Supplementary Information (SI) for Environmental Science: Advances.

Supplemental information

Local sources versus long-range transport of organic contaminants in the Arctic: Future developments related to climate change

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Table S1. The range of concentrations of selected POPs in the various glacier related environmental media in the Arctic. Data are based on the review by [1] except where noted with updated literature, including PFAS, published until 31st May 2023[1].

POPs[1]	Snow cover, 2000-2021 [pg L^{-1}]	Ref	Glacier ice, layers corresponding to years within the range 2000 – 2019 [pg L^{-1}]	Ref	Glacial runoff (2000 – 2017) [pg L^{-1}]	Ref	Proglacial lake sediments (2000 – 2015) [ng g^{-1}]	Ref
ΣPAHs	124 - 183 <LOD – $10.6\cdot10^3$ $2.6\cdot10^3$ – $0.299\cdot10^6$ <LOD – $3.78\cdot10^6$ $7.7\cdot10^3$ – $5.2\cdot10^6$	**17** **16** **20** **19** **18**	$3.13\cdot10^3$ – $21.1\cdot10^3$ 598 – $2.37\cdot10^3$ <LOD – $53\cdot10^3$ $2.3\cdot10^3$ – $103\cdot10^3$ 35 – $660\cdot10^3$	**22** **23** **24** **21** **25**	$0.243\cdot10^6$ – $3.90\cdot10^6$	**26**	1 – 429 <LOD – 640 11 – 1100	**28** **27** **14**
ΣPCBs	<LOD – 869 116 – 2000 45 - 2537	**19** **12** **32**	5.8 – 19 458 – 844	**29** **30**	ΣPCBs (2012) = 1.3 – 7.6 $\Sigma PCBs_{12}$ (2018) = 2.8 pg L^{-1} (D) $\Sigma PCBs_{14}$ (2018) = 21 pg g^{-1} dw	**2** **3** **3**	0.9 – 5.6 1.25 – 13.52 0.007-0.29 0.06 – 21	**28** **27** **1** **14**
Fragrances	7-10	**20**						
α-endosulfan	11.6 – 29.4 <LOD – 30	**9** **8**	6.8 10700	**11** **10**	*no data*		<0.01	**1**
α-HCH	6.50 – 44.6 17.1 – 382 <LOD - 1090	**9** **12** **32**	150 295 1100	**13** **11** **10**	190 – 270	**13**	0.01 – 0.27	**1**
γ-HCH	12.2 – 30.4 <LOD - 518 265 – 4390	**9** **32** **12**	150 369 7700	**13** **11** **10**	320 – 360	**13**	0.002-0.09	**1**
ΣHCHs	17.3 – 1126	**32**	*no data*		1.2 – 49.7	**2**	0.21– 7.0 0.014 – 0.36	**14** **1**
HCB	19.7 – 24.0 9.51 – 62.5	**9** **12**	*no data*		4.4 – 13.3 (2012)	**2**	0.014-1.24	**1**
4,4′-DDT	<LOD – 593	**32**	<LOD 2.93 510	**10** **11** **13**	470 – 580	**13**	*no data*	
ΣDDTs	1.73 – 8.5 9.54 – 5572	**12** **32**	*no data*		0.0 – 7.1 (2012)	**2**	<0.001 – 0.01 0.12 – 5.9	**1** **14**
ΣPBDEs	838 - $106\cdot10^3$	**31**	340 – 7070	**15**	*no data*		0.024 – 0.97	**14**
PFCAs(C6-C14)	*no data*		325 – 1030 266 – 1730	**4** **5**	230 – 8640	**7**	0.003 – 0.113	**6**
PFSAs (C4-C12)	*no data*		<1 – 226 12 – 404	**4** **5**	<10 – 506	**7**	0.003 – 0.038	**6**

[1]The time period for sampling is 2000-2023 except for PAHs where all reports are included due to the limited number of studies. The data generally represent ranges of concentrations reported for multiple sites within a given region.

References:

[1] Muir et al. Unpublished data for Lake Hazen sediment core (0-10 cm, sampled 2013)
[2] McGovern et al.[2] –- samples collected in 2012. Dissolved concentrations.
[3] Johansen et al.[3]- samples collected in 2018.** new data for comparison, from Ebbaelva river only, D = dissolved phase (from passive samplers), P = particulate phase (from sediment traps).
[4] Hartz et al.[4] - core from the Lomonosovfonna ice cap, Svalbard
[5] Pickard et al. [5] - core from the Devon Ice cap, Devon Island, Nunavut
[6] MacInnis et al [6] - Lake Hazen sediment core (0-10 cm, sampled 2011)
[7] MacInnis et al [7] – glacial rivers, Lake Hazen watershed, sampled summer 2012, 2013 and 2014
[8] Zhang et al..[8] - Devon Ice Cap, 2008
[9] Hermanson et al.[9] - Svalbard glaciers, 2013-2014
[10] Hermanson et al.[10] - Austfonna, Svalbard, 1943-1998 ice core layers. Maximum concentrations
[11] Ruggirello et al.[11] - Holtedahlfonna, Svalbard, 1953-2005 ice core layers
[12] Herbert et al. [12] - Tromsø on Storsteinen Mt., 2003
[13] Miner et al.[13] - Jarvis Glacier & Creek, Alaska, 2017
[14] Jiao et al.[14]- Svalbard/Ny – Ålesund, 2005
[15] Hermanson et al.[15] - Svalbard, Holtedahlfonna, 1953-2005
[16] Masclet et al.[16]- Greenland, 1993
[17] Currie et al.[17] - Greenland, Summit, 1996
[18] Abramova et al.[18]- Spitsbergen, 2012 - 2014
[19] Kozioł et al.[19] - Foxfonna, 2014
[20] Vecchiato et al.[20]- Ny–Ålesund, 2017; fragrances: sum of benzyl Salicylate, amyl Salicylate, hexyl Salicylate, Peonile
[21] Kawamura et al. [21] - Site-J, Greenland, 1500-1982
[22] Slater et al.[22] - Summit, Greenland
[23] Jaffrezo et al.[23] - Summit, Greenland, 1988 - 1991
[24] Vehviläinen et al.[24] - Spitsbergen, Lomonosovfonna, 1476-1989
[25] Peters et al.[25] - Agassiz Ice Cap, Ellesmere Island, Canada, 1963 – 1993
[26] Kosek et al.[26, 27]- Svalbard/Revelva, 2015–2016
[27] Rose et al.[28] - Svalbard, 1995
[28] Sapota et al.[29] - North Spitsbergen, 2005
[29] Garmash et al.[30] - Lomonosovfonna, 1957- 2010
[30] Hermanson et al.[31] - four glacier sites on Svalbard, 2013-2014
[31] Meyer et al.[32] - Devon Ice Cap snowpits
[32] Pawlak et al.[33] - Hans glacier (2019), Werenskiöldbreen, Ariebreen, Vestre Torrellbreen and Profilbreen (2021)

Table S2. Literature information about PAHs in the Arctic permafrost environment (peatlands, soils, sediments, water).

Media	Location/date of sample collection	Total PAHs (unless noted)	References	Sources of PAH and conclusions
		RUSSIA		
Lake sediment	Sediment core (borehole 1D-14)– 38.2 m Ivashkina lagoon on the Bykovskii Peninsula (Laptev Sea)	2,4-517 ng g^{-1}	34	Varied PAHs content in the particular layers indicates a time-varying deposition, 300-500 ng g^{-1} at a depth of 30m - archival record of the warmer phase of the Pleistocene, pyrogenic genesis. Pyrogenic and petrogenic; grass and forest fires, coal burning, biogenic (peat/sediment diagenesis), volcanic rocks, precambrian schists, alluvial sands
River sediment	Rivers flowing into the Arctic Ocean (08/2005)	Ob: 23.8 ng g^{-1} Yenisey: 129 ng g^{-1} Lena: 79.6 ng g^{-1} Indigirka: 84.6 ng g^{-1} Kolyma: 91.1 ng g^{-1}	35	Black carbon content weighted by the river runoff, amount to about 20% from vegetation/biofuel burning and 80% from 14C-extinct sources such as fossil fuel combustion and relict BC in uplifted source. PAHs may originate from forest and grass burning in the past.
Soils	Islands and capes at the shore of the Kara Sea and Laptev Sea	37-1400 ng g^{-1}	36	Soils contamination due to station activity. Pyrogenic and petrogenic; diesel fuel usage – station activity, biogenic (peat/sediment diagenesis)
Soils	Komi Republic, Vorkuta district (2009)	All soils horizons: 2.3-380 ng g^{-1} Organic horizons 91.2-240.3 ng g^{-1}	37	Pyrogenic and petrogenic; atmospheric, biogenic (peat/sediment diagenesis)
Soils	Komi Republic, Vorkuta district (2014) Inta (2015)	160-8500 ng g^{-1} 58-2800 ng g^{-1}	38 39	The accumulation of PAHs in the profiles of permafrost-affected peat mounds is related to certain groups of plant residues produced in the Atlantic climatic optimum of the Holocene. Pyrogenic and petrogenic; atmospheric, biogenic (peat/sediment diagenesis) PAHs composition at the boundary of seasonally thawed layers and permafrost in peatlands can be used as an indicator of the response of permafrost to climate change at high latitudes.
Soils	Organic horizon Komi Republic, Vorkuta district (2009)	249.8-908.5 ng g^{-1} (mean values) 471 - 1493 µg m^{-2}	40 41	Accumulation of PAHs from local atmospheric sources, accumulation in both active vegetation and peat, bioaccumulation, and the possibility of using PAHs as an indicator of environmental changes. Pyrogenic and petrogenic; atmospheric – coal combustion,

				biogenic (peat/sediment diagenesis)
Peatlands	Permafrost peatlands. Pechora basin, Pechora and lower Ob and Pur basins The south border of permafrost expands.	150–3700 ng g^{-1} 112 - 3673 ng g^{-1}	[42] [43]	Quantitative and qualitative differentiation (3-4 rings and 5-6) on various levels studied. Pyrogenic and petrogenic; fires, biogenic (peat/sediment diagenesis) Heavy 5-6 rings in deeper layers are of natural origin in melting permafrost, may be an indicator of the preservation of organic matter from the warm Holocene periods. The pyrogenic PAHs found form evidence of past fires. In the Eastern European peat plateaus, in particular, 6-nuclear benzo[ghi]perylene (1021 ± 707 ng g^{-1}) occurred, whereas in West Siberian permafrost peatlands, light PAHs were dominating, mostly naphthalene and phenanthrene (211 ± 87 and 64 ± 25 ng g^{-1}, respectively).
Soils	Yamal-Nenets autonomous region (65 – 72°N, 64 – 80 °E) (07/2017)	78.1 – 131 ng g^{-1}	[44]	Chromium mining area and background site. 16 unsubstituted PAH. The permafrost is semi-permeable to PAHs (low migration in profile), however, accumulation of 5 and 6-ring PAHs was found at the bottom of the active layer. The authors consider it to be PAHs migration, or some older source from past fires.
Soils	Tazovsky Peninsula (North-West Siberia); Yakutsk (Central Yakutia); Kolyma Lowland (North Yakutia) (2019)	36.0 - 331.4 ng g^{-1}	[45]	PAHs are strongly connected with the origin of the material and its total organic carbon content. The sum of high-molecular PAHs of anthropogenic origin were present in the samples of buried organo-mineral material and reached 5.7% of the total PAHs (background unaffected soils contain only 0.2-0.4% of "heavy" PAHs). This fact strengthens the idea of the possible long-term conservation of these pollutants in frozen deposits and buried soils.
SVALBARD and NORWAY [limited to freshwater sediments and soils]				
Soils	Ny-Ålesund (07-08/2007) 78° 55'N 11° 52'E to 78° 51'N 12° 33'E	37-324 ng g^{-1} d.w.	[46]	16 unsubstituted PAHs analysed by GC-MS
Freshwater & marine sediment	Sediment cores Bellsund (08/2002, 06/2004)	Lake: 2610 ng g^{-1} Marine: 3076 ng g^{-1}	[47]	
Freshwater	Hornsund, Fuglebekken catchment (07-09, 2011) stream outflow, 77.006 °N, 15.553 °E	ΣPAHs = 3.3 ng L^{-1} ΣPCBs = 4.2 ng L^{-1}	[48]	12 unsubstituted PAHs analysed by GC-MS, 7 OCB congeners (CB 28, 52, 101, 118, 138, 153, 180)
Freshwater	Hornsund, Revelva catchment (07-	ΣPAHs = up to 3141 ng	[26]	Atmospheric

	08,2015)	L^{-1} Naphthalene 76.1–1823 ng L^{-1} Anthracene 21–1450 ng $L^{\cdot 1}$		
Freshwater	Hornsund, Fuglebekken catchment (06-08, 2010-2013)	13.3–6797 ng·L^{-1}	49	Petrogenic and pyrogenic, including deposition from volcanic activity in Iceland (Eyjafjallajökull volcano 2010)
Freshwater	Hornsund, Revelva catchment (06-08, 2016)	Naphthalene 87–611 ng L^{-1} Anthracene 8.9–1871 ng L^{-1}	27	Snowmelt (secondary source; characteristic elution pattern observed);5-6 ring PAHs later in the season: proposed secondary source due to permafrost thaw
Freshwater & marine sediment	Sediment cores (lake and seashore) Norwegian Coast Nordland, Troms and Finnmark (08/2002, 06/2004)	Lake: 217-7045 ng g^{-1} Marine: 82-636 ng g^{-1}	47	
Canada and USA (Alaska)				
Coastal peat soils	70° 05.5'N, 152°16.8' W to 70°47.3'N 152° 16.8'W	40 - 700 ng g^{-1}	50	Samples of peat from exposed shoreline cliffs. ΣPAH = two- to five-ring PAH (N + F + P + D + 4-,5-PAH) includes those of petrogenic, and diagenetic origin eg perylene
Coastal river sediments	70° 04.9'N, 143°45' W to 70° 23.0'N, 150°30' W	40 - 640 ng g^{-1}	50	Sediment from mouths of the Canning, Sagavanirktok, Kuparuk and Colville Rivers. ΣPAH = two- to five-ring polynuclear aromatic hydrocarbons (N + F + P + D + 4-,5-PAH) includes those of petrogenic, and diagenetic origin eg perylene
Coastal peat soils	69° 05.2'N, 137° 55' W to 69° 25.0'N, 133° 08'W	63±63 ng g^{-1} phenanthrene/chrysene 100±110 ng g^{-1}4-6 ring PAHs	51	21 PAHs measured from naphthalene to benzo(ghi)perylene
Mackenzie River near shore sediments	69° 10.2'N 135° 01.6' W to 68° 53.4'N 135° 01.8'W	340±90 ng g^{-1} phenanthrene/chrysene 400±100 ng g^{-1} 4-6 ring PAHs	51	21 PAHs measured from naphthalene to benzo(ghi)perylene
Coastal peat soils	70° 30'N 151° 00' W to 70° 00'N 147° 30'W	121 - 737 ng g^{-1}	52	Peat from mouths of 4 North Slope rivers (4 samples). 41 target parent PAH and alkyl-PAH isomer groups
River sediment	Rivers flowing into the Bering Sea and Arctic Ocean (08/2005)	Yukon 85 ng g^{-1} Mackenzie 454 ng g^{-1}	35	14 unsubstituted PAHs + methyl- and dimethyl phenanthrenes, methyl-pyrenes, and retene

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