POPs and climate change

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Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

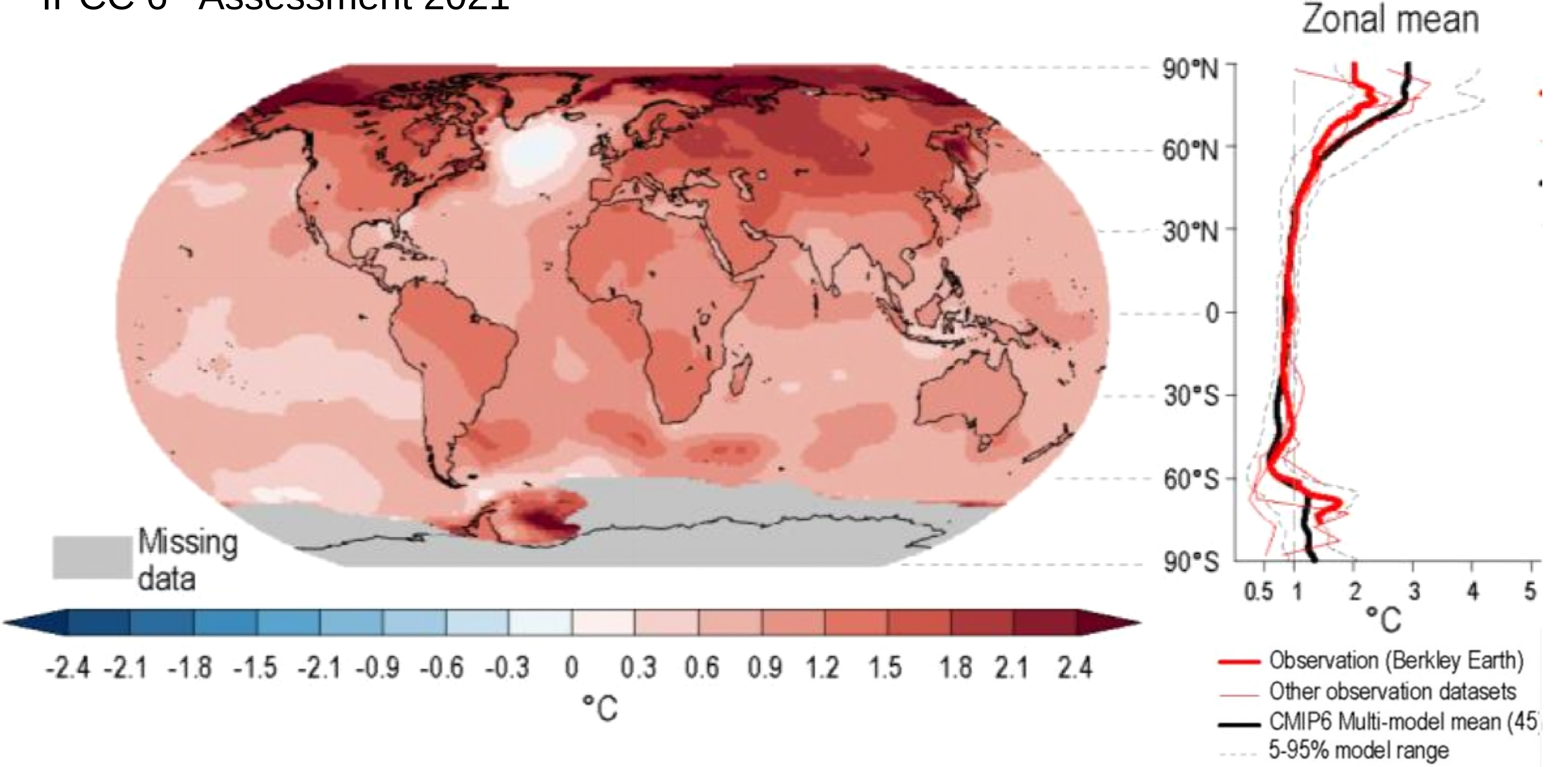
AMAP
Arctic Monitoring and
Assessment Programme

Outline

- Climate warming – recent predictions and observations
    - Extraordinary warming of the Arctic makes it a sentinel region
    - Influence of warming on pathways of pollutants from mid-latitude regions
- The Arctic Monitoring and Assessment Program and its environmental monitoring programs for POPs
    - Atmospheric trends of PAHs and PCBs – climate influences
    - Glacial runoff and permafrost thaw – influencing fluxes of PCBs to Arctic lakes
    - Changes in the food webs of polar bears and seals – impact on bioaccumulation of PCBs
- Summary and Knowledge gaps

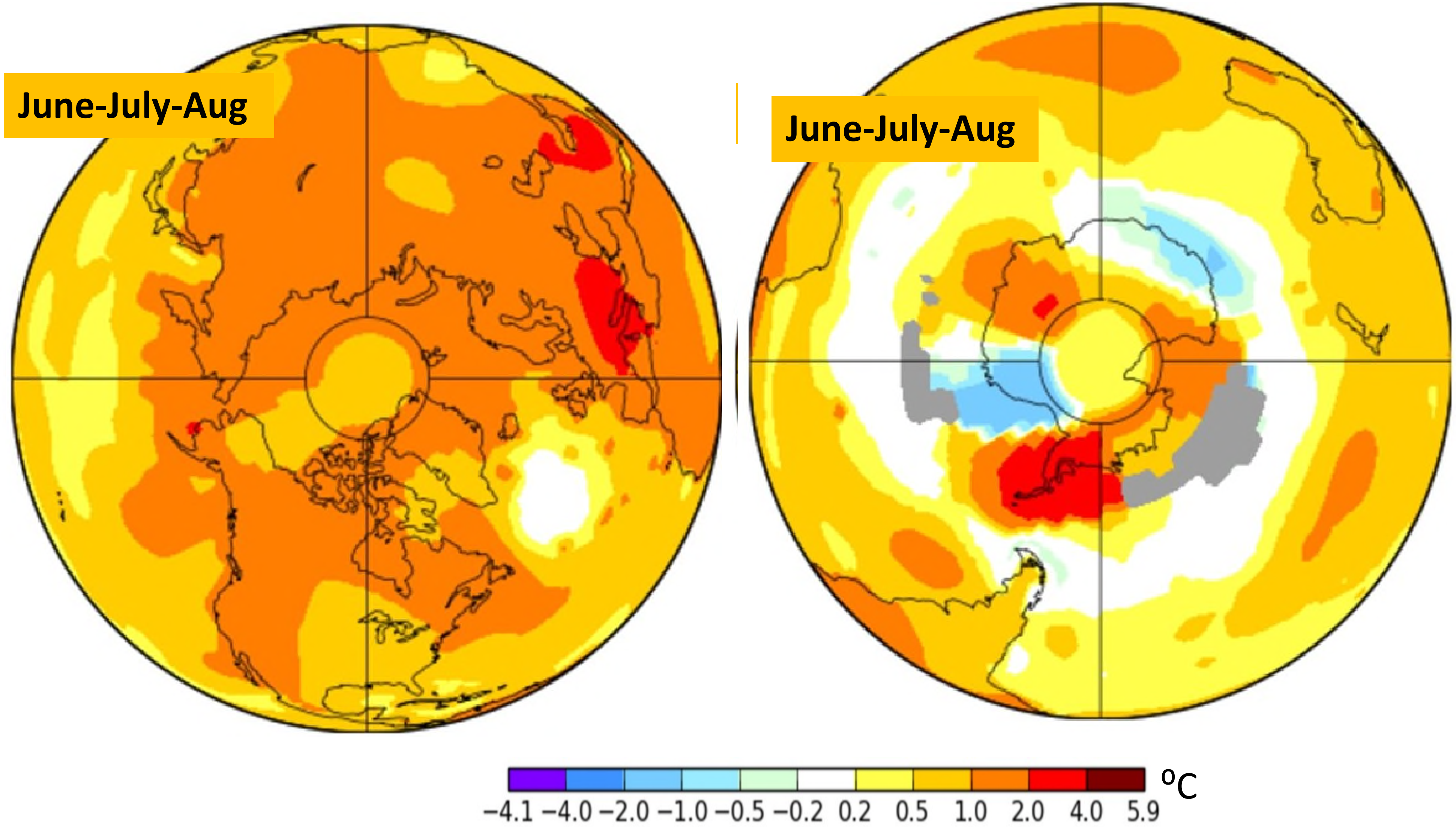
Predicted annual mean temperature change at a global warming level of 1 ºC

IPCC 6th Assessment 2021



How Could Climate Change Influence the fate of POPs?

Summer and Winter surface air temperatures (^{o}C) for the period 2011-2021 relative to 1951-1980



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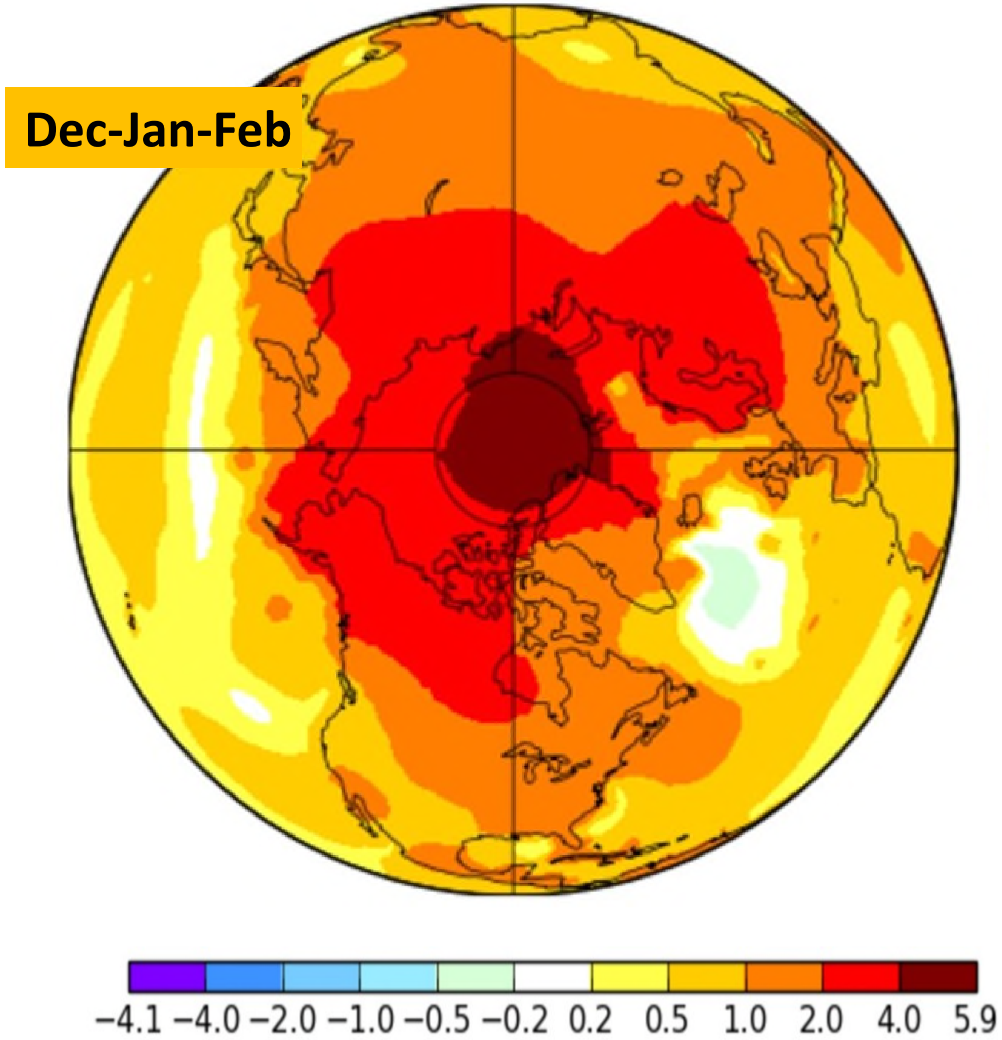


<u>Increased atmospheric transport</u>

- On dust particles or as gases from warmer soils
- Release from the expanded area of open ocean waters
- On smoke particles from more frequent forest fires

<u>Greater inputs from previously buried sources</u>

- From melting glaciers and thawing permafrost

<u>Changes in food webs and diets of top predators</u>

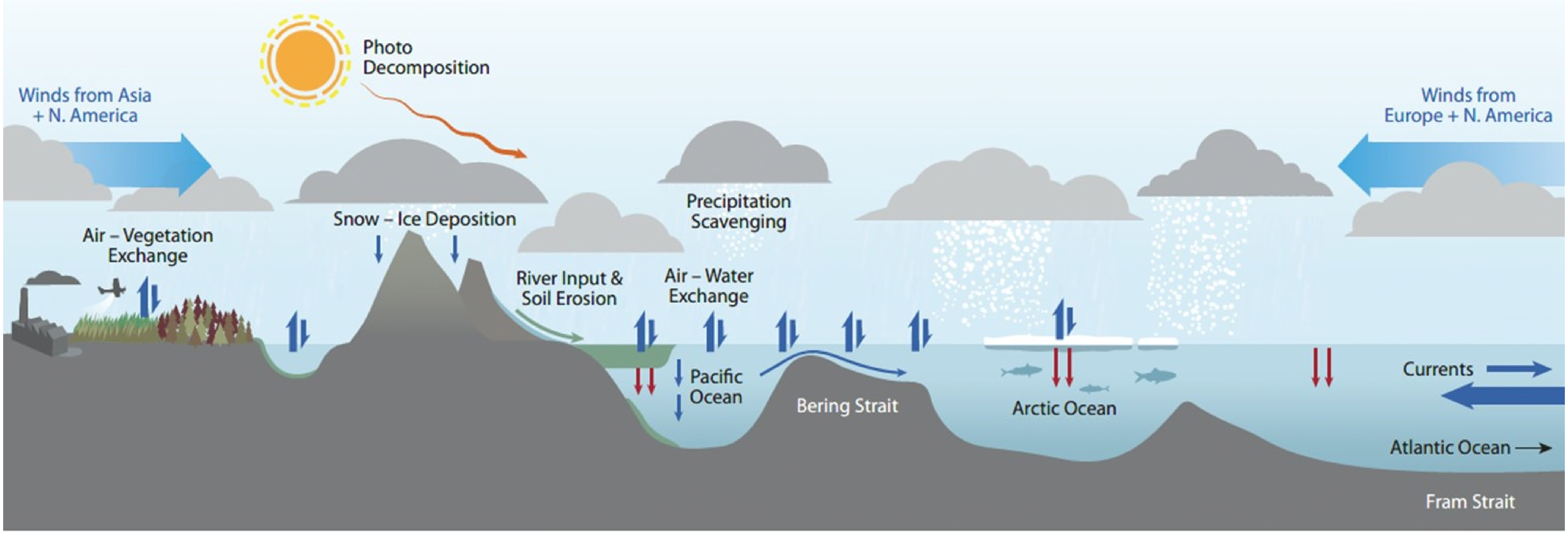
- Loss of Arctic sea ice habitat
- Change in sea ice associated diets
- Transient/subarctic species moving north

<u>Similar effects likely in the Antarctic peninsula</u>

°C

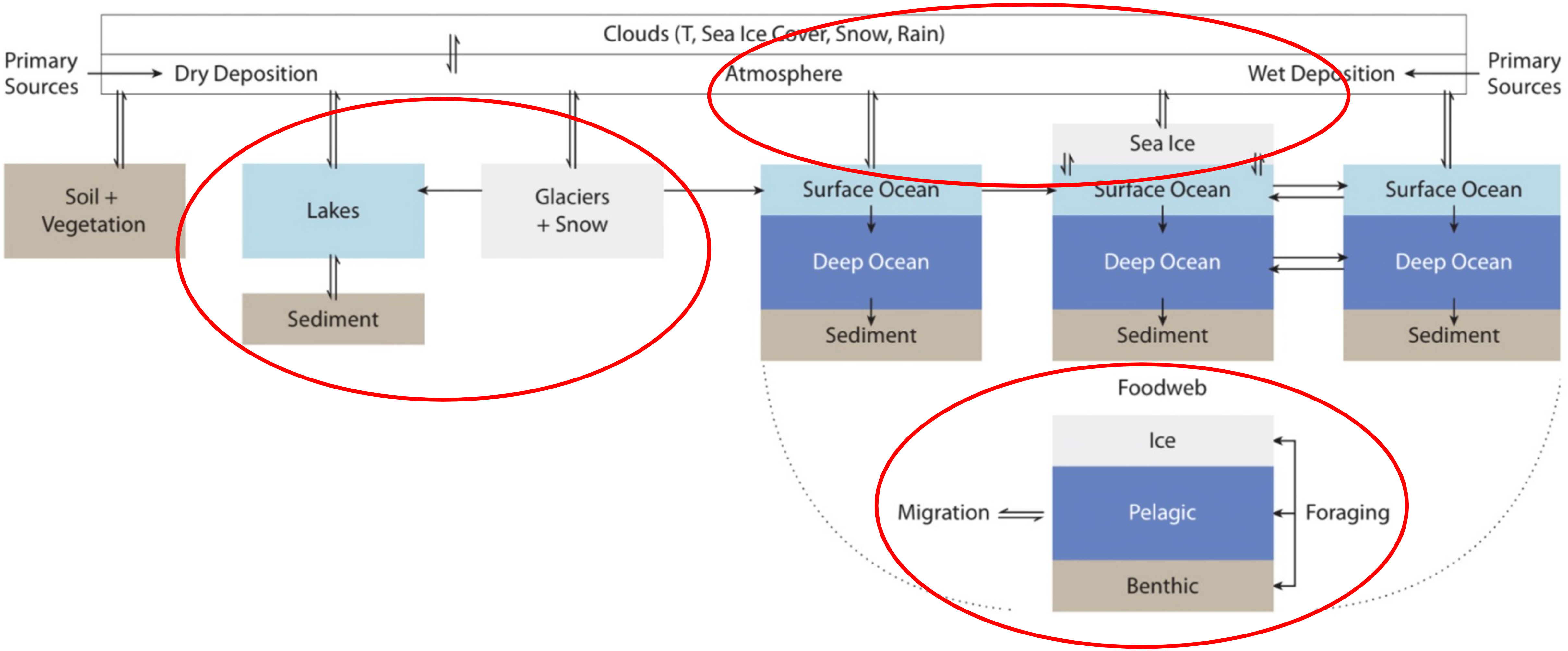
Pathways for POPs & CEACs to reach the Arctic or other remote regions that could be impacted by climate change

(Hung, Halsall et al. Ch 2.2 AMAP POPs-CEAC-Climate assessment; Ma et al. Global & Planet. Change 2016)



Simplified summary of climate change influences on transport pathways and transformation processes of POPs in the Arctic environment

(Hung, Halsall et al. Ch 2.2 AMAP POPs-CEAC-Climate assessment)



AMAP 2021. POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change. Nov 2021

ARCTIC MONITORING & ASSESSMENT PROGRAMME (AMAP)

- Working group of the Arctic Council
- Monitor/assess the status of the Arctic region with respect to pollution and climate change
- Involves all circumpolar countries and other countries active in Arctic research
- Results based on contributions from national programs
- Sound science-based, policy-relevant assessments

<u>Long term studies of contaminants in the Arctic</u>

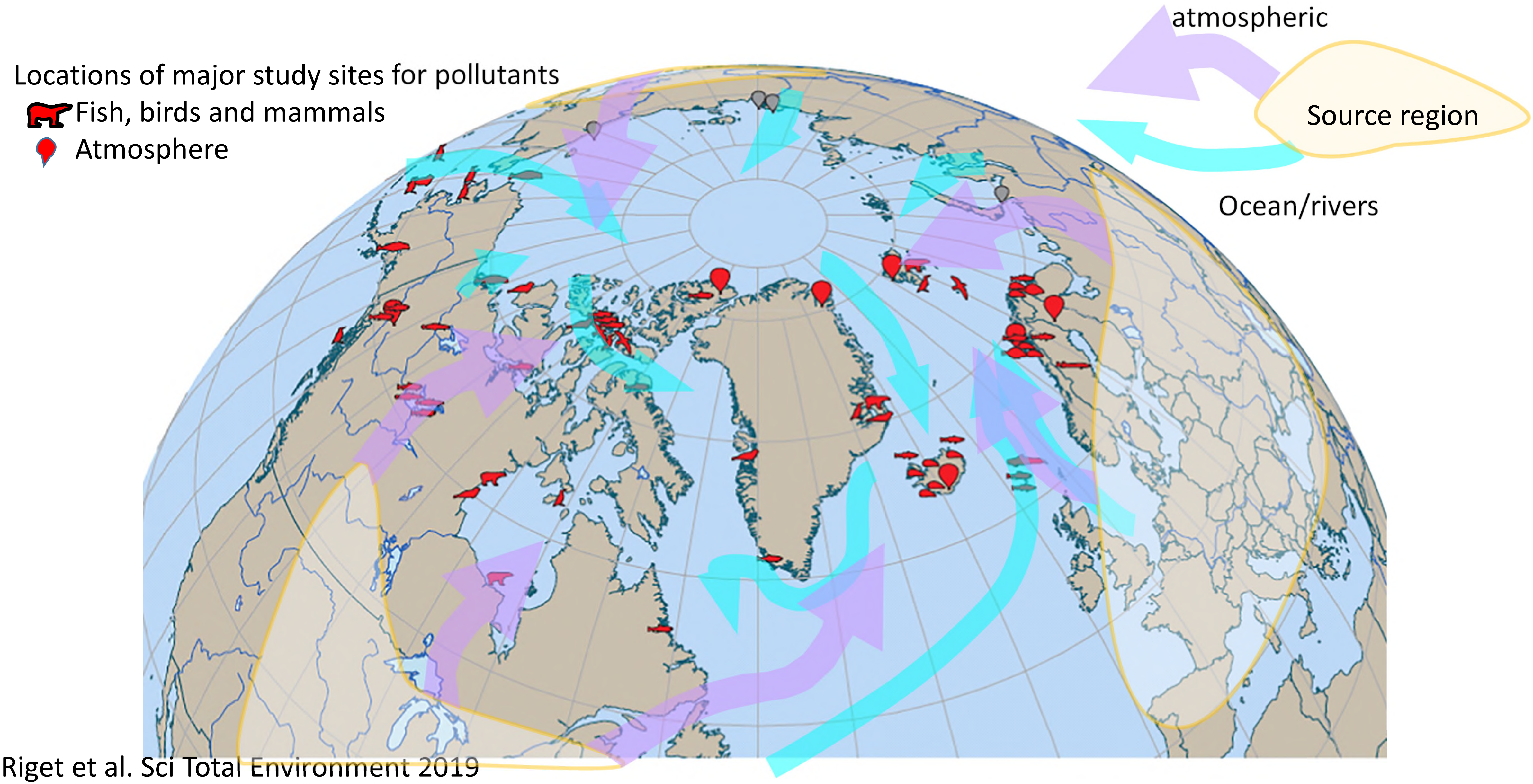
✓ Monitor & assess the status of contaminants & climate change issues

✓ Monitoring & surveillance of contaminants in air & wildlife

✓ Assess climate change –contaminant interaction

✓ Inform Arctic policy & decision making

Studies of chemical pollutants in air and wildlife in the Arctic: Transport pathways and major sampling locations



Riget et al. Sci Total Environment 2019

Persistent Organic Pollutants (POPs) &
Chemicals of Emerging Arctic Concern (CEACs)

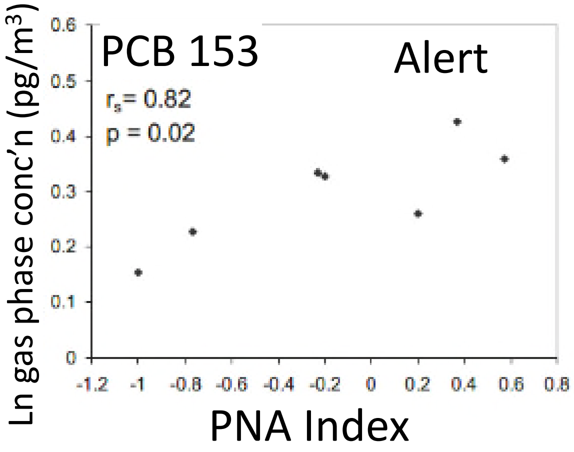
- **Pesticides**
- **Industrial emissions and byproducts (eg. HCB, HCBD)**
- **Personal care products (eg UV-filters, siloxanes)**
- **Commercial chemicals (eg flame retardants, stain repellents)**
- **Microplastic & plastic additives**
- **Products of combustion (Dioxins/furans, PAHs)**

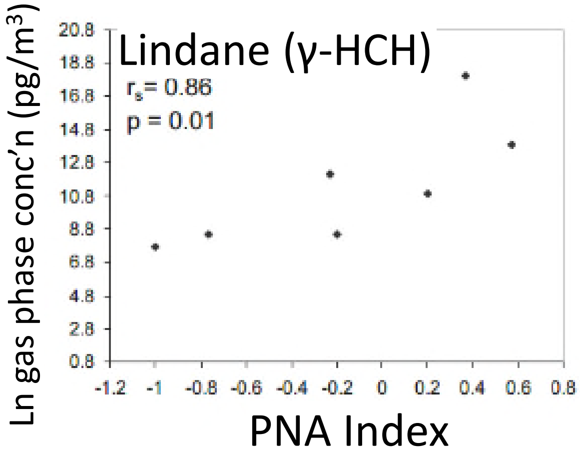
Concerns

- **Persistent**
- **Bioaccumulative**
- **Potential adverse effects for humans & the environment**
- **Long-range transport to remote regions**

Increased Atmospheric Mobility of POPs

- Correlations found between air concentration of some POPs and large-scale climate variation patterns





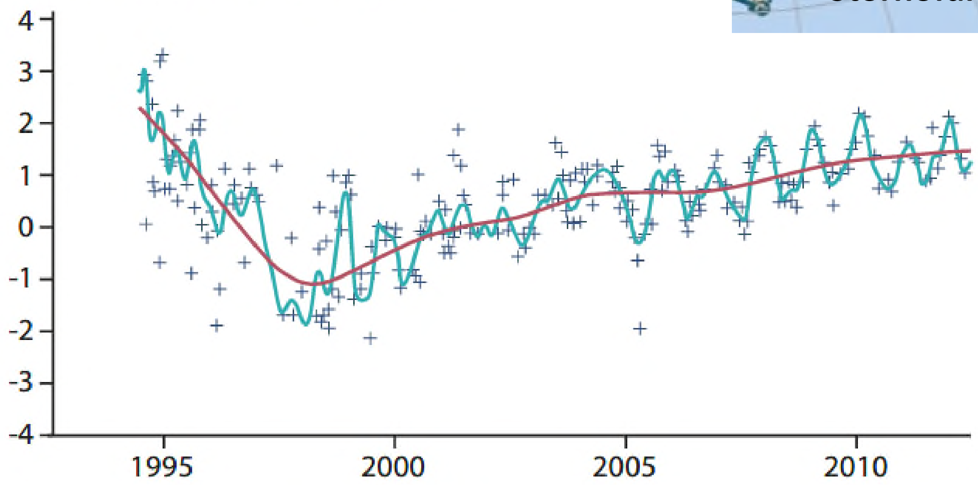
Pacific/North American (PNA) Pattern

- Pressure anomalies that influences air mass transport, temperatures and precipitation.
- PNA+: higher-than-average pressure over Hawaii, lower-than-average pressure south of Alaska.

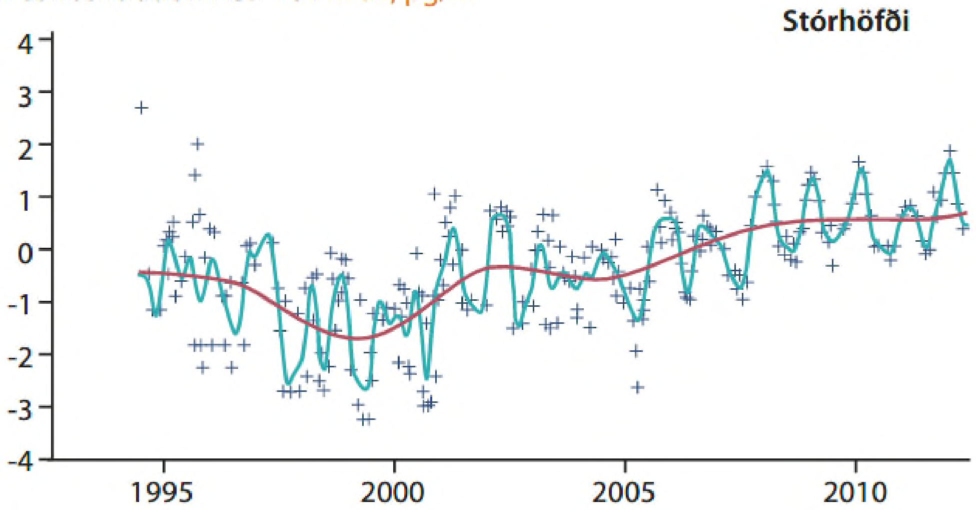
Hung et al., 2016, Environ. Pollut. 217: 52-61; Hung et al., 2005, Sci. Total Environ., 342:119-144; Becker et al., 2008, Atmos. Environ. 42: 8225-8233

- Increasing atmospheric PCBs at Storhofdi, Iceland
- May be related to deglaciation of ice caps and increased volatilization from the ocean

ln concentration PCB-52 in air, pg/m³

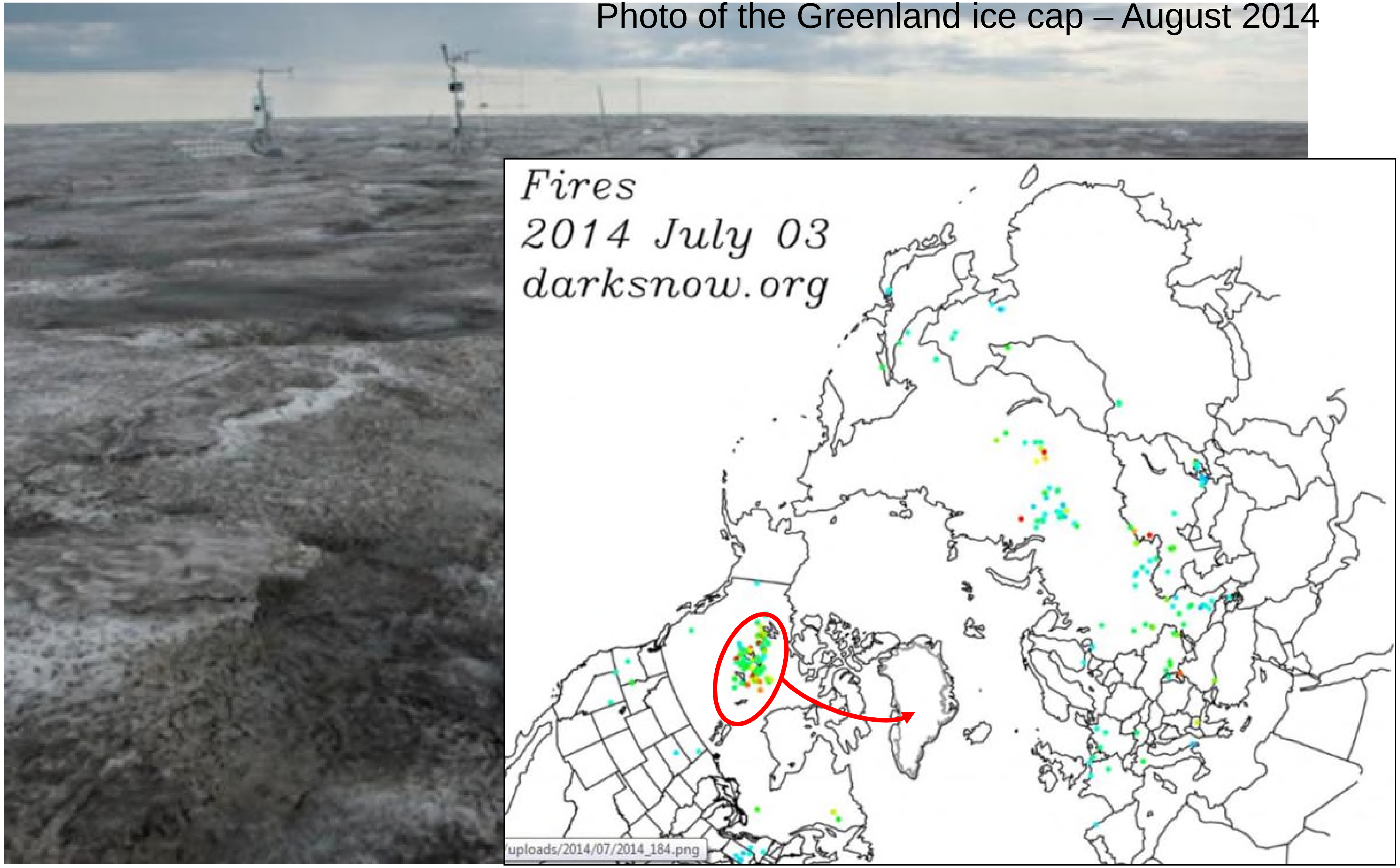


ln concentration PCB-101 in air, pg/m³



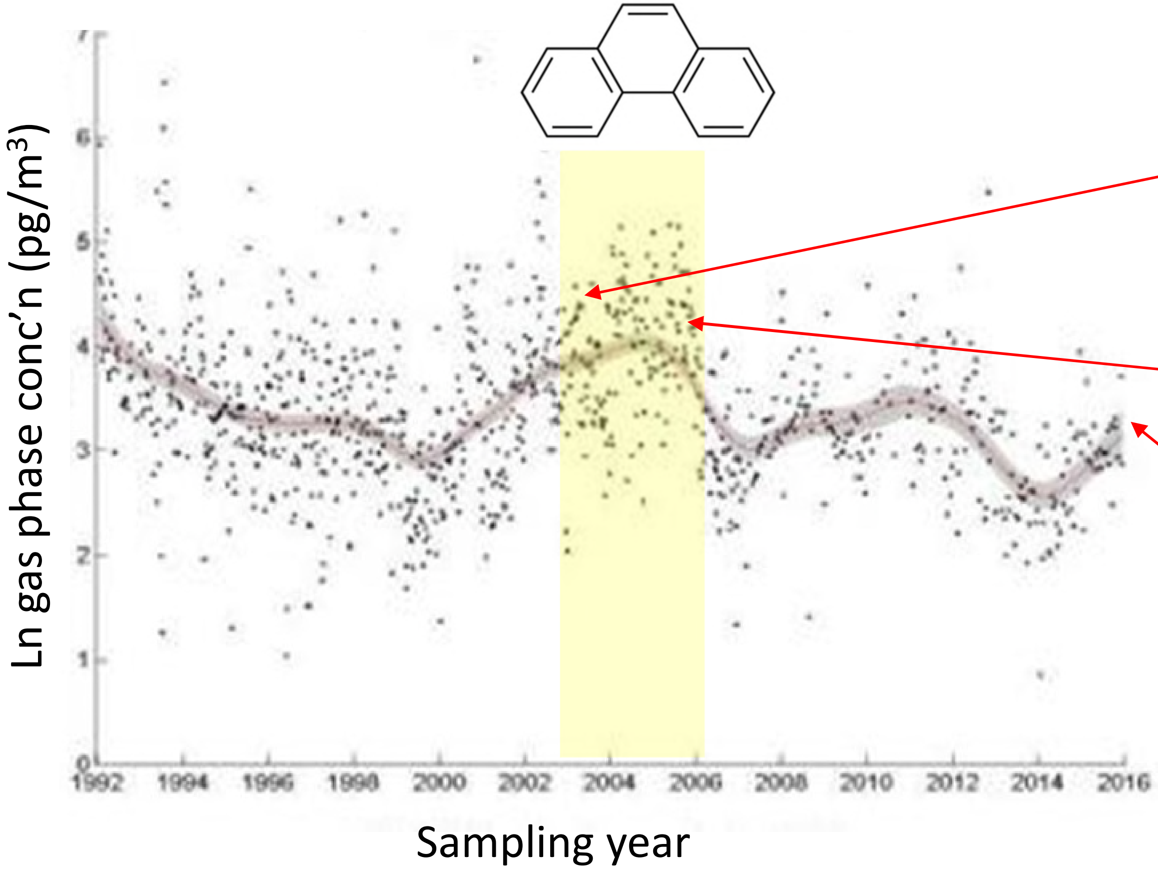
Forest fires in the northern boreal forests – another climate- contaminants linkage

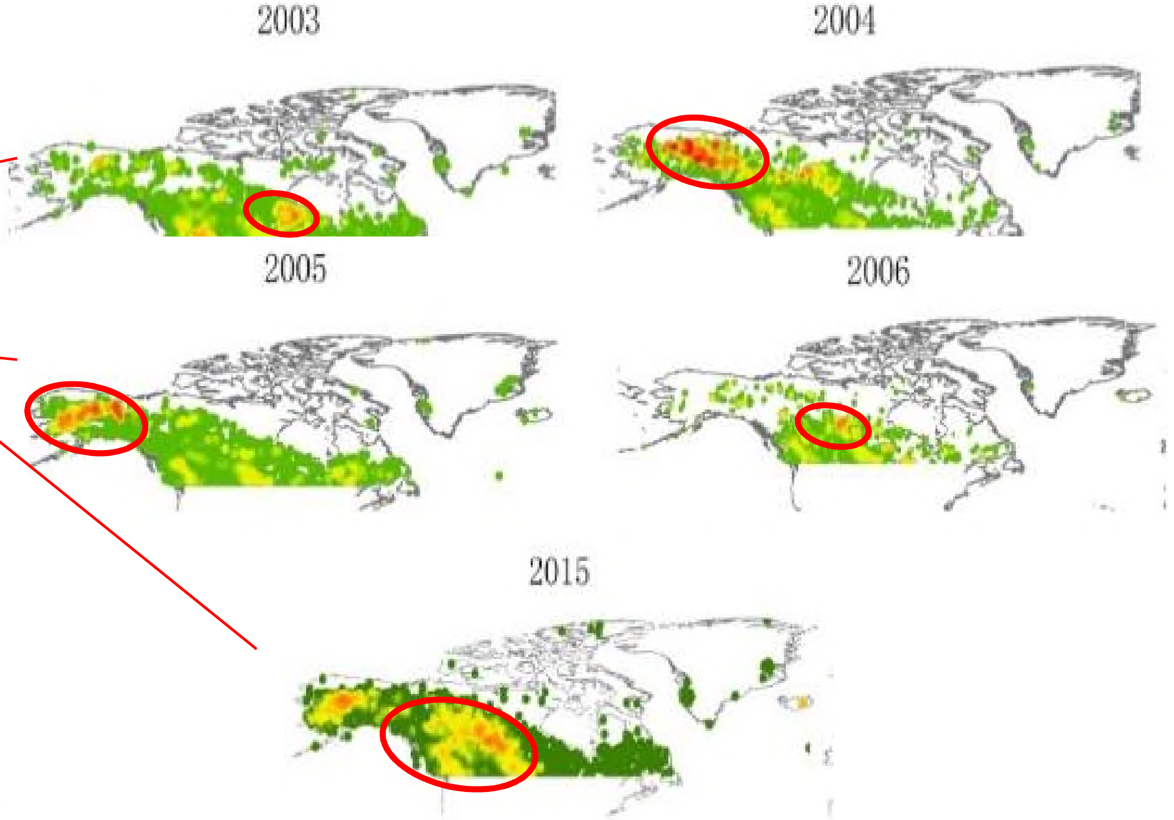
Photo of the Greenland ice cap – August 2014



Increase in wildfires leads to higher phenanthrene in air at Alert in Northern Ellesmere Island

- Higher air concentrations of PHE and other PAHs coincided with frequent and extensive summer forest fire events

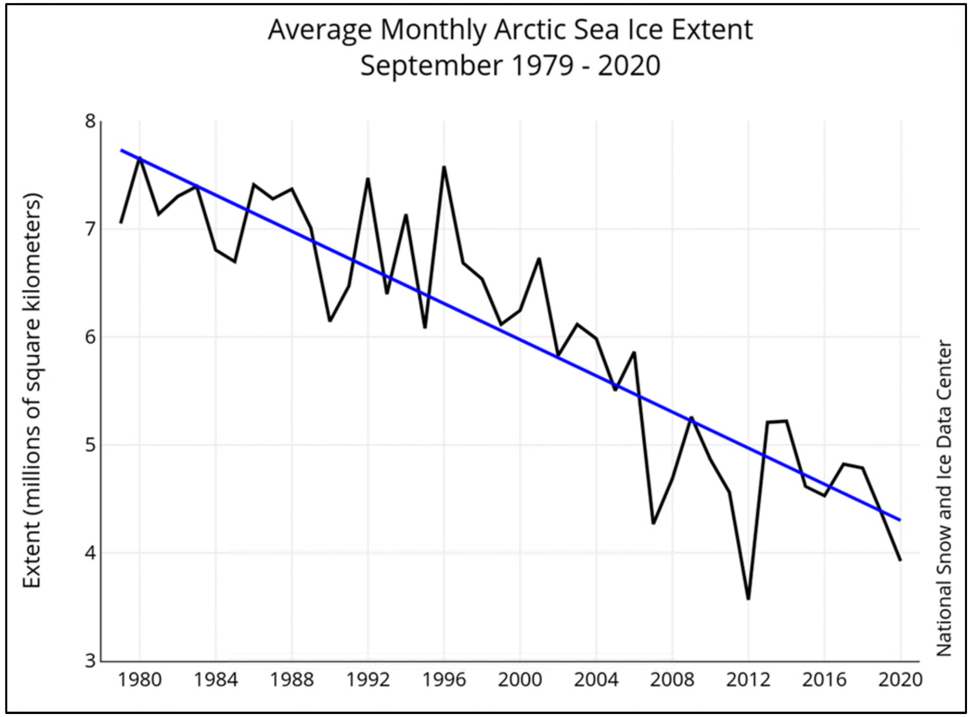


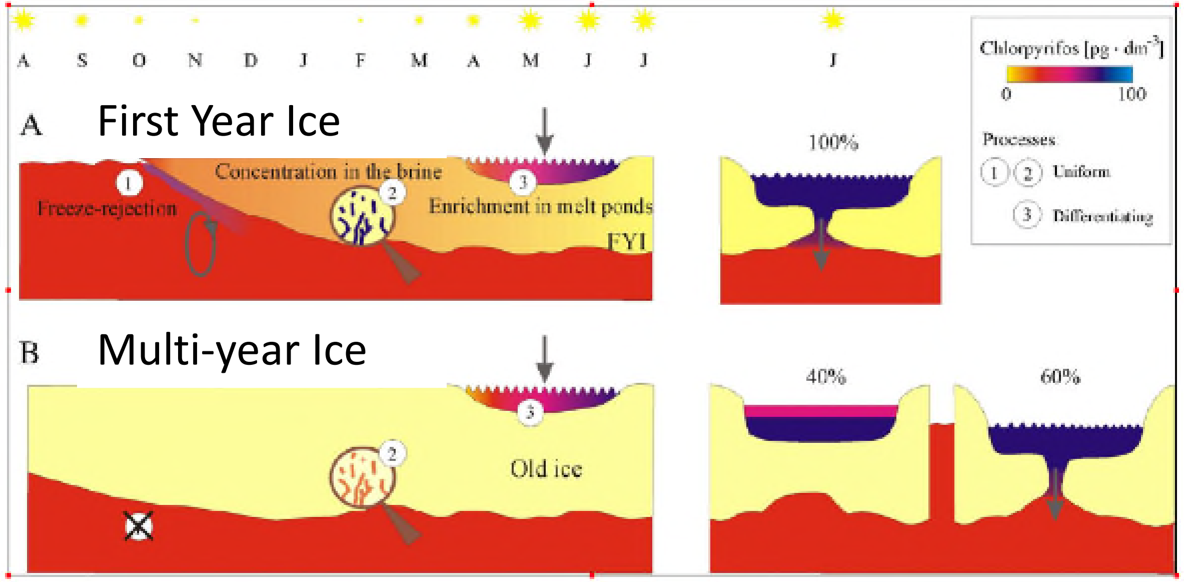


Yu et al. Environ. Sci. Technol. 2019, 53, 2375-2382

Arctic Ocean Sea Ice retreat

- Reductions in the extent of Arctic sea ice by nearly 50% from 1979 to the present
- Longer period and larger surface area of open water result in air-water exchange





- **Biogeochemical-modulated transport** of contaminants

  primary production

  contaminants **sedimentation**

  air-water concentration gradient, **draw down** gaseous contaminants from **air to ocean**

First Year Ice vs. Multi-year Ice

- Contaminants **enriched in brine** channels of first year ice enter the ocean annually while they are retained in multi year ice
- **Melt ponds** on sea ice surface **concentrate** POPs deposited from the atmosphere and **drained** into ocean underneath
- Implication on exposure of **sympagic organisms** that thrive in and under the ice

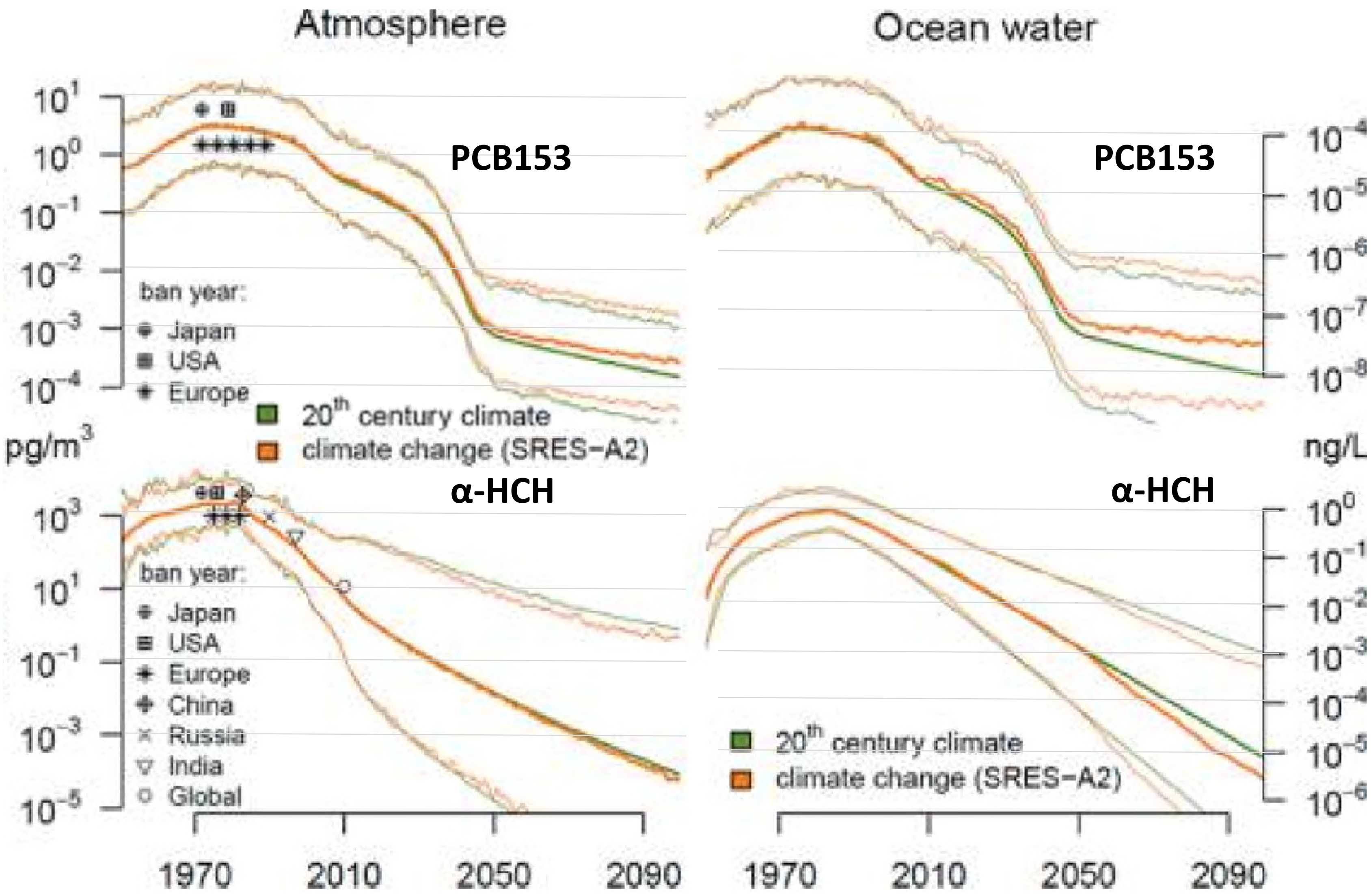
Pućko et al., 2015, Sci. Total Environ. 506–507: 444–452; Galbán-Malagón et al., 2013, ES&T, 47: 7195-7203

Modeled PCB153 and α-HCH concentrations in Arctic air and ocean water between 1950 and 2100, under the 20th century climate and the IPCC's SRES-A2 climate change scenario

Wöhrnschimmel MacLeod and Hungerbuhler ES&T 2013

Model results with SRES-A2

- Increased PCB153 in air (1.9x) and seawater (3.9x)
- Decline of α-HCH in air (0.7) and water (0.4)
- Concentrations mainly determined by changes in primary emissions, minor effect of climate change



Special Report on Emissions *Scenarios – SRES_A2 from IPCC 2000 is a relatively high CO2 emission scenario*

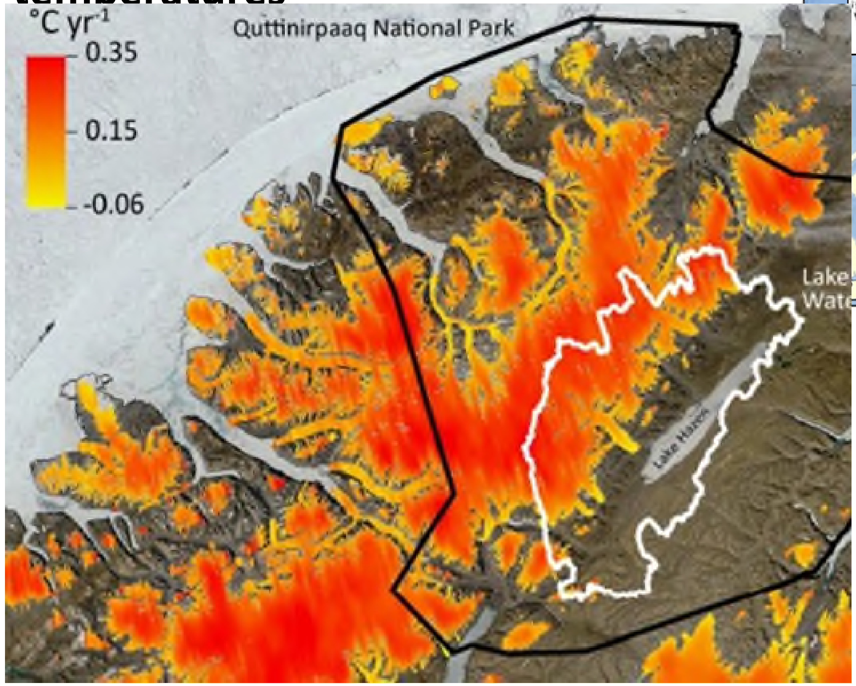
Lake Hazen, the largest High Arctic lake, responds rapidly to climate warming

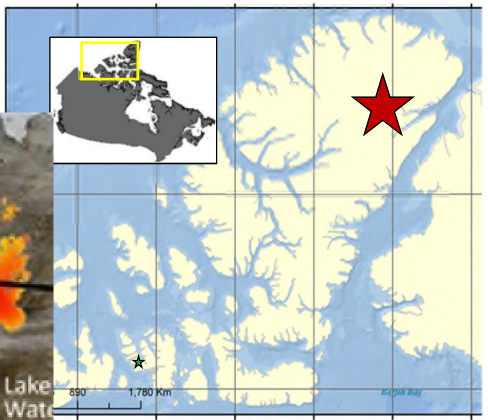
Lehnherr et al. Nature Comm 2018

St Pierre et al. Scientific Rpts 2019

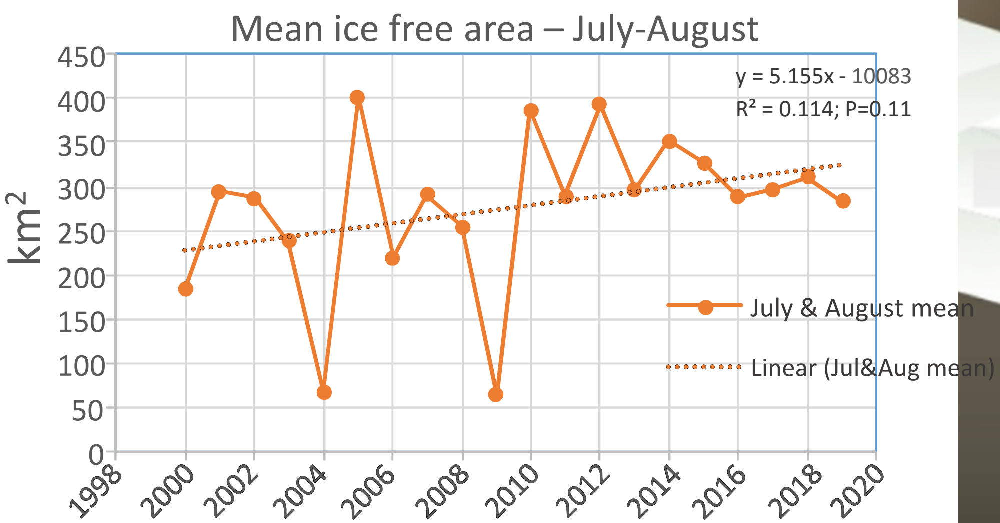
Mitchelutti et al. Proc.Royal Society B: Biol. Sci. 2020

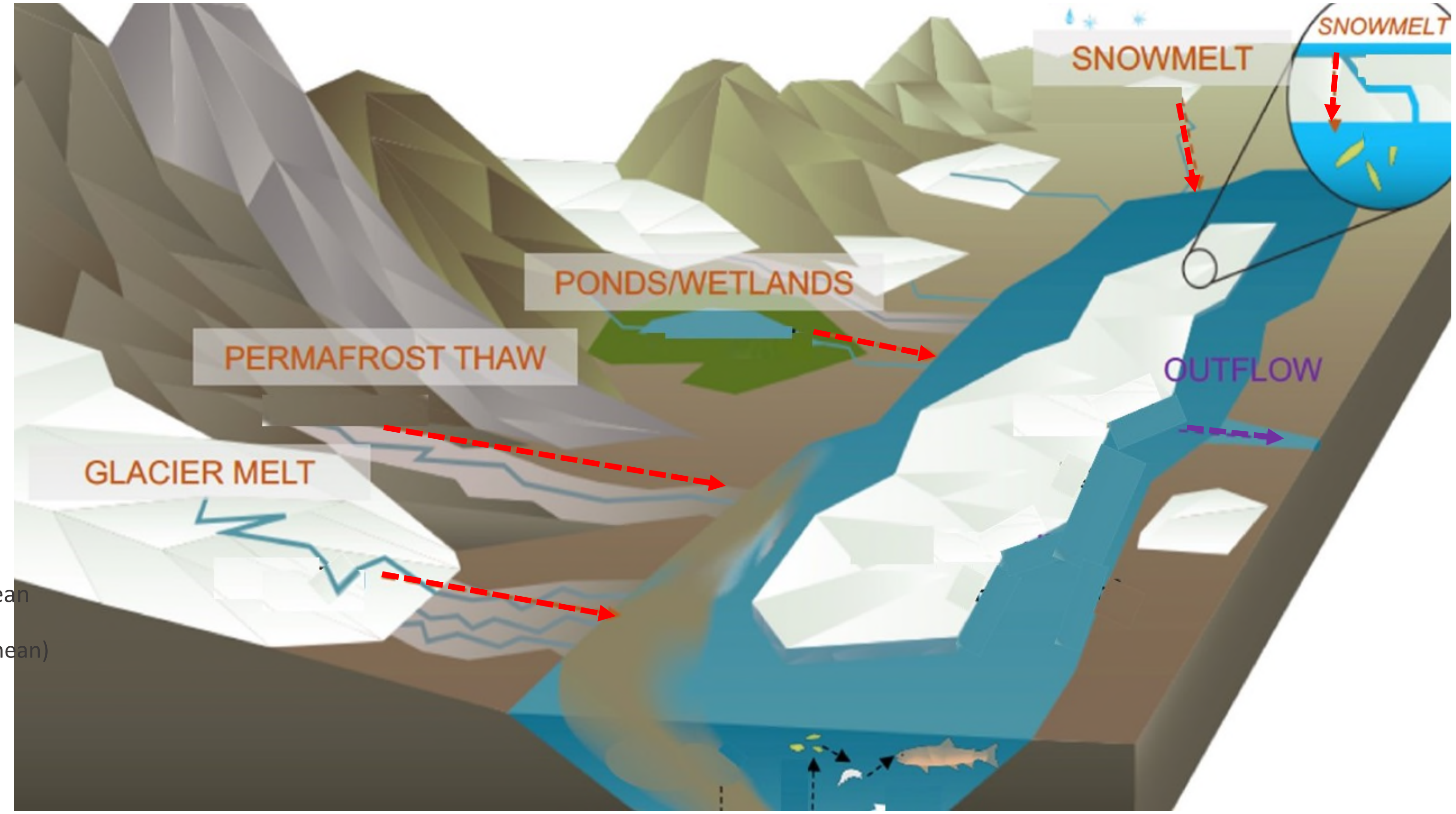
Increasing summer glacier surface temperatures





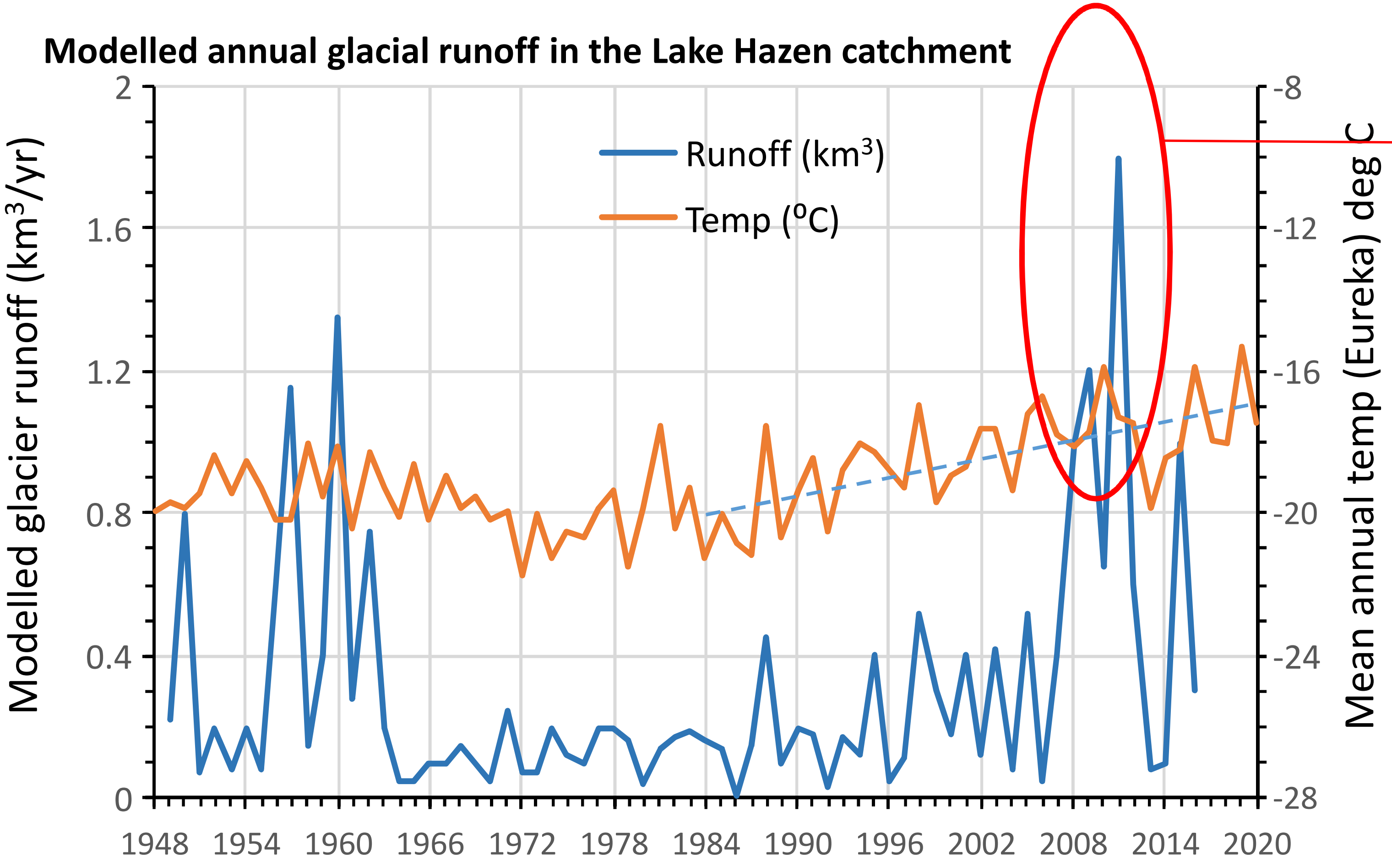
Increasing rate of ice free areas

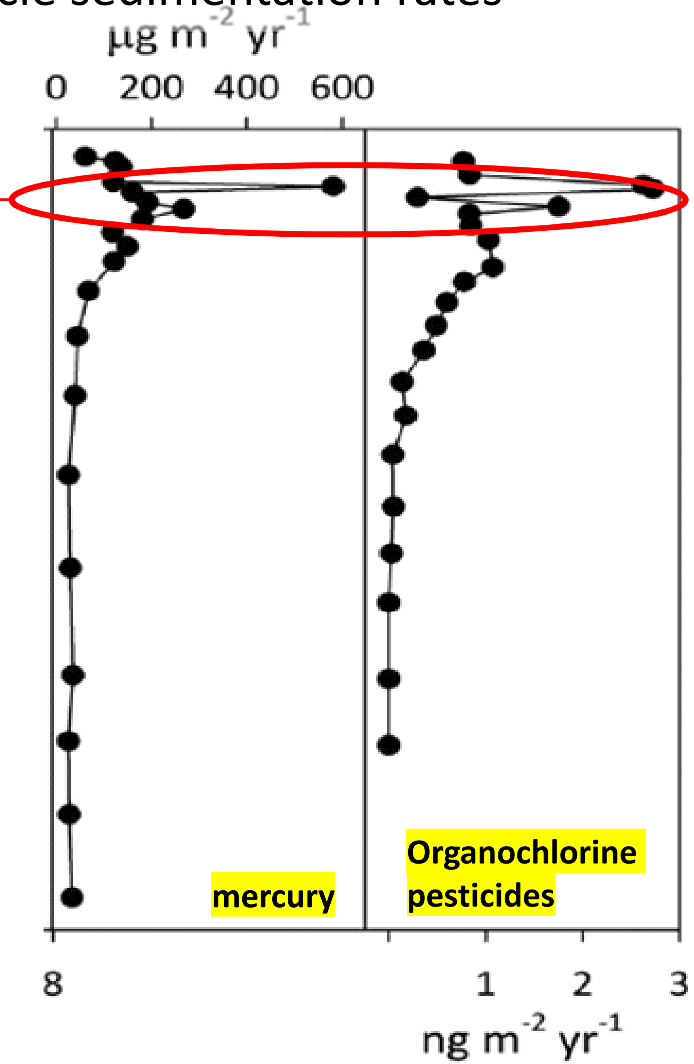




Effects of climate warming on runoff and sedimentation in Lake Hazen

- Regional annual mean temperature has increased 2.8 ^{o}C since mid-1980s
- Climate warming resulted in an 4x increase in glacial meltwater for the period 2008-2012 (Lehnherr et al. 2018)
- Average ice-free lake area has increased ~40% from 2000-04 to 2015-19
- Higher fluxes of POPs and mercury to lake sediments due to higher particle sedimentation rates

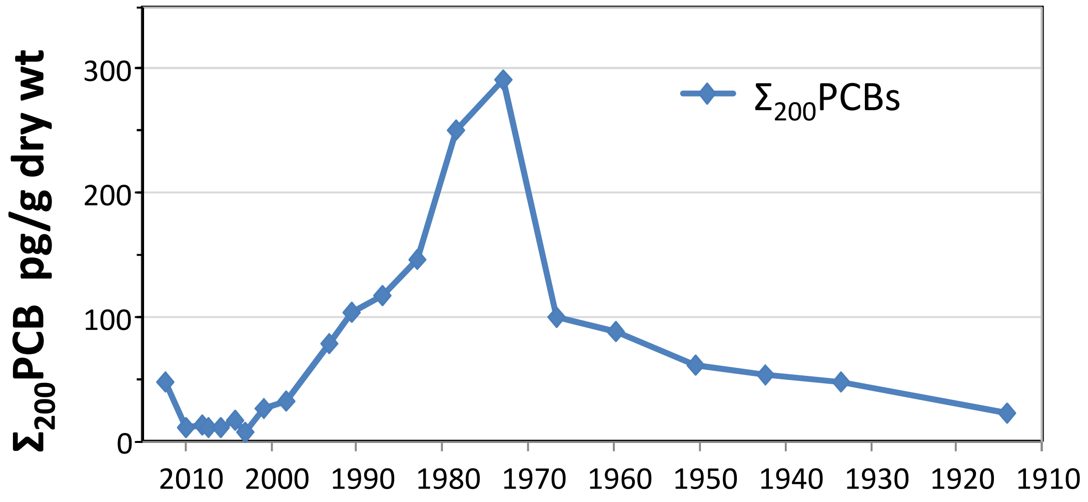


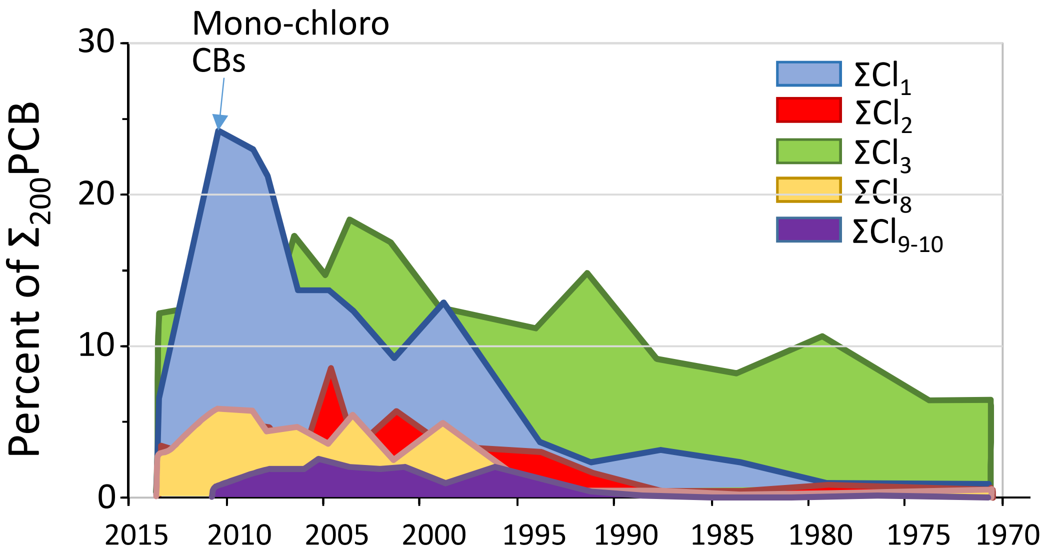


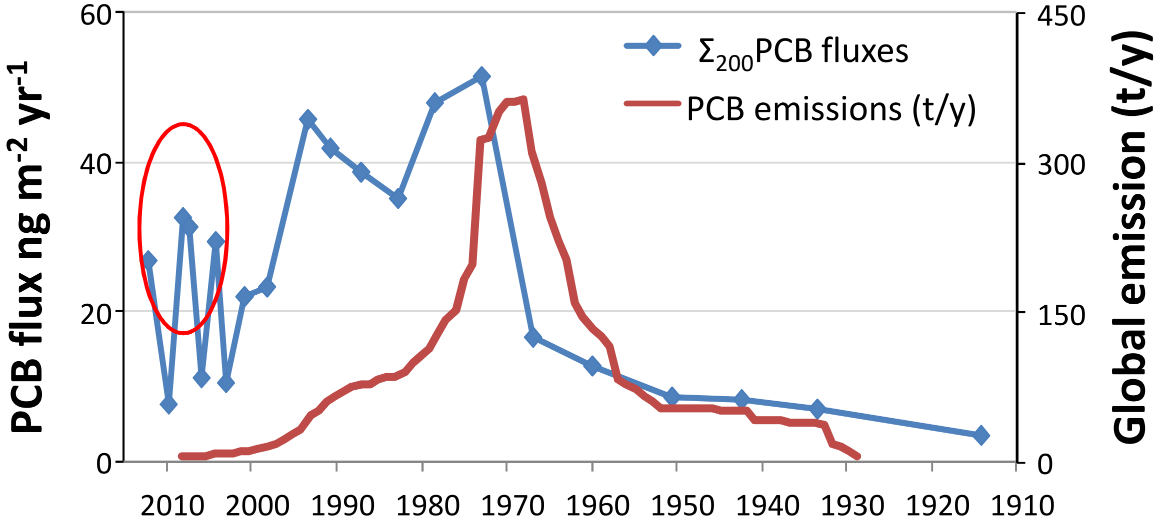
Lehnherr et al. Nature Comm 2018; St Pierre et al. Scientific Rpts 2019; Mitchelutti et al. Proc.Royal Society B: Biol. Sci. 2020

PCB profile in the dated sediment core from Lake Hazen. Comparison with modelled global emissions (Breivik et al 2007;2016)

- Maximum concentrations and fluxes coincide well with timing of global emissions
- PCB fluxes are elevated in the period 2005-2012 during high glacial runoff and sedimentation period
- Mono-chloro-biphenyls (CB-1,2 & 3) were up to 25% of Σ_{200}PCB (GC-HRMS analysis)
- Octa-chloro CBs and decachlorobiphenyl also more prominent post-2000



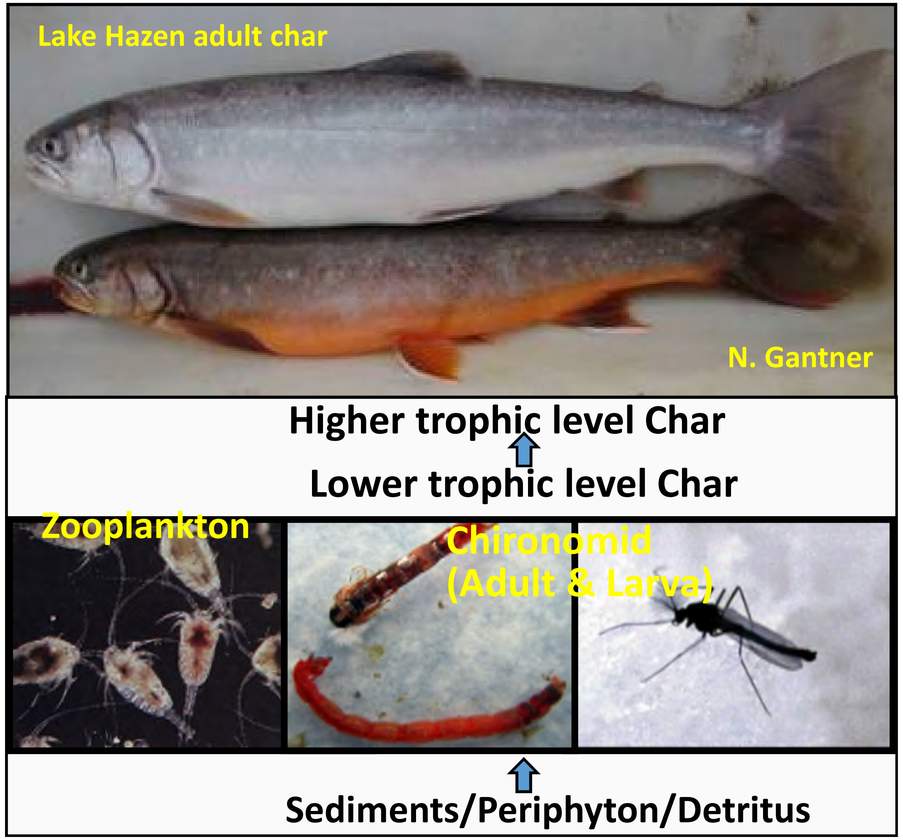


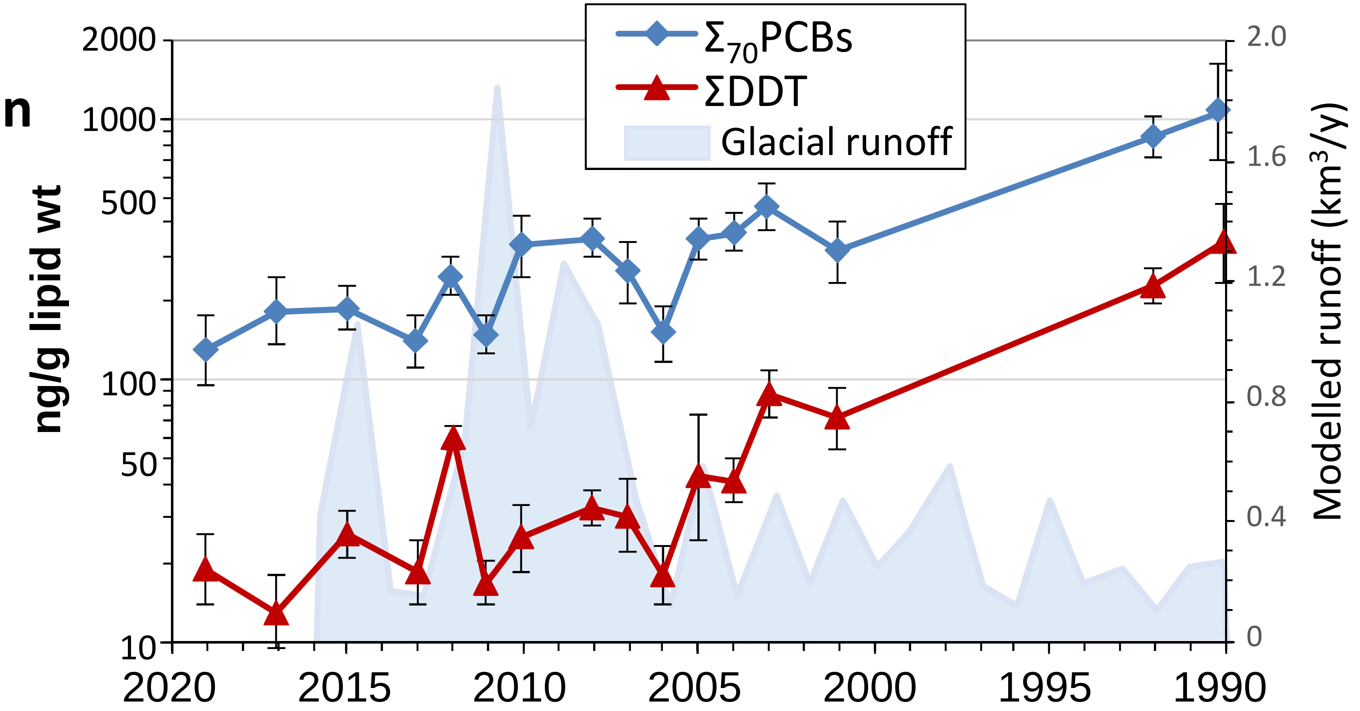


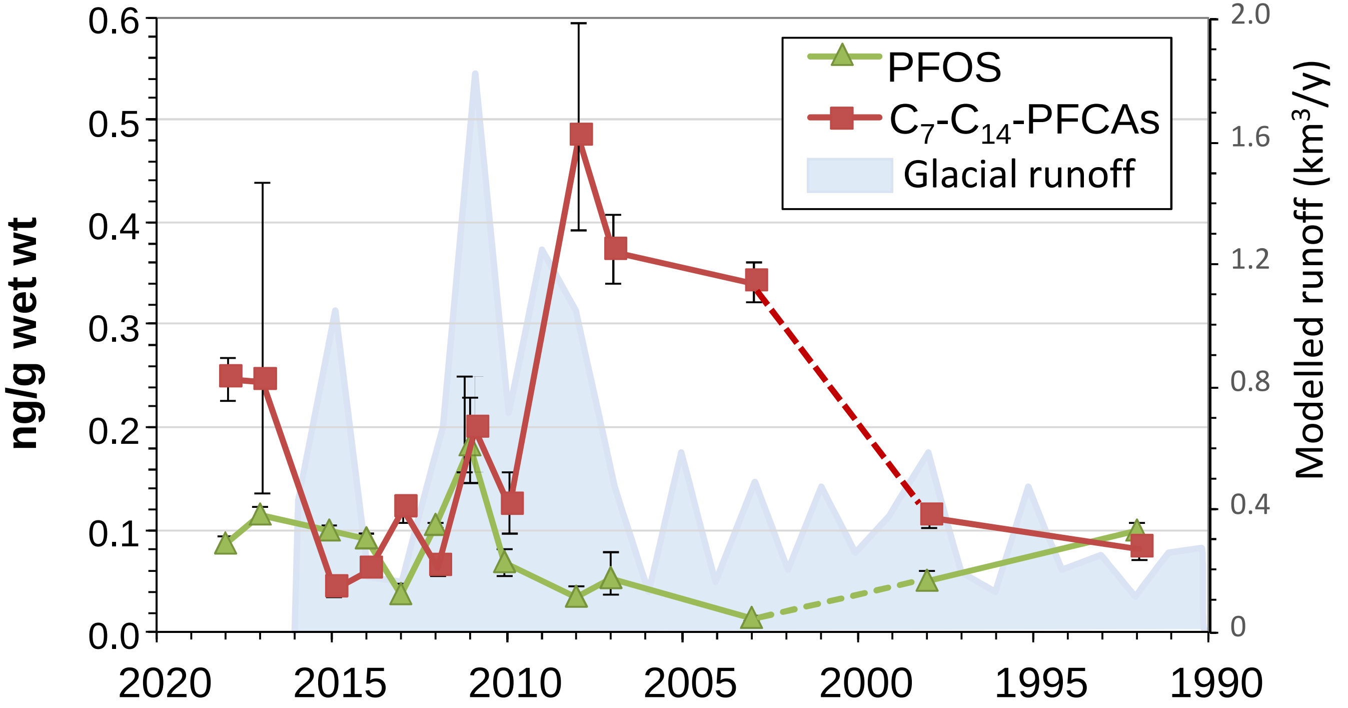
Muir et al. Unpublished data 2020

Long term trends of PCBs, DDTs and PFAS in muscle of landlocked Arctic char from Lake Hazen compared with increased runoff and deposition

- Landlocked char are the sole top predator in Lake Hazen
- Benthic organisms are the major food source
- **PCBs and DDTs** in char mainly influenced by global emissions rather than within lake or catchment effects
- **PFOS** concentrations correlate with glacial runoff (R^2=0.46 P=0.046) while PFCAs do not







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journal homepage: www.elsevier.com/locate/scitotenv

Temporal trends of persistent organic pollutants in Arctic marine and

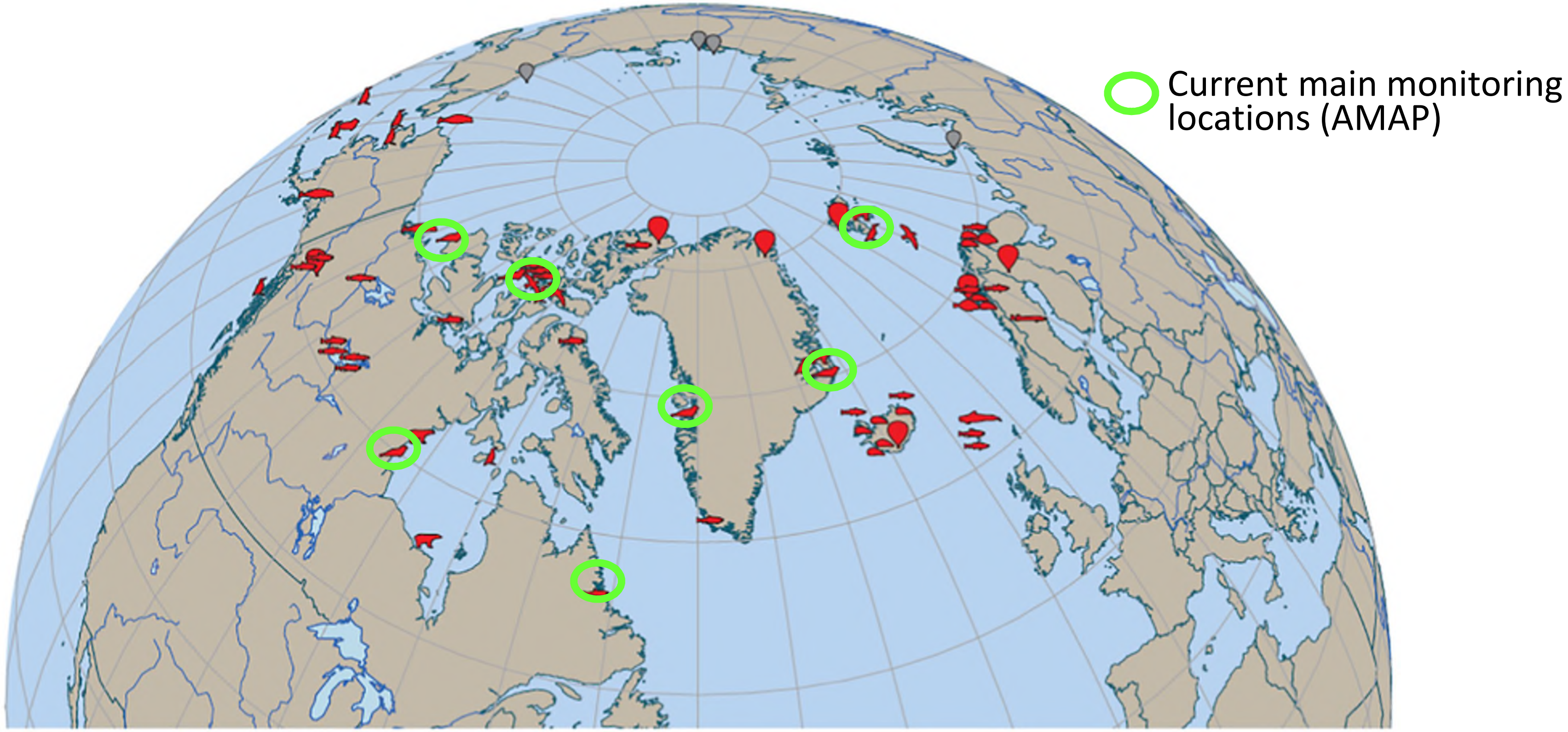
Number of long-term time-series (starting before year 2000) by country and species group

Country	Long-term time-series	Species group	Long-term time-series
United States (Alaska)	186	Blue mussels	145
Canada	323	Freshwater fish	197
Greenland	184	Marine fish	112
Faroe Islands	102	Seabirds	114
Iceland	109	Marine mammals	506
Norway	155	Total	1074
Sweden	15		

Only a limited number have examined effects of climate on trends

Ringed seals and polar bears: Key Arctic animals for the long-term monitoring of environmental contaminants and climate impacts

- Circumpolar distribution
- Highly sea-ice dependent
- Seals are main prey for polar bears
- Samples and indigenous knowledge from the Inuit
- Biology (diet, life history) of polar bears and seals increasingly well studied

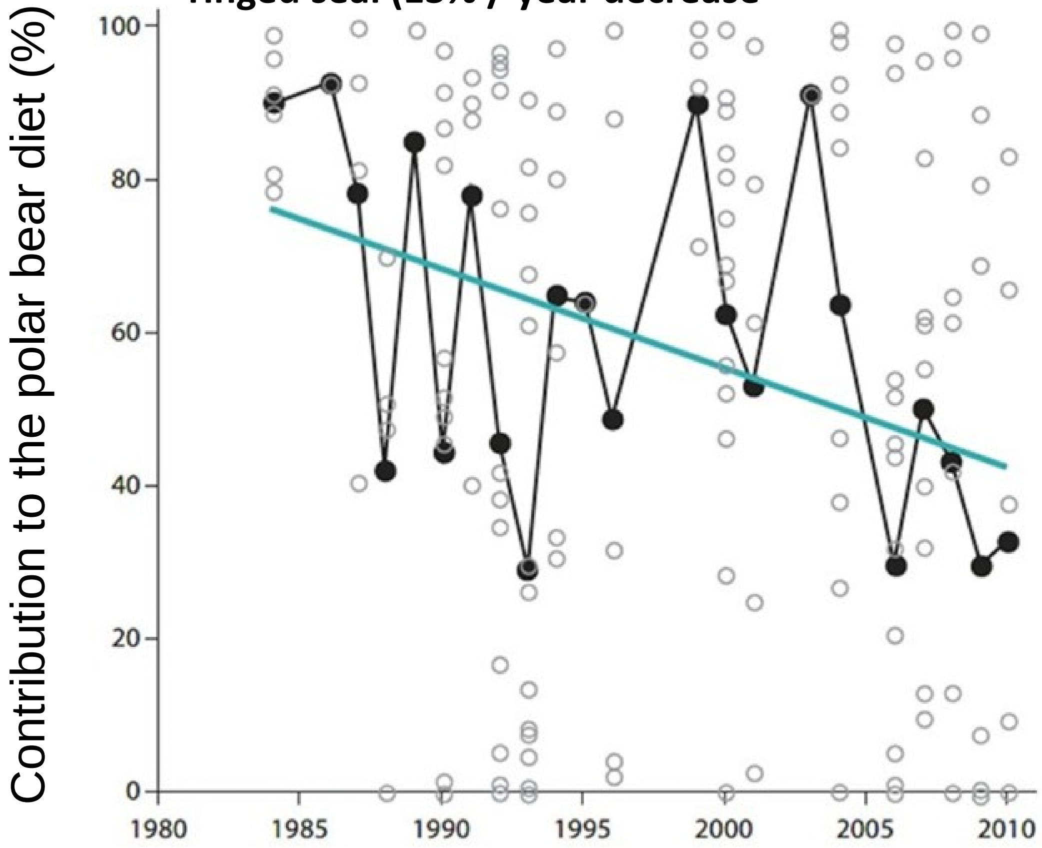


Map in Rigét et al
STOTEN 2019

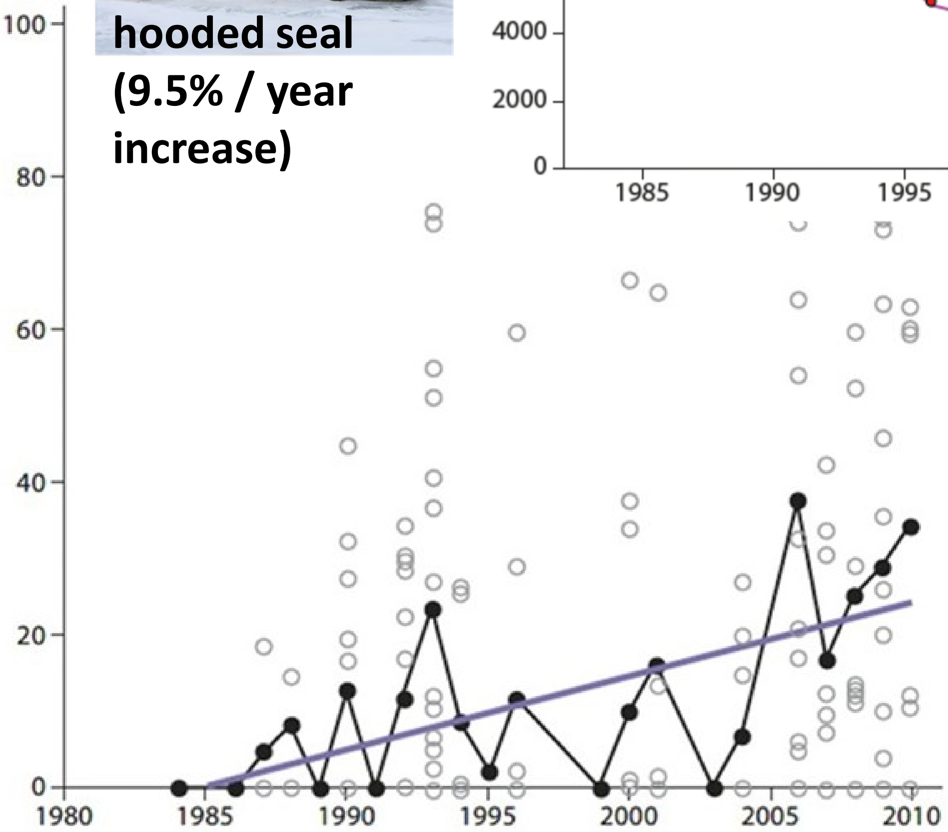
Dietary trends and POP concentrations in East Greenland polar bears

- Contribution of ringed seal and hooded seal to polar bear diets based on estimates from quantitative fatty acid signature analysis
- Hooded seals are a subarctic species now migrating further north

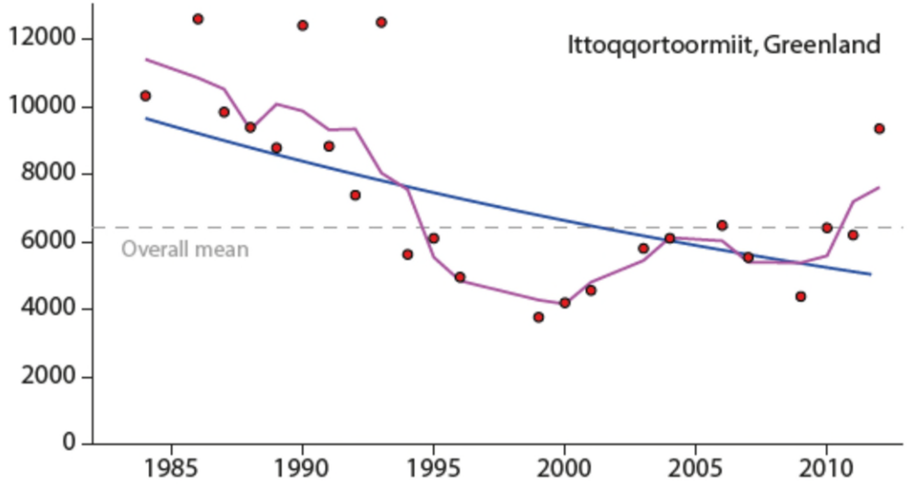
ringed seal (13% / year decrease



hooded seal (9.5% / year increase)



Σ_{10}PCBs in juvenile polar bear fat fat

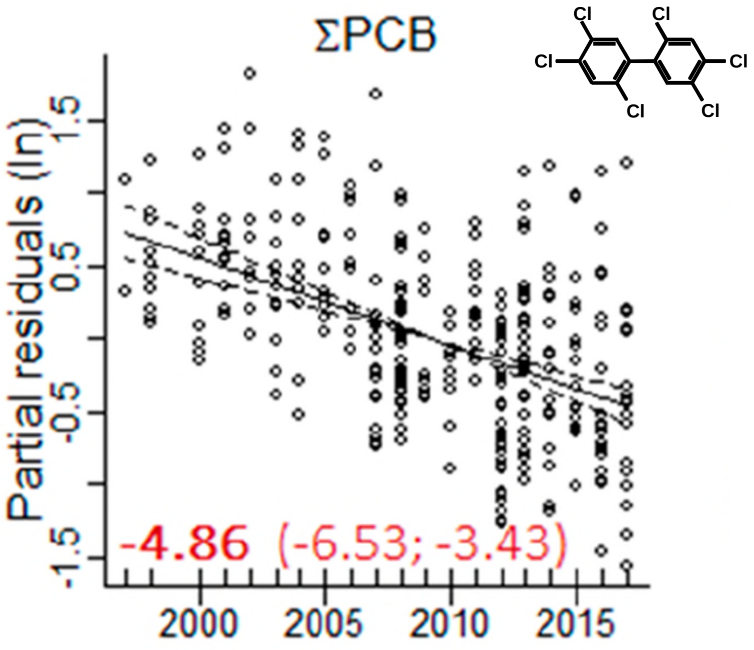


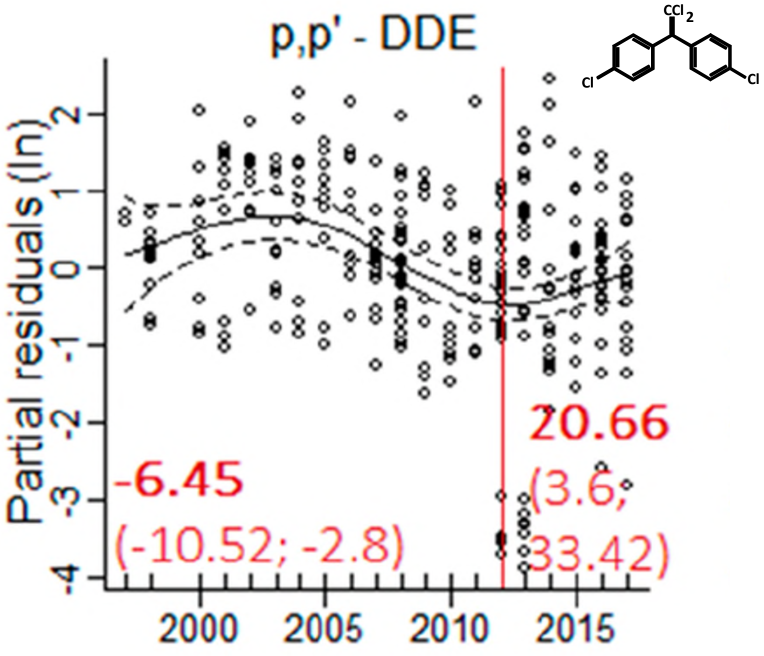
(McKinney et al. Global Change Biol. 2013)

Temporal trends of Σ_4PCB and p,p'-DDE in blood plasma of adult female polar bears from Svalbard (1997-2017)

Lippold et al ES&T 2019

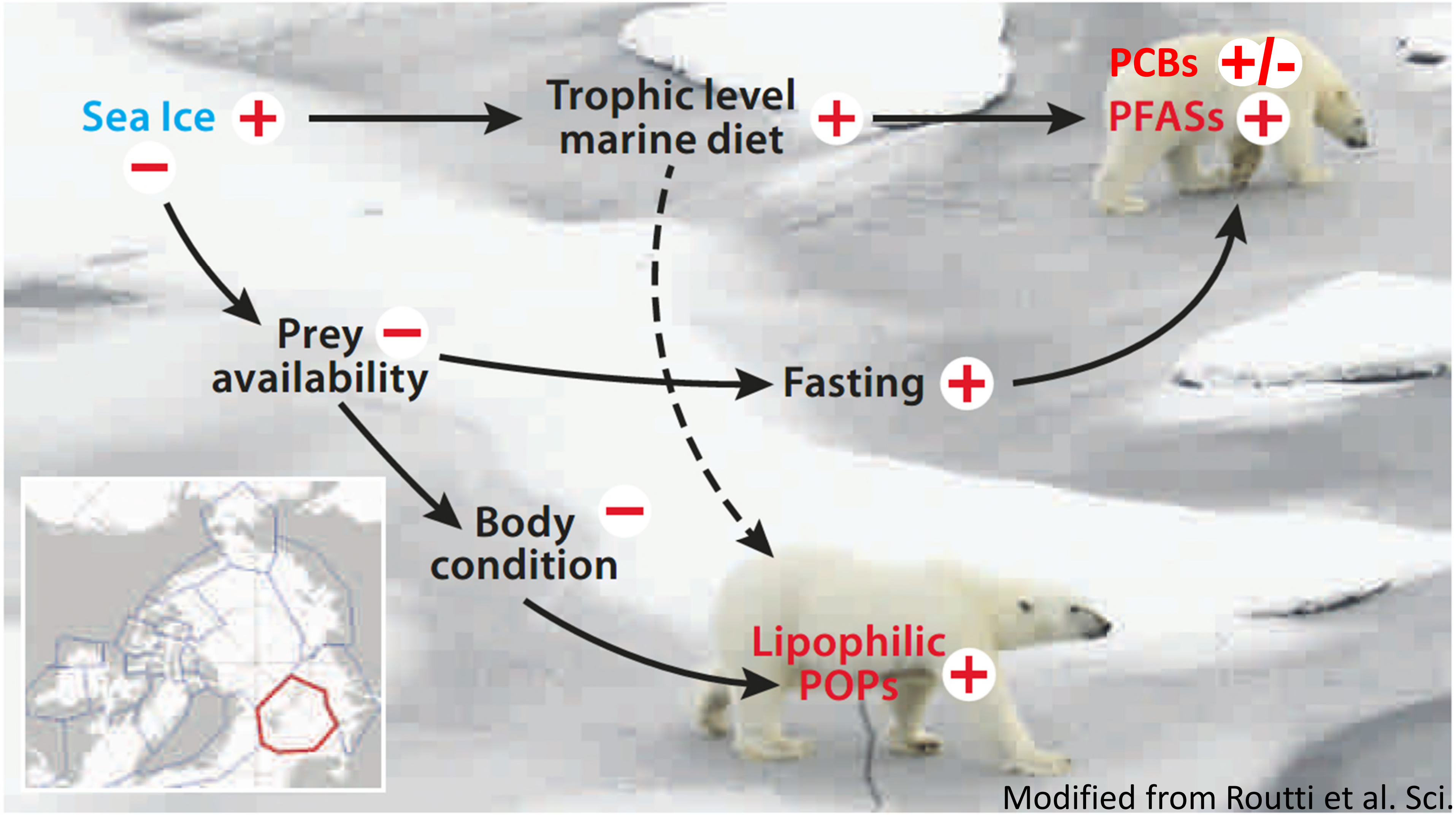
- Adjusting results for trophic level ($\delta^{15}N$) and body condition index (BCI)
- % change in Red text
- Increase concentrations for p,p'-DDE after 2012





Relationship between sea ice and diet variations and concentrations of POPs in polar bears in the Barents Sea

- Greater sea ice coverage enhances the marine diet leading to better body condition index (BCI)
- Less sea ice reduces prey availability and BCI
- On a lipid basis concentrations of lipophilic POPs are higher with reduced BCI

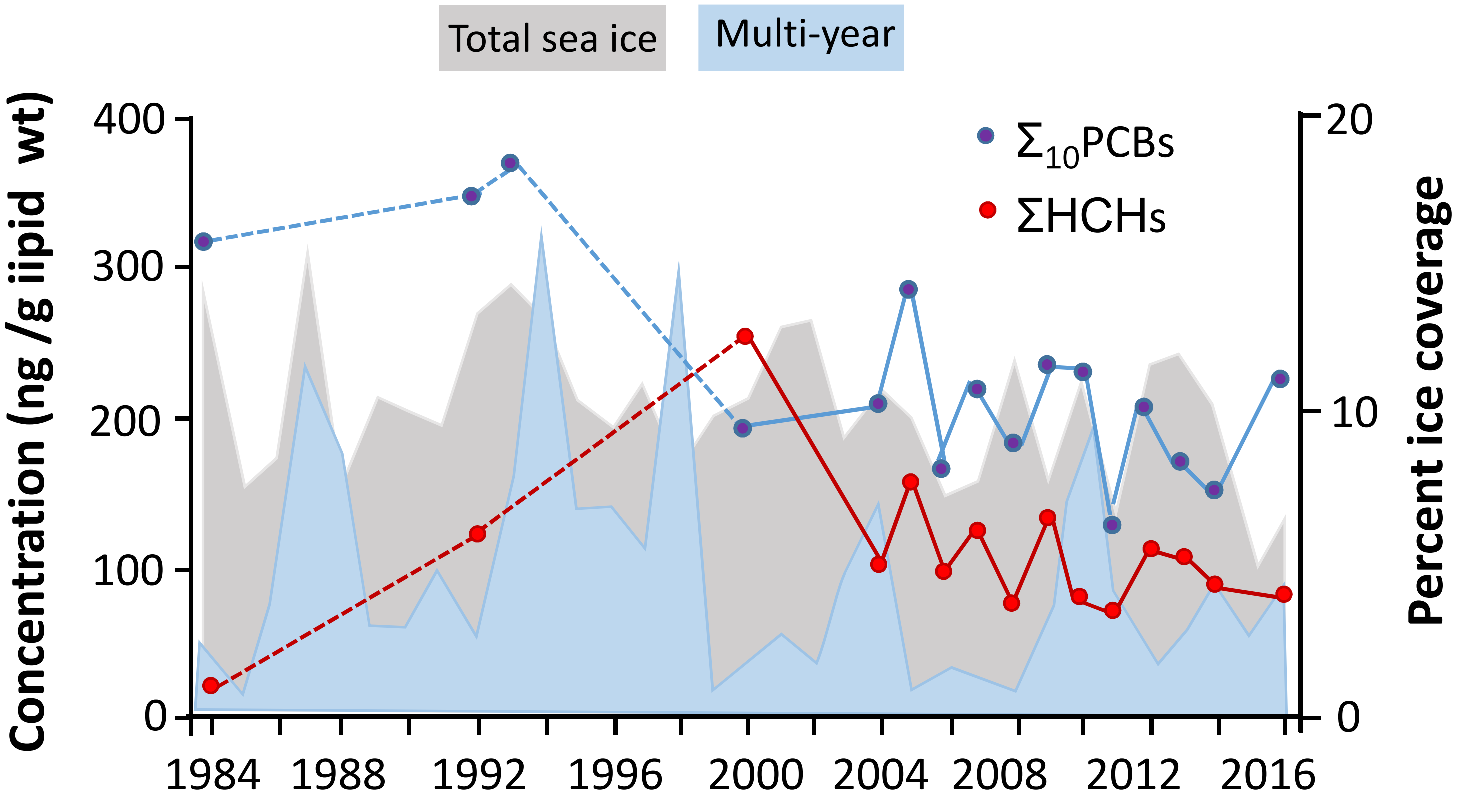


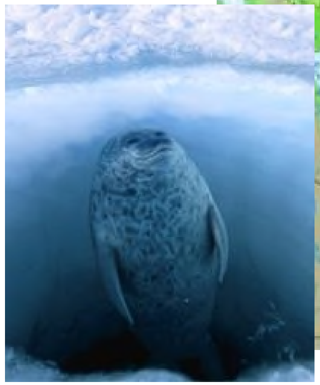
Modified from Routti et al. Sci. Total Environ 2019

Trends in concentrations of Σ_{10}PCBs and ΣHCH in ringed seal blubber (ng/g lipid wt) in the Central Canadian archipelago

(Houde et al. Sci. Total Environ 2019)

- compared with multi year sea-ice coverage (%), total sea-ice coverage (%)
- Stronger relationship to multi-year ice



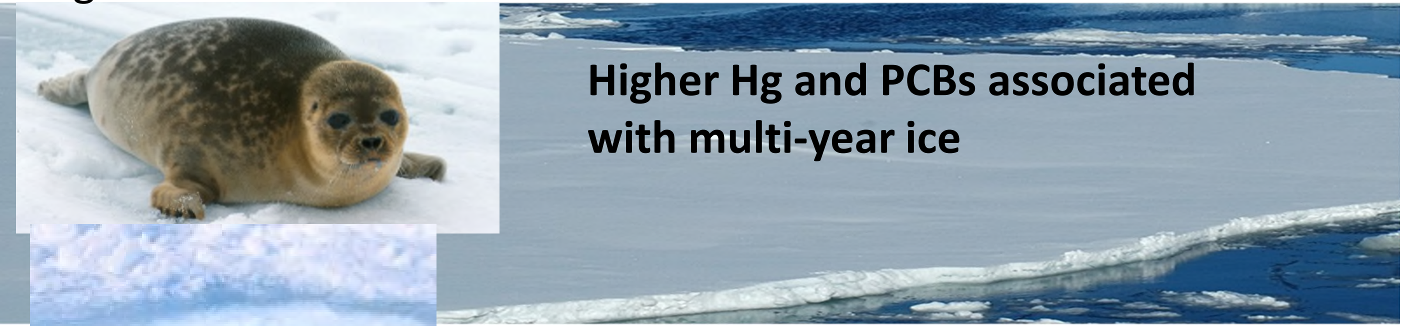


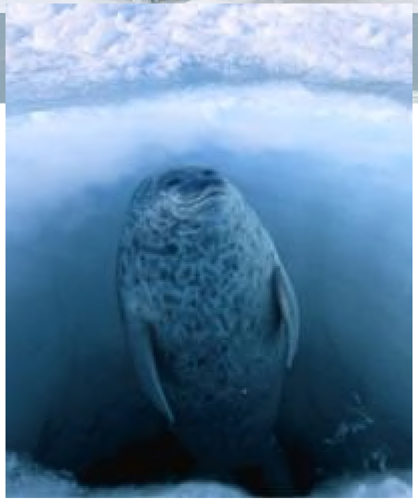
Significant R^2 values (P <0.01) for POPs concentrations vs % sea ice

	Total sea ice	Multi-year sea ice
Σ_{10}PCB	-	0.26
ΣHCH	-	0.50
ΣCHL	-	0.26
ΣCBz	0.36	0.52

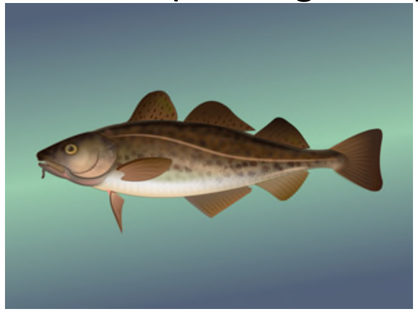
Positive relationship of mercury and PCBs with greater multi-year ice may be due to greater abundance of arctic cod and a longer food web

Ringed Seal





Arctic cod (*Boreogadus*) and Polar Cod (*Arctogadus*)

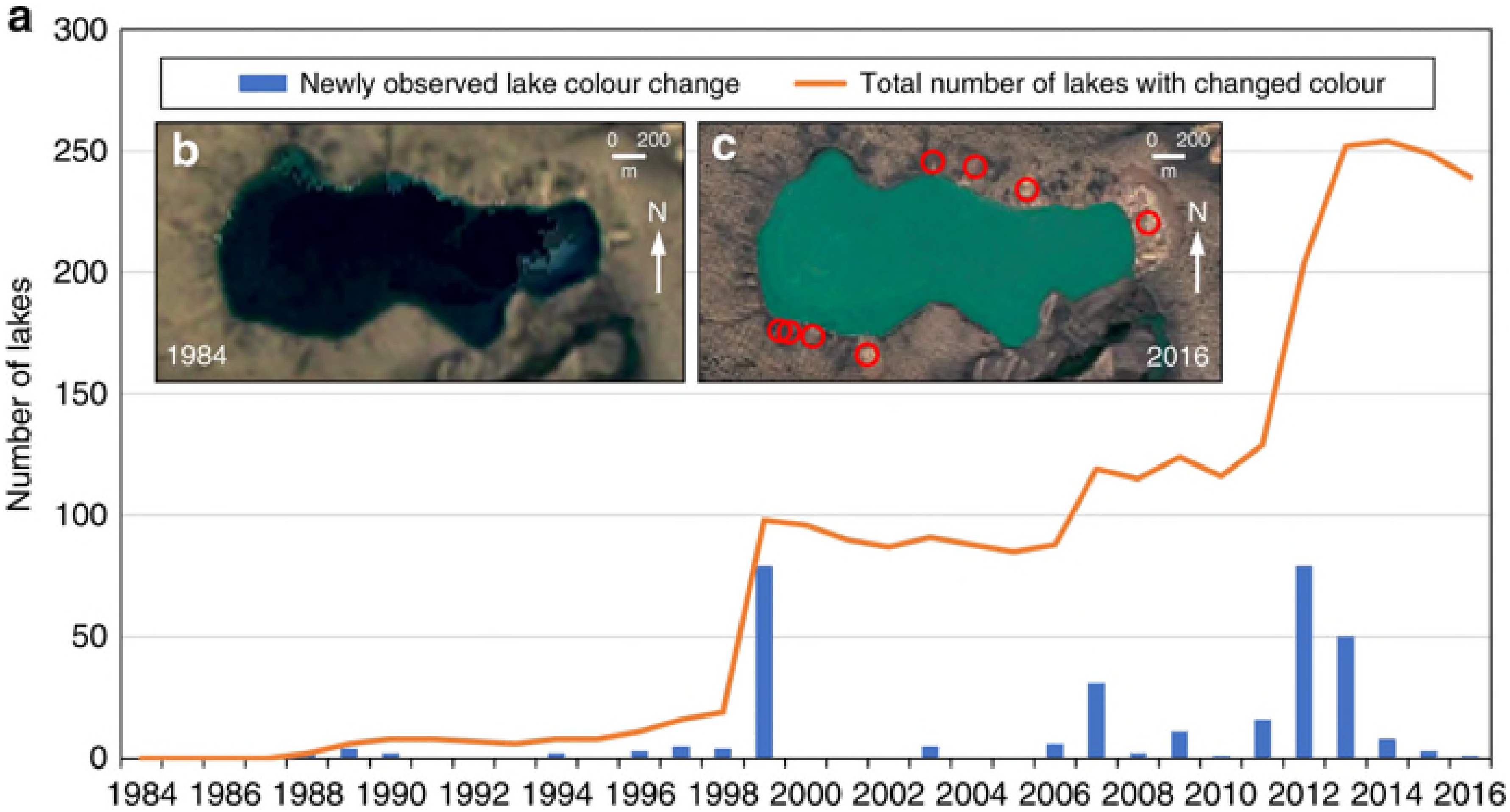


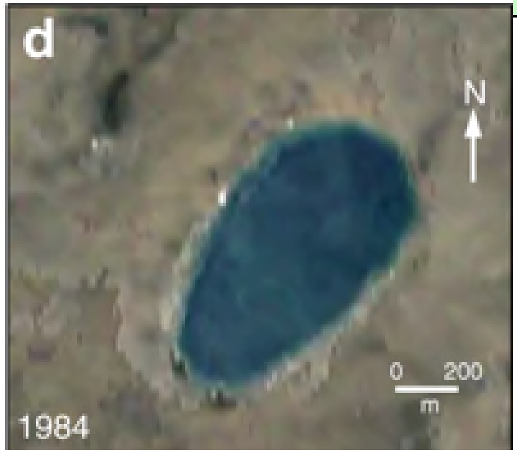
under ice **amphipods** (*Gammarus wilkitzkii*), *Mysis* sp., **shrimp** (*Lebbeus* sp.), *Themisto libellula*,

Turbid lakes – another effect of Arctic climate warming

- Lake colour change due to retrogressive thaw slump activity observed for 288 lakes on Banks Island (1984–2016)
- Annually resolved time series of numbers of lakes visually changing colour (from dark blue to turquoise or beige) using Google Timelapse (Lewkowicz & Way, Nature Comm 2019)

Banks Island

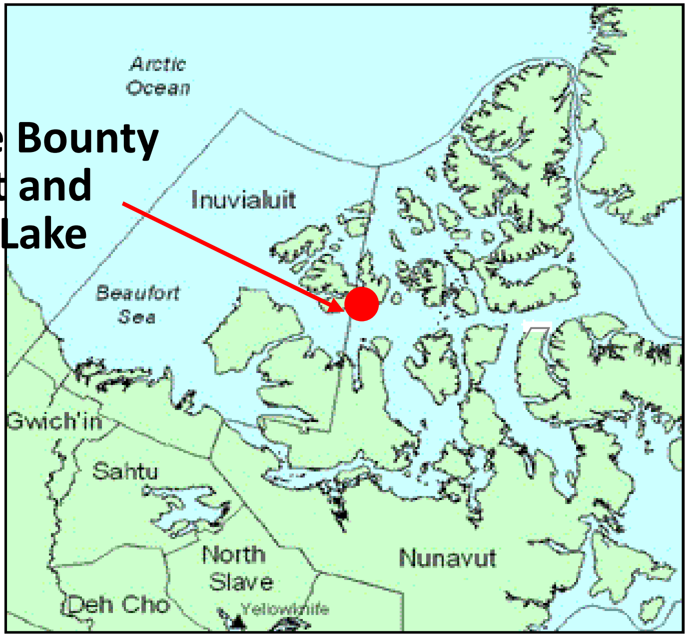


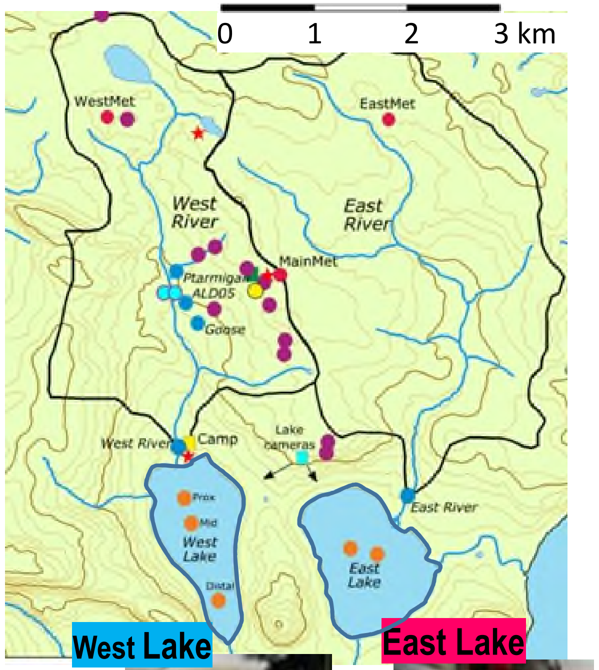


Permafrost degradation in the West Lake watershed has influenced PCBs and mercury in river water. Subaqueous slumps in West Lake have changed its turbidity

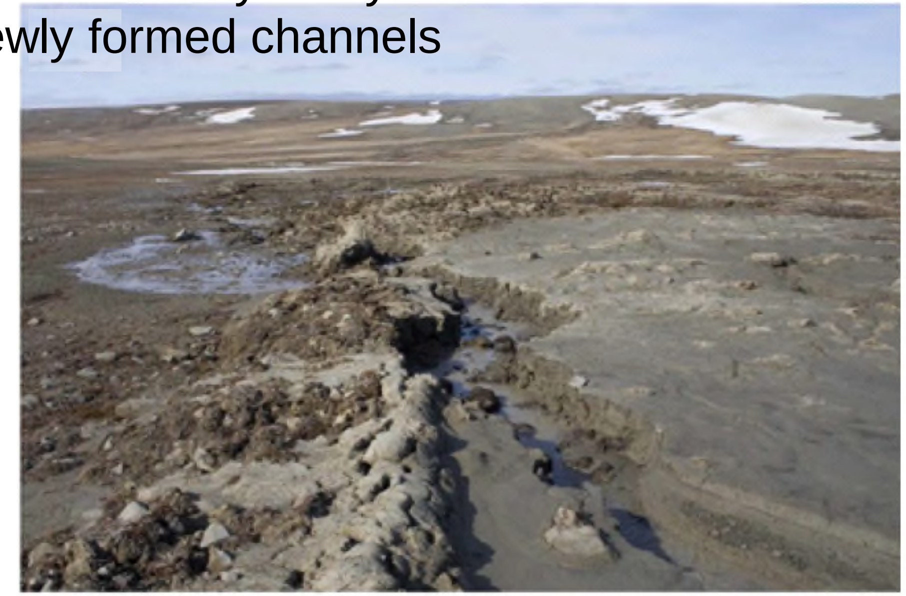
- Disturbed terrain within the West lake catchment

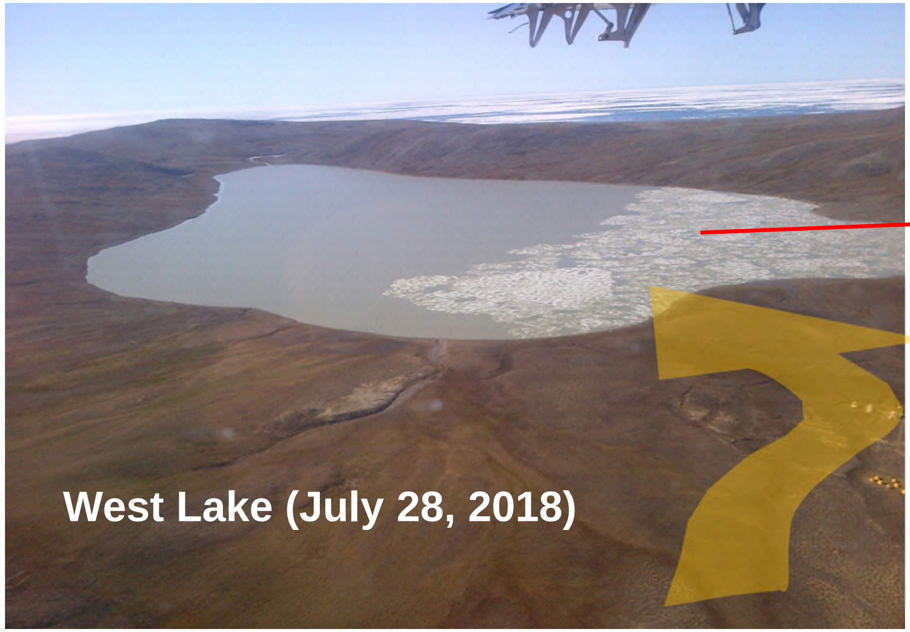
Cape Bounty West and East Lake

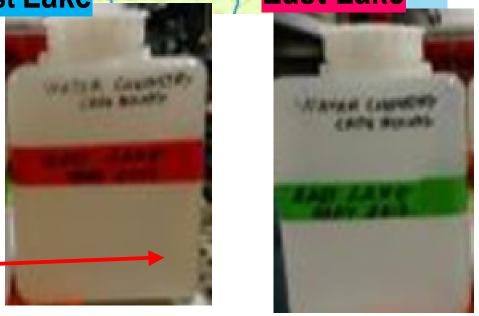




- Saturated clay slurry surface flows and newly formed channels





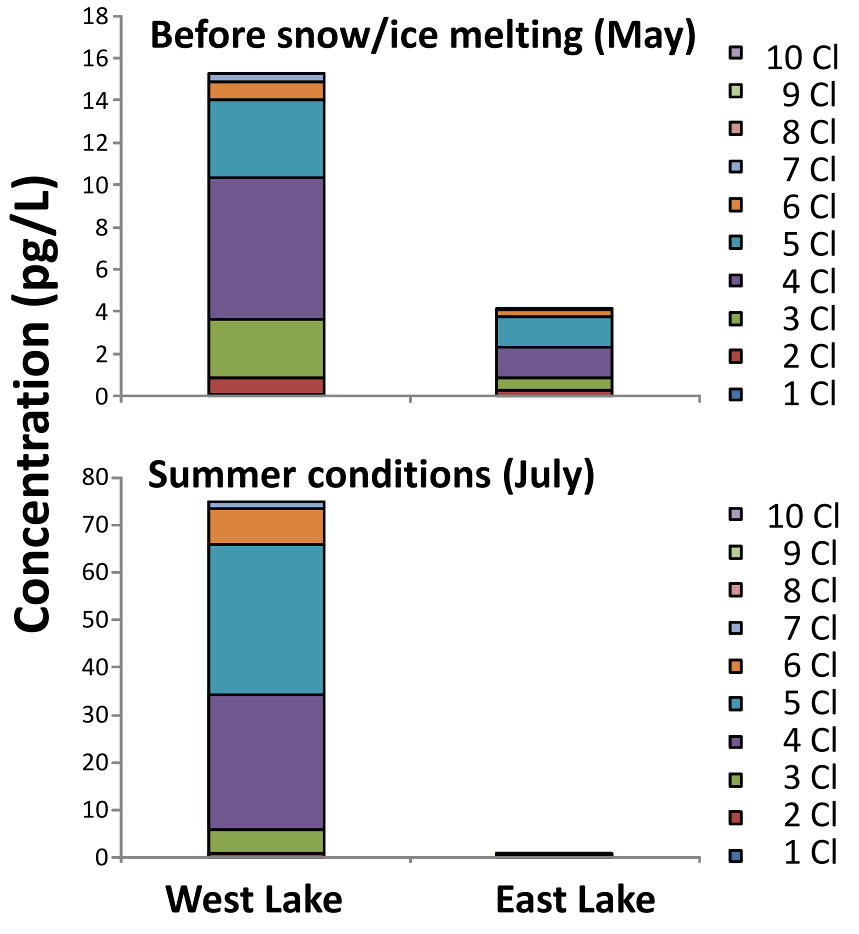


Highly turbid water

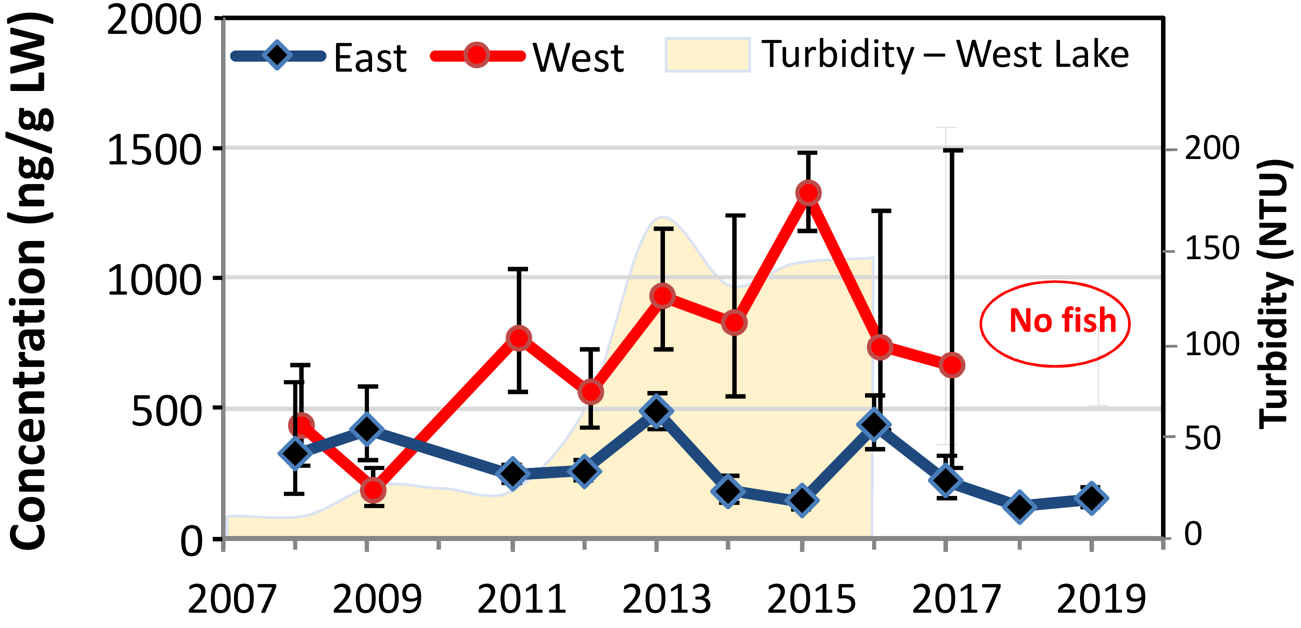
Increased PCB inputs to West Lake have increased concentrations in landlocked Arctic char

- Much higher PCBs in West Lake suspended particulates – after snow and permafrost melting
- PCBs in West Lake char have increased when expressed on lipid weight basis
- PCBs have declined in East Lake, similar to trends in char in other Arctic lakes

Suspended particulates in lake water (2017)

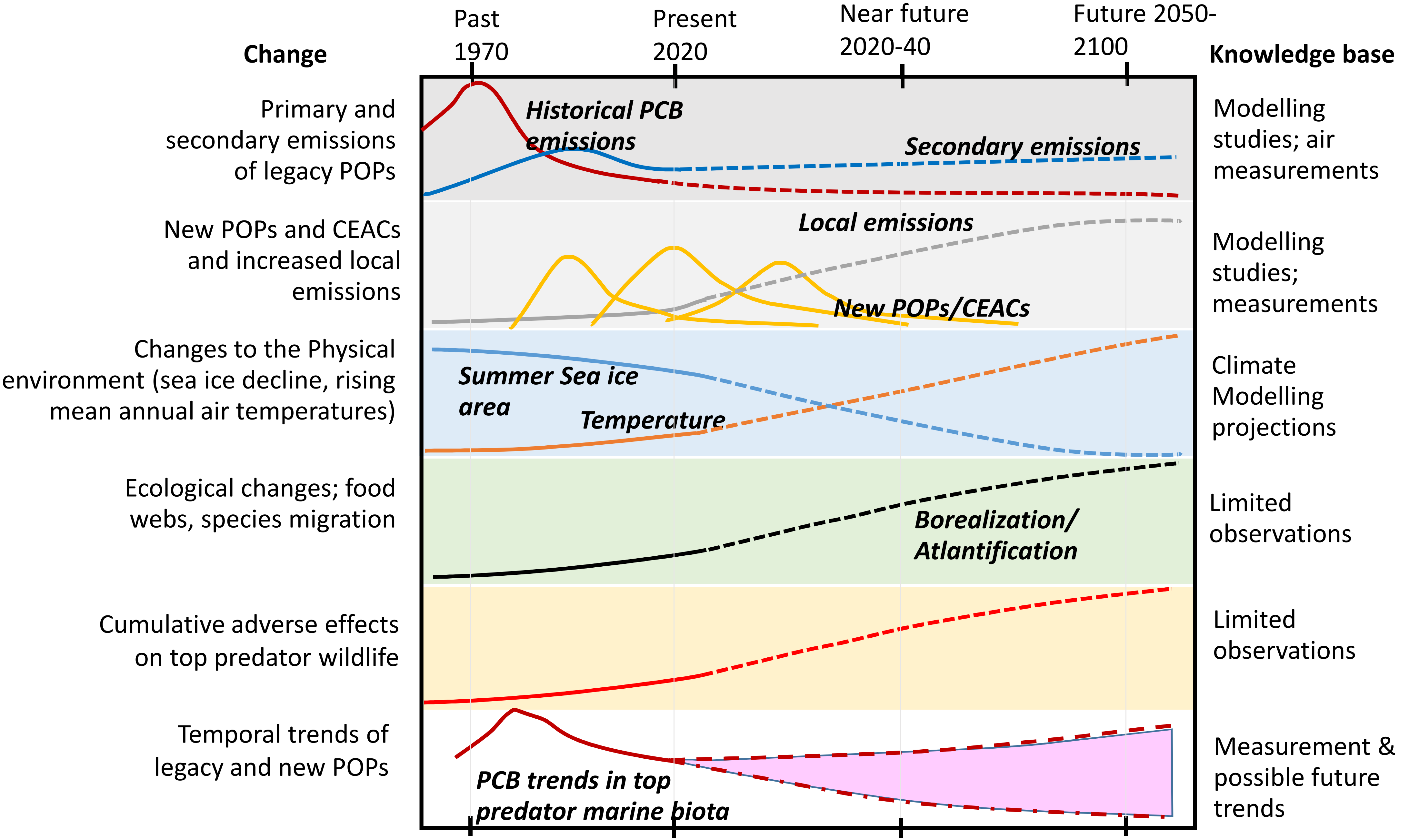


Total Σ_{70}PCBs in muscle (geomean ± SE)



Cabrerizo, Muir et al. unpublished data 2019

Projected changes in chemical emissions, environmental conditions, and ecosystems that illustrate the complexity in trends of POPs in the Arctic under future climate change



Summary and Knowledge Gaps

Where are the primary sources of POPs, and how do they reach the Arctic?

Known

- Mid-latitude urban/industrial areas are the sourc regions
- Atmospheric transport and deposition for most POPs. Ocean transport for PFOS.

Partially Known/Uncertain

- Balance between primary and secondary sources, especially in forecasts due to uncertain mass transfer and degradation
- Emission inventories for PCBs, HCHs, HCB, PAHs, (PCDD/Fs)…

Unknown

- Transport mechanisms for chemicals with novel properties.
- Emission inventories for other POPs and CEACs!

Summary and Knowledge Gaps

How are emissions and source locations of POPs and potential future POPs affected by climate change?

Known

- Higher temperature > higher volatilization emissions of SVOCs
- Climate change will lead to migration of people and resource exploitation in the north

Partially Known/Uncertain

- Scenarios for increased emissions of chemicals in the Arctic have been proposed
- Higher incidence of forest fires and associated release of PAH and PCDD/F expected. Fires could re-mobilize PCBs & other POPs.

Unknown

- Re-introduction of banned POPs to address other CC-induced problems (eg. DDT?)
- Non-compliance due to lack enforcement because CC causes bigger problems that take away attention.

Summary and Knowledge Gaps

Q3. How does climate change affect transport of pollutants to the Arctic?

Known

- Higher temperature > higher secondary emissions of SVOCs
- Ice cover loss from Arctic Ocean > increased deposition of PCBs, volatilization of HCHs

Partially Known/Uncertain

- Temperature dependence of degradation half-lives. Likely degradation is a bit faster but highly uncertain!
- Regional-scale case studies on mobilization and deposition

Unknown

- Net effect of increased incidence of extreme weather events on mobilization and transport?

Summary and Knowledge Gaps

How well can we anticipate how old and new persistent chemicals w impact the Arctic in a changing future climate?

Known

- We can control the level of exposure of the Arctic by controlling primary emissions.

Partially Known/Uncertain

- Models are more certain for non-ionizable organics. For these substances, persistence is the key property that determines potential to be a global-scale pollutant
- Climate scenario analysis is available for selected POPs (PCBs, DDT, HCHs)

Unknown

- Future chemicals with novel properties (analogous to PFAS)
- Occurrence of “tipping point” events that break our scenarios

Summary and Knowledge Gaps

Implications for trend assessments and effectiveness evaluations

Known

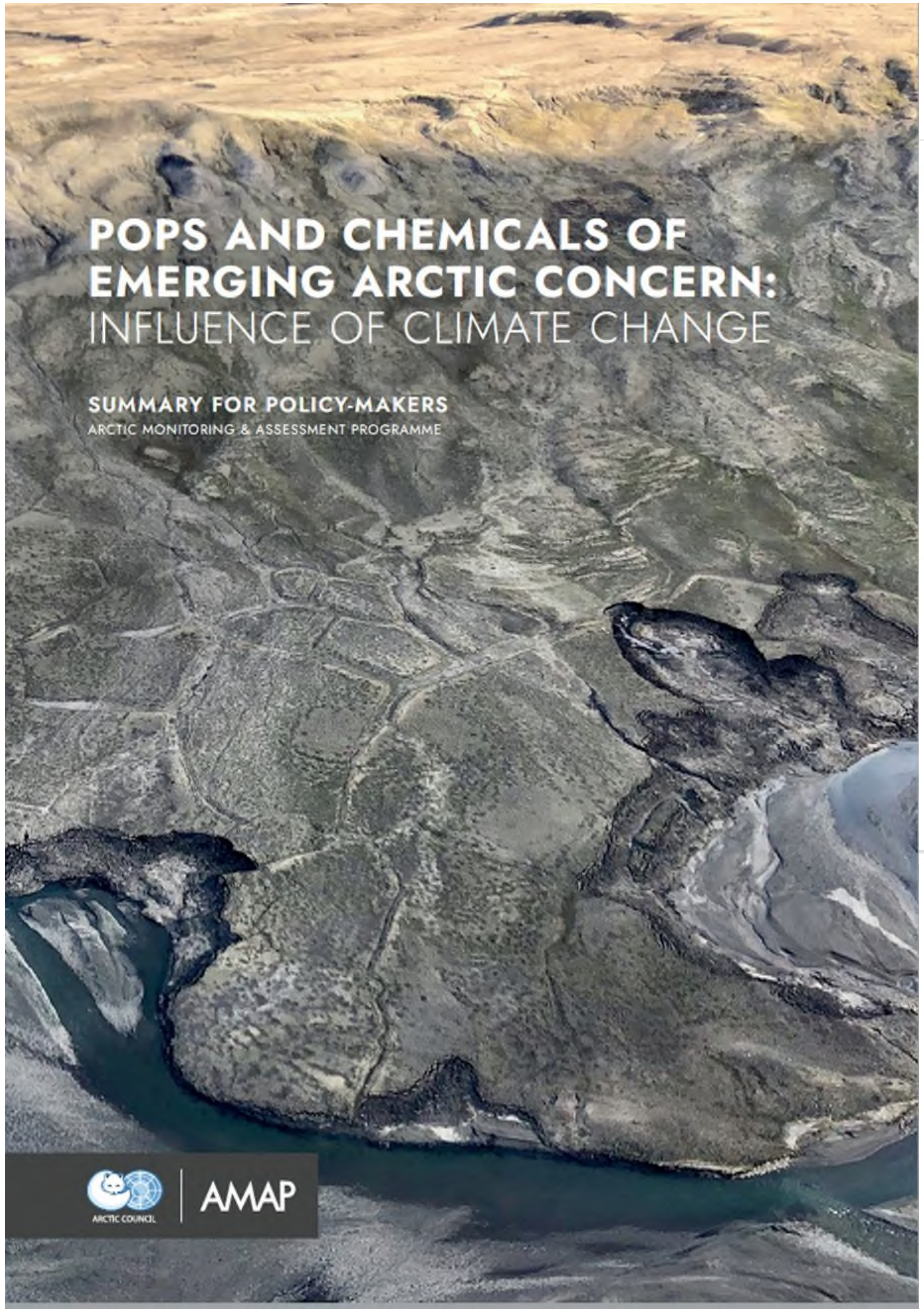
- Climate change can affect trends, via direct and indirect processes (e.g. POP availability and food web changes, respectively).

Partially Known/Uncertain

- including climate and biological parameters in trend analyses affected decreasing rates, but rarely the general trend.
- There are indications of time-lags and more pronounced effects in recent years.

Unknown

- What other chemicals in commerce have the potential for transport and accumulation due to warming of sub-Arctic and mid-latitudes adjacent to the Arctic?
- Will local pollution from growing communities and development in a warming Arctic out rank long range transport?



Available at www.amap.no

SUMMARY

POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change. Summary for Policy-makers

AMAP, 2021. POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change. Summary for Policy-makers

Forthcoming Assessment Report – Nov 2021

AMAP
Arctic Monitoring and Assessment Programme