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Title

Work package: **1: Mapping stressors of Arctic biodiversity: Tolerance and adaptation of organisms**

Deliverable No. (D1.1) – Title**:** **Inventory of geographic distribution of relevant water column stressors of Arctic biodiversity**

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Submission Date: 27/11/2021

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Executive Summary

This deliverable presents an overview about environmental stressors with the potential to impact Arctic ecosystems, or parts thereof. We report properties, which reveal such potential either through change over time or as new property introduced into the Arctic realm. We report a likely non-exhaustive list of stressors, both from observations and simulations, and give some details on geographic distributions, if known, on a subset of stressors, which appear directly relevant for ECOTIP.

Overview

We present a non-exhaustive list of properties, which can be considered as stressors in the Arctic marine realm. This list does not necessarily imply that a property does act as a stressor, neither does the list imply degree, severity or evolution (in many cases) of any particular stressor. Rather we present properties, which potentially fall into the category "stressor", some of which will be investigated more closely in ECOTIP.

2.1 Physical Stressors

The following physical properties or changes thereof might act as stressors:

- Temperature (shown below)
- Salinity (shown below)
- Wind
- Stratification
- Light penetration/Turbidity
- Sea ice cover
- Land ice run-off

2.2 Chemical Stressors

The following chemical properties or changes thereof might act as stressors:

- pH, properties of the marine carbonate system (pH shown below)
- nutrients
- Hg, Fe, V, Pb, other trace metals (selected trace metals shown below)
- Oxygen

2.3 Biological Stressors

The following biological properties or changes thereof might act as stressors:

- invasive species (discussed below)
- exploitation (e.g. fishing)
- harmful blooms

2.3 Anthropogenic Stressors

The following anthropogenic properties or changes thereof might act as stressors:

- fishing
- mining
- fuel combustion (link to heavy metals, V, Hg)
- oil
- plastics

Detailed considerations

3.1 Invasive Species

Invasive species are defined as species found outside of their native distribution range. If these have a negative influence on the new ecosystem then term "invasive" applies. For as long as the effect of the species on the new ecosystem is unknown they are called non-indigenous. Outside of their distribution range species need to find new ways to adapt to the ecosystem in order to survive. During this process, the species can significantly change the dynamics of the ecosystem. As such, stable and functioning ecosystems tend to be more resilient these changes s opposite to ecosystems already under pressure. Thus, introduction of invasive species can destabilize ecosystems to the degree that cascading effects are inevitable - a tipping point as we define it in ECOTIP. The work package 1 focuses on identifying invasive and non-indigenous species occurring in the Arctic, and by means of monitoring over larger geographical scale species' distribution ranges will be defined. Additionally, a series of planned experiments on selected occurring invasive species, and on some putative invasive species (expected to arrive in near future) will investigate their tolerance ranges and their resilience to the Arctic ecosystem under the known and future conditions (abiotic stressors defined under Tasks 1.1-1.2).

As of today, we have conducted a literature search identifying invasive and non-indigenous species occurring in the Atlantic Sector of the Arctic Ocean (Table 1). We extended this list by allowing for putative invasive species (.e.g. species expected to occur in near future). This catalogue of species serves for the developing of appropriate monitoring tools for the Deliverable 1.3 and as means for selecting appropriate species for the experimental work (Deliverable 1.5).

References for the compiled species list:

———————————Chan, Farrah T., Keara Stanislawczyk, Anna C. Sneekes, Alexander Dvoretsky, Stephan Gollasch, Dan Minchin, Matej David, Anders Jelmert, Jon Albretsen, and Sarah A. Bailey. 2019. "Climate Change Opens New Frontiers for Marine Species in the Arctic: Current Trends and Future Invasion Risks." *Global Change Biology* 25: 25–38.

European Marine Observation and Data Network (EMODnet). n.d. "Alien Species."

Goldsmit, Jesica, Christopher W. McKindsey, Robert W. Schlegel, D. Bruce Stewart, and Kimberly L. Archambault, Philippe Howland. 2020. “What and Where? Predicting Invasion Hotspots in the Arctic Marine Realm.” *Global Change Biology* 26 (9): 4752–71.

Heuvel-Greve, M.J. van den, A.M. van den Brink, S.T. Glorius, G.A. de Groot, I. Laros, P.E. Renaud, R. Pettersen, J.M. Węsławski, P. Kuklinski, and A.J. Murk. 2021. “Early Detection of Marine Non-Indigenous Species on Svalbard by DNA Metabarcoding of Sediment.” *Polar Biology* 44 (4): 653–65.

Table 1. List of species identified as invasive or non indigenouse in the Atlantic Sector of the Arctic Ocean. Species list contains present species and species expected to occur in the near future. A total of 92 species from 63 families were identified in a literature survey.

Family	Genus	Species
Sabellidae	Chone	Chone mollis
Spionidae	Spiophanes	Spiophanes kroyeri
Capitellidae	Heteromastus	Heteromastus filiformis
Podonidae	Podon	Podon leuckartii
Podonidae	Evadne	Evadne nordmanni
Acartiidae	Acartia	Acartia (Acanthacartia) tonsa
Acartiidae	Acartia	Acartia clausii
Calanoidae	Calanus	Calanus helgolandicus
Centropagidae	Centropages	Centropages hamatus
Centropagidae	Centropages	Centropages typicus
Centropagidae	Isias	Isias clavipes
Centropagidae	Sinocalanus	Sinocalanus doerrii
Clausocalanidae	Pseudocalanus	Pseudocalanus elongatus
Parapontellidae	Parapontella	Parapontella brevicornis
Pseudodiaptomidae	Pseudodiaptomus	Pseudodiaptomus forbesi
Pseudodiaptomidae	Pseudodiaptomus	Pseudodiaptomus marinus
Temoridae	Eurytemora	Eurytemora affinis
Temoridae	Eurytemora	Eurytemora americana
Temoridae	Temora	Temora longicornis
Temoridae	Temora	Temora turbinata
Tortanidae	Tortanus	Tortanus dextrilobatus
Oithonidae	Oithona	Oithona davisae
Oithonidae	Oithona	Oithona similis

Ameiridae	Nitocra	Nitocra lacustris
Laophontidae	Heterolaophonte	Heterolaophonte stroemii
Laophontidae	Paronychocamptus	Paronychocamptus huntsmani
Miraciidae	Schizopera	Schizopera clandestina
Tachidiidae	Euterpina	Euterpina acutifrons
Acartiidae	Acartiella	Acartiella sinensis
Ampeliscidae	Ampelisca	Ampelisca abdita
Aoridae	Grandidierella	Grandidierella japonica
Caprellidae	Caprella	Caprella mutica
Corophiidae	Crassicorophium	Crassicorophium bonellii
Corophiidae	ocorophium	Sinocorophium heteroceratum
Corophiidae	Monocorophium	Monocorophium acherusicum
Gammaridae	Gammarus	Gammarus daiberi
Gammaridae	Gammarus	Gammarus tigrinus
Gammaridae	Gammarus	Gammarus zaddachi

Family	Genus	Species
Ischyroceridae	Jassa	Jassa marmorata
Canacridae	Cancer	Cancer irroratus
Canacridae	Cancer	Cancer pagurus
Crangonidae	Crangon	Crangon Crangon
Grapsidae	Eriocheir	Eriocheir sinesis
Lithodidae	Paralithodes	Paralithodes camtschaticus
Nephropidae	Homarus	Homarus americanus
Oregoniidae	Chionoecetes	Chionoecetes opilio
Portunidae	Carcinus	Carcinus maenas
Varunidae	Hemigrapsus	Hemigrapsus takanoi

Cirolanidae	Eurydice	Eurydice pulchra
Idoteidae	Idotea	Idotea linearis
Mysidae	Mesopodopsis	Mesopodopsis slabberi
Cyclopettidae	Limnoithona	Limnoithona tetraspina
Austrobalanidae	Austrominius	Austrominius modestus
Balanidae	Amphibalanus	Amphibalanus amphitrite
Balanidae	Amphibalanus	Amphibalanus eburneus
Balanidae	Amphibalanus	Amphibalanus improvisus
Balanidae	Amphibalanus	Amphibalanus modestus
Balanidae	Amphibalanus	Amphibalanus reticulatus
Balanidae	Balanus	Balanus trigonus
Balanidae	Megabalanus	Megabalanus coccopoma
Balanidae	Megabalanus	Megabalanus spinosus
Balanidae	Megabalanus	Megabalanus tintinnabulum
Lepadidae	Conchoderma	Conchoderma virgatum
Membraniporidae	Membranipora	Membranipora membranacea
Schizoporellidae	Schizoporella	Schizoporella unicornis
Pleuronictidae	Platichthys	Platichthys flesus
Salmonidae	Oncorhynchus	Oncorhynchus gorbuscha
Salmonidae	Oncorhynchus	Oncorhynchus kisutch
Salmonidae	Oncorhynchus	Oncorhynchus mykiss
Salmonidae	Oncorhynchus	Oncorhynchus nerka
Molgulidae	Molgula	Molgula manhattensis
Cionidae	Ciona	Ciona intestinalis
Styelidae	Botrylloides	Botrylloides violaceus
Styelidae	Botryllus	Botryllus schlosseri
Bougainvilliidae	Calyptospadix	Calyptospadix cerulea

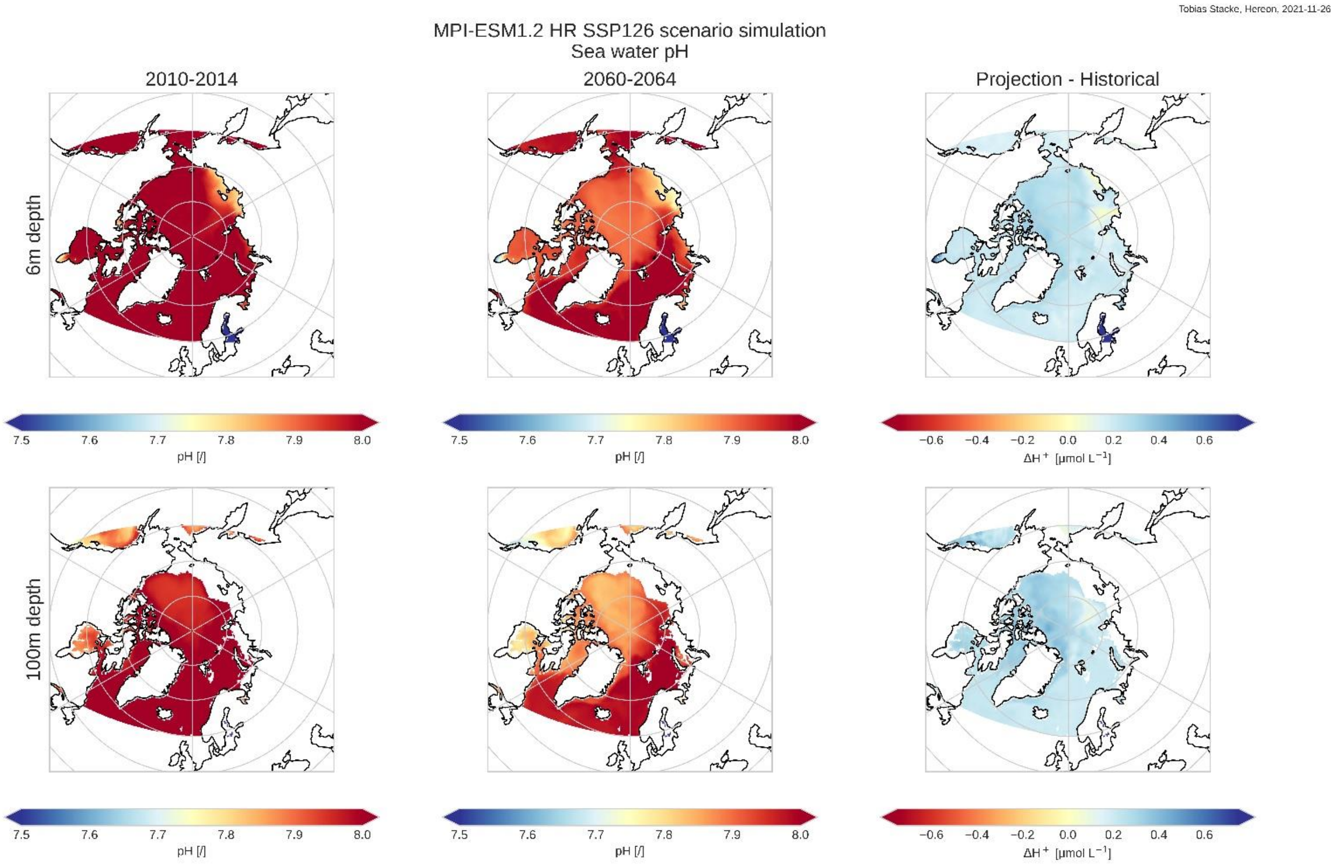
Ulmaridae	Aurelia	Aurelia limbata
Bolinopsidae	Mnemiopsis	Mnemiopsis leidyi
Dinophysaceae	Dinophysis	Dinophysis caudata
Dinophysaceae	Dinophysis	Dinophysis dens
Gonyaulacaceae	Gonyaulax	Gonyaulax polygramma
Pyrocystaceae	Alexandrium	Alexandrium tamarense

Family	Genus	Species
Kareniaceae	Karenia	Karenia mikimotoi
Kryptoperidiniaceae	Kryptoperidinium	Kryptoperidinium triquetrum
Trochamminidae	Trochammina	Trochammina hadai
Cardiidae	Cerastoderma	Cerastoderma edule
Veneridae	Ruditapes	Ruditapes philippinarum
Calyptraeidae	Crepidula	Crepidula fornicata
Littorinidae	Littorina	Littorina littorea
Myidae	Mya	Mya arenaria
Chromadoridae	Prochromadora	Prochromadora orleji
Monhysteridae	Geomonhystera	Geomonhystera sp.
Clionaidae	Cliona	Cliona thoosina

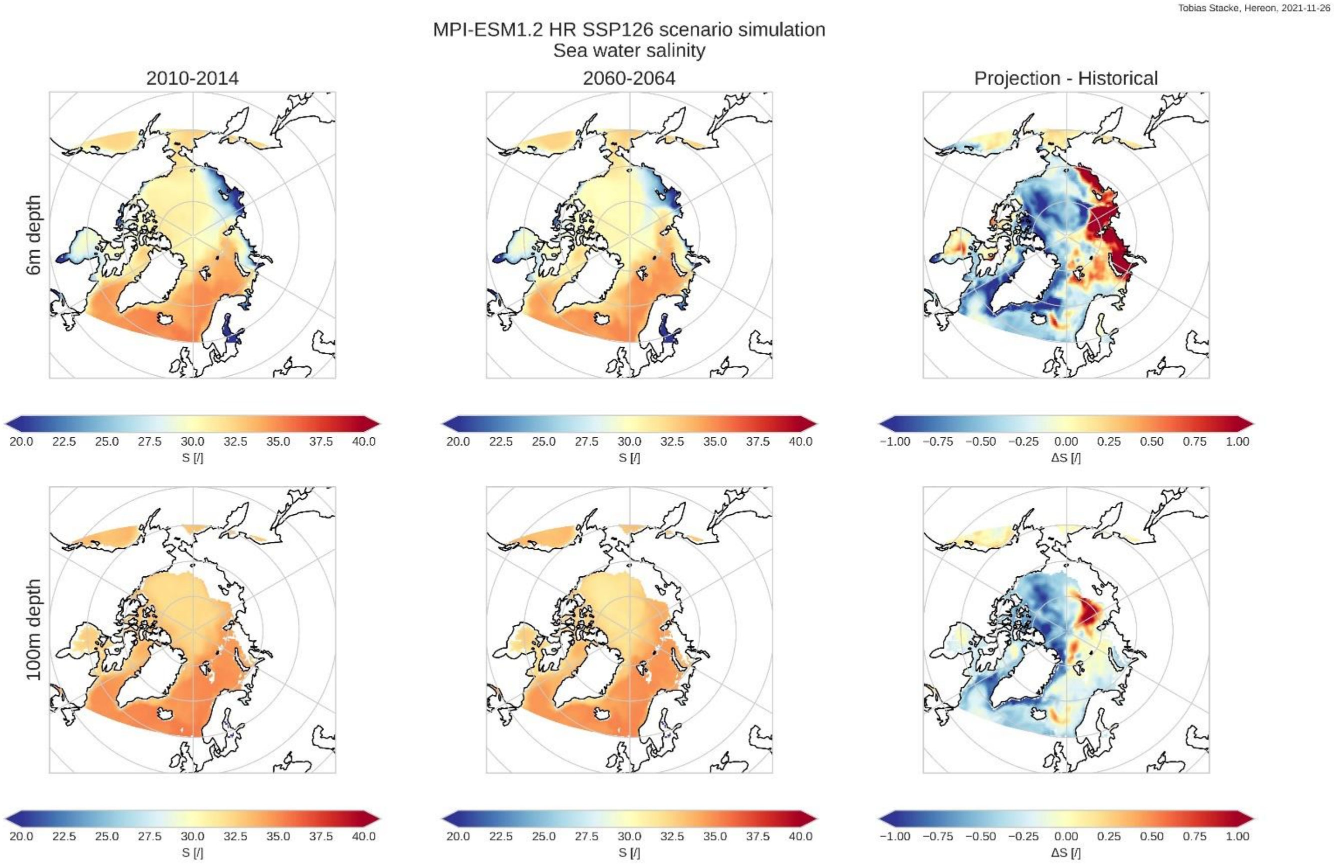
3.2 Large Scale Oceanographic Stressors

We present for the Atlantic Ocean hemisphere north of 60ºN changes in pH ([ΔH$^+$]), salinity and temperature for two depth levels (surface and 100m) between now and 50 years in the future. Simulations have been performed with the MPI-ESM1.2 HR model for 3 SSPs: SSP126, SSP370, SSP585. Baseline is the mean of the historical simulations 2010-2014, the future, i.e., the projections are represented as the mean of the years 2060-2064.

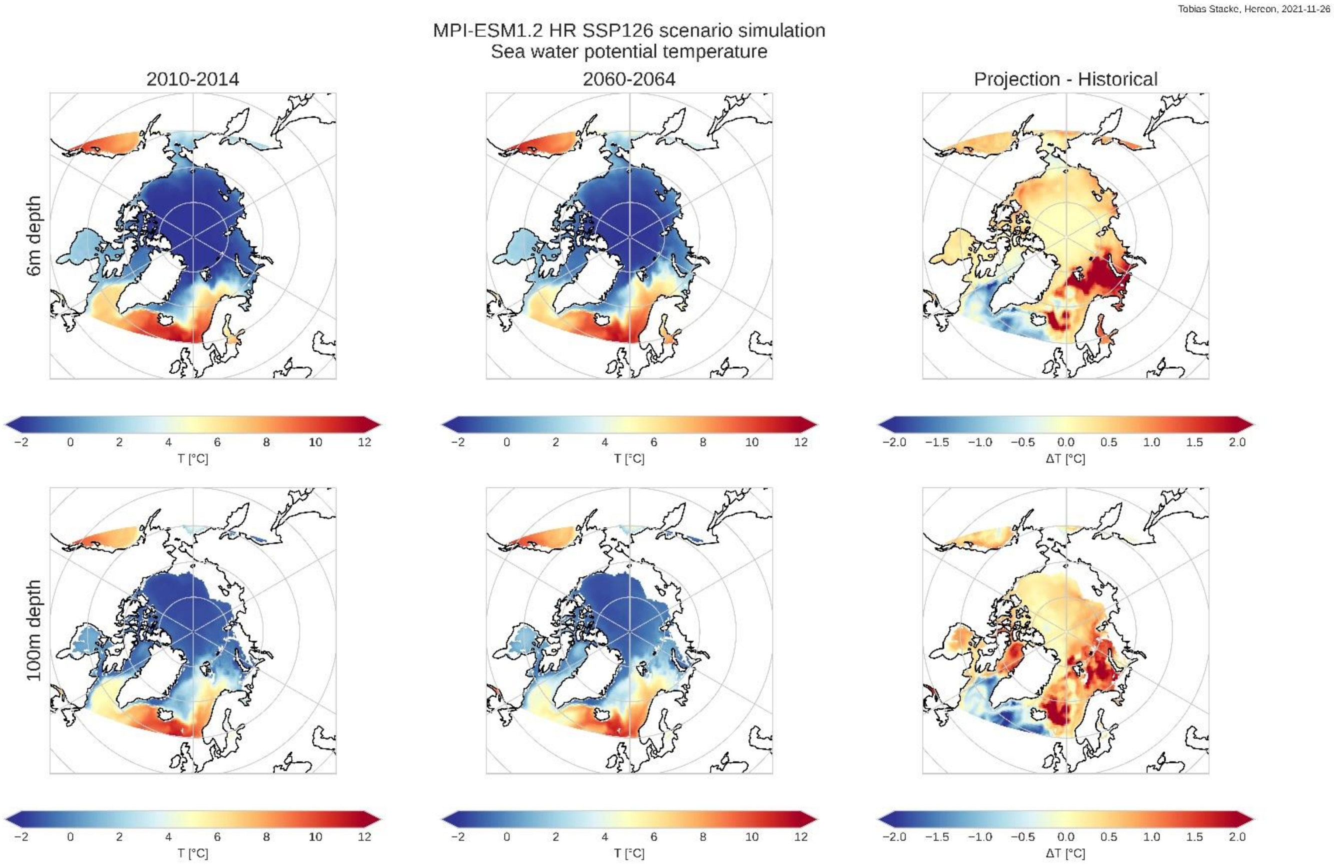
SSP126:



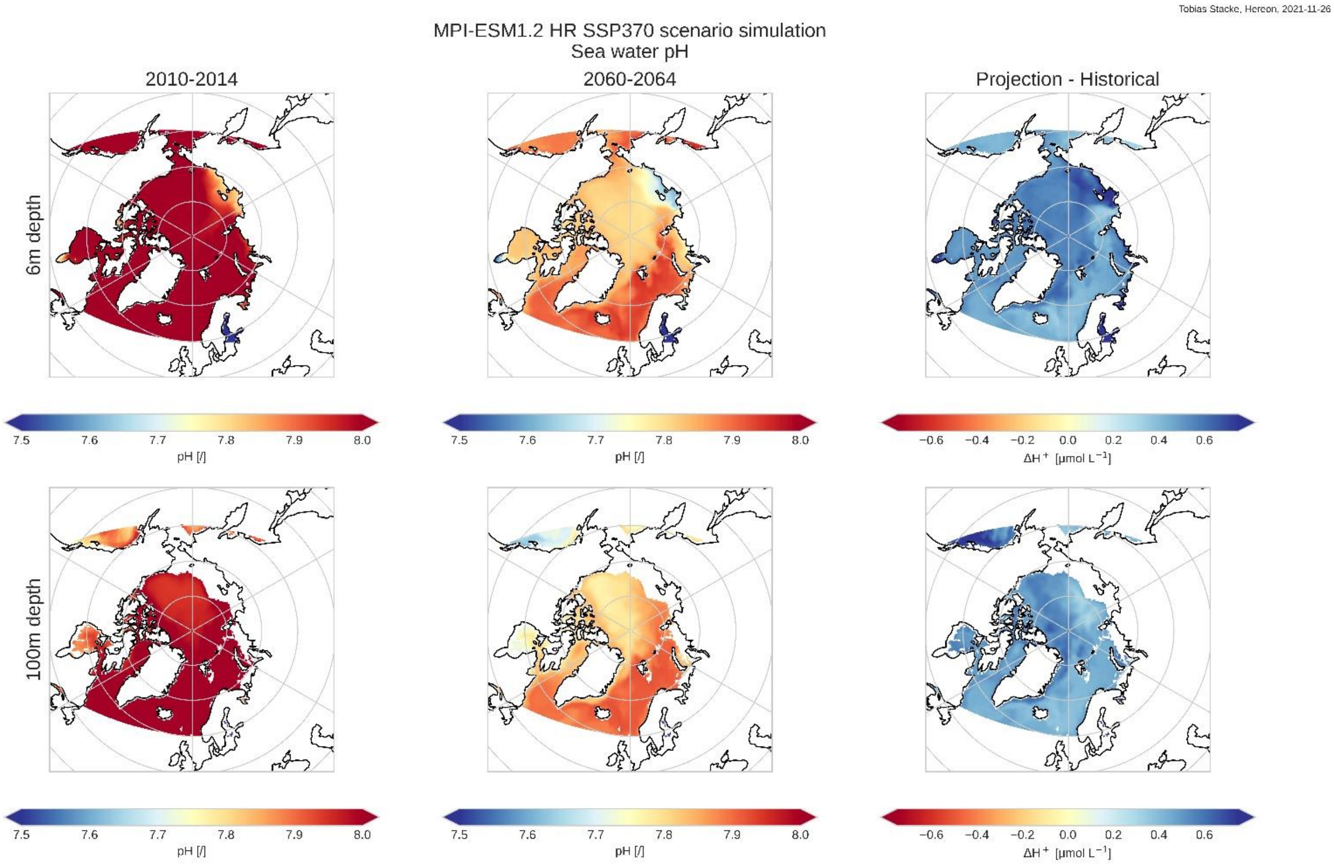
SSP126:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP126 scenario simulation
Sea water salinity
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5 40.0
S [/]
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
ΔS [/]

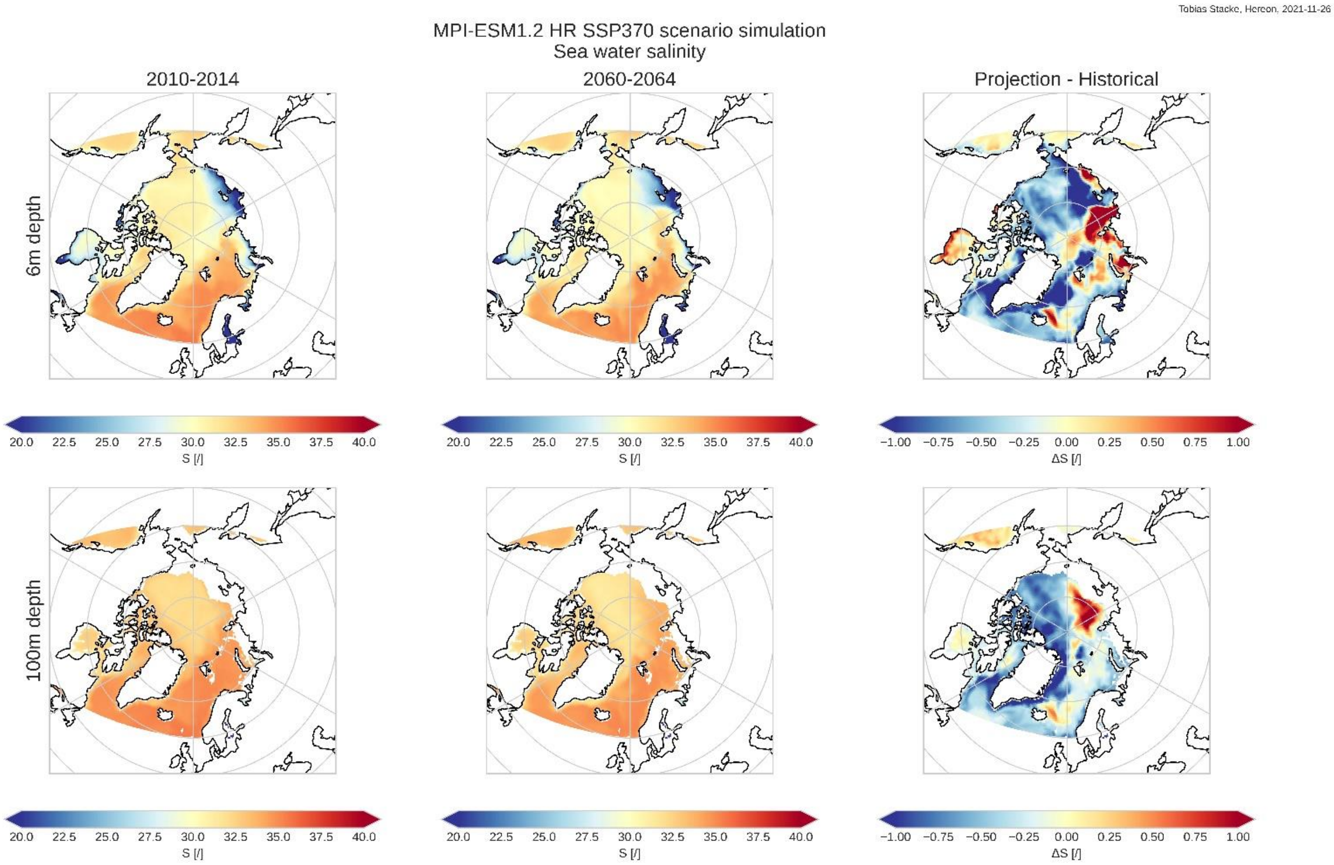
SSP126:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP126 scenario simulation
Sea water potential temperature
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
T [°C]
ΔT [°C]

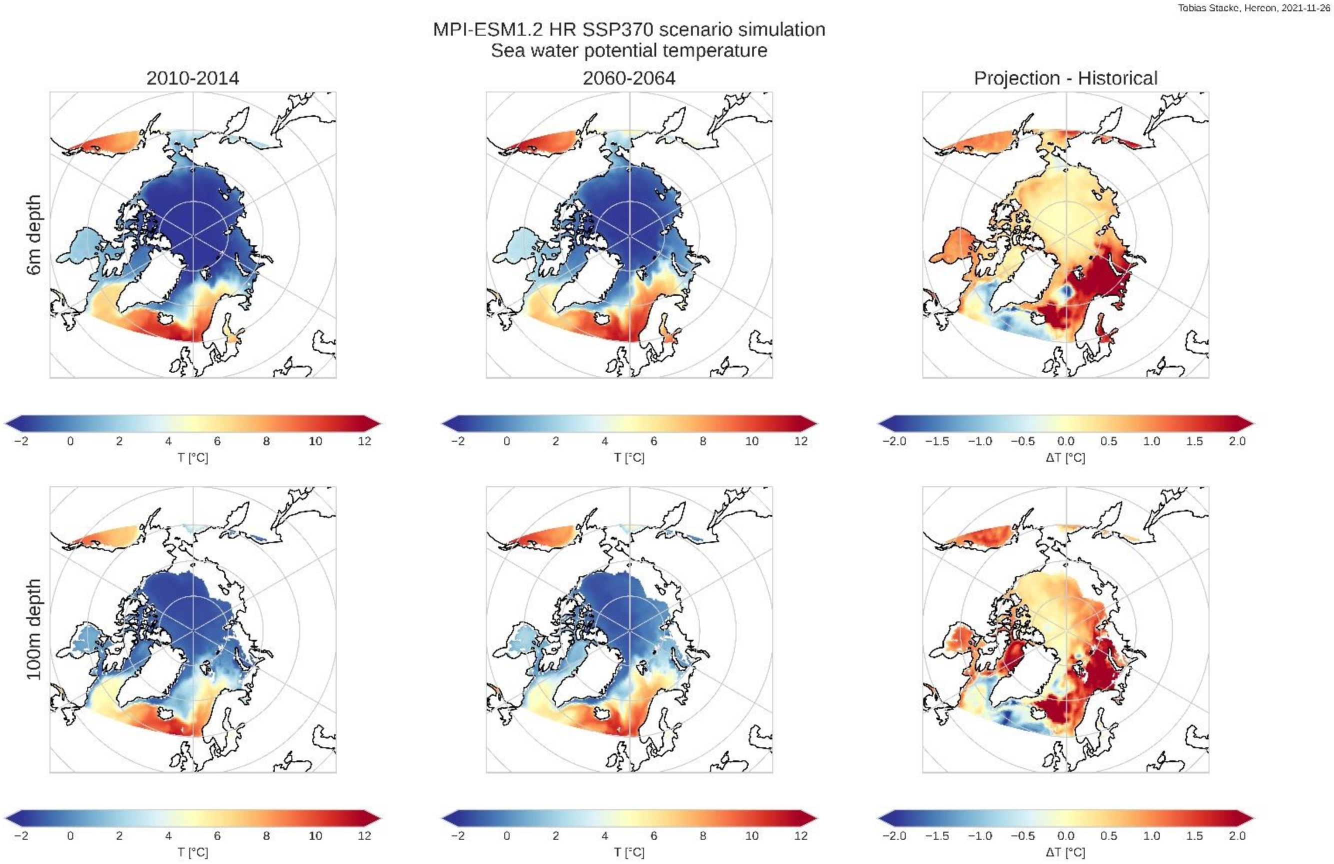
SSP370:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP370 scenario simulation
Sea water pH
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
7.5 7.6 7.7 7.8 7.9 8.0
pH [/]
−0.6 −0.4 −0.2 0.0 0.2 0.4 0.6
ΔH+ [μmol L−1]

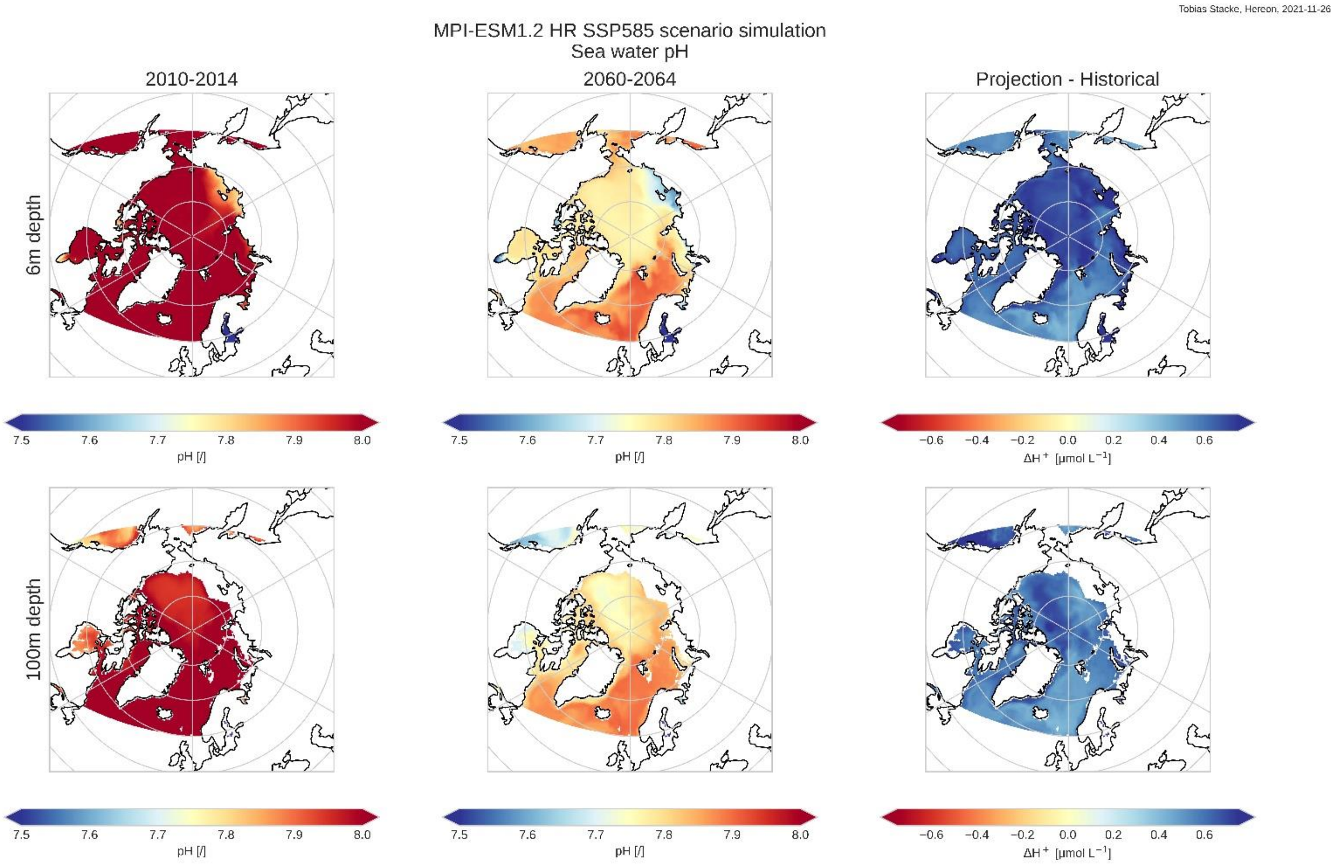
SSP370:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP370 scenario simulation
Sea water salinity
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5 40.0
S [/]
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
ΔS [/]

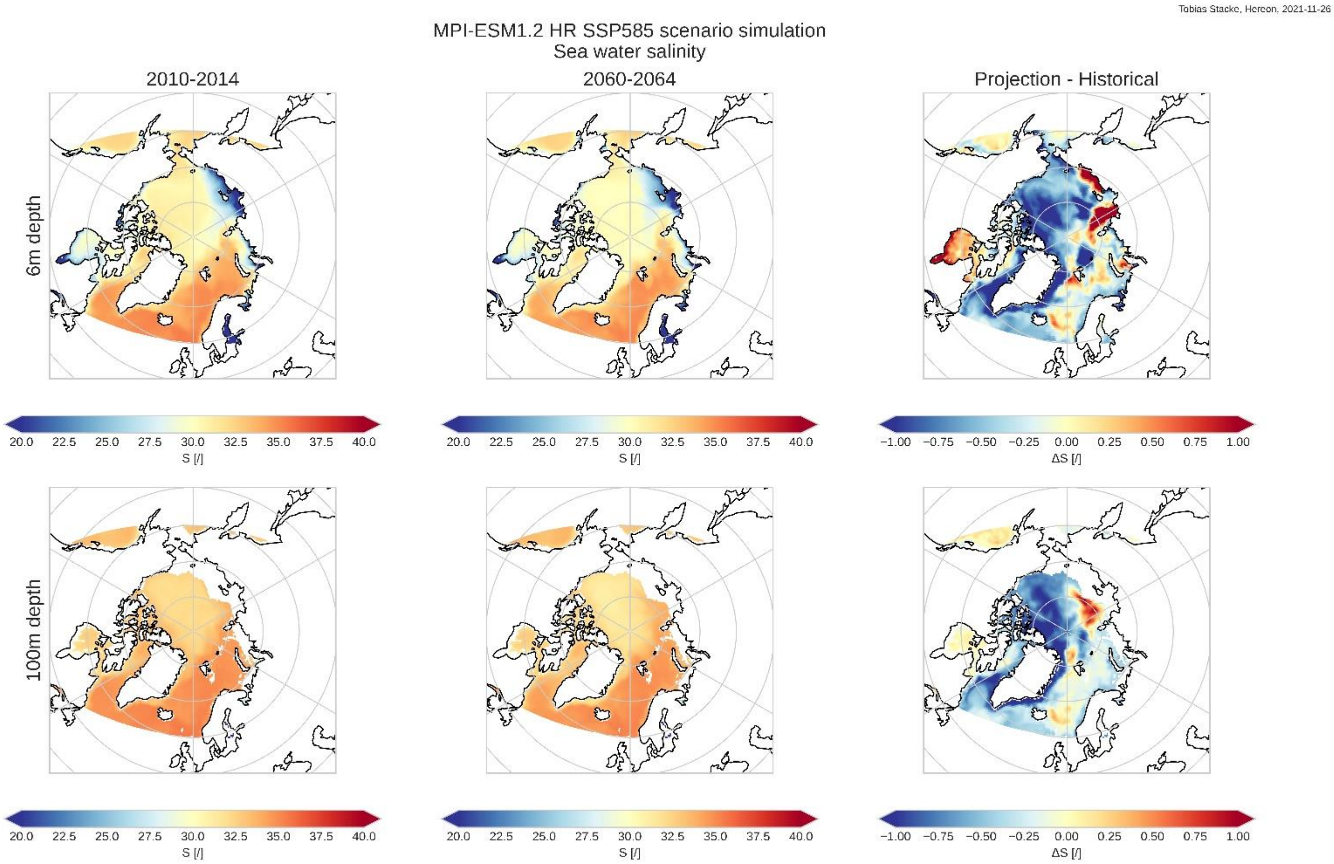
SSP370:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP370 scenario simulation
Sea water potential temperature
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
T [°C]
ΔT [°C]

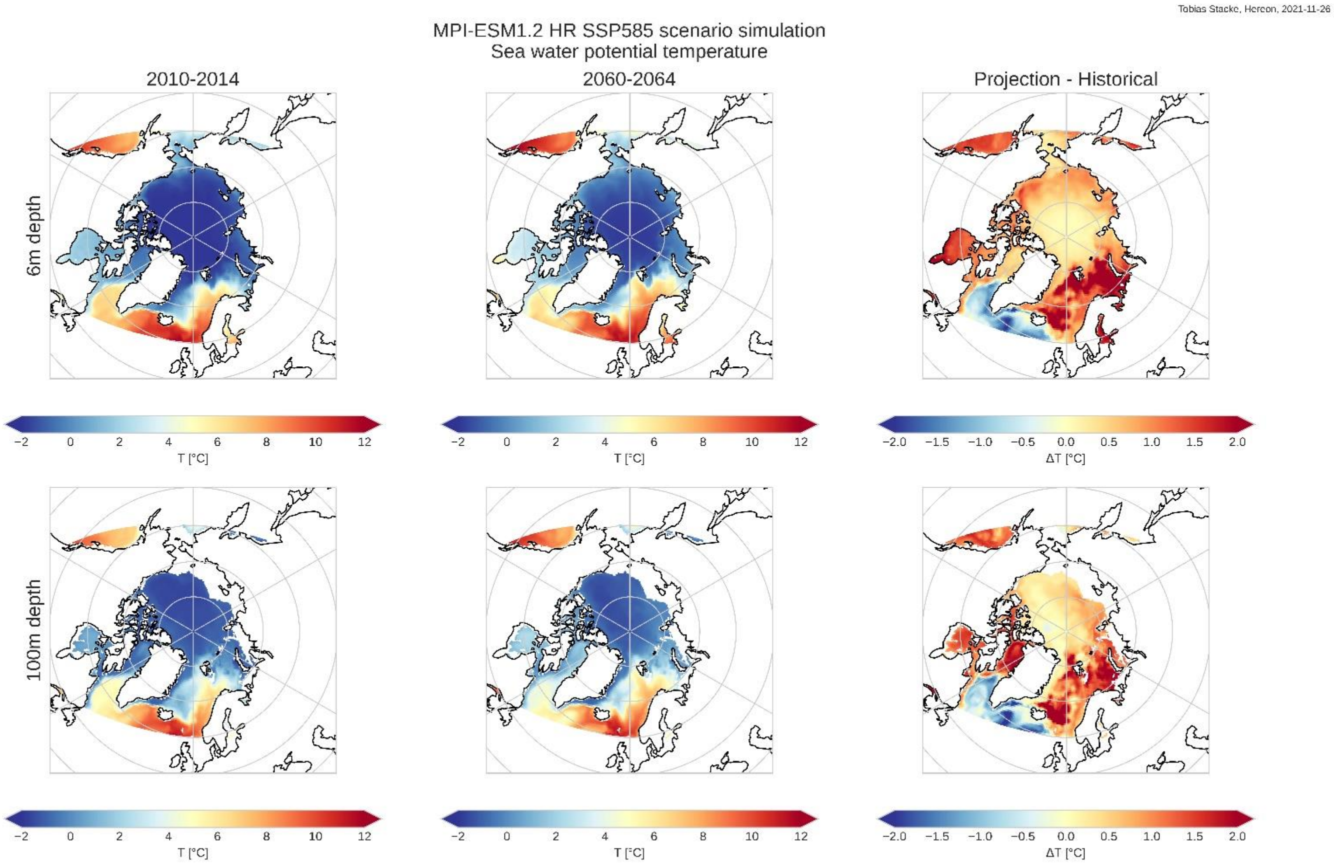
SSP585:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP585 scenario simulation
Sea water pH
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
7.5 7.6 7.7 7.8 7.9 8.0
pH [/]
−0.6 −0.4 −0.2 0.0 0.2 0.4 0.6
ΔH+ [μmol L−1]

SSP585:


Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP585 scenario simulation
Sea water salinity
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5 40.0
S [/]
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
ΔS [/]

SSP585:

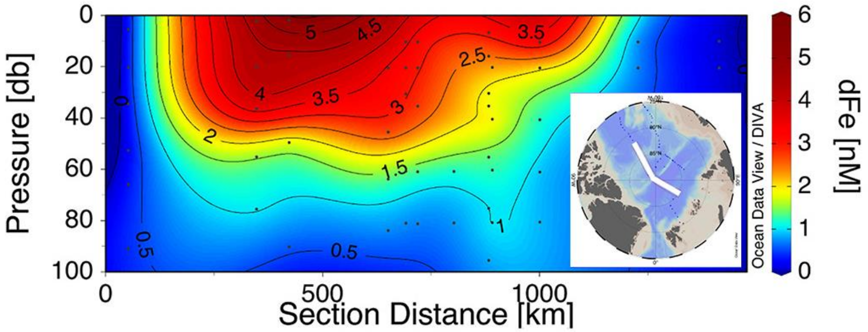
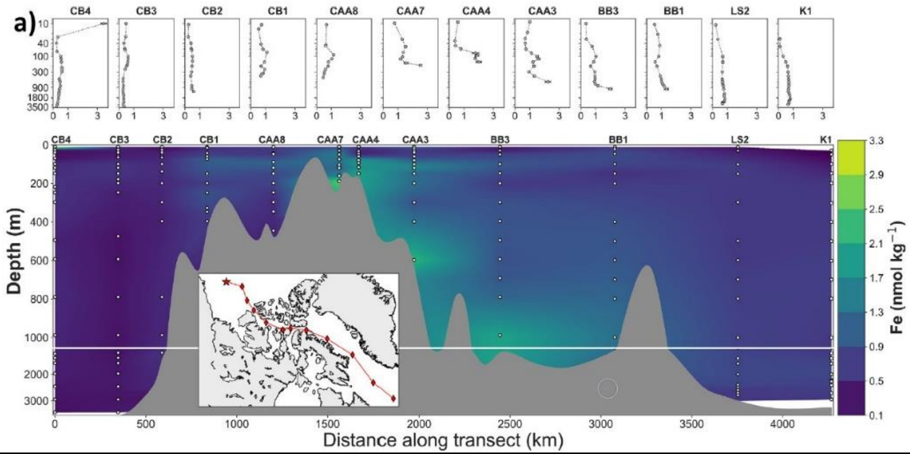

Tobias Stacke, Hereon, 2021-11-26
MPI-ESM1.2 HR SSP585 scenario simulation
Sea water potential temperature
2010-2014
2060-2064
Projection - Historical
6m depth
100m depth
−2 0 2 4 6 8 10 12
T [°C]
−2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0
ΔT [°C]

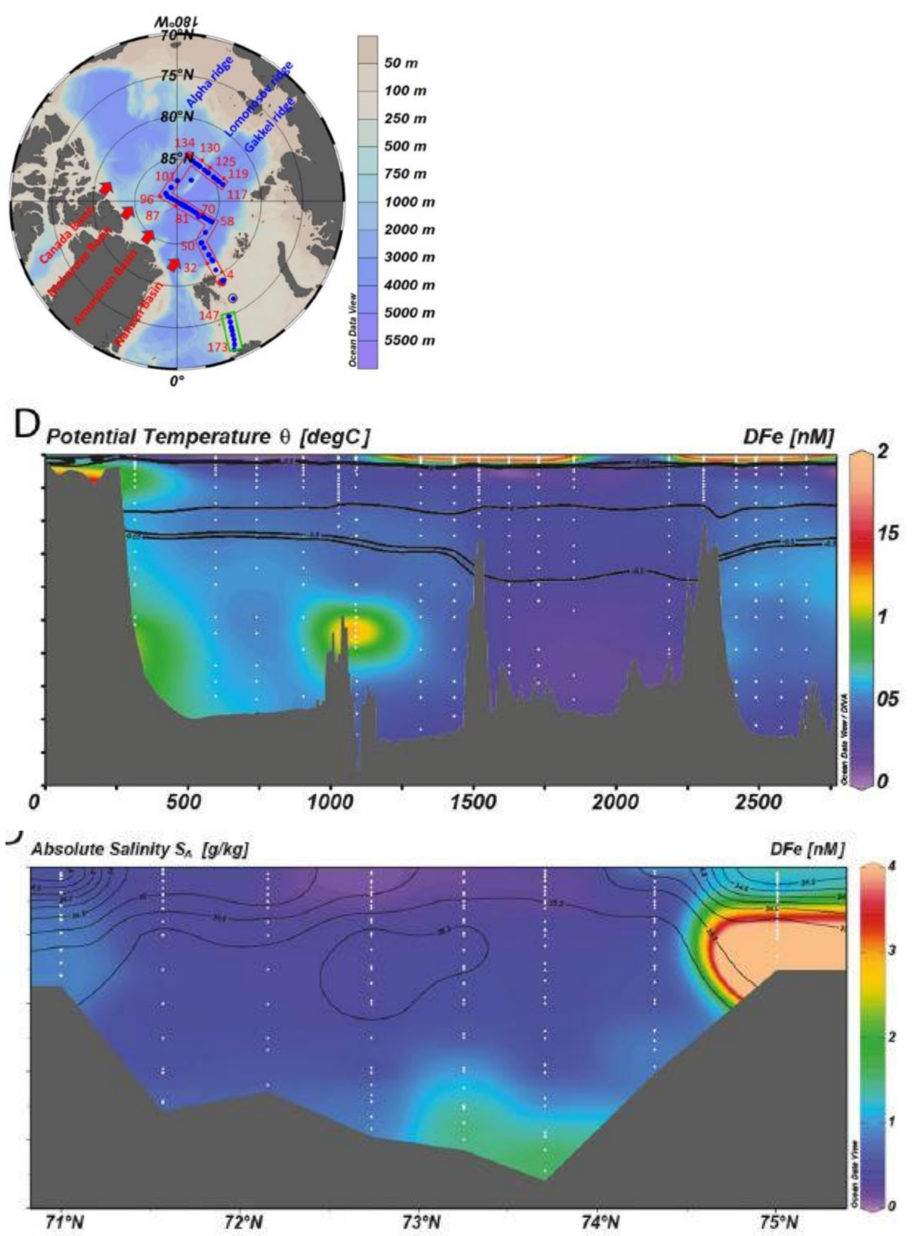
3.3 *Trace Metals*

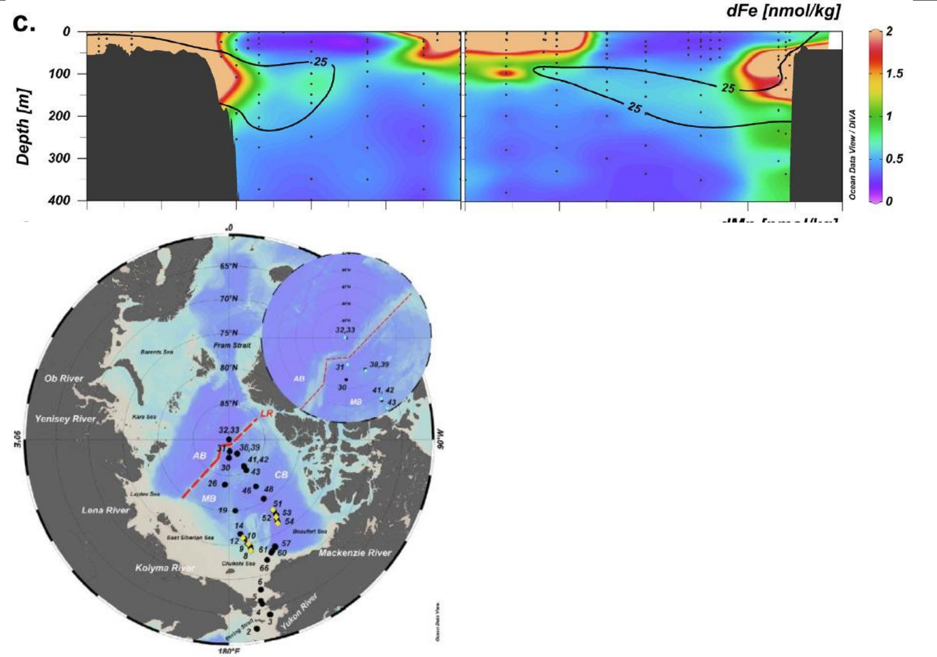
3.3. Trace Metals

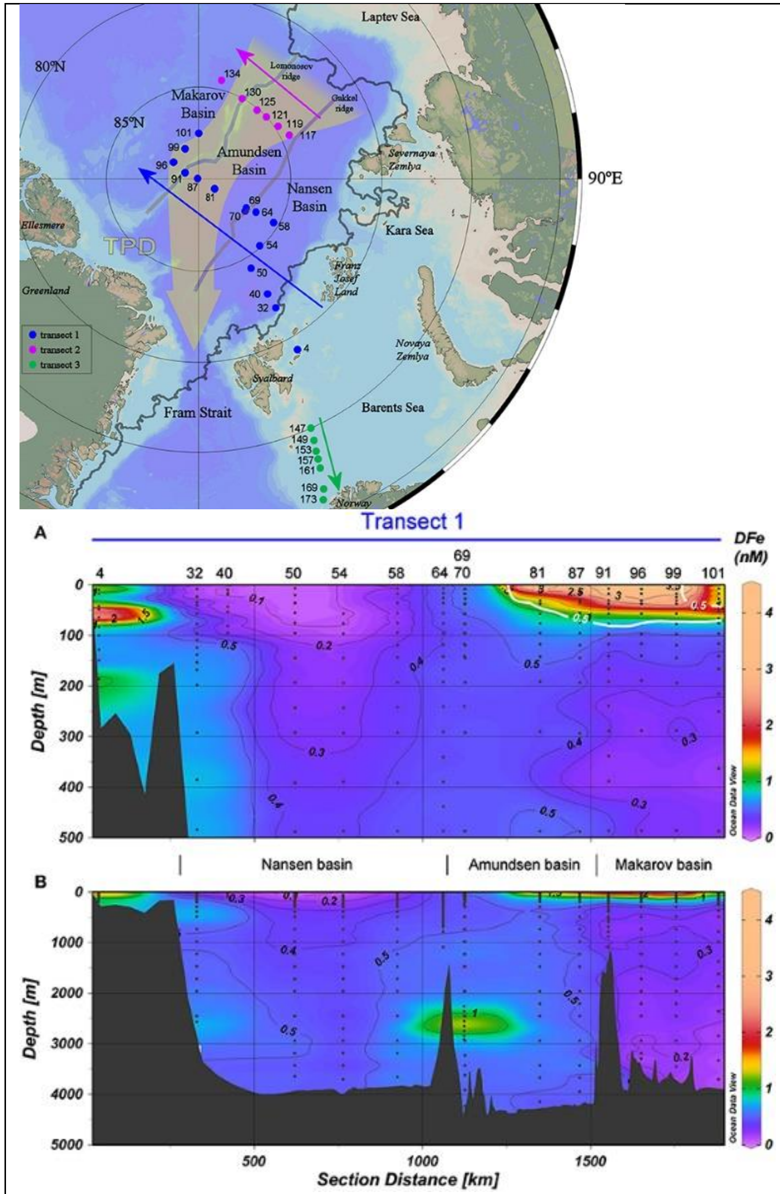
Stressors in Arctic Seas

1. **<u>Iron</u>**

Map	Comments	Source
	• anomalously high concentrations dFe in Arctic Ocean surface waters → combination of larger external sources and less biological uptake and/or scavenging removal under the sea ice • riverine source that originated in the eastern Arctic Ocean • largely scavenged/aggregated in the estuary and/or over the shelf before being transported offshore • increase in dFe due to projected future increases in Arctic riverine discharge as well as fluxes of DOM-derived organic ligands that stabilize dissolved phase	**The Transpolar Drift as a Source of Riverine and Shelf-Derived Trace Elements to the Central Arctic Ocean** Charette et al. (2020) https://doi.org/10.1029/2019JC015920
	• surface distributions in the Canadian Arctic Ocean controlled by fresh water sources, mostly riverine inputs • high concentrations: Canadian Arctic Archipelago (CAA) → coastal region receiving a large flux of freshwater from numerous river systems • low concentrations: Surface waters in the Labrador Sea → reduced freshwater inputs and increased phytoplankton uptake in the region	**Dissolved iron and manganese in the Canadian Arctic Ocean: On the biogeochemical processes controlling their distributions** Colombo et al. (2020) https://doi.org/10.1016/j.gca.2020.03.012

	• River input, inflow of Pacific water and sea ice formation (brine rejection) as a source for dFe • Nutrient type profile for dFe → consumption by phytoplankton • depletion of dFe is likely to expand upon future reduction in sea-ice coverage	**Dissolved Cd, Co, Cu, Fe, Mn, Ni, and Zn in the Arctic Ocean** Gerringa et al. (2021) https://doi.org/10.1029/2021JC017323

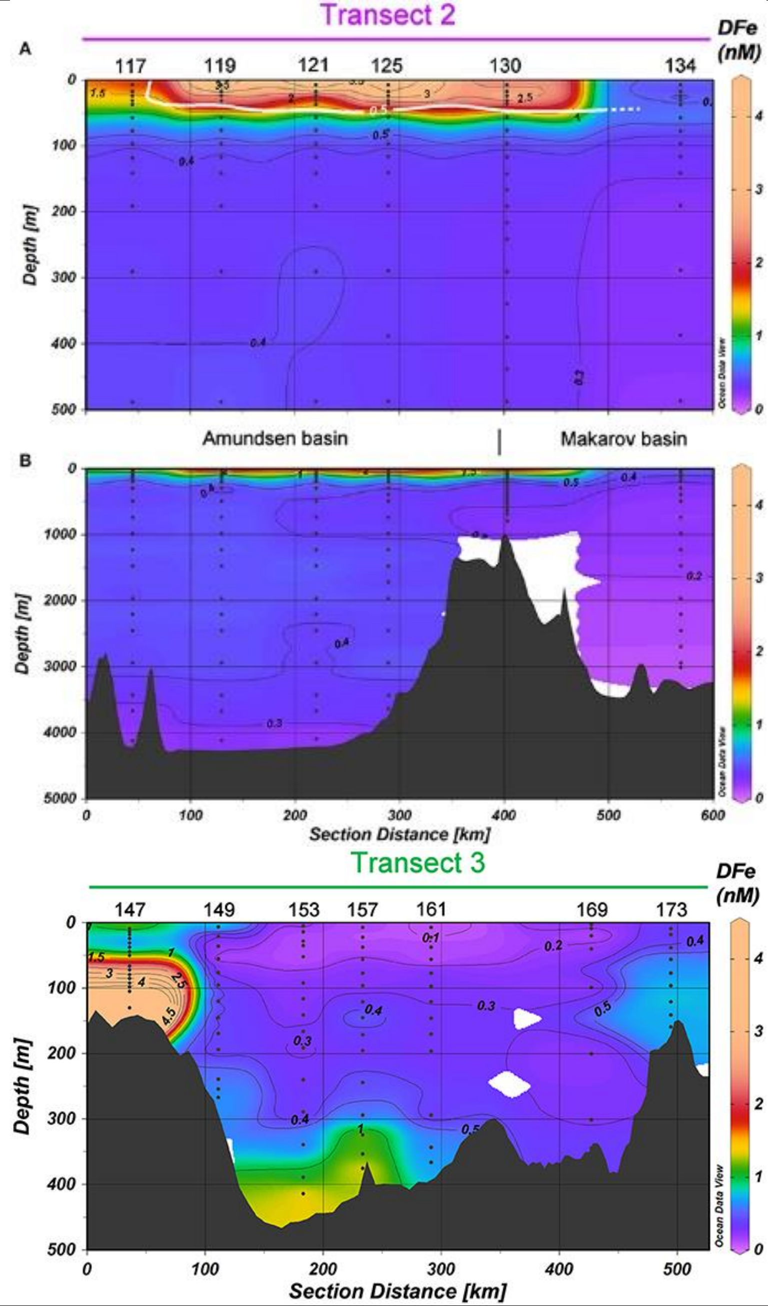
	• common sources and sinks for dFe: release from sediments, dust fluxes, hydrothermal venting, biological uptake, and scavenging to the particulate phase • Rapid decrease of dFe from shelf/strait stations to off-shelf stations, increase again at North Pole due to Transpolar Drift (TPD) • Large fluxes from continental shelf, smaller contribution from sea ice • Low dFe concentrations + low chlorophyll a in offshore waters → indicative of Fe limitation for surface primary producers	**A comparison of marine Fe and Mn cycling: U.S. GEOTRACES GN01 Western Arctic case study** Jensen et al. (2020) https://doi.org/10.1016/j.gca.2020.08.006



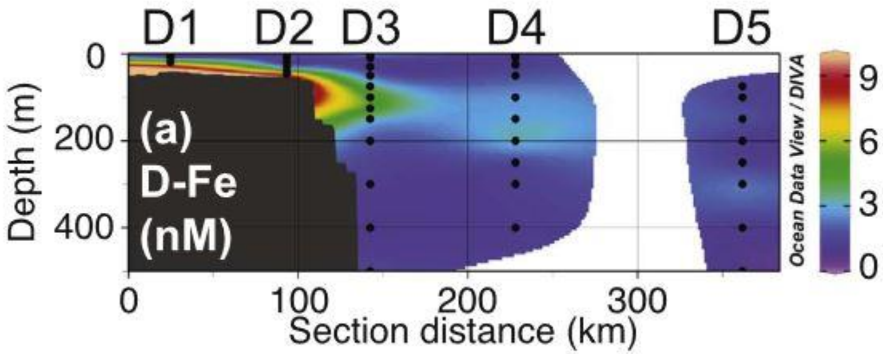
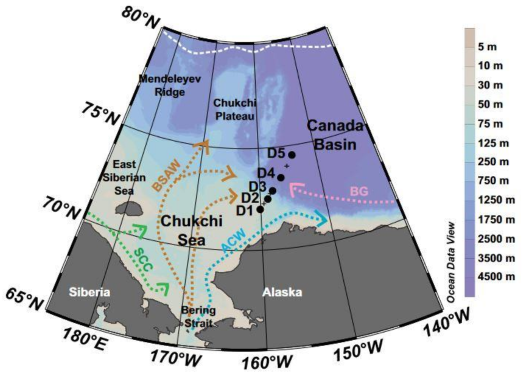
- Sources of dFe to surface Arctic Ocean: sea ice melt, atmospheric inputs, lateral input from land with rivers as the main contributor, Atlantic inflow and mixing with deep water
- Additional dFe input from melting sea ice → important for biological uptake under ice and ice edge blooms
- main source of dFe in the surface was Transpolar Drift (TPD) → lateral transport from the coast, shelves and land-fast-glaciers, with or without further transport by mesoscale eddies
- TPD as major surface current over the Arctic Ocean, transporting sea ice and river water from the Arctic shelf seas toward Fram Strait → distinct influence on the distribution of dFe
- Higher concentrations in deeper waters → resuspension on the continental slope + hydrothermal activity (Gakkel Ridge)
- Fe limitation potentially prevented up to 54% of the available nitrate and nitrite from being used for primary production → may have large consequences for primary production, Arctic ecosystem and

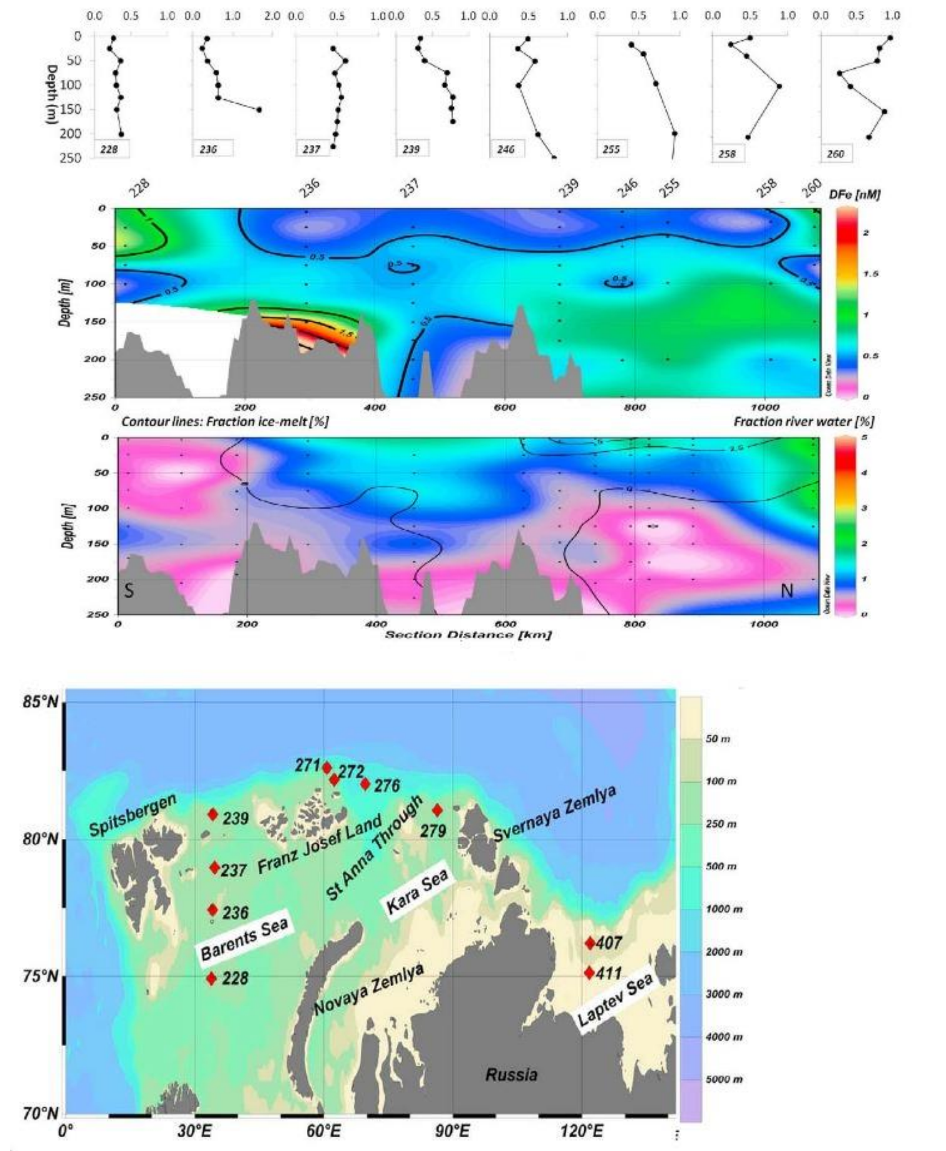
Dissolved Fe in the Deep and Upper Arctic Ocean With a Focus on Fe Limitation in the Nansen Basin

Rijkenberg et al. (2018)
https://doi.org/10.3389/fmars.2018.00088



subsequent drawdown of carbon dioxide

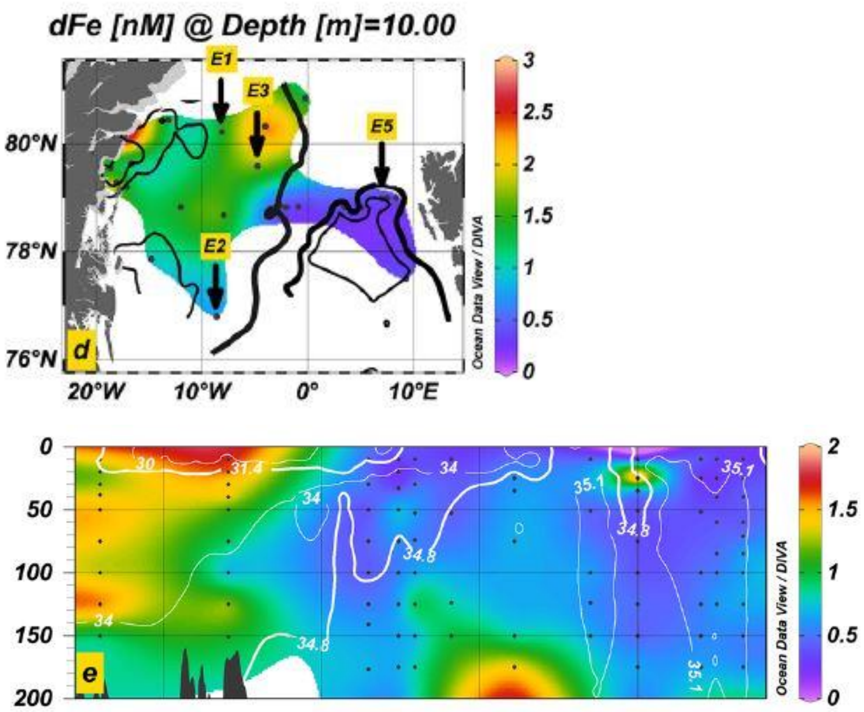
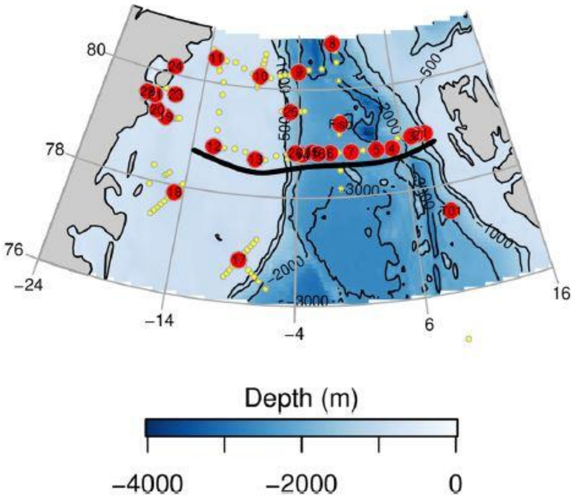
 	• several potential external sources of trace metals: re-suspension of sediment particles from the shelf, sea-ice melting, river discharge and water inflow from Bering Strait • sea ice near the continental margins in particular could supply dFe to the water column via melting • Maxima in vertical profiles occurred in halocline and/or near-bottom waters → inflow of low-salinity Pacific-origin water from the Bering Strait, as well as local fresh water inputs such as river water and melting sea-ice, influenced dFe concentrations • Logarithmical decrease of Fe concentrations along the distance from the shelf break → distributions controlled mainly by input from shelf sediment and removal through scavenging processes	**Transport of trace metals (Mn, Fe, Ni, Zn and Cd) in the western Arctic Ocean (Chukchi Sea and Canada Basin) in late summer 2012** Kondo et al. (2016) https://doi.org/10.1016/j.dsr.2016.08.010



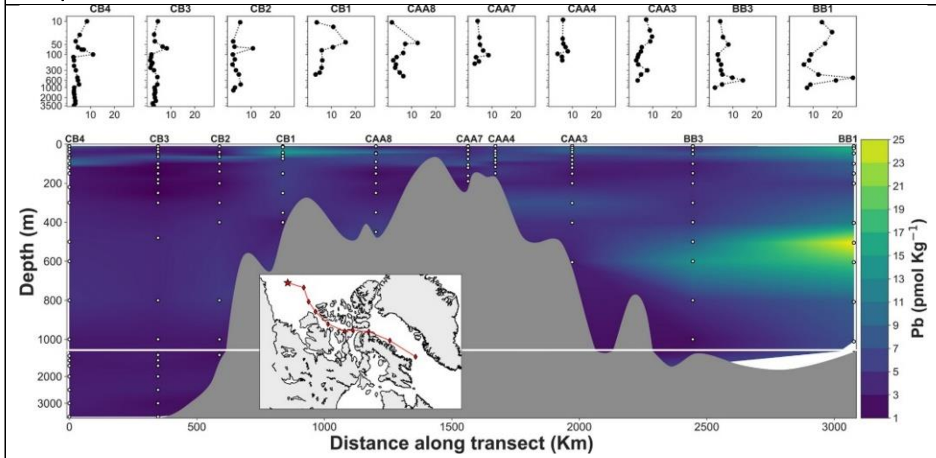
- inverse linear relationship between dFe and salinity → demonstrates the important role of Arctic rivers in the delivery of dFe to the Arctic Ocean
- nevertheless, significant deviations from the linear trend indicate that there are also other important sources and processes → e.g. melting of seasonal sea-ice
- inflow of river water is major source of dFe to surface waters. However, removal of large amount of dFe expected by precipitation/flocculation and sinking in the estuaries
- Biological depletion by phytoplankton growth → dFe minima at high chlorophyl a concentrations
- dFe more strongly influenced by external sources and/or removal from the water column than e.g. dCd

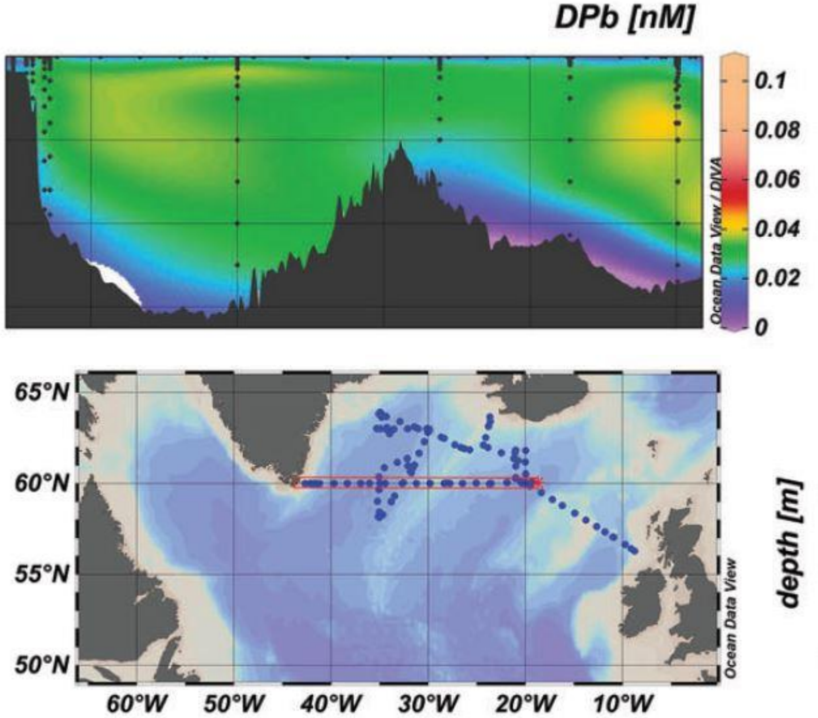
Dissolved iron in the Arctic shelf seas and surface waters of the central Arctic Ocean: Impact of Arctic river water and ice-melt

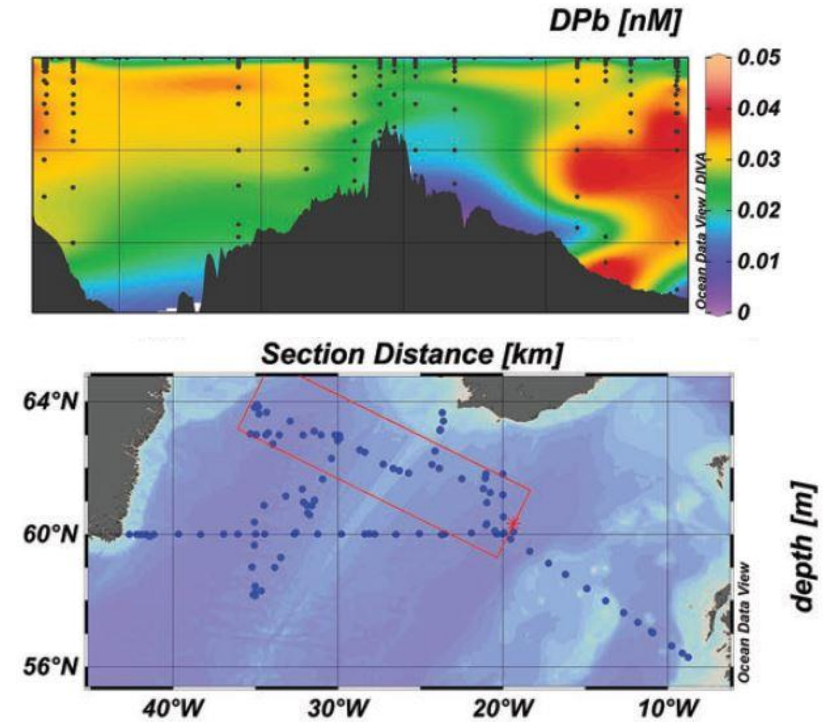
Klunder et al. (2012)
https://doi.org/10.1029/2011JC007133

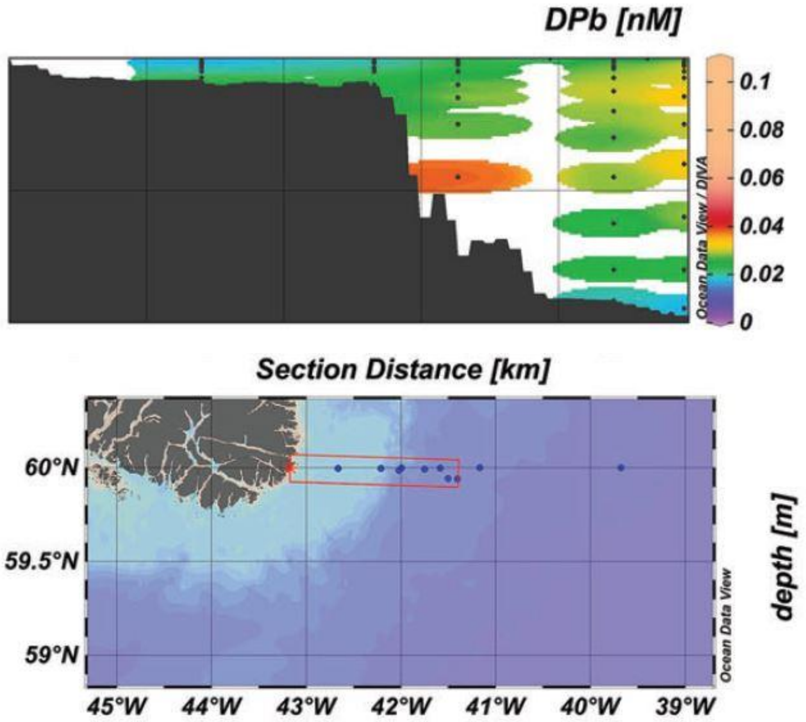
 	• dFe deficiency in surface seawater relative to typical phytoplankton requirements → Fe becoming more deficient towards Svalbard, potential secondary Fe limitation • sedimentary inputs likely cause sporadic enrichments in depth profiles • rapid scavenging of dFe sources along the Greenlandic shelf	**The influence of Arctic Fe and Atlantic fixed N on summertime primary production in Fram Strait, North Greenland Sea** Krisch et al. (2020) https://doi.org/10.1038/s41598-020-72100-9

2. Lead

Map	Comments	Source
	• anthropogenic influence + natural processes occurring at the continent–ocean interface → glacial water runoff and sea ice melt (inputs), and at the sediment–water boundary (scavenging removal–sinks) • lowest dPb concentrations: Canada Basin and the Canadian Arctic Archipelago → relatively isolated from anthropogenic inputs • highest concentrations: Labrador Sea → influence of the subpolar gyre circulation advecting warm, salty, and anthropogenically elevated Pb waters	**Tracing Dissolved Lead Sources in the Canadian Arctic: Insights from the Canadian GEOTRACES Program** Colombo et al. (2019) https://doi.org/10.1021/acsearthspacechem.9b00083

	• Elevated dPb concentrations attributed to historical atmospheric anthropogenic Pb inputs to the North Atlantic • Removal of dPb through particle scavenging is evident in the vicinity of the Reykjanes Ridge • dPb distributions influenced by atmospheric inputs, sediment supply, and scavenging and association of Pb with organic matter remineralization • lower dPb at elevated particulate Mn and Fe concentrations related to scavenging • convective supply of dPb → subsurface stocks with elevated concentrations were accessed during deep winter mixing, which resulted in a replenishment of depleted surface water stocks	**Trace Element Biogeochemistry in the High-Latitude North Atlantic Ocean: Seasonal Variations and Volcanic Inputs** Achterberg et al. (2020) https://doi.org/10.1029/2020GB006674

 DPb [nM] 0.05 0.04 0.03 0.02 0.01 0 Ocean Data View / DIVA Section Distance [km] depth [m] 64°N 60°N 56°N 40°W 30°W 20°W 10°W Ocean Data View		


DPb [nM]
0.1
0.08
0.06
0.04
0.02
0
Ocean Data View / DIVA
Section Distance [km]
60°N
59.5°N
59°N
45°W
44°W
43°W
42°W
41°W
40°W
39°W
Ocean Data View
depth [m]

3. Vanadium

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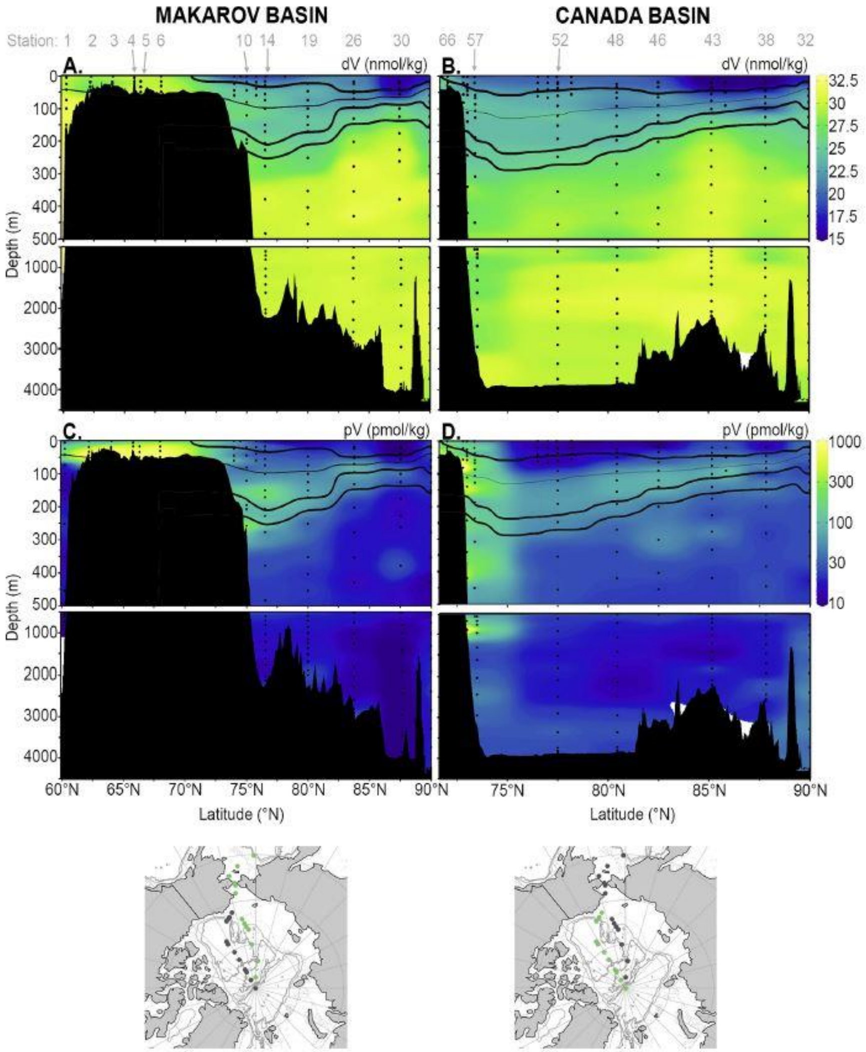

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Western Arctic Ocean shows lower dV concentrations than profiles observed elsewhere in the open ocean → adsorption onto particles as dominant factor in dV removal
dV concentrations increase with depth and are slightly higher in Pacific halocline
significant removal in estuarine and/or shelf environment
surface depletion of 24–49% with respect to deep water dV → scavenging of V by Fe oxyhydroxides and Mn oxyhydroxides and delivery to the sediments + biological removal in the surface layer
sea ice melt and riverine inputs characterized by low dV
biological input may contribute to dV removal in surface waters

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<td>
Vanadium cycling in the Western Arctic Ocean is influenced by shelf-basin connectivity

Whitmore et al.
https://doi.org/10.1016/j.marchem.2019.103701
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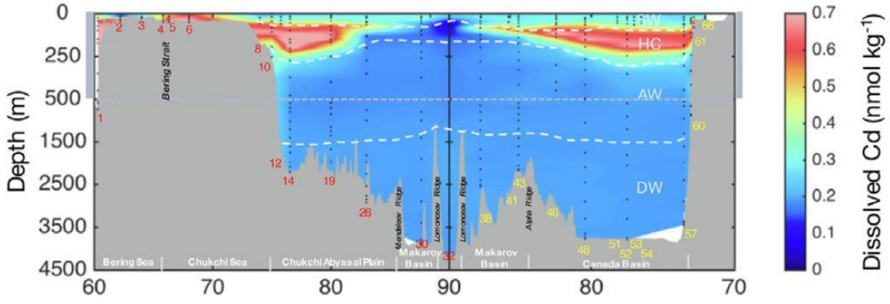
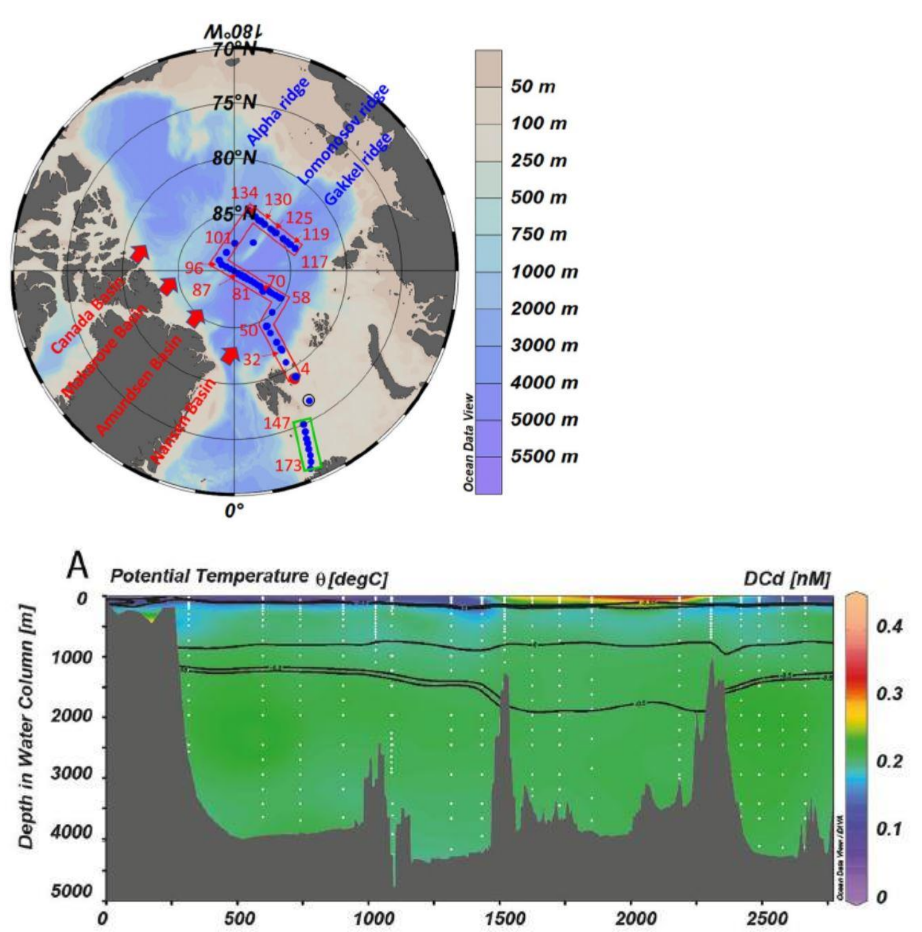
4. <u>Cadmium</u>

Map	Comments	Source
	• Accumulation of Cd along the deep ocean conveyor belt • surface water depletion: biological uptake, dilution by low-Cd sea ice melt • lower concentrations in open Arctic surface water compared to shelf waters: depletion due to biological uptake	**Dissolved cadmium and cadmium stable isotopes in the western Arctic Ocean** Zhang et al. (2019) https://doi.org/10.1016/j.gca.2019.05.028

	• dCd displays clear nutrients type profile outside TPD → phytoplankton consumption in Nansen Bay • riverine supply cannot be detected → fast precipitation or river supply is small/not present, indicating that dCd does not vary much due to river input • interference of the dominant Pacific influence • average higher concentrations in the TPD, implying a riverine source with elevated dCd in dominant Pacific water coming from the Bering Strait and apparently additional sea-ice melt	**Dissolved Cd, Co, Cu, Fe, Mn, Ni, and Zn in the Arctic Ocean** Gerringa et al. (2021) https://doi.org/10.1029/2021JC017323

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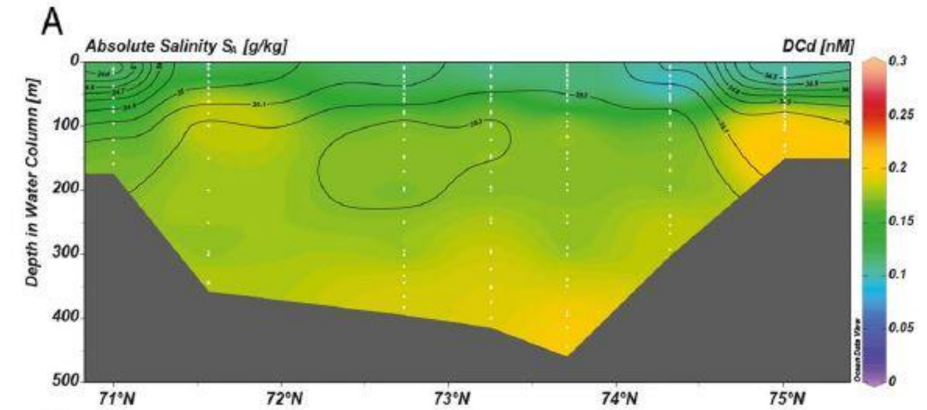
<td>
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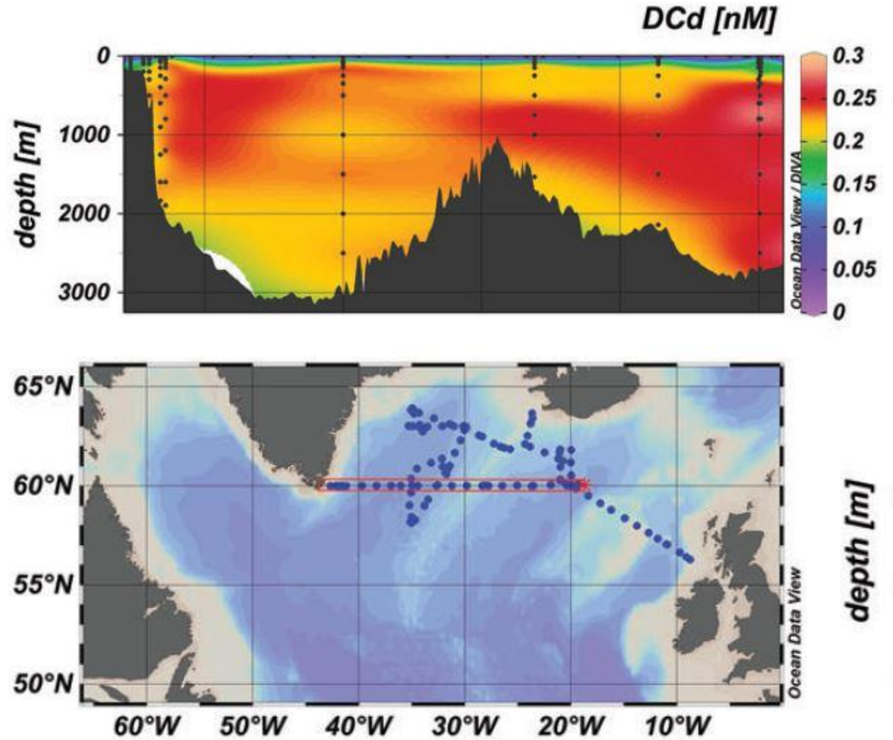
<td>
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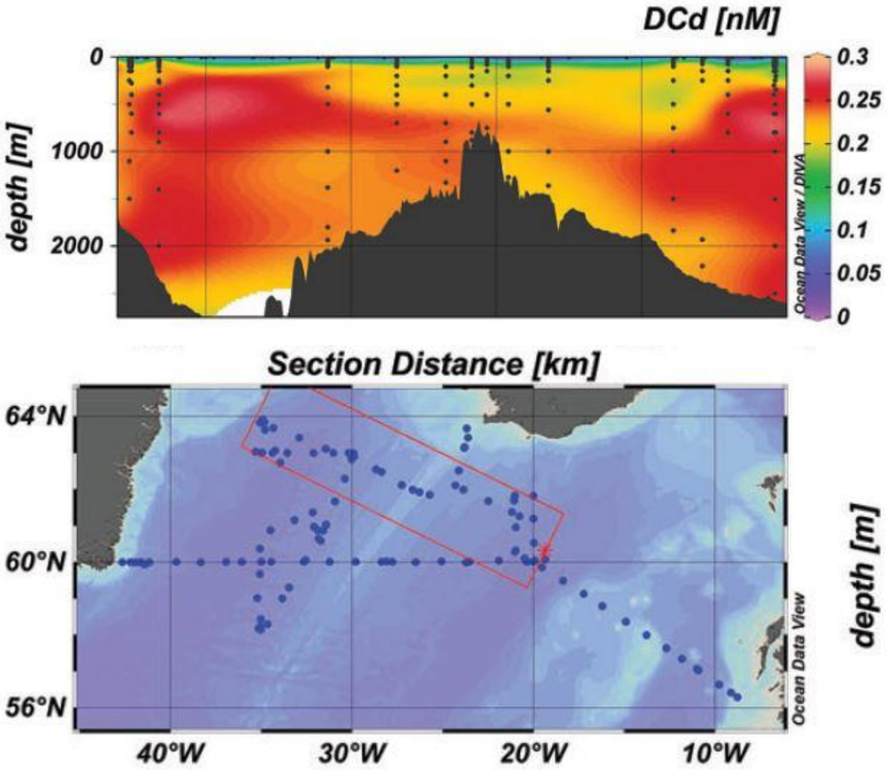
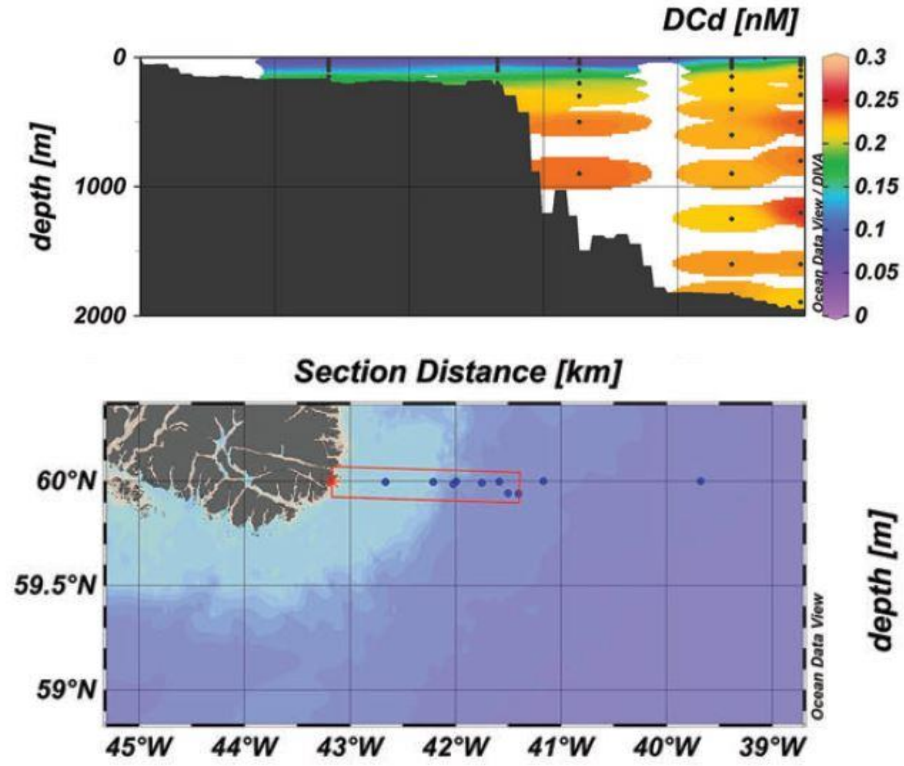
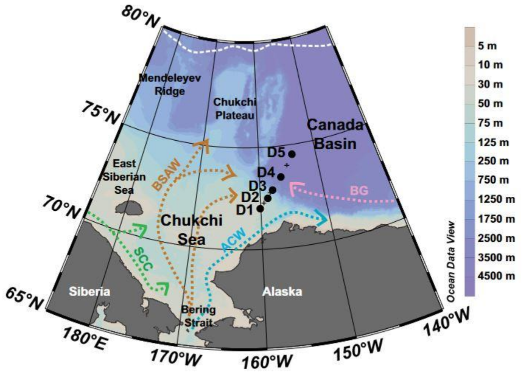
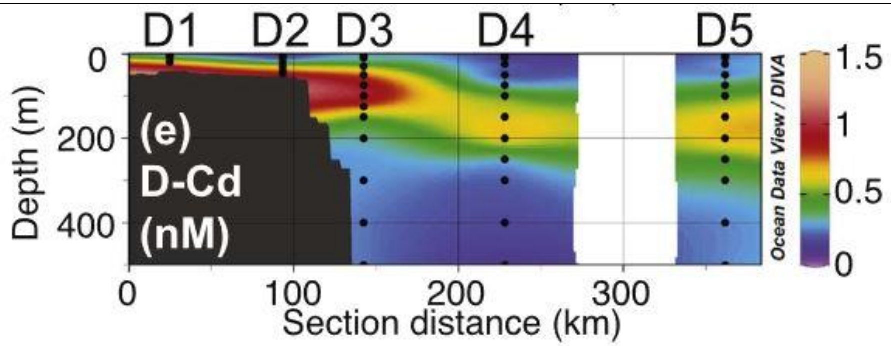
dCd as nutrient type element → depleted surface concentrations, increase with depth → uptake by microorganisms and deep water remineralization or transport of deep waters upstream
depth dependent increase controlled by organic matter production and remineralization
deep winter mixing as dominant source, with diffusive mixing being a minor source
predicted increases in water column stratification may reduce supply, with potential consequences for primary production and the biological carbon pump

</td>
<td>Trace Element Biogeochemistry in the High-Latitude North Atlantic Ocean: Seasonal Variations and Volcanic Inputs

Achterberg et al. (2020)
https://doi.org/10.1029/2020GB006674</td>
</tr>
</table>

DCd [nM] 0 1000 2000 depth [m] 0.3 0.25 0.2 0.15 0.1 0.05 0 Ocean Data View / DIVA Section Distance [km] 64°N 60°N 56°N 40°W 30°W 20°W 10°W Ocean Data View depth [m]		

		
	• rivers in industrialized regions as most important source of dCd in coastal areas after atmospheric input • Pacific-origin: inflow water from Bering Strait contains high concentrations of trace metals + various additional sources contribute to enrichment such as continental shelf sediments, river water discharge, melting sea ice and re-mineralization of organic matter • generally high concentrations in Chukchi Sea continental shelf and	**Transport of trace metals (Mn, Fe, Ni, Zn and Cd) in the western Arctic Ocean (Chukchi Sea and Canada Basin) in late summer 2012** Kondo et al. (2016) https://doi.org/10.1016/j.dsr.2016.08.010

	slope regions; similar concentration to coastal areas • transport of dCd further offshore from Chukchi Sea shelf break to Canada Basin • Characteristic distribution in western Arctic Ocean → halocline water most enriched in dCd • Strong correlation with phosphate levels → distributions are generally controlled by internal biogeochemical cycles • Influence on phytoplankton growth since dCd can act either as a nutrient or as a toxin	

5. Mercury

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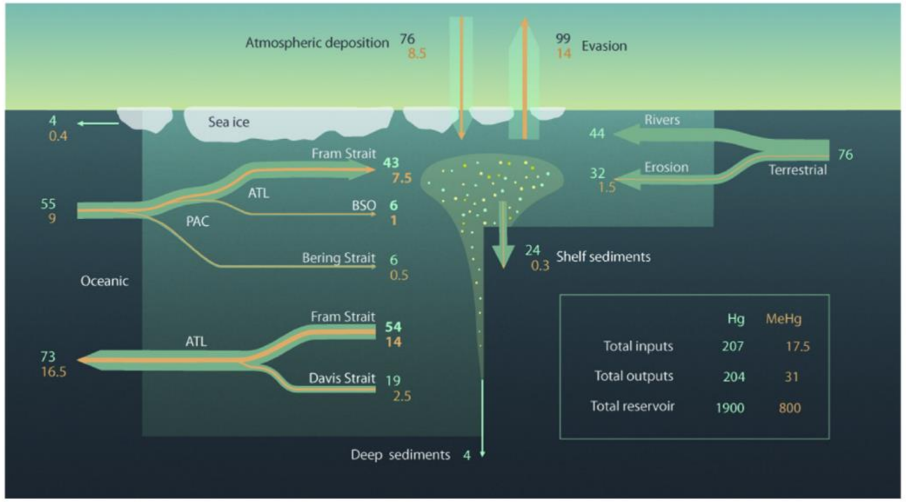

Figure: Arctic Ocean budget (Mg) and fluxes (Mg y⁻¹) for tHg (blue) and MeHg (orange).
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Annual total inflow of Hg corresponds to about 10 % of the total reservoir size (of 1900 Mg)
Total Hg is relatively reactive to changes in inputs and outputs (from e.g. climate change forcing, permafrost thawing, etc.)
Vertical diffusive flux to atmosphere higher than influx

</td>
<td>Mariia V. Petrova, Stephan Krisch, Pablo Lodeiro, Ole Valk, Aurelie Dufour, Micha J.A. Rijkenberg, Eric P. Achterberg, Benjamin Rabe, Michiel Rutgers van der Loeff, Bruno Hamelin, Jeroen E. Sonke, Cédric Garnier, Lars-Eric Heimbürger-Boavida,(2020), Mercury species export from the Arctic to the Atlantic Ocean, Marine Chemistry, 225 DOI:10.1016/j.marchem.2020.103855</td>
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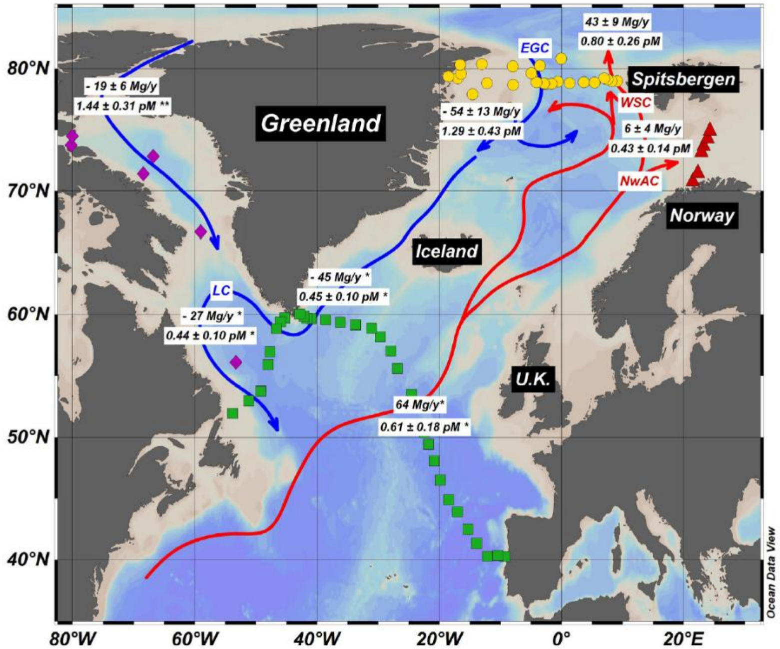

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Shallow methylmercury (MeHg) max. found in outflowing Arctic waters carrying MeHg to the North Atlantic
East Greenland current: outflowing upper Arctic water displays higher surface water total Hg compared to inflowing Atlantic-water
Methylated species over shelf greater than open ocean

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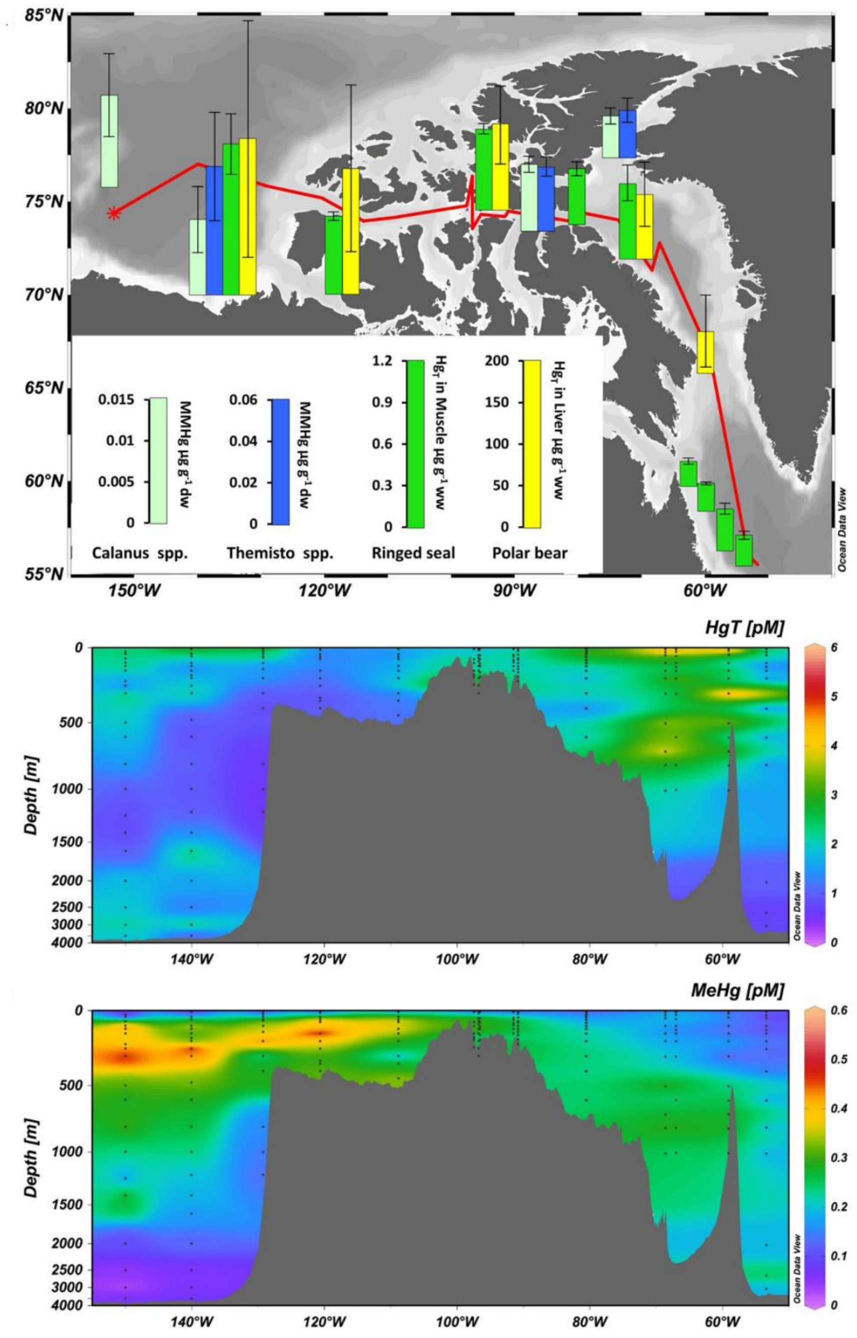

- Bioaccumulative and –magnifying effect of Hg is largely resembled in Arctic marine biota
- Since decades, Hg observations in marine biota across Canadian Arctic generally show higher Hg concentrations in the west than in the east
- Total Hg concentrations are lower in the western Arctic, opposing the biotic Hg distribution
- Contrarily, MeHg concentrations exhibit distinctive subsurface max. between 100-300m
- Subsurface max. depth is inherent with habitat of zooplankton and other lower trophic-level biota thus explaining the biotic Hg concentration gradient
- Understanding the processes that generate and maintain subsurface MeHg are crucial for risk assessments of MeHg to the Arctic marine ecosystem and Indigenous Peoples

Wang, K., Munson, K.M., Beaupré-Laperrière, A. *et al.* Subsurface seawater methylmercury maximum explains biotic mercury concentrations in the Canadian Arctic. *Sci Rep* **8,** 14465 (2018). https://doi.org/10.1038/s41598-018-32760-0

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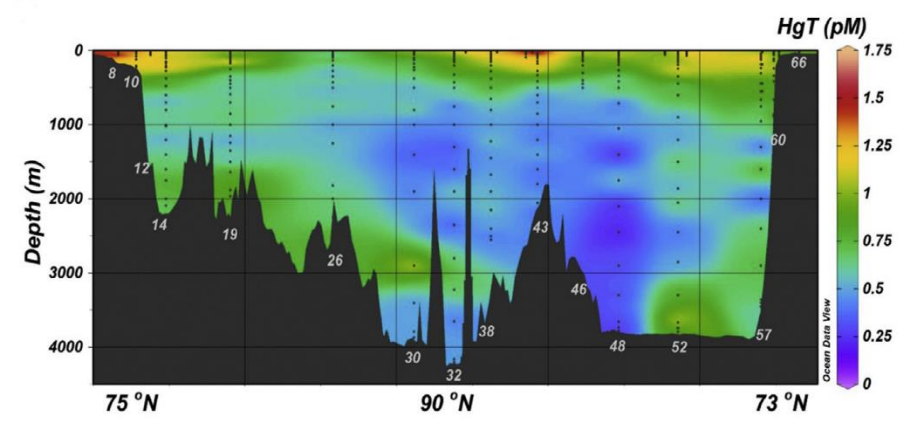
<td>
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Many water masses in the Western Arctic Ocean appear to be enriched with anthropogenic Hg
Transpolar Drift supplies inorganic Hg to central Arctic Ocean, however, not MeHg
Elemental Hg enriched under ice-coverage
Low MeHg levels in Western Arctic Ocean does not explain anomalously high Hg levels in Arctic animals

</td>
<td>Alison M. Agather, Katlin L. Bowman, Carl H. Lamborg, Chad R. Hammerschmidt (2019), Distribution of mercury species in the Western Arctic Ocean (U.S. GEOTRACES GN01), Marine Chemistry, 216
DOI: 10.1016/j.marchem.2019.103686</td>
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