Table 2.1 Recent list of priority target POPs for international regulations according to the global convention on POPs regulations (Stockholm Convention); for information, see: www.pops.int

No	Compound/compound group	Pollutant group	Characteristics	Abbreviation
1	Aldrin	Pesticide	Cyclodiene pesticide	
2	Dieldrin	Pesticide		
3	Chlordane	Pesticide		
4	Endrin	Pesticide		
5	Chlordecone	Pesticide		
6	Hepachlor	Pesticide		
7	Hexabromobiphenyl	Brominated flame retardant		
8	Hexabromocyclododecane	Brominated flame retardant		HBCDD
9	Hexabromodiphenylether	Brominated flame retardant		
10	Heptabromodiphenylether	Brominated flame retardant		
11	Hexachlorobenzene	Unintended bi-product		HCB
12	α-Hexachlorocyclohexane	Pesticide		α-HCH
13	β-Hexachlorocyclohexane	Pesticide		β-HCH
14	γ-Hexachlorocyclohexane	Pesticide		Lindane
15	Mirex	Pesticide		
16	Pentachlorobenzene	Unintended bi-product		PeCB
17	Polychlorinated biphenyls	Industrial product	209 congeners	PCB
18	Technical endosulfan (incl. isomers)	Pesticide	2 isomers	
19	Tetrabromodiphenyl ether	Brominated flame retardant	Technical mixture	
20	Pentabromo diphenyl ether	Brominated flame retardant	Technical mixture	
21	Toxaphene®	Pesticide	Chlorobornanes and derivatives	
22	Dichlorodiphenyltrichloroethane	Pesticide		DDT
23	Perfluorooctane sulfonate	Industrial product	Perfluorinated alkylated substance (PFAS)	PFOS
24	Polychlorinated dibenzodioxins	Unintended bi-product	75 isomers/congeners	PCDD
25	Polychlorinated dibenzofurans	Unintended bi-product	135 isomers/congeners	PCDF

In addition to these internationally prioritized substances, the national monitoring authorities usually include additional national priority substances in accordance with national and regional regulations and the local monitoring priorities. Therefore, the national priority lists for atmospheric POPs monitoring may deviate from in the different countries contributing to the international research and monitoring of POPs. The actual lists can be found in the national monitoring reports. For details, please consult the respective national monitoring authorities.

Relevant Project Overview

For scientific research associated with POP-related atmospheric distribution processes and pathways, IPY 2007–2009 paved the way for important follow-up activities for many of todays' internationally coordinated Polar research initiatives. A series of campaign-based field studies with potential for long-term commitment were conducted during the IPY period both in Antarctic and in Arctic locations. The atmospheric POPs monitoring coordinated by AMAP and EMEP, as well as the associated atmospheric data repository (ebas.nilu.no), played an important role in channeling, shaping, and establishing innovative research in atmospheric pollution research (fate and distribution) including POPs associated with IPY 2007–2009. Already in the initial phase of IPY 2007–2009, the scientific assessment of already-available monitoring and research data indicated that distribution and fate of POPs including long-range atmospheric transport are potentially influenced by climate change (CC) processes (Hung et al. 2005). First signs for the influence of CC were reported in national reports from the atmospheric POP monitoring at the Norwegian Atmospheric research station "Zeppelin station" (Ny-Ålesund, Svalbard) and summarized in a comprehensive publication (Kallenborn et al. 2012).

Arctic Monitoring and Assessment Programme (AMAP)

Today, AMAP plays a key role in coordinating and harmonizing pollutant monitoring (POPs, metals, radionuclides) in the Arctic. AMAP is one of six Working Groups of the Arctic Council. AMAP has the official task and obligation to:

- Monitor and assess the status of the Arctic region with respect to pollution and climate change issues;
- Document levels and trends, pathways and processes, and effects on ecosystems and humans, and propose actions to reduce associated threats for consideration by governments;

- Produce sound science-based, policy-relevant assessments, and public outreach products to inform policy and decision-making processes.

AMAP's work is directed and supervised by the Ministers of the Arctic Council and their Senior Arctic Officials, who have requested AMAP to also support international processes that work to reduce the global threats from contaminants and climate change. These include the UNEP Framework Convention on Climate Change, the Stockholm Convention on POPs, the UNECE CLRTAP (EMEP), and the Global Mercury Agreement. More information on the AMAP activities can be found at the dedicated program Web page (www.amap.no) as well as in the comprehensive status reports, which can be downloaded from here.

Atmospheric Monitoring Network for Anthropogenic Pollution in Polar Regions (ATMOPOL)

The ATMOPOL project (IPY 76) received no direct national funding for the coordinative research and screening work planned from the national IPY funding programs. However, the INCATPA initiative, developed as a direct result of the ATMOPOL planning efforts, was supported by national Canadian research funds and is separately described below in this summarizing report. ATMOPOL planned to establish a comprehensive atmospheric station network on distribution of anthropogenic pollutants (metals and organic contaminants) in the Antarctic and Arctic environment.

The final ATMOPOL research during the IPY period was restricted to scientific work funded directly via several minor research projects supported by the Norwegian national research funds (RCN), AMAP, the Nordic Council of Ministers (NCM) as well as the 7th EU Framework Programme (as collaboration with the FP7 project "Arctic Health Risks: Impacts on health in the Arctic and Europe owing to climate-induced changes in contaminant cycling; ArcRisk"). The international research performed as contribution to the ATMOPOL studies encircled the influence of CC on atmospheric distribution patterns and the identification of new emerging contaminants in Arctic environments (Grannas et al. 2013; Kallenborn et al.2012a, b; Carlsson et al. 2012; Becker et al. 2012; Olsen et al. 2011; Bengtson Nash 2011; Barber et al. 2010).

A long-term Norwegian atmospheric monitoring program on POPs was established in 2007 at the Norwegian Troll/Trollhaugen research station (Queen Maud Land, Antarctic, see below). The first monitoring period (2007–2011) on POPs in Antarctic air has been initiated, funded by the Norwegian Antarctic Research Expedition (NARE) and published with contribution from the ATMOPOL co-operation (Hansen et al. 2009). The long term first trend analysis on POP distribution in atmospheric samples from the Trollhaugen monitoring program was published in 2012 (Kallenborn et al. 2013).

Inter-Continental Atmospheric Transport of Anthropogenic Pollutants to the Arctic (INCATPA)

The *INterContinental Atmospheric Transport of anthropogenic Pollutants to the Arctic* (INCATPA, IPY 327, http://www.ec.gc.ca/api-ipy/default.asp?lang=En&n=8EBD7558-1) project was endorsed by IPY in 2006 and established in order to measure toxic chemicals produced from human activity and carried through the air to the Arctic. INCATPA focused on the environmental risks associated with the emissions of POPs and mercury (Hg) in the Pacific region for the contaminant loads in the Arctic. Before the IPY, Arctic air monitoring of POPs and Hg was performed mainly at Alert (Canada), Zeppelin (Norway), Pallas (Finland), and Storhofdi (Iceland) since the 1990s under national monitoring programs, reported to and coordinated by AMAP. Hg has also been continuously measured in air at Whistler (BC, Canada) and Amderma (Russia). During the IPY, air measurements of POPs and Hg were initiated at Little Fox Lake (Yukon, Canada) and Waliguan (China), as well as Valkarkai (Russia) (POPs only), Barrow (Alaska, USA) (Hg only), Dillingham and Fairbanks (Alaska, USA) (POPs only), Mt. Changbai (China) (Hg only), Wudalianchi and Xuancheng (China) (POPs only), Hedo Island (Japan) (POPs only), and Ba Vi (Vietnam) (POPs only). Soil and air samples were collected along the Chilkoot Trail (Yukon/Alaska, USA) in summer 2007, at different elevations. The purpose was to investigate the atmospheric deposition of POPs and emerging chemicals on mountain ranges in the Kluane National Park (Yukon, Canada). Combined with the air concentration data collected at Little Fox Lake, this work has provided insight on the roles that mountains and forests play in intercepting POPs carried by trans-Pacific air masses.

IPY INCATPA is an international collaboration among Canada, Russia, China, Vietnam, Japan, and the USA. with linkages to international air monitoring networks such as AMAP. The project aims to provide information to help determine what relative risks chemical emissions from the Pacific region pose on the Arctic environment compared to emissions from other parts of the world. These chemicals were simultaneously measured in air in the Canadian, Russian, and American Arctics, as well as at potential source regions on the Pacific Rim. Global-scale multimedia transport models were used to forecast trans-Pacific and intracontinental transport to the Arctic. The impact of changes in emissions and climate on contaminant levels and trends in Arctic air were assessed. Moreover, under INCATPA, an active outreach and communication component enhanced the general public's understanding on contaminant transport and behavior in the Arctic.

The sampling and chemical analytical protocols applied for the INCATPA collaboration and the respective samples followed the sampling and quality control procedure developed for the Canadian National Northern Contaminants Programme which is in line with the AMAP quality requirements (Hung et al. 2005).

Global Atmospheric Passive Sampling (GAPS) Network

The GAPS Network was established already before IPY2007–2009. The GAPS program was initiated in December 2004 as an initial two-year pilot study before evolving into a long-term monitoring network. Today, the monitoring network consists of more than 50 sites on seven continents using polyurethane foam (PUF) passive air samplers to monitor POPs (Bengtson Nash et al. 2011).

The GAPS Network is a long-term international passive air monitoring program that supports the research and policy needs of Canadian and international programs on POPs. Internationally, GAPS helps to assess effectiveness of control measures that have been implemented for POPs under treaties such as the Stockholm Convention on POPs, and the POPs Protocol of the CLRTAP under the UNECE.

GAPS was the only global-scale program for air that reported to the first global monitoring plan (GMP) of the Stockholm Convention on POPs, adopted at COP4 in May 2009 in Geneva. Air is one of two core media (human tissues being the other) under the GMP. The GAPS approach to passive air sampling is promoted in the Guidance Document for the GMP as a feasible and cost-effective way to improve spatial coverage. For some of the UN regions and subregions, air measurements from GAPS represent the only available data for POPs in air. The GAPS Network promotes and assists in capacity building projects that aim to fill data GAPS and develop regional air sampling networks for POPs that employ passive samplers (Xiao et al. 2007).

Results from GAPS measurements of POPs in air are integrated with other information (Fig. 2.2) to assess temporal trends of POPs (effectiveness of control measures) and for investigating regional and long-range transport of POPs and other priority chemicals. The role of variable meteorology and climate has also been shown to be critical for this analysis. The GAPS Network is a today key program for producing comparable global-scale data for POPs in the troposphere. The GAPS Network conducts measurements of POPs and priority chemicals in air with the following objectives:

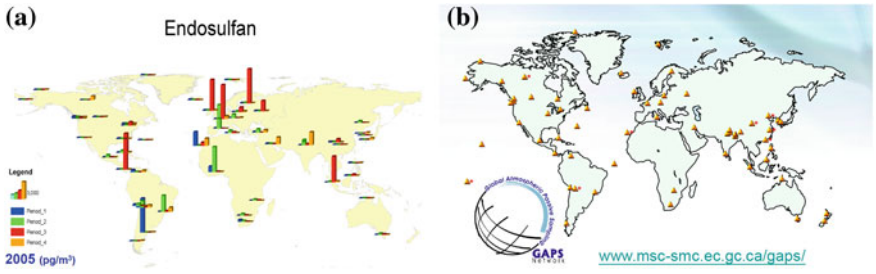

Fig. 2.2 **a** Spatial distribution of pollutants (example: endosulfan 2005) as well the station network **b** for the GAPS Network

1. Demonstrate the feasibility of passive air samplers (PAS);
2. Determine spatial and temporal trends in air;
3. Screen for and identify new chemicals in air; and
4. Contribute useful data for assessing regional and global long-range atmospheric transport.

Target chemicals include legacy POPs listed under the Stockholm Convention such as PCBs and organochlorine pesticides (OCPs) as well as emerging priority pollutants—e.g., brominated flame retardants, polyfluorinated chemicals, and current-use pesticides, to name a few. Under the GAPS Network, seasonality and long-term temporal trends can be investigated.

Pilot studies are currently undertaken in order to assess a modified PUF disk sampler comprising XAD powder impregnated onto PUF disks (sorbent-impregnated PUF or SIP disks). SIP disks have a higher retention capacity compared to PUF disks and are well suited for capturing the more polar and volatile priority chemicals. The modified samplers also are useful for screening and identifying new compounds of interest that may be present in the atmosphere.

Circumpolar Flaw Lead (CFL)

The circumpolar flaw lead (CFL), which forms in the Arctic sea ice each year, is a path of thinner ice and interconnected polynyas (areas of open water). It separates the mobile pack ice from coastal ice attached to the land. As a warming climate causes the sea ice to decline, the structure of the CFL changes. The main goal of the CFL study was to better understand changes in the flaw lead, and their repercussions for other physical and biological processes in the Arctic. The research priorities of IPY-CFL were performed in 10 thematic subgroups: (1) Physical oceanography, (2) Sea ice, (3) Primary production, (4) Pelagic and benthic food web, (5) Marine mammals, (6) Gas fluxes, (7) Carbon fluxes, (8) Contaminants, (9) Modeling, and (10) Arctic people. In addition, several public outreach initiatives were also part of IPY-CFL.

However, atmospheric POPs research was an integrated part in this large interdisciplinary scientific program. More details on the science program and the outcome of the CFL initiative can be found in a comprehensive review recently published (Bengtson Nash et al. 2008).

Organic Atmospheric Pollutants: Research and Monitoring in Antarctica

The establishment of atmospheric environmental pollutant research and monitoring in Antarctica is a demanding task, both from an economic and from a logistical point of view. In addition, as the major POP source regions have traditionally been

located in the Northern hemisphere, pollutant distribution and environmental effects in the comparatively pristine Antarctic environments have to date been considered as of minor relevance for comprehensive environmental risk assessment. Therefore, pollutant research in Antarctica is documented only in relatively few scientific reports and studies. However, during IPY 2007–2009, several national Antarctic research programs established pollutant monitoring and screening in various environmental media including the atmosphere. Also the GAPS atmospheric monitoring program is maintaining several atmospheric units in Antarctic stations. These monitoring- and research-based scientific data will without doubt contribute to a better understanding of the global distribution processes underlying the ubiquitous distribution profiles identified for many legacy POPs. Here, few examples are described in order to illustrate the importance of these types of investigations and long-term commitment for the scientific understanding of fate and distribution of POPs in pristine environments.

Atmospheric POPs Monitoring at the Antarctic Troll Station (Trollhaugen)

Initiated and motivated by IPY supported priority funding, the Norwegian Antarctic Research Expedition (NARE) program extended the already-established Norwegian Summer Research station "Troll" in Dronning Maud Land (Queen Maud Land, Antarctica) into a year-around research station in 2005. In 2007, several IPY funded activities were conducted at Troll including the atmospheric pollutant monitoring. Currently, research campaigns and monitoring in a variety of research field are carried out at Troll.

The scientific monitoring and research program at the Troll Atmospheric Observatory is managed by the Norwegian Institute of Air Research (NILU). In 2014, the atmospheric measurements were moved from the Troll Atmospheric Observatory to the less perturbed site Trollhaugen situated one km east of research station Troll, 235 km from the Antarctic coast. Since 2007, NILU is performing continuous year-around measurements of Hg, surface ozone, CO, aerosols (chemical, physical, and optical properties), UV radiation and total ozone, selected POPs, and an extended number of light hydrocarbons and chlorofluorocarbons (CFCs).

The year-around atmospheric monitoring of the above-listed wide variety of pollutants at the Troll/Trollhaugen atmospheric monitoring station aims at improving today's scientific knowledge on distribution mechanisms for atmospheric transport of pollutants into Antarctica. The overall strategies for the monitoring activities are comprehensively summarized in a scientific review publication (Bengtson Nash et al. 2013). The monitoring is also coordinated with other ongoing campaign-based screening activities at other stations in Antarctica, such as Germany's Neumayer Station, the Australian Casey observatory, and the UK's Halley Research Station.

POPs are measured at Troll/Trollhaugen using high-volume active air samplers. Samples are collected on a weekly basis (i.e., 52 samples per year). The

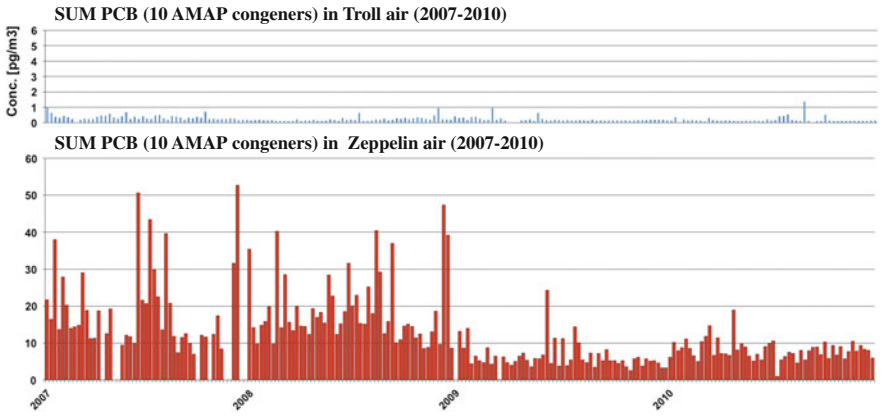

Fig. 2.3 Comparison of air concentrations (pg/m^3) of sum 10 priority PCBs (integrated weekly samples, PCBs: 28, 52, 99, 101, 118, 138, 149, 153, 170, 180) from Antarctica (Troll station) and Arctic (Zeppelin Atmospheric observatory, Ny-Ålesund, Svalbard) for the period 2007–2009 (Hung et al. 2010; Hansen et al. 2009; Kallenborn et al. 2013)

here-established year-around monitoring of POPs is currently considered as the longest continuous monitoring program in Antarctic air covering the time period 2007–2015. Details on the POPs atmospheric monitoring at the Troll station including discussion on POPs monitoring data collected in the weekly samples during the period 2007 until 2010 are summarized in a recent publication (Hansen et al. 2009; Kallenborn et al. 2013).

Targeted POPs are 32 PCB congeners, α- and γ-HCH, trans- and cis-chlordane, *trans*- and *cis*-nonachlor, *p,p′*- and *o,p*-DDT, DDD, and DDT as well as HCB. In general, the monitored concentrations of POPs at Troll in 2007–2010 are one order of magnitude lower than those measured in the Norwegian Arctic atmospheric background site; Zeppelin in Ny-Ålesund, Svalbard (Fig. 2.3). Similarly as observed in Arctic air samples, HCB is the predominant POP compound at the air samples from Troll with levels of around 20 pg/m^3 throughout the years (22.9 pg/m^3 average concentration in 2010). In general, the following concentration distribution has been found in air samples from Troll: HCB > Sum HCH > Sum PCB > Sum DDT > Sum chlordanes.

Even when considering the much lower POP concentration levels in Antarctic air compared to POP levels in Arctic air, atmospheric transport episodes were identified in the already-available data provided from the Troll/Trollhaugen observatory (Hansen et al. 2009; Kallenborn et al. 2013). The long-term monitoring data from Troll also confirm that atmospheric long-range transport is a major contamination source for POPs in atmospheric environments above the Troll station observatory. Several long-range transport events were identified characterized by unusual elevated levels of pesticides and/or industrial originated compounds. Back-trajectory calculations and complex transport modeling (FLEXPART) were applied for source apportionment and confirmation of transport pathways. In all

cases, contaminated air masses arriving from potential South American and South African sources were identified.

The air concentrations of POPs at Troll station are comparable with earlier measuring campaigns reported from other Antarctic research station from the past 18 years. For all compounds, higher levels were found in samples collected during the early 1990s except for HCB for which in all samples regardless time period similar concentration distribution was observed. These concentration reductions for most of the target substances are obviously a direct consequence of international regulations restricting the usage of POP-like chemicals on a worldwide scale (Hansen et al. 2009; Kallenborn et al. 2013).

Atmospheric POPs Monitoring at the Antarctic Casey Station

In 2009, the Southern Ocean POPs Program of Griffith University was tasked by the Australian federal Department for Environment to undertake continuous atmospheric monitoring for POPs in the Australian Antarctic Territory to serve Australia's obligations under the GMP. The first year's worth of data, reported in the 2011 project report (Wild et al. 2014), provided the first information regarding the chemical composition of air masses of the Australian Antarctic Territory (constituting 42 % of the Antarctic continent) in over two decades.

Atmospheric sampling via a high flow through passive sampler has been continuously measuring POPs at the selected sampling site, the abandoned Wilkes station, near Australia's all-year Casey station (66°16'54"S and 110°31'27"E), since sampling was initiated in 2009. The routine repertoire of chemicals monitored at this location includes OCPs, PCBs, and polybrominated diphenyl ethers (PBDEs). The first results from the program found HCB and Endosulfan-I to be the compounds detected in the highest quantities. Findings of HCB are in accordance with previous reports which have shown HCB to be a dominant compound accumulating in Southern Ocean food webs. Sampling found strong indications of the active all-year Casey station acting as an emitter of PBDEs to the local environment, a finding that has since been further investigated and published by the SOPOP Program.

Analysis of the Casey Station air shed was ineffectual at linking contaminants to potential lower latitude source regions. The study hereby highlighted the limited application of back-trajectory-based analysis in Antarctica due to the circumpolar vortex and effective mixing of air masses that occurs once wind masses reach south polar latitudes.

Quantification of the chemical composition of Antarctic air masses provides information regarding system input from hemispheric sources via this pathway. Continuous long-term measurements are still needed to facilitate evaluation of temporal contamination trends and hereby the effectiveness of the aims of the Stockholm Convention in reducing or eliminating these chemicals from the environment. To this effect, sampling at Casey station remains ongoing with further reports and articles in preparation.

Achievements and Perspectives

The national IPY supporting programs officially funded only two project initiatives; from ca. 30 officially IPY-IPO endorsed initiatives, where the in-depth research on atmospheric distribution of POPs was an important scientific goal. The INCATPA and the (CFL) initiative were both funded by the Canadian IPY funding program. However, the establishment of extended atmospheric POP monitoring activities, where already-operative national programs were substantially extended with new emerging target substances, recently identified as relevant long-range transported pollutants, is considered a significant spin-off of IPY and the related research on polar environmental pollutants. In many circum-Arctic countries (i.e., Canada, USA, Norway, and Russia), already-operative POP monitoring programs were extended and upgraded. These updated long-term polar atmospheric POPs monitoring programs are today considered important data providers for a variety of interdisciplinary research activities in environmental sciences including fate modeling and environmental impact assessments. In Antarctica, two new POP atmospheric monitoring programs were established: one at the Norwegian "Troll/Trollhaugen" station and one at the Australian research station "Casey." Both monitoring programs follow today similar sampling and quality control protocols established according to the quality control guidelines of the AMAP atmospheric monitoring network. These new stations, thus, complement the already-established (Arctic) monitoring network with an Antarctic module, where data and results are easily comparable. Therefore, this established multinational network has the potential to develop into a global network of active sampling and monitoring for POPs in background polar environments.

The GAPS Network has been established before IPY, but was significantly advanced by establishing new stations during IPY. Today, GAPS is utilized actively and constantly referred to by the UNEP's global regulation for POPs (Stockholm Convention) as important surveillance tool for the evaluation of spatial and temporal trends of priority POPs on a global scale.

During the INCATPA initiative, a strong focus was laid upon identification and characterization of potential source regions for the atmospheric POP transport across the Pacific Ocean. In this context, several new atmospheric monitoring locations were established (i.e., in Vietnam, China) and are still operative, maintained by the hosting national institutions.

The CFL initiative followed a strongly interdisciplinary approach, where a research platform (in this case the RV Amundsen) was located in the Beaufort Sea during one year, allowing scientists coordinated research programs and fieldwork under Arctic environmental conditions. The here-obtained results could be discussed and interpreted already aboard across the disciplinary borders among the participating scientific groups. The CFL initiative has been highly productive and produced a large number of highly cited scientific publications (http://umanitoba.ca/ceos/research/cfl.html). The already-demonstrated efficiency of this strategy motivated other national program to embark on similar field studies. Recently, the field

campaign of a Norwegian National Arctic research program has been finalized where the Norwegian Research Vessel Lance was located for six months in the marginal ice Zone northwest of Svalbard as research platform for interdisciplinary research on Arctic climate change (N-ICE; see www.npolar.no).

Although only two projects were officially supported by IPY national funding, a variety of ongoing research projects linked into IPY research activities gained considerable scientific profit from the national and international funding priorities and collocation with other funded IPY projects. New infrastructures for POPs research and monitoring were established (ATMOPOL, INCATPA, and GAPS). New future directed research strategies were developed and applied in the field (CFL). A significant legacy component for atmospheric monitoring of POPs in Polar Regions is associated with the establishment of the new POPs atmospheric monitoring locations in Antarctica, where the Troll/Trollhaugen and the Casey site are adding complementary value to the already-established circum-Arctic atmospheric POPs monitoring, officially established during the early 1990. In this way, the long-term circum-Arctic atmospheric POPs monitoring was extended into a clearly Polar network and hopefully many other stations will join this undertaken in the near future.

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