

# Passive Air Sampling of Polychlorinated Biphenyls and Organochlorine Pesticides at the Korean Arctic and Antarctic Research Stations: Implications for Long-Range Transport and Local Pollution

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To assess levels and patterns of polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs) in polar regions, XAD-resin based passive air samplers were deployed for one year at the Korean polar research stations at Ny-Ålesund, Norway (2005–2006) and King George Island, Antarctica (2004–2005). Backward trajectories suggest that these stations are affected by long-range transport from source regions in Northern Europe and Russia and the southern tip of South America, respectively. Relatively high levels of PCB-11, averaging  $60 \text{ pg} \cdot \text{m}^{-3}$ , were observed in Antarctica, suggesting an unusual source of PCB-11 to the Southern Hemisphere. Reflecting the hemispheric distribution of global PCB emissions, the average level of  $\Sigma_{205}\text{PCB}$  (excluding three mono-CBs and PCB-11) was five times higher in the Arctic ( $95 \text{ pg} \cdot \text{m}^{-3}$ ) than in the Antarctic ( $19 \text{ pg} \cdot \text{m}^{-3}$ ). Levels of  $\Sigma_9\text{PCB}$  at Ny-Ålesund were similar to those reported for other Arctic sites, while levels at King George Island were lower than at other sites on the Antarctic Peninsula but 1 order of magnitude higher than background levels measured at a more remote Antarctic site. Light homologues were predominant in all samples (except for one Arctic sample), consistent with the hypothesis of global fractionation

and predictions of long-range transport potential. Dominance of heavy PCBs on the roof of the main building at Ny-Ålesund and a concentration gradient with distance from the main building at King George Island strongly indicated the influence of local sources. OCP levels were also influenced by long-range transport but not by local sources. This study highlights the feasibility of using passive air sampling to assess both long-range transport and local pollution in remote regions.

## Introduction

Polychlorinated biphenyls (PCBs) and many organochlorine pesticides (OCPs) are classified and regulated as persistent organic pollutants (POPs) under the Stockholm Convention. Produced for industrial purposes, global PCB production and emissions are relatively well established and were centered around Northern midlatitude regions (1–3). POPs are ubiquitous, being detected regularly in samples from remote polar regions. The occurrence in these pristine environments has been explained by the process of global cold-trapping and fractionation (4), and long-range atmospheric transport (LRAT) has been identified as one of the main pathways for POPs to polar regions (5–7). The potential additional influence of anthropogenic activities within the polar regions is illustrated by reports of elevated levels of PCBs in atmosphere and sediments at McMurdo station, Ross Island, Antarctica (8, 9). Antarctic soils were also reported to be contaminated by remote and local sources of PCBs (10). These studies suggest that both LRAT and local pollution play a key role in determining the level and pattern of POPs at polar research stations.

Atmospheric monitoring of POPs in remote regions traditionally relies on high volume air samplers (HiVol). However, active air sampling is typically limited to short time periods. Also, there is often no electricity supply at truly remote sites, i.e. away from research stations and their generators. In recent years, various types of passive air samplers (PAS) have been developed and used for POPs monitoring (11–15). A PAS consists of a sorbent material (e.g., XAD resin, triolein, and polyurethane foam) placed in a protective chamber. POPs physically sorb to the sorbent after diffusion to the sorbent surface. Details on the theory of passive air sampling can be found elsewhere (16). Because of their simplicity, PAS can be installed at multiple sites, yielding relatively highly spatially resolved air concentrations from the local to the global scale (17–23).

Here we compare passive air sampling data collected at north and south polar sites with the aim to investigate the influence of LRAT and local pollution on atmospheric POPs levels at remote research stations. Specifically, we report annual average concentrations of several OCPs and of the full slate of PCB congeners at sites with variable distance from the Korean polar research stations in Ny-Ålesund, Spitsbergen, Norway and King George Island, Antarctica. The measured data are compared among sampling sites and with the results of previous studies conducted in the polar regions. Meteorological data and model simulations are used to identify the potential influence of LRAT and local pollution.

## Materials and Methods

**Passive Air Sampler.** XAD 2-resin based PAS were used in this study because their sampling rate is not strongly dependent on wind speed (13), and semivolatile organic compounds do not approach equilibrium between air and the PAS's XAD resin for more than one year (13, 24).

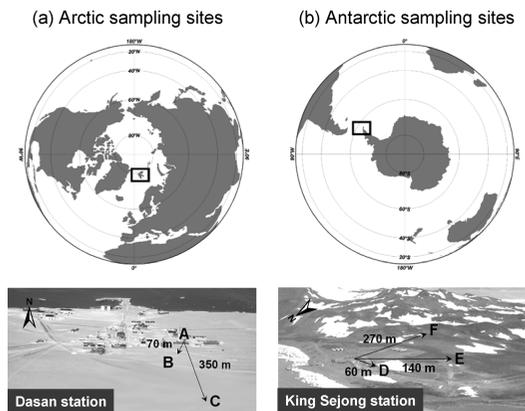
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**FIGURE 1.** Locations of passive air sampling sites at the Korean polar research stations: (a) Dasan station ( $78^{\circ}55'N$ ,  $11^{\circ}56'E$ ) at Ny-Ålesund, Spitsbergen, Norway and (b) King Sejong station ( $62^{\circ}13'S$ ,  $58^{\circ}47'W$ ) on the Barton Peninsula, King George Island, Antarctica.

Accordingly, POPs are believed to remain within the linear uptake phase of the PAS during a one-year deployment, and air concentrations ( $\text{pg}\cdot\text{m}^{-3}$ ) can be estimated semiquantitatively from the amounts of chemicals sequestered by the PAS ( $\text{pg}\cdot\text{PAS}^{-1}$ ) using a sampling rate of  $0.52\text{ m}^3\cdot\text{day}^{-1}\cdot\text{PAS}^{-1}$  (13). This PAS has been used for year-round monitoring of PCBs and OCPs at various sites, including some in the Canadian Arctic (17, 20, 25). Prior to PAS deployment, XAD resin was Soxhlet extracted with acetone for 24 h, followed by two extractions with toluene. The XAD resin (60 mL for each PAS) was dried in a clean desiccator and transferred to a precleaned stainless steel mesh container and sealed in an airtight stainless steel tube with Teflon stoppers. These PAS columns were stored at  $-4^{\circ}\text{C}$  until being shipped to sampling sites. Details on sampler preparation and sampling procedures can be found elsewhere (13, 25).

**Sampling Sites.** “Dasan”, operating since April 2002 and located in Ny-Ålesund on the high Arctic island of Spitsbergen, Svalbard, Norway ( $78^{\circ}55'N$ ,  $11^{\circ}56'E$ ), is part of an international research station involving France, Germany, Italy, Japan, Korea, Norway, and the United Kingdom. “King Sejong”, located on the Barton Peninsula, King George Island, Antarctica ( $62^{\circ}13'S$ ,  $58^{\circ}47'W$ ), has been operating as a permanent research station since February 1988. These two stations are supported by the Korea Polar Research Institute. The PAS were deployed for one year at three sites (A, B, C) in Ny-Ålesund (August 7, 2005–August 1, 2006) and three sites (D, E, F) on King George Island (December 18, 2004–December 5, 2005). In order to investigate the influence of local pollution, the sampling sites varied in terms of their distances from the main buildings (Figure 1). After one year of deployment, the XAD-filled mesh cylinders were retrieved using airtight stainless steel tubes with Teflon stoppers and were transported to the laboratory along with field-blank samples (17). The retrieved samples were stored at  $-4^{\circ}\text{C}$  until extraction.

**Meteorological Parameters.** Hourly data for wind speed, wind direction, and air temperature were measured by automated weather systems operating in the vicinity of the sampling sites. Temporal changes in air temperature and wind speed were plotted, and wind-rose diagrams were constructed to find the dominant wind directions and to investigate the relationship between air concentrations and the location of the sampling sites. To identify the origin of air masses arriving at the Arctic and Antarctic stations, five-day backward trajectories with a starting height of 50 m were calculated once a day at 0 UTC (Coordinated Universal Time) for the entire sampling period using HYSPLIT 4 (<http://www.arl.noaa.gov/ready/hysplit4.html>).

**Chemical Analysis.** A full description of the analytical procedure is provided in the Supporting Information. In summary, XAD 2-resin samples were analyzed in batches of six, each consisting of two procedural blanks, a field blank, and three real samples. The resin samples were Soxhlet extracted, and the extracts were cleaned up by silica gel chromatography and activated alumina chromatography. All 209 PCB congeners and the OCPs (HCH, aldrin, dieldrin, heptachlor, octachlorostyrene, endosulfan (I and II), endosulfan sulfate, chlordane, nonachlor, DDE, DDD, DDT, and mirex) were analyzed by an Agilent-6890 gas chromatograph coupled to a Micromass Ultima (Micromass, U.K.) high-resolution mass spectrometer. Recoveries of internal surrogate standards for both PCBs and OCPs were between 65 and 110%, and the accuracy of determining PCBs and OCPs in spiked samples was between 15 and 20%.

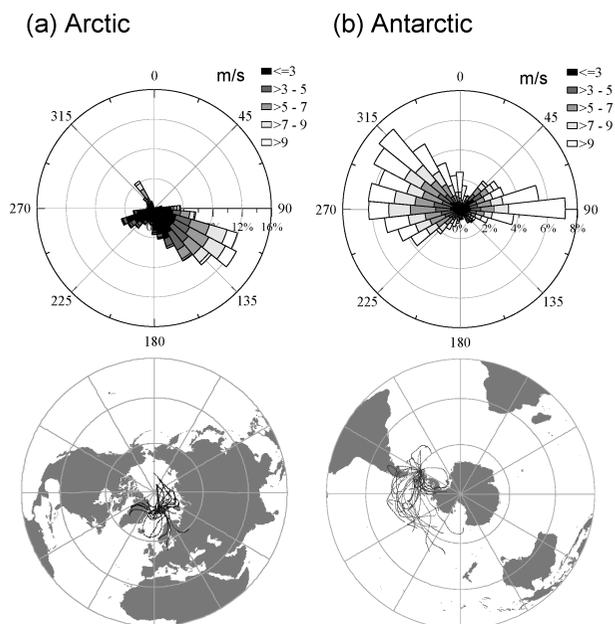
**Multimedia Environmental Model.** The measured PCB data were compared with simulation results obtained with the zonally averaged global multimedia environmental model Globo-POP. The Arctic and Antarctic regions are two of 10 climate zones in this model. Each climate zone is represented by four vertical air layers, different types of soils (cultivated, uncultivated, coniferous and deciduous forest soils), forest canopies (coniferous and deciduous), fresh water, fresh water sediment, and the surface ocean. A full description of the model and a history of modifications can be found elsewhere (26–29). Model-input properties for 11 selected congeners (PCB-8, 28, 31, 52, 101, 105, 118, 138, 153, 180, 194) have been described elsewhere (4). Historical emission data were obtained from the updated global PCB emission inventory (3). The high emission scenario in ref 3 was used because it was previously found to produce levels and patterns of PCBs in the Arctic atmosphere that are comparable with measured data (4). Whereas the uncertainty of predicted absolute concentrations would be high, predicted congener patterns are believed to be reliable because these patterns are mostly determined by the fairly well established compositions of technical PCB mixtures.

## Results and Discussion

**Meteorological Conditions.** Time series of air temperature and wind speed for the sampling periods are depicted in Figure S1 in the Supporting Information. The average temperature and wind speed at the Arctic station were  $3.8\text{ m/s}$  and  $-4.3^{\circ}\text{C}$ , respectively; those at the Antarctic station were  $7.4\text{ m/s}$  and  $-1.9^{\circ}\text{C}$ , indicating relatively mild meteorological conditions at both sites. The daily maximum wind speeds were generally less than  $10\text{ m/s}$  at the Arctic station and less than  $15\text{ m/s}$  at the Antarctic station. Wind tunnel experiments suggested that wind speeds up to  $15\text{ m/s}$  had little effect on the sampling rate of the XAD resin-based PAS (13).

Wind-rose diagrams and five-day backward trajectories were considered to evaluate potential pollution within the stations and the influence of LRAT (Figure 2). All monthly trajectory plots are presented in Figure S2. Southeasterly winds were prevailing at Dasan, while Northern and North-western winds were dominant at King Sejong. The wind-rose diagrams in combination with the site map (Figure 1) suggest that the Antarctic sampling sites are located down-wind from the main building. Those sites (D, E, F) may therefore have been influenced by emissions from buildings or other potential local sources within the station. This is not the case for the Arctic sites.

The trajectory analyses show the influence of the polar easterlies at Dasan and the prevailing westerlies at King Sejong (Figure S2). There are no large seasonal differences in trajectory patterns at either station. Considering these patterns, the levels of PCBs at the Arctic station may be considerably affected by emissions from Russia and Northern



**FIGURE 2.** Wind-rose diagrams during the whole sampling periods and five-day backward trajectories in August 2005 at the Korean Arctic and Antarctic stations.

European countries. Indeed, high levels of coplanar PCBs were measured in the Barents Sea when air parcels originated from Norway, the United Kingdom, and the North Sea (30). On the other hand, most air at the Antarctic station came from the South Pacific Ocean, and 14% of the total air trajectories passed over the southern tip of South America. On the basis of a global emission map of PCBs for the year 2005 (Figure S3) with  $1^\circ \times 1^\circ$  resolution (3), the Antarctic peninsula might be under the slight influence of emission in Argentina and Chile. Air concentrations of light PCB congeners at the Brazilian station on King George Island were reported to increase with the passage of frontal systems from South America (5).

**PCB Concentrations.** Field and procedural blank data ( $\text{pg} \cdot \text{PAS}^{-1}$ ) and time-averaged concentrations ( $\text{pg} \cdot \text{m}^{-3}$ ) of 206 PCB congeners measured at the six sites are provided in the Supporting Information (Tables S1 and S2). Three monochlorinated PCBs are not reported due to low recovery. Field-blank values were generally higher than procedural-blank values (Table S1), thus the congener values in Table S2 were field-blank corrected. The annual mean concentrations of PCB congeners and total homologues are summarized in Table 1. A total of 31 PCB congeners including 22 congeners (IUPAC number 5, 8, 18, 28, 31, 52, 70, 90, 101, 105, 110, 118, 123, 132, 138, 149, 153, 158, 160, 180, 194, 199) that have global emissions estimates (3) and 12 coplanar (dioxin-like) congeners (77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, 189) were selected for discussion in the text below. Their total TEQ (Toxic Equivalency Quantity) concentrations were calculated using WHO-TEFs (Toxic Equivalency Factors) (31).

The average concentration of total PCBs ( $\Sigma_{206}\text{PCB}$ ) is higher at Ny-Ålesund ( $105 \text{ pg} \cdot \text{m}^{-3}$ ) than on King George Island ( $78 \text{ pg} \cdot \text{m}^{-3}$ ), but only Site A shows a significantly higher level of  $\Sigma_{206}\text{PCB}$  than the Antarctic sites. The sum of selected congener concentrations ( $\Sigma_{31}\text{PCB}$ ) accounts for 43 and 6% of the total ( $\Sigma_{206}\text{PCB}$ ) for the Arctic and Antarctic sites, respectively. This difference resulted from high levels of PCB-11 (average:  $60 \text{ pg} \cdot \text{m}^{-3}$ ) at King Sejong (see Table S2). Much lower levels of PCB-11 (average:  $9 \text{ pg} \cdot \text{m}^{-3}$ ) were detected at Dasan, but they are still higher than those of most other congeners in Table 1, except for several hexachlorinated congeners. When PCB-11 is excluded, the average of  $\Sigma_{205}\text{PCB}$  is five times larger at Dasan ( $95 \text{ pg} \cdot \text{m}^{-3}$ ) than at King Sejong

( $19 \text{ pg} \cdot \text{m}^{-3}$ ), reflecting the hemispheric distribution of global PCB emissions.

Among the technical PCB mixtures, only Aroclor 1232 contains 0.08% of PCB-11 (32–34). We would thus expect to detect no or only very low levels of PCB-11. After thorough investigation of potential contamination during sample processing, interference from other compounds during GC/MS analysis, and the QA/QC process, we concluded that high concentrations of PCB-11 were real. The identification of PCB-11 meets all the QA/QC criteria: retention time within 2 s of that established from the standard solution, monitoring of two corresponding isotopic ions at 10,000 resolution, the isotope ratio being within 15% of the theoretical value, and the two isotopes eluting within 2 s from each other. Levels of PCB-11 in the procedural blanks are only 1.1% of those in the samples. Accordingly, there may be a unique source of PCB-11, especially in the Southern Hemisphere. A recent study revealed that PCB-11 was one of the predominant congeners in refuse-derived fuel and automobile shredder residue (35). Significant production of PCB-11 was also observed during manufacturing of organic pigments near the New York/New Jersey Harbor, with PCB-11 contributing 5–20% of total PCBs (36, 37). PCB-11 was also found to be a useful tracer for wastewater inputs in the Delaware river (38). PCB-11 was detected in the stack gas of municipal solid waste incinerators (MSWI) in South Korea (39), even though the contribution of PCB-11 to the total PCBs was only 0.1%. Relatively high levels of atmospheric PCB-11 ( $56$ :  $15$ – $244 \text{ pg} \cdot \text{m}^{-3}$ ) at an urban site in South Korea were also reported (40), and unexpected high levels (1–9 mol %) of PCB-11 were detected in human milk samples from Korean women (41). In addition, air monitoring (February 2006–March 2007) data for the South Pacific research station at Chuuk, Micronesia (unpublished data) show the dominance of PCB-11, demonstrating that not only polar sites but also tropic background sites are significantly influenced by unknown sources of PCB-11. In conclusion, we believe that there are unidentified global sources of PCB-11. More intensive investigations on PCB-11 are required to explain why PCB-11 is more abundant in the Antarctic atmosphere and to reveal global sources of this congener.

Only a few studies have reported the levels of coplanar (dioxin-like) PCBs in the polar atmosphere (30, 42, 43). The average coplanar PCB concentration in this study is three times higher at Dasan ( $1.43 \text{ pg} \cdot \text{m}^{-3}$ ) than King Sejong ( $0.49 \text{ pg} \cdot \text{m}^{-3}$ ), whereas total TEQ values showed the opposite (Dasan:  $0.05 \text{ fg} \cdot \text{m}^{-3} <$  King Sejong:  $0.17 \text{ fg} \cdot \text{m}^{-3}$ ) due to higher levels of PCB-169 (TEF = 0.03) in the South. Coplanar PCB levels at Ny-Ålesund are lower than those in the Barents Sea (average:  $6.22 \text{ pg} \cdot \text{m}^{-3}$ ) and comparable to those in the Eastern Arctic Ocean (average:  $0.98 \text{ pg} \cdot \text{m}^{-3}$ ) (30), reflecting a gradient with increasing distance from emissions in Northern Europe and Russia. The coplanar PCB levels at the Russian Arctic station on Dunai Island ( $0.44 \pm 0.19 \text{ pg} \cdot \text{m}^{-3}$ ) and low levels at two Canadian Arctic stations at Alert ( $0.10 \pm 0.05 \text{ pg} \cdot \text{m}^{-3}$ ) and Tagish ( $0.05 \pm 0.03 \text{ pg} \cdot \text{m}^{-3}$ ) in 1994–1995 also indicate the influence of Eurasian sources (42).

**Comparison of PCB Levels among Polar Sites.** As most previous studies of PCBs in the polar atmosphere report concentrations of the nine congeners (PCB-18, 52, 101, 118, 128, 138, 153, 180, 187), they were used for comparison of circumpolar levels. Concentrations of each congener and the sum of nine congeners at various Arctic (7, 25, 44, 45) and Antarctic stations (5, 46–48) are listed in Table S3. In most cases, particle-phase concentrations were not reported because the majority of the PCBs were found in the gas phase. Table S3 only allows for a rough comparison between polar sites, as sampling time and period differ, and season was found to be important in controlling PCB levels in the polar atmosphere (49). Levels of  $\Sigma_9\text{PCB}$  at

**TABLE 1. Annual Mean Concentrations ( $\text{pg}\cdot\text{m}^{-3}$ ) of Selected PCB Congeners and Homologues at the Arctic Sites (A, B, C) in 2005/2006 and at the Antarctic Sites (D, E, F) in 2004/2005<sup>a</sup>**

congener	Arctic site			Antarctic site		
	A	B	C	D	E	F
DiCB-5/8	6.28	3.63	2.55	1.42	0.20	0.68
TrCB-18	6.95	4.33	3.52	1.22	0.53	0.77
TrCB-28	5.95	3.30	2.61	0.55	0.32	0.15
TrCB-31	4.50	1.80	2.44	0.85	0.33	0.51
TeCB-52	5.74	2.29	2.03	0.76	0.26	0.58
TeCB-70 (76)	1.45	0.72	0.66	0.31	0.01	0.18
<b>TeCB-77</b>	0.10	ND	0.04	0.20	0.07	0.04
<b>TeCB-81</b>	ND	ND	ND	ND	ND	ND
PeCB-90	0.46	ND	0.05	ND	ND	ND
PeCB-101	6.31	1.19	1.19	0.46	0.04	0.33
<b>PeCB-105</b>	0.30	0.11	0.11	0.15	ND	0.05
PeCB-110	2.12	0.64	0.69	0.44	0.07	0.24
<b>PeCB-114</b>	ND	ND	ND	0.02	ND	ND
<b>PeCB-118</b>	1.34	0.45	0.47	0.42	0.05	0.18
<b>PeCB-123</b>	0.40	0.05	0.05	ND	ND	ND
<b>PeCB-126</b>	ND	ND	ND	ND	ND	ND
HxCB-132	2.36	0.22	0.26	0.16	0.03	0.06
HxCB-138 (163/164)	12.79	0.43	0.60	0.46	0.12	0.14
HxCB-149	10.03	0.37	0.50	0.35	0.05	0.15
HxCB-153 (168)	14.84	0.45	0.49	0.31	0.04	0.09
<b>HxCB-156</b>	0.48	0.03	0.05	0.04	0.01	0.01
<b>HxCB-157</b>	ND	ND	ND	0.01	0.05	0.06
HxCB-158 (160)	0.87	0.06	0.04	0.05	0.02	0.01
<b>HxCB-167</b>	0.30	ND	ND	0.04	ND	0.02
<b>HxCB-169</b>	ND	ND	ND	0.01	ND	0.01
HpCB-180	11.54	0.01	0.08	0.16	0.02	0.06
<b>HpCB-189</b>	ND	ND	ND	0.01	ND	ND
OcCB-194	0.69	ND	0.00	ND	0.01	0.01
OcCB-199	0.13	ND	0.02	ND	ND	ND
$\Sigma_{31}\text{PCB}$ ( $\text{pg}\cdot\text{m}^{-3}$ )	95.94	20.05	18.36	8.07	2.10	4.19
$\Sigma\text{Coplantar PCB}$	2.92	0.65	0.72	0.91	0.18	0.37
$\Sigma\text{TEQ}$ ( $\text{fg}\cdot\text{m}^{-3}$ )	0.09	0.02	0.02	0.29	0.01	0.21

homologue	Arctic site			Antarctic site		
	A	B	C	D	E	F
di	24.13	12.64	16.11	91	60.99	32.79
tri	36.36	19.27	18.01	17.35	9.17	7.01
tetra	21.63	11.24	10.82	3.45	0.36	2.35
penta	27.95	6.64	6.31	3.11	0.40	1.90
hexa	56.51	2.04	2.77	2.17	0.47	0.84
hepta	36.95	0.08	0.66	0.72	0.21	0.30
octa	3.45	0.02	0.03	ND	0.02	0.02
nona	0.04	ND	ND	ND	ND	ND
deca	0.01	ND	0.01	ND	ND	ND
$\Sigma_{206}\text{PCB}$ ( $\text{pg}\cdot\text{m}^{-3}$ )	207.02	51.92	54.71	117.80	71.64	45.21
$\Sigma_{205}\text{PCB}$ ( $\text{pg}\cdot\text{m}^{-3}$ ) <sup>b</sup>	195.63	46.73	43.45	30.75	11.07	14.17

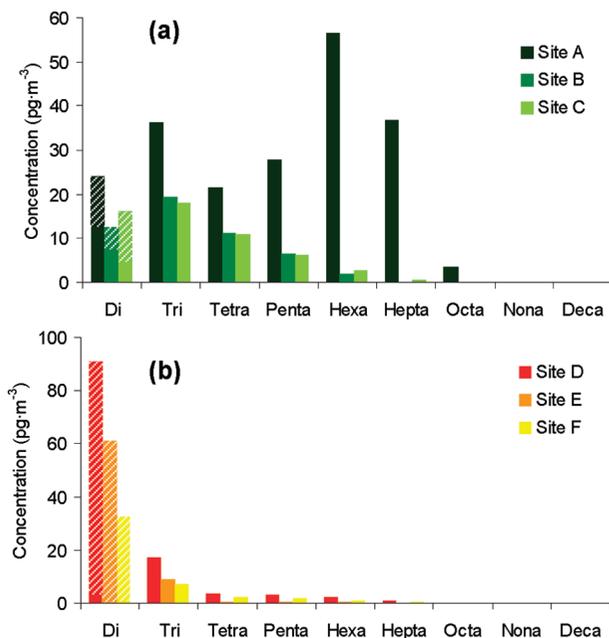
<sup>a</sup> ND: not detected. Bold congener numbers are for 12 coplanar congeners. <sup>b</sup> Total PCBs excluding monoCBs and PCB-11.

Ny-Ålesund reported here are generally similar to those reported for other Arctic sites, except that Site A shows much greater levels ( $65.7 \text{ pg}\cdot\text{m}^{-3}$ ), suggesting the influence of local pollution. On the other hand, levels at King George Island ( $2.5 \text{ pg}\cdot\text{m}^{-3}$ ) were lower than at other sites on the Antarctic Peninsula but 1 order of magnitude higher than background levels measured at a more remote Antarctic site (48). A more detailed discussion is provided in the Supporting Information.

**PCB Homologue Profiles and Signals of Local Pollution.**

Compared to the other sites, the PCB composition at site A was characterized by a relatively high fraction of highly chlorinated homologues (penta–hepta) (Figure 3). Since the PAS at Site A was installed on a roof, building emission probably influenced the type and amount of PCBs sequestered. Meanwhile, Sites B and C have similar homologue patterns with high fractions of di- and triCBs (Figure 3). A prevalence of the volatile congeners 28, 31, and 52 had

previously been noted at Ny-Ålesund (45). Such prevalence of volatile homologues is consistent with measurements and simulations of global fractionation (50), which indicate that the PCB composition experiences a shift toward more volatile congeners with increasing latitudes. Because of the large span of air/surface exchange properties of PCBs, volatile congeners are expected to move to polar regions faster, whereas less volatile congeners tend to remain in the surface compartments within, or in the vicinity of, source regions (4, 25). Rapid degradation in the atmosphere is predicted to prevent the accumulation in polar regions of the most volatile congeners with less than three chlorines (mono and diCBs) (4). In this study, the most dominant homologue was diCBs. Without PCB congener 11, triCBs dominate the homologue pattern at both Korean polar stations, in agreement with those at Alert, Dunai, and Tagish (44), implying that LRAT and global fractionation processes indeed determine PCB patterns in polar regions.



**FIGURE 3. PCB homologue patterns for the Arctic sites (a) and Antarctic sites (b). Boxes with white diagonal lines indicate PCB 11 concentrations.**

The Antarctic samples are even more dominated by the lightest homologues compared with Arctic samples B and C (Figure 3). Di- and triCBs are dominant homologues accounting for 79 and 14% of the total homologue concentrations, respectively, whereas the contribution of intermediate and heavy PCBs is small. Even if PCB-11 is not considered, the contribution of di- and triCBs to the total PCBs in the Antarctic samples (71%) is higher than in Arctic samples B and C (55%). This result also can be explained by LRAT and global fractionation (50). In particular, global scale LRAT is more important for the Antarctic because distances from areas of significant PCB usage are much larger than in the North (Figure S3).

As the distance from the main building in King Sejong increases (Figure 1b), the PCB levels generally decrease for both light and heavy congeners. Considering the prevailing northwesterly and westerly winds and the location of the sampling sites relative to the station, emissions from buildings and other installations potentially could have influenced the measured PCB levels. In addition, King Sejong is located downwind from other research stations on King George Island operated by Chile, China, the Czech Republic, Russia, and Uruguay. A Chilean air force base on the island is also considered an important pollution source. As a result, it is possible that the PCB levels at the Korean station may have been affected not only by LRAT but also local emissions.

**Comparison between Measured and Simulated PCB Concentrations.** A full description is provided in the Supporting Information. In summary, the congener levels and patterns simulated for the Arctic are very similar to those measured at Sites B and C (Figure S4). On the contrary, the simulated concentrations for the Antarctic do not match well the measured data, both with respect to levels and patterns. The simulated concentrations are much lower than those measured on King George Island but of the same magnitude as those measured in Terra Nova Bay (48). Meanwhile, the model results suggest that Antarctic air should be characterized by a higher relative abundance of heavier PCB congeners (PCB-118, 138, 180) than Arctic air (Figure S4). The reasons for these observations and a more detailed discussion can be found in the Supporting Information.

**OCP Concentrations.** OCP concentrations at the six sites and mean concentrations for both stations are shown in Table

S4 and Figure S7, respectively. Several OCPs were not detected, particularly in Antarctica.  $\alpha$ - and  $\gamma$ -HCHs and endosulfan I were dominant compounds in the North. Whereas HCHs were not detected at King Sejong, levels of endosulfan I, chlordanes, and heptachlor were comparable to those recorded in the Arctic. Higher concentrations of HCHs, DDT-related compounds, and dieldrin in the Arctic compared to the Antarctic probably reflects the shorter distance from global source regions of these pesticides. In general, the levels and pattern of OCPs in this study are consistent with those in a previous passive air sampling study reporting OCP levels at several polar sites (23). In particular, the dominance of endosulfan I in the samples from King Sejong is in agreement with relatively high levels reported in the Southern Hemisphere (23).

The mean *trans*-/*cis*-chlordane (TC/CC) ratio of 0.54 in this study is much lower than the technical value of 1.56 (51). The *p,p'*-DDT/DDE ratio at Site A of 0.16 is also low. Both ratios indicate a very aged signature, as would be expected for remote polar locations. As expected, no concentration gradients with distance from station buildings could be observed. Sources of OCPs are unlikely to exist at a polar research station. This also implies that the concentration of OCPs in this study should be exclusively determined by LRAT.

**Implications.** This study highlighted the potential influence of local pollution when measuring PCBs at polar research stations. Because of the need for electric power, active air samplers are often installed on, or in the immediate vicinity of, a building. As the results from Ny-Ålesund suggest, concentrations measured in this manner could easily be compromised, whereas samples taken only a few hundred meters from the station are not. We suggest that prior to selecting a sampling site for long-term air monitoring, it may be worthwhile to perform an initial passive air sampling study around a research station, such as the one presented here. This way it could be assured that a sampling site is not impacted by local sources and truly reflects background contamination levels and contributions from LRAT.

Short-term monitoring campaigns relying on active air samplers may not always produce representative air concentrations because they may be significantly affected by local meteorological conditions during the sampling period. A passive air sampling technique may allow for the cost-effective establishment of long-term trends and spatial variability of POP levels within the polar regions, thus complementing continuous active air sampling such as that by the Northern Contaminants Program (52). The global atmospheric passive sampling (GAPS) study demonstrated the feasibility of using passive air samplers to assess the spatial distribution of POPs on a global scale, including Arctic and Antarctic sites (23).

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## Supporting Information Available

Additional figures and tables. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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