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Editorial

Persistent organic pollutants and chemicals of emerging Arctic concern in the Arctic environment

Environmental pollutants, such as persistent organic pollutants (POPs), enter the Arctic mainly via long-range transport (LRT) through atmospheric and ocean/river currents. On the other hand, chemicals of emerging Arctic concern (CEACs) are often introduced as local contaminants from industrial, municipal, or infrastructure-related releases. Regardless of their origins, all these contaminants negatively impact the health of the environment and the indigenous populations. Furthermore, in recent decades, the Arctic has been experiencing unprecedented climate changes. The combination of Arctic environmental changes and the introduction of new anthropogenic contaminants as chemical aids for exploiting Arctic resources led to a severe imbalance in the Arctic ecosystems. Therefore, an international consortium of Arctic experts asked for internationally coordinated actions to mitigate the serious problems that environmental pollution causes on Arctic ecosystems and people, according to the Berlin statement [1].

As a follow-up of the recently published Berlin statement, in this virtual special issue (VSI), we explore the current status of contaminants, their sources, LRT potentials and pathways, fate, spatial and temporal trends, multimedia partitioning processes, and impacts on the polar environment, ecosystem, and humans in the changing Arctic.

In this VSI, there are three studies [2–4] featuring measured concentrations and time trends of POPs and CEACs in different matrices and one study [5] investigating the air sampling technique. Sühring and co-workers [2] studied the occurrence and pattern of various plastic-related contaminants in two seabird species from the Canadian Arctic. These plastic-related contaminants include plastic additive contaminants (containing legacy POPs, such as polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCDD), perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), and tris(2-chloroethyl) phosphate (TCEP), and the CEACs, such as several alternative brominated flame retardants (aBFRs), Dechlorane Plus isomers (syn-DDC-CO and anti-DDC-CO), per- and poly-fluoroalkyl substances (PFAS), organophosphate esters (OPEs), plasticisers, and other contaminants that may be transported adsorbed onto plastic particles (essential elements and trace metals (TMs) and organochlorine pesticides (OCPs)). Their study focuses on the potential connection between these plastic-associated contaminants and plastic pollution burdens in birds. It reveals the importance of treating plastic particles and plastic-associated organic additives as co-contaminants rather than separate pollution issues.

Bartley et al. [3] investigated the source types of both POPs and CEACs, including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), heavy metals, and PFAS, by analysing dated marine sediment cores collected in Koojesse Inlet near Iqaluit in Frobisher Bay, Nunavut, Canada. Like many POPs, these contaminants primarily reach the Arctic through long-range atmospheric and oceanic transport. However, the authors also found evidence showing that local sources within the Arctic also contributed to the levels observed in the environment, including legacy sources and new sources that arise from activities associated with increasing commercial and industrial development. The source types of Halomethoxybenzenes (HMBs), a group of compounds with natural and anthropogenic origins, along with bromoanisoles (BAs), were studied by Bidleman and co-workers [4], who report the spatial distributions of HMBs and BAs in the air and precipitation at Råo on the Swedish west coast and Pallas in Subarctic Finland. It was found that BAs were dominated by atmospheric long-range transport at Pallas and by both local and distant sources at Råo. The distant transport at both sites for pentachloroanisole (PeCA) and local exchange for (1,2,4,5-tetrachloro-3,6-dimethoxybenzene) DAME and 1,2,3,4-tetrachloro-5,6-dimethoxybenzene (TeCV).

Cai et al. [5] studied the impact of temperature on the sampling efficiency of polyurethane foam discs for several POPs using a flow-through sampling (FTS) column. A new sampling technique is developed to improve the accuracy of sampling and thus better quantitatively describe the environmental behaviour of POPs, especially for sampling in the polar regions due to the low concentrations of targeted POPs and low temperature in these regions. The new technique makes it possible to correct temperature effects and loss rates on the historical data from long-term monitoring networks in polar or other remote regions.

Development of global gridded emission inventories and modelling the transport and transfer of POPs are two of three important research elements for POPs study (The other is long-term environmental monitoring). Gridded global emissions for benzo[a]pyrene (BaP), a congener of PAHs with high carcinogenicity, from forest and grass fires from 2001 to 2020 were developed by Song and co-workers [6]. It is found that global wildfires contributed 29.3% to annual averaging BaP concentrations in the Arctic from 2001 to 2020, which possibly explains why the levels of this compound in Arctic ecosystems remain stable even when the global emissions of PAHs with anthropogenic origin have been reduced.

Clarifying sources and pathways of POPs to the Arctic have been major objectives of Arctic research and contaminant assessments. In this regard, studies on the two hexachlorocyclohexane (HCH) isomers, α-HCH and β-HCH, have played an exceptional role in understanding the different pathways for POPs to enter the Arctic, the former as the representative compound to enter the Arctic through

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long-range atmosphere transport (LRAT) and the latter as the representative compound via the long-range ocean transport (LROT). Encouraged by the successful modelling of the budget and fate of α-HCH in the Arctic Ocean [7], in this work, Yang and co-workers [8] study the historical annual loading to, removal from, and cumulative burden in the Arctic Ocean in 1945−2020 for β-HCH using a modified Arctic Mass Balance Box Model (AMBBM 2.0) similar to that applied to α-HCH earlier [7]. The results indicate that even though β-HCH and α-HCH had almost identical temporal and spatial primary emission patterns, these twins have shown different major pathways entering the Arctic. The much higher tendency of β-HCH to partition into the water, mainly due to its much lower Henry's Law Constant than α-HCH, produced an exceptionally strong pathway divergence with β-HCH favouring slow transport in water and α-HCH favouring rapid transport in air. The concentration and burden of β-HCH in the Arctic Ocean are also predicted for the year 2050, when 4.4−5.3 t will remain in the Arctic Ocean under the influence of climate change.

Li et al. [9] reviewed POP's fractionations in soil. The authors suggest that all fractionations can be clarified as primary and secondary fractionations. The primary fractionations, caused by primary factors, include point, urban, longitudinal, and latitudinal fractionations, whereas the secondary fractionation contains latitudinal fractionation caused by the secondary factors, temperature gradient, for example. The authors also suggest that both longitudinal and latitudinal fractionations are global fractionations, and the decreasing temperature trend along latitude is not the major reason for POPs to be fractionated into the polar ecosystems but drives the longer-term accumulation of POPs in cold climates or polar cold trapping.

The Arctic Monitoring and Assessment Programme (AMAP), one of the six working groups under the Arctic Council, was established in 1991 to fulfil parts of the Arctic Environmental Protection Strategy, signed by the Ministers of Environment of the eight Arctic Countries in the same year, concerned with monitoring and assessment of several identified priority 'pollution issues of concern', including POPs, mercury, and radioactivity. In this VSI, a paper authored by Reiersen and co-workers [10] introduced the history and evolution of AMAP and its major roles in monitoring and assessing the pollution of the Arctic environment and associated pollutant exposure of humans, especially of Arctic indigenous and local communities, and providing the Arctic policy recommendations based on scientific assessments.

Although the information given in this special issue is not exhaustive with regard to all environmental aspects of POPs and CEACs in the Arctic, it covers all three major element aspects of Arctic POP/CEAC pollution research, the global gridded emission inventories, monitoring, and modelling, provides some new datasets and knowledge, contributing to the whole Arctic research, which can be used by scientists worldwide to better understand linkages and to assess and improve the effectiveness of the Stockholm Convention.

This special issue is dedicated to Dr. Robie W. Macdonald, one of the world's foremost environmental scientists in Arctic research, who passed away on February 13, 2022. Although aware of his terminal illness, until a few months prior to passing, Robie insisted and pursued the research activities that he loved so much. Throughout his active years as a researcher, Dr. Macdonald made many significant contributions to Environmental pollution research in the Arctic. In this special issue, he is among the co-authors of the papers by Yang et al. [8] and Li et al. [9]. A memory article by Li [11] introduced Robie's academic achievements and his friendship with Robie.

As pointed out by Reiersen et al. [10], "This scientific work has been a significant peace process to keep the Arctic as a low-tension area where one could solve questions through dialogue and joint work.", which, we believe, speaks out the same wishes for many other scientists worldwide.

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Dr. Yi-Fan Li, a senior research scientist of Environment and Climate Change Canada before 2013, is now a professor at the School of Environment, Harbin Institute of Technology, a member of the Norwegian Scientific Academy for Polar Research, and the Director of the UArctic-HIT Training Centre, the first UArctic regional center outside the eight Arctic countries. He received his Ph.D. in the University of Waterloo, Canada. His research interests include development of gridded inventories of emissions and soil residues of persistent organic pollutants (POPs) and chemicals of emerging Arctic concern (CEAC), the transport and fate of POPs in the environment, especially in the atmosphere, and the pathways of POPs to enter the Arctic. Recently, Dr. Li and co-workers developed a steady-state particle-gas partitioning theory for POPs in the atmosphere, and are now focusing on its applications in different areas, the Arctic research in particular. Dr. Li has published more than 300 peer-reviewed papers, among which, more than 100 are Arctic-related. He has been selected as one of the most Cited Chinese Researchers by Elsevier since 2014.

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