Sewage as important local pollutant source in the Arctic aqueous environments.

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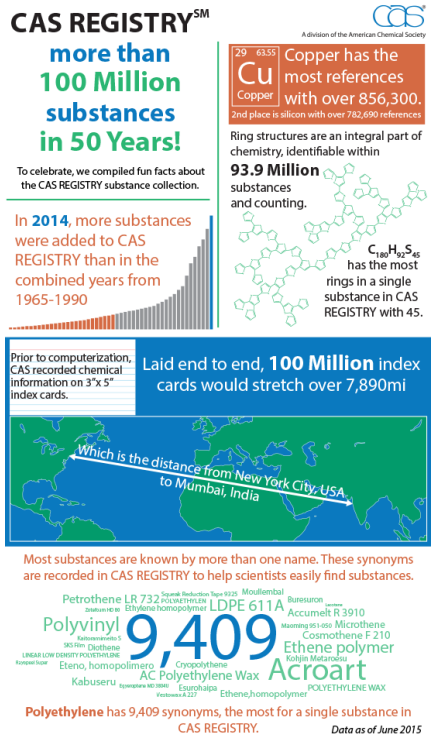


According CAS (up-dated September 2017):

- 132 Million substances registered
- 387 225 substances regulated
- 200 000 substances identified as toxic

Estimated ca. 10 000 substances covered by current available analytical methods for quantitative analysis

CAS celebrates more than 100 Million registered chemicals in 2015

AMAP Chemicals of Emerging Concern (CEAS)

SUBSTANCES CONSIDERED IN THE ASSESSMENT OF CHEMICALS OF EMERGING ARCTIC CONCERN

- Brominated flame retardants (BFRs)*
- Chlorinated flame retardants (CFRs)
- Chlorinated paraffins*
- Current-use pesticides (CUPs)*
- Halogenated natural products (HNPs)**
- Hexachlorobutadiene (HCBD)***
- Organophsophate-based flame retardants (PFRs)
- Organotins
- Pentachlorophenol (PCP)***
- Per- and polyfluroalkyl substances (PFASs)*
- Pharmaceuticals and personal care products (PPCPs)
- Phthalates
- Plastics and microplastics
- Polychlorinated naphthalenes (PCNs)***
- Polycyclic aromatic hydrocarbons (PAHs)
- Siloxanes
- Unintentionally generated polychlorinated biphenyls (PCBs)

*Contains at least one chemical currently being evaluated or considered for listing by Stockholm Convention

** Most HNPs have natural (biogenic) sources, however some may have anthropogenic sources

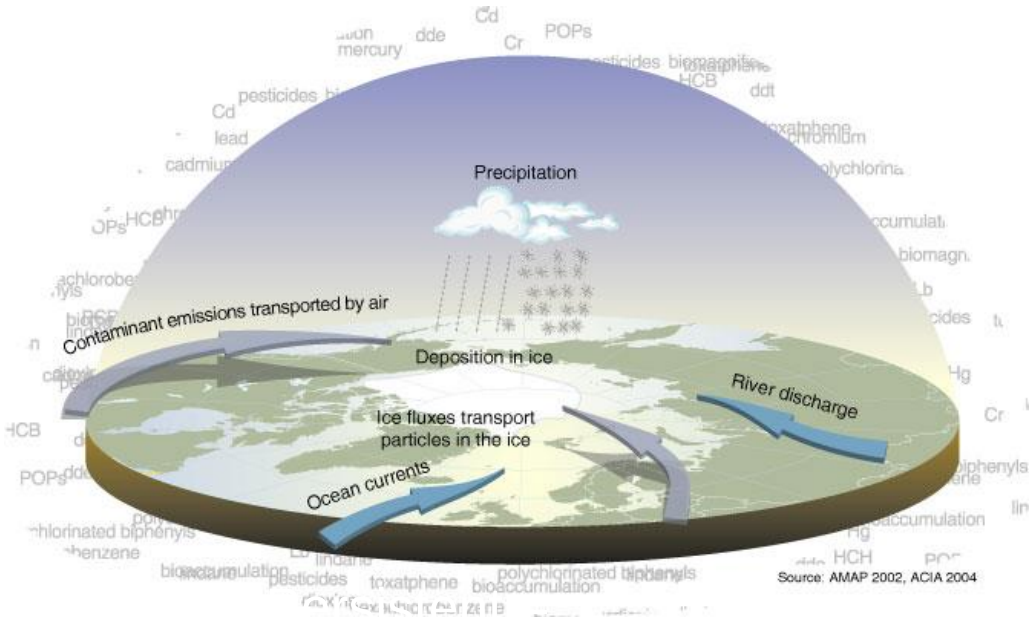
*** Added to Stockholm Convention in 2015

- 16 relevant compound groups identified.
- ***Chemical of emerging concern (CEC):*** Either newly introduced substances or identified due to advancements in technology.
- ***Chemicals of Emerging Arctic concern (CEAC):*** CECs found in the Arctic environment
- Non-POPs like compounds included

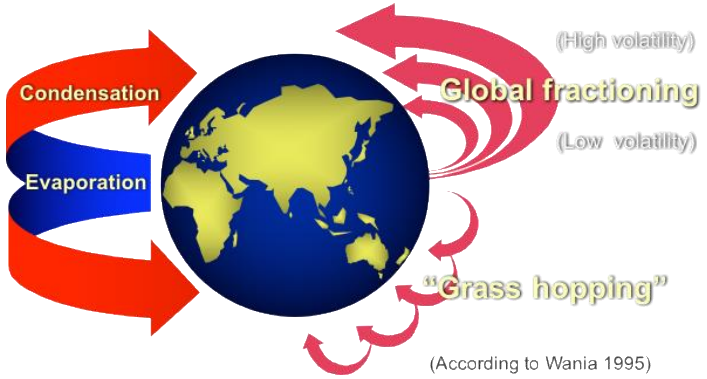
Background information

- North of 66 º N (Polar Circle)
- Average Temp. < 10 ºC (July)
- Eight Arctic nations (Arctic Council)
- 14.5 mill. km^2 area (mainly marine)
- Ca. 13.1 Mill. people are living in the Arctic
- 20% of the global water resources are found in the Arctic (ice caps, glaciers, cryosphere)

Arctic pollution



- Global distribution processes
- Remote sources
- Bioaccumulation
- Seasonal distribution patterns (photochemistry & microbiology)
- Local sources ?



Local pollution issues

- ***Anthropogenic activities:*** Industry – Households – Transportation – Energy production

"Human foot-print"

Sanitation and Sewage treatment in the Arctic

- Direct release (veterinary, aquaculture, households), sanitation and sewage treatment identified as major sources
- Decentralized or even absent
- Low technological standards (absent, filtration, storage)
- Direct release into ponds, local and coastal aqueous recipients or transported to storage/ treatment facilities.

Examples for local emission of pollutants

- **Power plants and domestic heating:** Polycyclic aromatic hydrocarbons (PAH), metals (Hg, Cd, Pb etc.), volatile organic pollutants (VOCs)
- **Vehicles (fossile fuel combustion):** PAHs, VOCs, aromatic compounds, metals
- **Local industry** (mining, refining, fishery, off-shore): plastics, polymerrs, Metals, PAH, industrial chemicals (polychlorinated biphenyls (PCB), brominated flame retardants (BFR), perfluoroalkyl substances (PFASs) others, VOCs, anti corrosives, surfactants etc.
- **Agriculture (incl. infrastructures):** Anticorrosives, plastics, pesticides, PFAS, PCB, BFR, pharmaceuticals and personal care products (PPCPs), surfactants, etc.
- **Municipale installations (Sewage treatment plants, others):** Anticorrosives, pesticides, PFAS, PCB, BFR, pharmaceuticals and personal care products (PPCPs), surfactants, cosmetics, bioactive compounds, food preservation, plastics, polymers, additives, pesticides, ……..

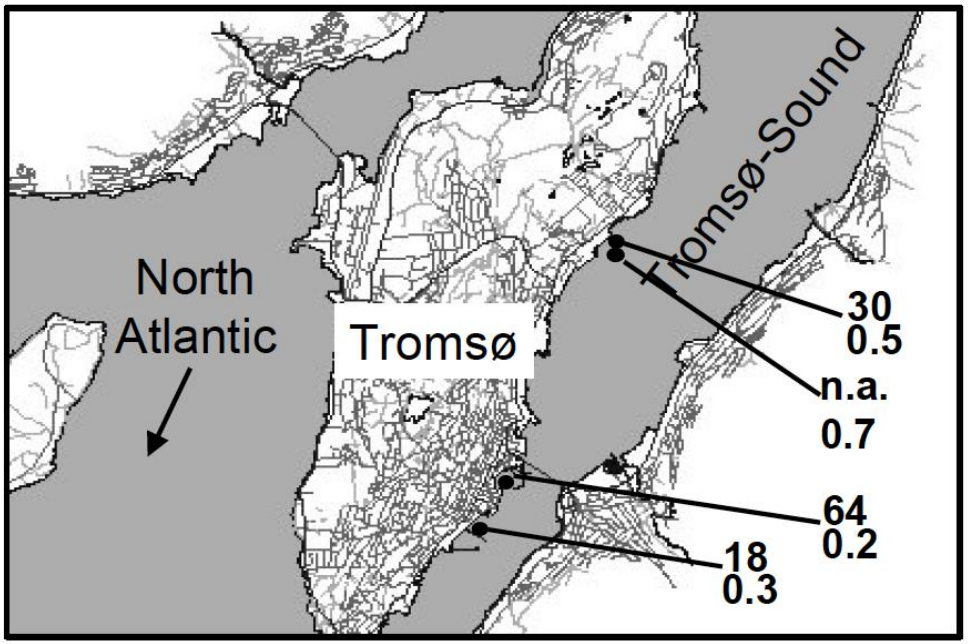
1. Pharmaceuticals and personal care products (PPCPs)

- Indicator chemicals for human activities
- **Sources:** Hygiene products, Cosmetics, supplementary food, Veterinary & Human therapeutic applications etc.
- **Accessibility:** PPCPs open available; vendors, stores; Medical therapy: Over the counter (uncontrolled) & Prescriptions (controlled)
- **Release:** Introduction mainly via Sewage and sewage treatment (faces & urine), Direct (husbandry, aquaculture), uncontrolled disposal of outdated products via sewage/ manure and/o e dumps.

Photo: Wikipedia

Release pattern and distribution pathways

- Sewage sludge and sewage effluents identified as main emission source in the Arctic
- First studies from summer 2001/2002, Tromsø, Norway (Weigel et al. 2004):



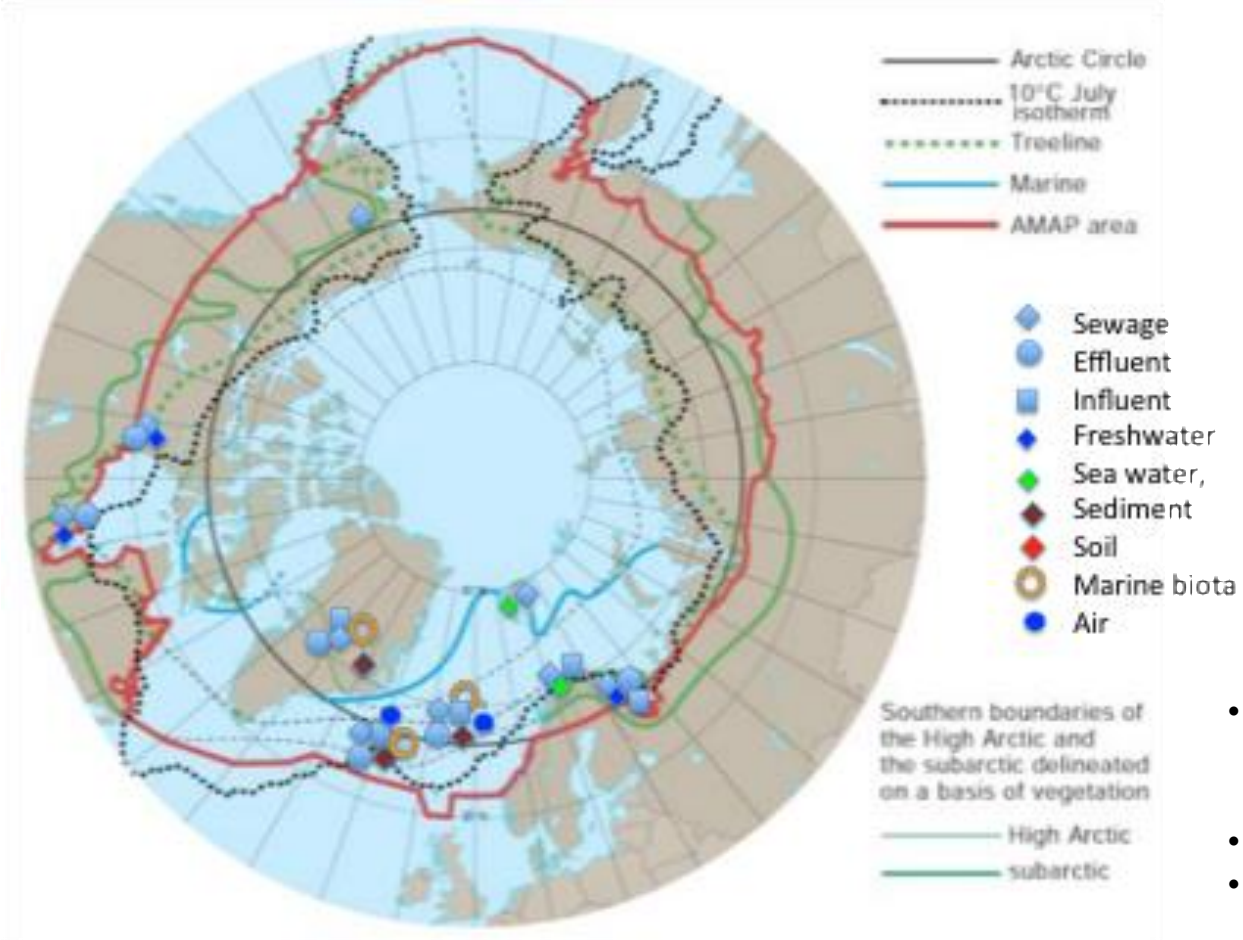
Caffeine (upper) and Ibuprofen (lower) in Tromsøsund surface

PPCPs in Norwegian Sewage effluents and recipients (2006): A first comparison

	Concentration range [ng/L]					
	Oslo (VEAS)		Tromsø		Longyearbyen	
Target PPCPs	**Effluent (n=1)**	**Sea water (n=2)**	**Effluent (n= 8)**	**Sea water (n= 8)**	**Effluent (n=5)**	**Sea water (n=2)**
Ibuprofen	10	n.d. – 52	448	n.a.	30 – 403	0.4- 1
Hydroxy-ibuprofen	126	188 – 243	3614	n.a.	8 – 1398	2 – 34
Carboxy-ibuprofen	42	109 – 213	70170	n.a.	411 – 34028	6 – 26
Diclofenac	25	n.d. – 48	78	n.a.	30 – 1074	1 – 4
Triclosan	11	n.d.	350	n.a.	28 – 803	2 – 2.3
Caffeine	23	5 – 96	n.a.	n.a.	501 – 50704	24 – 41
Citalopram	238	n.a.	63 – 102	<LOQ	<LOQ	n.d.
Desmethyl-citalopram	310	n.d.	118 – 215	<LOQ	<LOQ	n.d.
Didesmetyl-citalopram	10	n.a.	6 – 10	n.d.	n.d.	n.d.
Fluoxetine	8	n.a.	1 – 5	n.d.	n.d.	n.d.
Norfluoxetine	2	n.a.	0.7 – 2.5	n.d.	n.d.	n.d.
Fluvoxamine	1	n.a.	0.8 – 1.7	n.d.	n.d.	0.5 – 0.8
Sertraline	8	n.a.	8 – 90	n.d.	n.d.	<LOQ
Desmethylsertraline	6	n.a.	n.d.	n.d.	n.d.	n.d.
Paroxetine	4	<LOQ	3 – 13	n.d.	n.d.	0.6 – 1.4
Tetracycline	n.d.	n.d.	n.a.	n.a.	0.6 – 1.1	n.d.
Trimethoprim	0.8 – 0.9	n.d.	n.a.	n.a.	0.07 – 0.15	n.d.
Sulfamethoxazole	0.2 – 0.3	n.d.	n.a.	n.a.	n.d.	n.d.

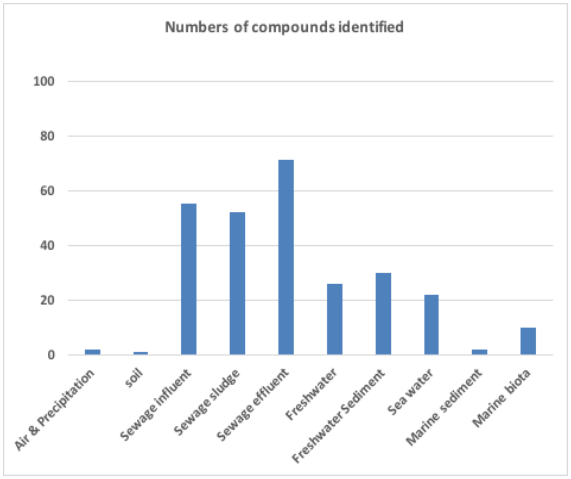
LOQ = Limit of quantification, n.a. = not analysed, n.d. = not detected

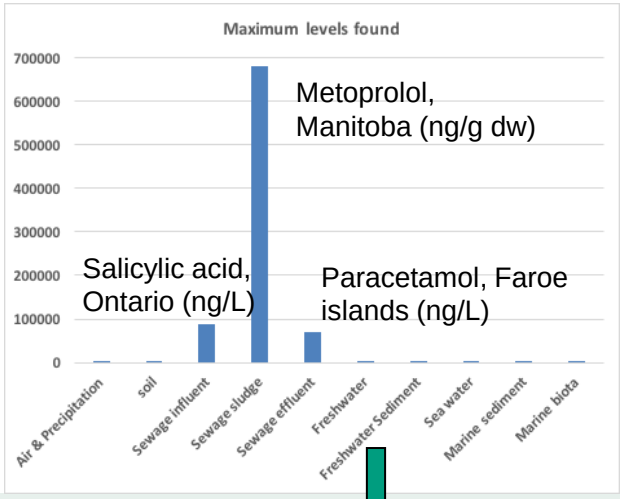
PPCPs in the Arctic: CEAC summary

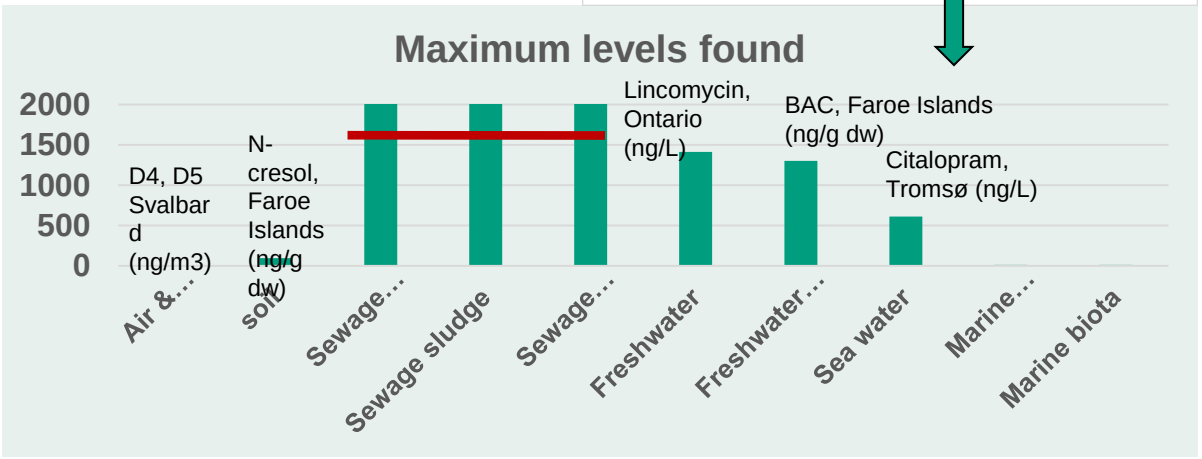


- 110 PPCPs (including transformation products) identified
- Conc. range: ppb – ppm
- Environmental fate largely unknown

PPCPs in the Arctic environment





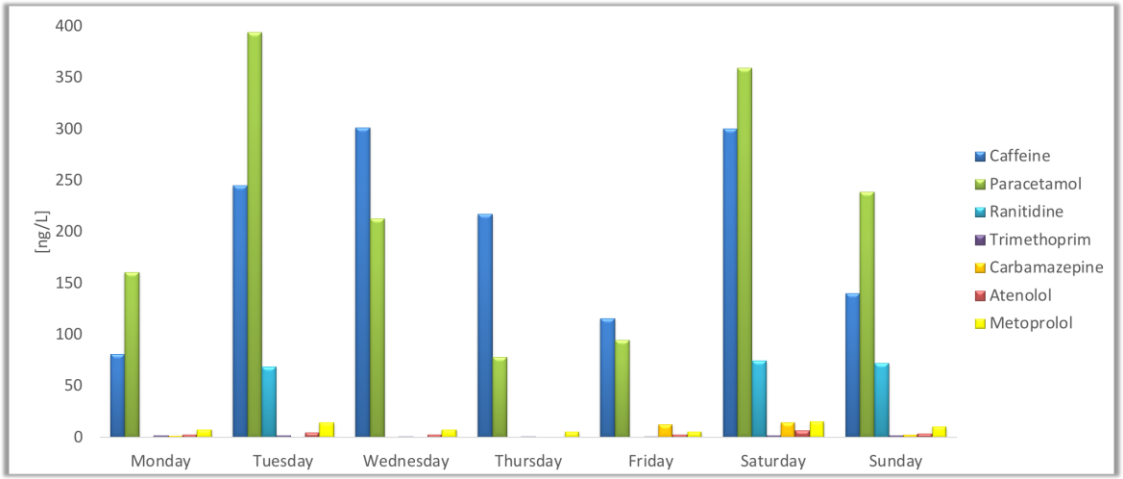


Comparison with other regions

ng/m^3	Siloxanes (D4, D5)	Air	4	1100	Chicago	Yucuis et al. (2013) Chemosphere 92: 905-910
ng/g	cresol	soil	96	2000	Russian soil	Korenman et al. (2001) J. Anal. Chem. 56/2: 166-169
ng/L	Ibuprofen	Sewage influent	87400	3600	Källby (SWE)	Bendz et al. (2005) J. Haz. Materials 122/3: 195-204
ng/g	Metoprolol	Sewage sludge	680000	500	WWTP Terrassa, Spain	Radjenovic et al. (2009) Water Res. 43: 831-841
ng/L	Paracetamol	Sewage effluent	71000	150	Källby (SWE)	Bendz et al. (2005) J. Haz. Materials 122/3: 195-204
ng/L	Lincomycin	Freshwater	1413	40	Biscayne Bay (Florida US)	Wang & Garinaldi(2012) Anal. Bioanal. Chem. 404: 2711-2720
ng/g	BAC	Freshwater Sediment	1300	1500	Long Island (NY)	Li & Brownawell (2010) Env. Sci. Technol 44: 7561-7568
ng/L	Citalopram	Sea water	612	27	San Francisco Bay	Nödler et al (2014) Marine Pol. Bull. 85: 50-59
ng/g	Bisphenol A	Marine sediment	11	10500	Taiwan	Huang et al (2012) Environ. International 42: 91-99
ng/g	Siloxanes (D5)	Marine biota	10	36	Walleye (Canada)	Goldrick et al. (2014) 186: 141-148

PPCPs in Tromsø (2016)

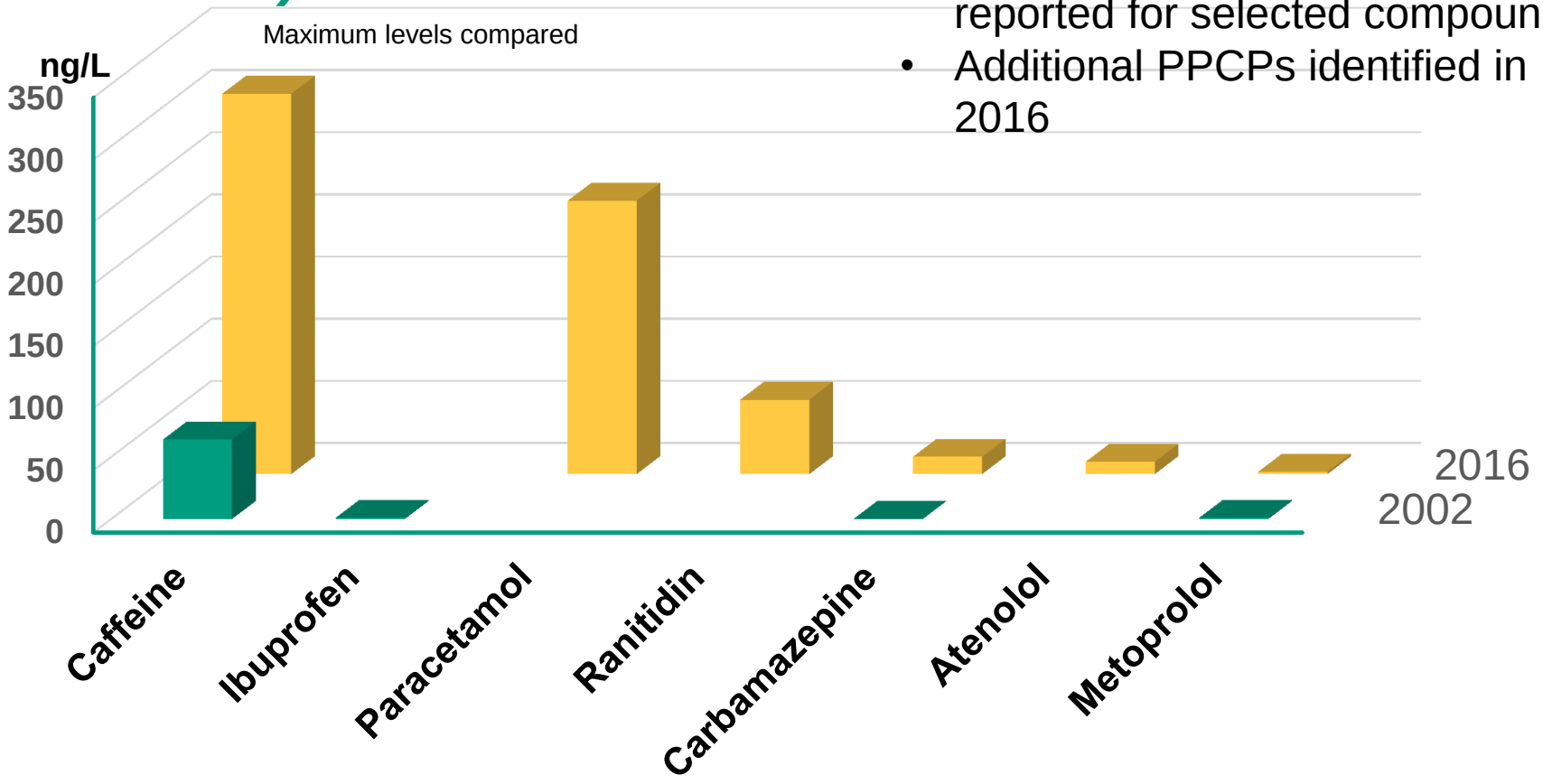
- PPCPs in similar and in some cases even higher concentration ranges as reported in earlier studies were from the same area (Weigel et al. 2004).
- Considerable variations reveal differences in consumption behavior and release patterns



Julie Strømberg, Masters thesis,NMBU,2016 (in collaboration with Terje Vasskog,UiT)

Tromsø studies (2002 versus 2016)

- Increased overall emission rate reported for selected compounds
- Additional PPCPs identified in 2016



2.) Poly- and perfluoroalkyl substances (PFAS)

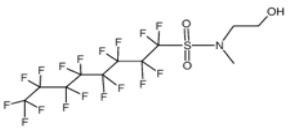
- Known as Arctic pollutants since the early 2000s
- Many compounds are introduced via precursors and subsequent transformation into persistent compounds (PFOS, PFOA)
- Identified as relevant pollutants in all environmental compartments in the Arctic
- Local sources identified in the Arctic

Perfluoro octansulfonate (PFOS)

Perfluoro octanoic acid (PFOA)

8:2 Fluoro telomer alcohol (8:2 FTOH)

Perfluoro octansulfonamide (PFOSA)



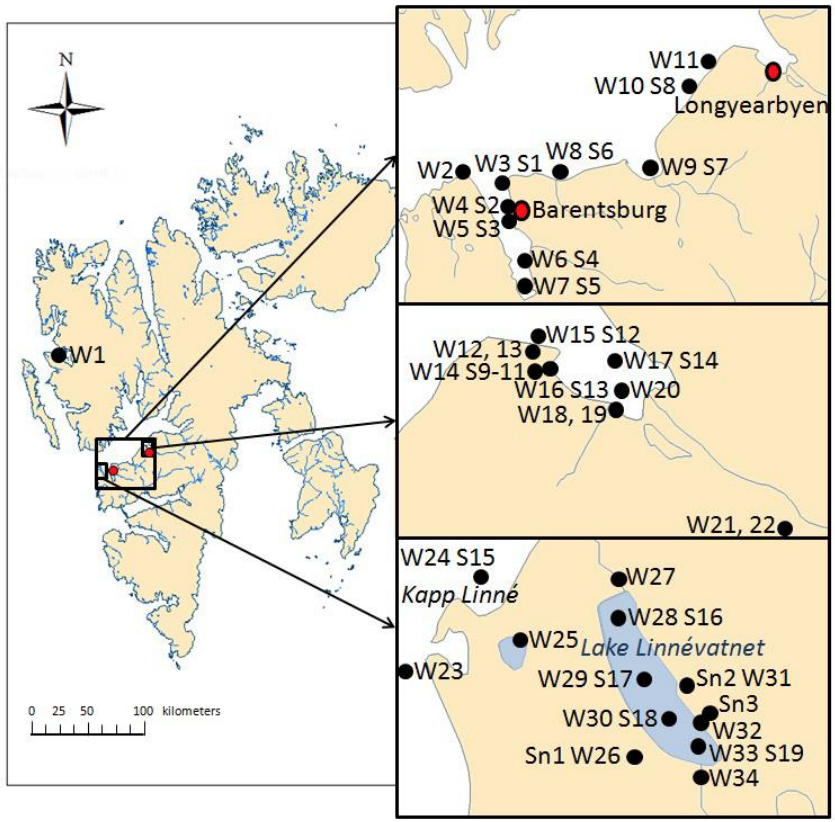
Perfluorooctane sufonamido ethanoles (FOSEs)

PFASsource characterisation

Local sources in the Arctic

- Firefighting training facilities (airfields, municipal, industrial facilities)
- Sewage effluents and sewage storage ponds
- Landfills
- Outdoor equipment and clothing (Impregnation of surfaces)
- Other recreational activities (skiing,skidoos etc.)

PFAS:Fluoros impact 2026

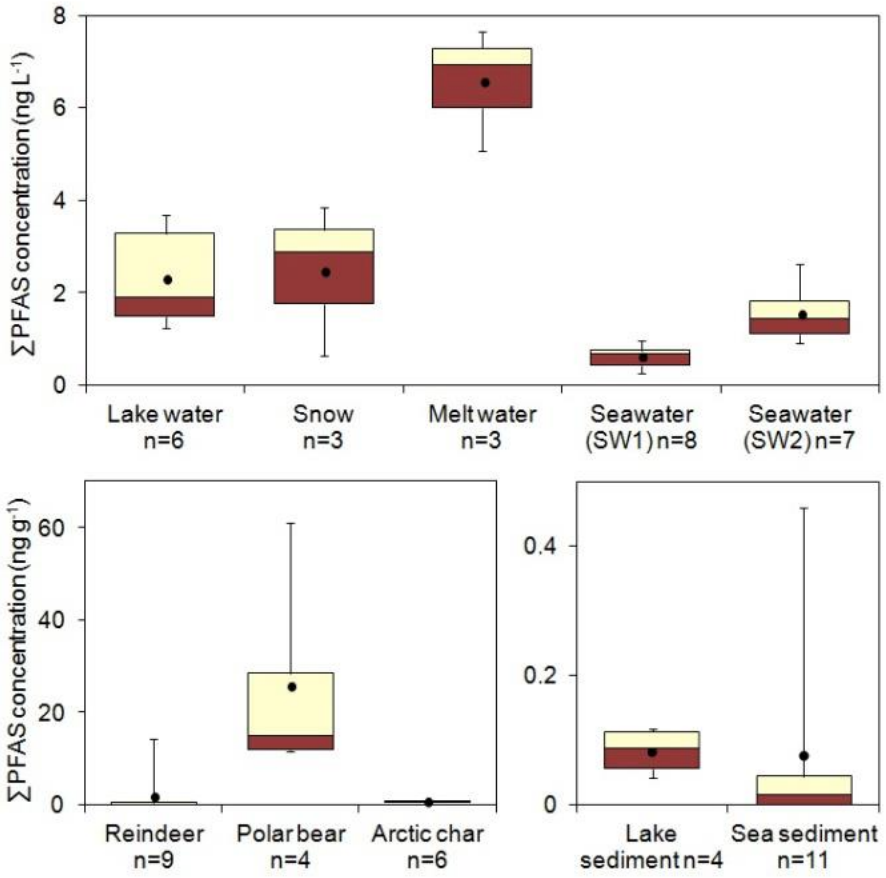


Local survey on PFAS sourcesand distribution pathways on Spitsbergen (*collaboration, SLU; UNIS, NMBU*)

Report available on the web-page of the Svalbard Miljøvernfond (SMF)

PFAS on Svalbard

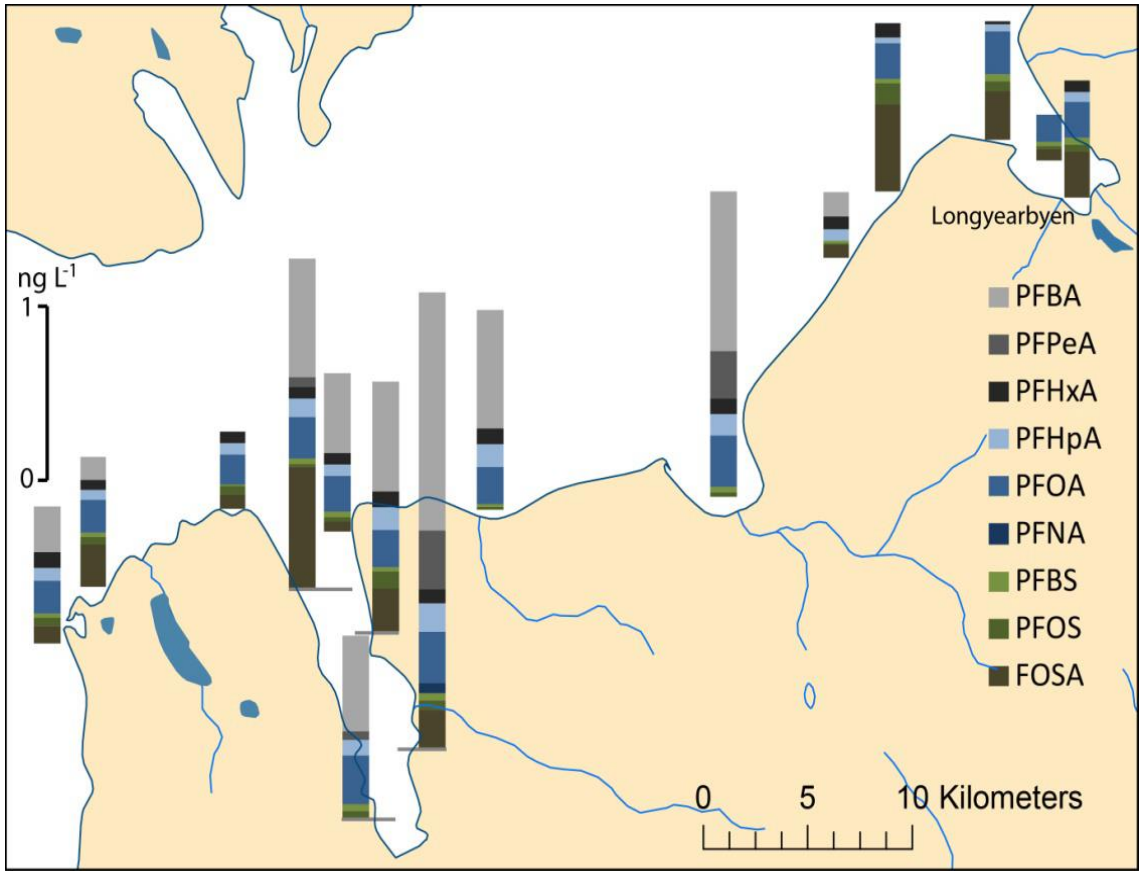
- Overall distribution (background)



FluorosImpact report 2016, SMF.

- Elevated levels found in snow melt
- Snow melt and run-off from glaciers =major water resource for drinking water in the Arctic

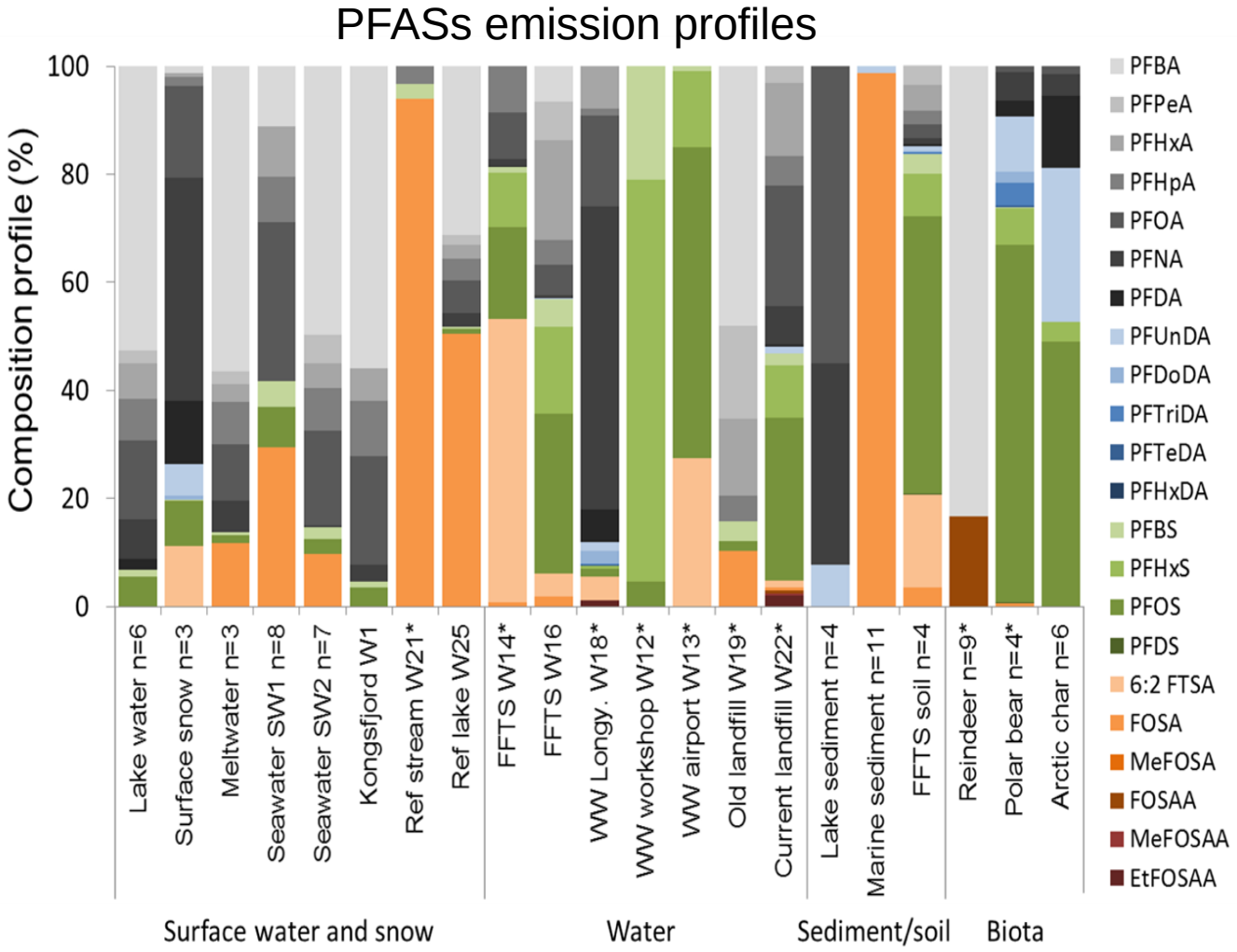
PFASs in Svalbard



- Different PFASs patterns in coastal surface sea water, close to Barentsburg and Longyearbyen
- Indication for local differences in PFASs emissions

FluorosImpact report 2016, SMF.

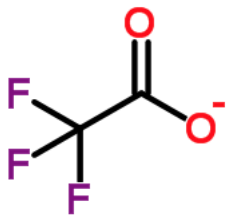
PFASs in Svalbard



Distinct emission profiles identified. FFTS, landfills and Sewage emission identified as major sourse for PFAS

3. Trifluoroacetic acid (TFA)

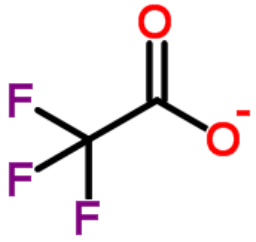
- Significant amounts of trifluoroacetate (TFA) are formed in the atmosphere by photochemical transformation of fluorinated refrigerants and subsequently introduced into the aquatic environment by wet deposition.
- TFA is also a known transformation products of PFAS.
- TFA is a High Production Volume Chemical and was identified as biodegradation product of different pesticides.
- Reported concentrations of TFA in European surface waters are usually <1 µg/L (= 1000 ng/L).
- Due to industrial discharge, high concentrations of TFA (up to 100 µg/L) were detected in a tributary of the River Rhine.



TFA in the Arctic

First screening in Oslo and Longyearbyen 2017:

- Oslo drinking water = average 150 ng/L
- Longyearbyen Drinking water: average 200 ng/l
- Longyearbyen surface snow: average 60 ng/L



TFA is ubiquously found in surface waters

Various pathways into water are identified (industry, domestic, atmosphere)

Commonly applied techniques in waterworks do not remove TFA

Analysis conducted by Karsten Nødler, DVGW-Technologiezentrum Wasser in 2017

Novel brominated flame retardants (BFRs)4.)

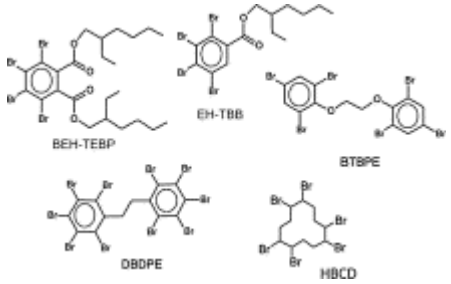
- Known as Arctic pollutants since 1990s
- Additional CEAC compounds recently identified:

Deca-BDE, BEH-TEBP, BTBPE, DBDPE, DBE-DBCh, EH-TBB, HBBz, HBCDD, OBTMPI, PBB-Acr, PBBz, PBEB, PBT, TBBPA, TBBz, TBCT, TBP-AE, TBP-BAE, TBP-DBPE, TBX (*name list available upon request*)

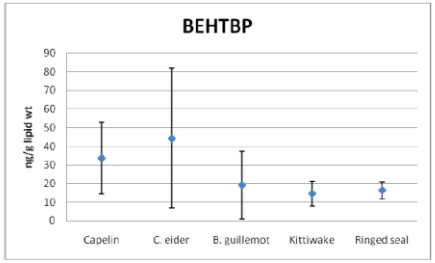
Identified in air, water and biota (marine predominantly

Levels were found low with predominant occurence in the marine enviroment.

Released through ølocal sources included industry and sewage



Source: Olukunle et al. (2015) Waste Manag. 43: 300-306



(BEHTBP) (ng/g lw) in birds. Source: Sagerup et al (2010) New brominated flame retardants in Arctic biota. Norwegian EPA report 1070/2010 – TA2630

CEACs relevant as surface water contaminants

- **Chlorinated flame retardants:** Dechlorane plus and others - 8 comp.; Identified in the terrestrial andmarine environment; Remote and local sources identified; ppt Concentration range in aqueous and solid samples
- **Organo-phosphate based flame retardants:** Organophosphate esters (OPE) – 20 comp.; Confirmed in the Arctic atmosphere and biota mainly; conc. in low/medium ppt range (max. 2300 pg/m^3 air).
- **Phthalates:** Esters of phthalic acid – 11 comp.; Confirmed in air and mainly the marine Arctic enviroment; conc. In the low/ medium ppb r
(Torshavn DINP: 17000 ng/g dw sed.)

CEACs relevant as surface water contaminants

- **Marine plastics and microplastics**: Strong focus on the marine environment incl. Sea ice. Up to 250 particles/m3 in sea ice cores. Plastic ingestion by Arctic biota confirmed
- **Unintenionally generated PCBs:** Generated by thermal decomposition, pigment manufacture (impurities); 93 congeners: found in Arctic air and terrestrial samples; in low/ medium ppt range (Ny-Ålesund soil: 167 pg/g dw).

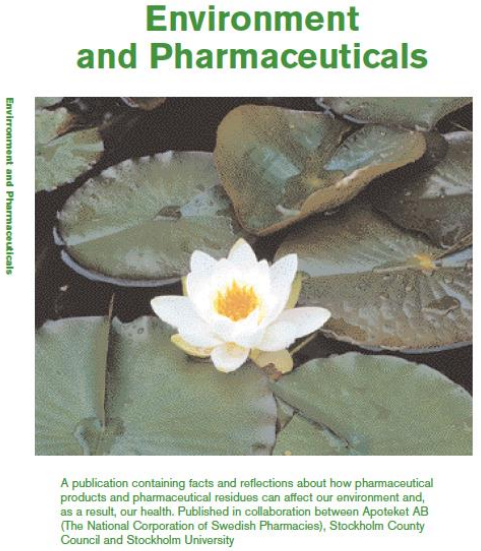
Potential adverse effects

Significant knowledge gaps evident for all CEAC groups

- PFASs: Protein associated; immunotoxicity
- nBFRs: Endocrine disrupting, neurotoxicity
- Phthalates: Endocrine disrupting, reproductive effects, pre-birth development
- TFA: Immunotoxicity,
- PPCPs: Target effects, cytotoxicity, neurotoxicity, immuntoxicity

Remediation and mitigation strategies

- Coordinated sanitation strategies required
- High technological standards for Sewage treatment for decentralized systems
- Community awareness: Disposal strategies and public awareness in the communities (i pharmacies as return points for outdated pharmaceutical products)
- Continuous communication of all critical aspects with the public
- Development of sanitation technology for cold High North environments



Knowledge gaps

- Medium and long term monitoring data need for source evaluation.
- Time and spatial trend investigations for priority CEACs are needed.
- Comprehensive information on source apportionment and assessment of source strength is missing
- Research on mitigation and abatement strategies on CEACs in Arctic waters required.
- The elucidation of transformation processes as an integrated part of fate assessment is not available.
- Reliable environmental toxicology and effects studies for the Arctic environments are missing.
- Joint Research & Development strategies for PPCP remediation and abatement in the Arctic

Conclusions

- CEACs are present in Artic environments.
- STP release into aquatic environments identified as major environmental source in the Arctic
- Level can reach high μg range in contaminated sites
- No spatial trends identified in the registered studies
- Level can be higher than for middle latitude regions
- Low Technological standards or even absence of Sewage treatment
- Concentration range depends on usage patterns and sanitation treatment
- Adequate remediation and mitigation strategies required.

Acknowledgement

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