The Canadian Arctic GEOTRACES Program:

Biogeochemical and tracer study of a rapidly changing Arctic Ocean

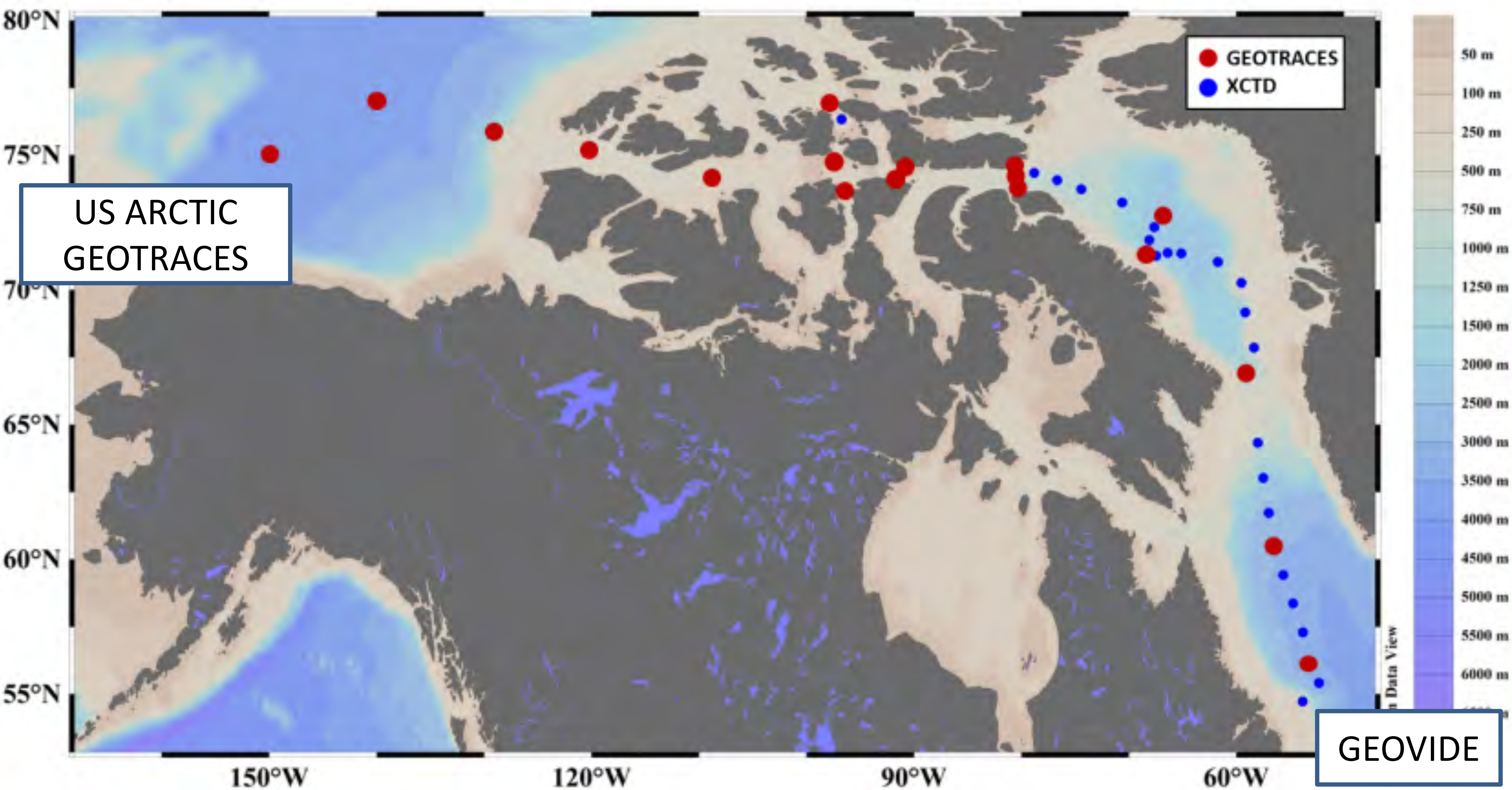
27 co-PIs from:

9 Canadian Universities

University of Victoria
University of British Columbia
University of Alberta
University of Saskatchewan
University of Manitoba
Trent University
University of Toronto
McGill University
Dalhousie University

2 DFO research institutions

Institute of Ocean Sciences
Bedford Institute of Oceanography



80°N
75°N
70°N
65°N
60°N
55°N
150°W
120°W
90°W
60°W
GEOTRACES
XCTD
50 m
100 m
250 m
500 m
750 m
1000 m
1250 m
1500 m
2000 m
2500 m
3000 m
3500 m
4000 m
4500 m
5000 m
5500 m
6000 m
US ARCTIC GEOTRACES
GEOVIDE

13 Stations

- 67 hydrocasts with AN CTD-rosette
- 31 hydrocasts with TM CTD- rosette
- 24 LVP casts
- 1 trace metal clean deck pump deployment for large volume incubation experiments

278 incubations
- 88 two-hour ^{14}C incubations/FRRF
- 60 ^{13}C and ^{15}N incubations
- 60 ^{32}Si incubations
- 60 ^{18}O incubations
- 10 ^{55}Fe incubations

+ ArcticNet's 156 12h ^{14}C incubations

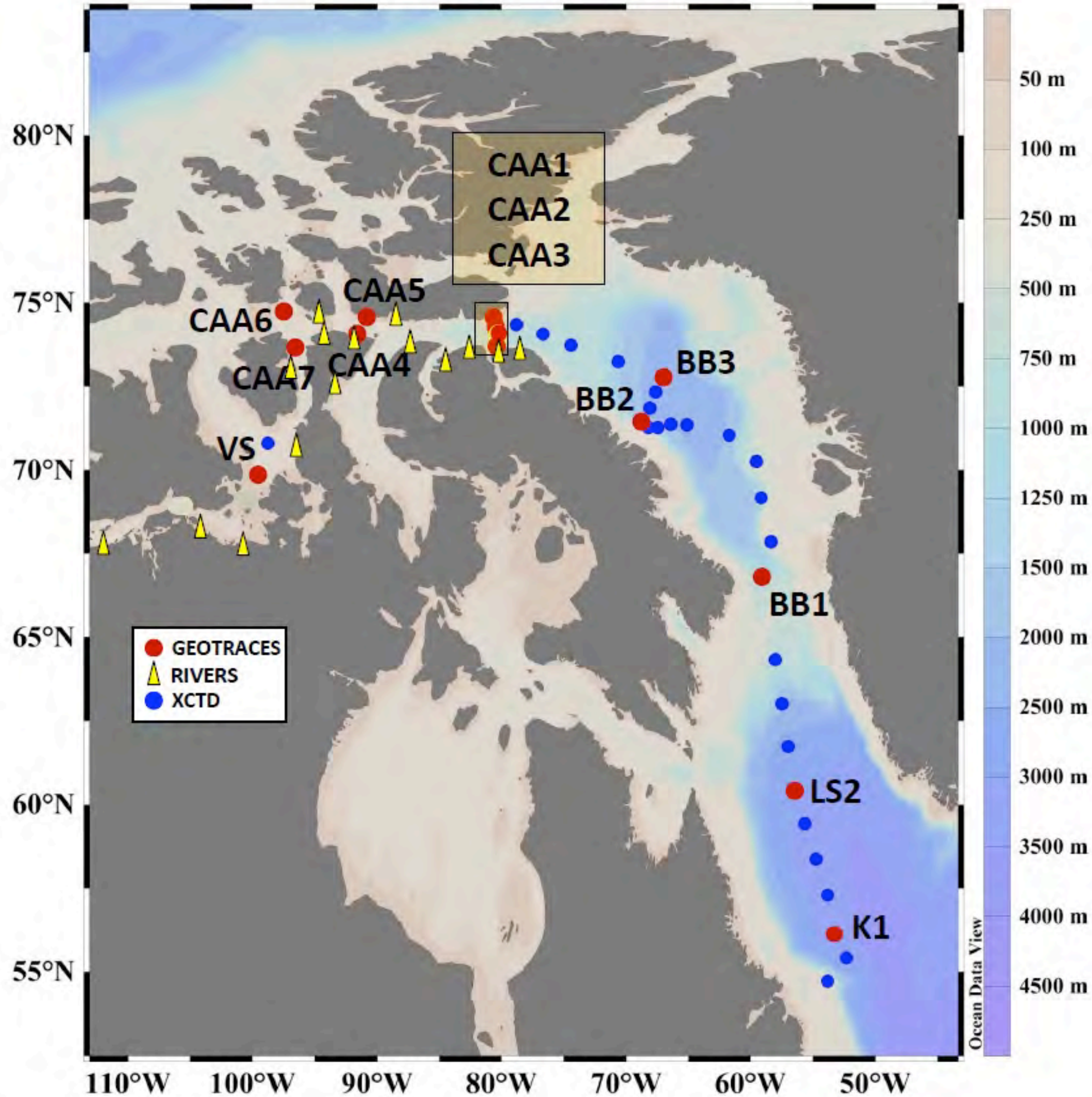
Underway trace gas analysis

Two CO_2 / light manipulation experiments

Sampling at 15 Arctic rivers draining in the CAA

Aerosol sampling

First leg
Quebec City - Kugluktuk
July 10 – August 20, 2015



First leg

Chemical and biological parameters measured or sampled in the water column

Underway sampling/analysis:

- Aerosols
- Atmospheric Hg concentration (Gaseous Elementary Mercury [GEM], Reactive Gaseous Mercury [RGM] and Particulate Hg [PHg])
- Surface gas measurements
    - gas chromatography (DMS/P/O)
    - membrane inlet mass spectrometry (CO_2, ΔO_2/Ar, and DMS)
- Photo-physiological measurements (FRRF)

Hydrography/CTD sensors	**Trace gases**
Pressure	Biogenic gases
Temperature	CH4, N2O
Salinity	O2/Ar, N2/Ar (K1; LS2; BB1, 2, 3; CAA1, 3, 4, 5, 6, 7)
Oxygen	Triple oxygen isotopes (K1; LS2; BB1, 2, 3; CAA1, 3, 4, 5, 6, 7)
Fluorescence	Noble gases (K1 and BB2)
Light transmission	**Trace elements and isotopes**
Nutrients	Dissolved and particulate trace metals
Phosphate	Al, Mn, Fe, Cd, Zn, Cu, Pb, Ga, Ba, REE, Hg, MeHg
Nitrate/Nitrite	Dissolved and particulate radioisotopes
Ammonia	^{230}Th, ^{231}Pa, ^{234}Th, ^{228}Ra, ^{224}Ra, ^{223}Ra
Silicate	Dissolved and particulate radiogenic isotopes
Chemical parameters	Nd, Pb
Dissolved inorganic carbon	Dissolved and particulate stable isotopes
Total alkalinity	δ^{18}O in water
pH	δ^{13C} in DIC
Dissolved organic carbon	δ^{15}N and δ^{18}O in nitrate
Fluorescent dissolved organic matter	δ^{30}Si
Coloured dissolved organic matter	δ^{53}Cr
Thiols	δ^{56}Fe
Organic ligands	Anthropogenic isotopes
Biological parameters	^{129}I, ^{236}U, ^{135}Cs
Particulate organic carbon	**Large volume in-situ pumps**
Particulate organic nitrogen	Paticulate ^{230}Th, ^{231}Pa, ^{234}Th
Size fractionated chlorophyll a	Paticulate Si, Nd and Cr isotopes
Pigments	
Particulate biogenic silica	
Flow cytometry	
Genomics	
Proteomics	
Incubations	
^{14}C uptake (K1; LS2; BB1, 2, 3; CAA1, 2, 3, 4, 5, 6, 7; VS)	
^{13}C uptake (K1; LS2; BB1, 2, 3; CAA1, 3, 5, 6, 7)	
^{15}NO3 uptake (K1; LS2; BB1, 2, 3; CAA1, 3, 5, 6, 7)	
^{15}NH4 uptake (LS2; BB1, 2, 3; CAA1, 3, 5, 6, 7)	
^{32}Si uptake (LS2; BB1, 2, 3; CAA1, 3, 5, 6, 7)	
$H_2^{18}O$ uptake (K1; LS2; BB1, 2, 3; CAA1, 3, 5, 6, 7)	
^{55}Fe uptake (CAA3, 7)	

Second leg
September 4 – October 1, 2015
Sachs Harbour – Resolute

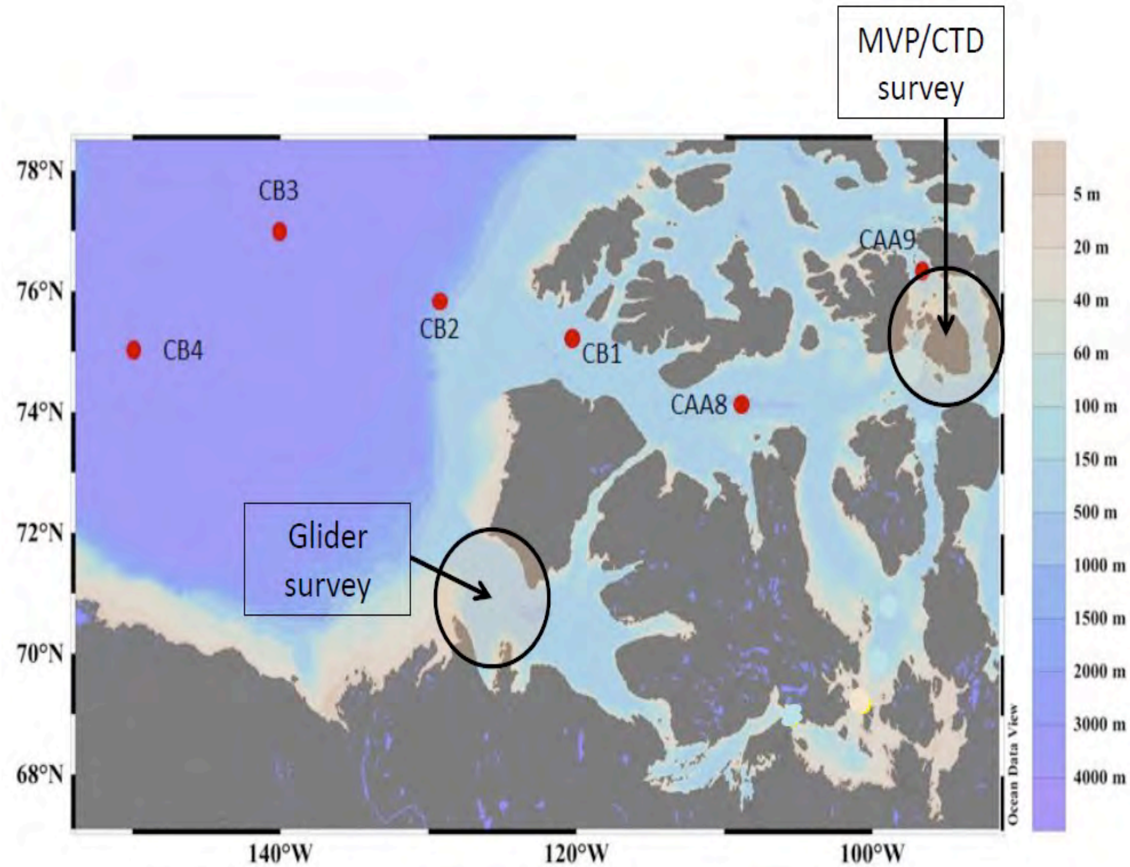
6 Stations

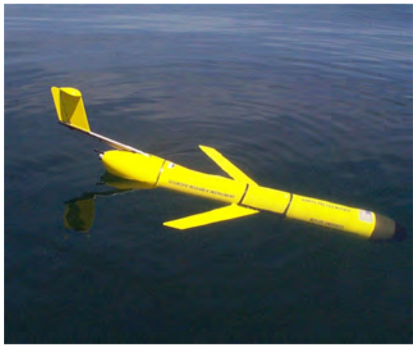
- 22 hydrocasts with AN CTD-rosette
- 21 hydrocasts with TM CTD-rosette
- 12 LVP casts

Aerosol sampling

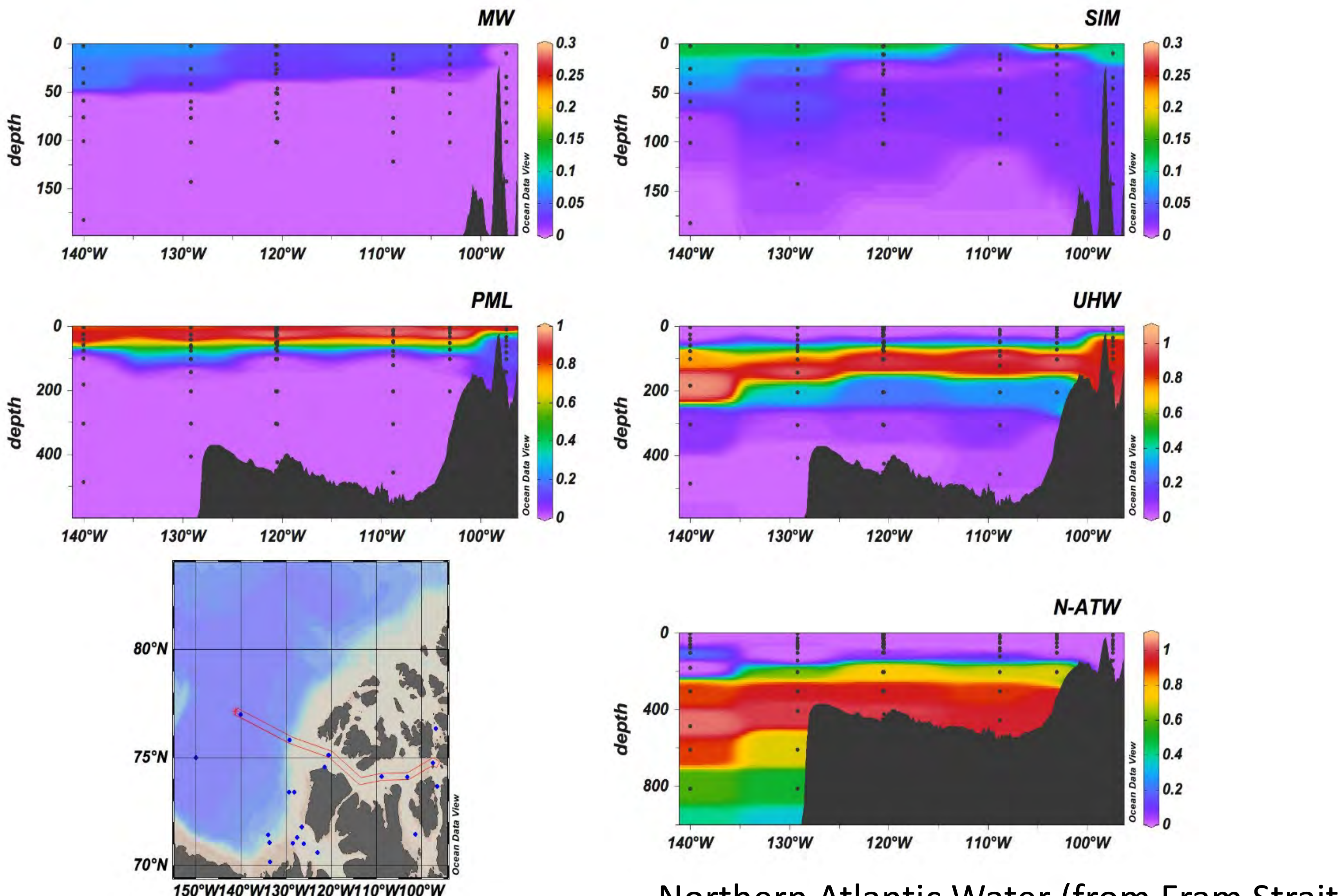
MVP survey

Glider survey (Leg 3a)





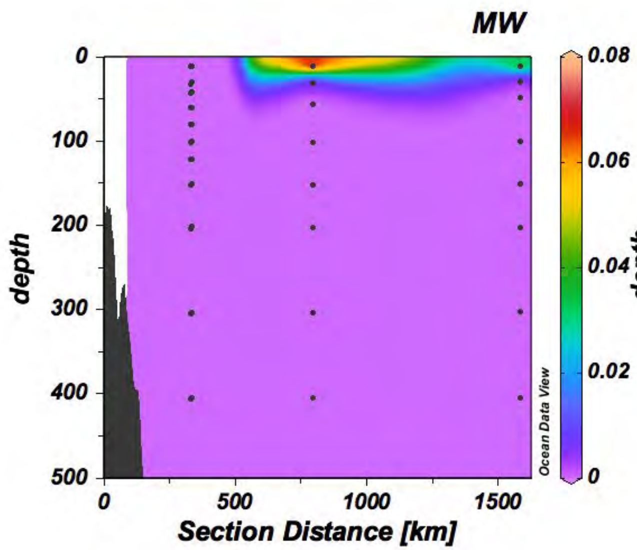
Source-water mass fractions in the water column of the western Canadian Arctic using an optimum multiparameter algorithm (S, $\delta^{18}O$, TA, DIC, θ).

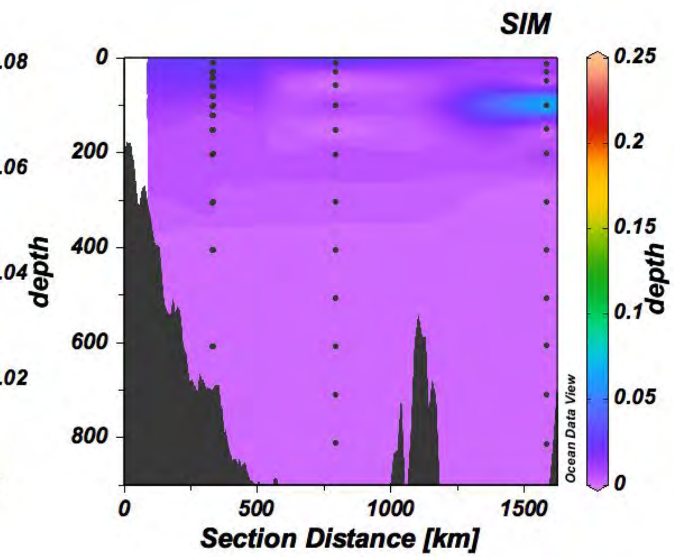


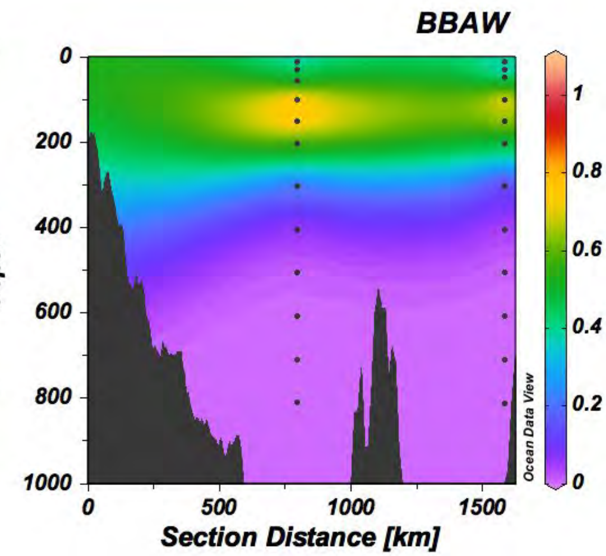
Northern Atlantic Water (from Fram Strait)

Mucci et al.

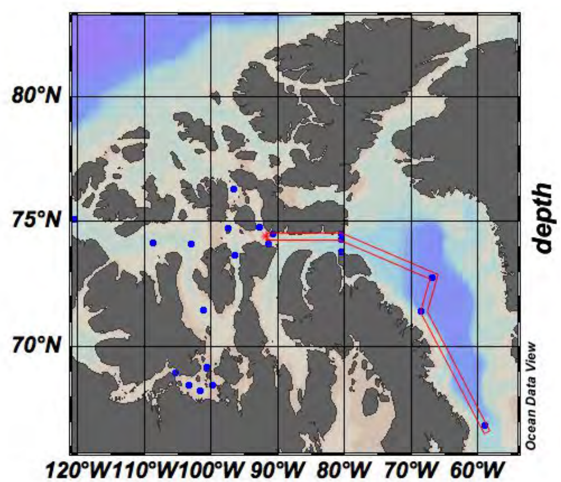
Source-water mass fractions in the water column of the eastern Canadian Arctic:

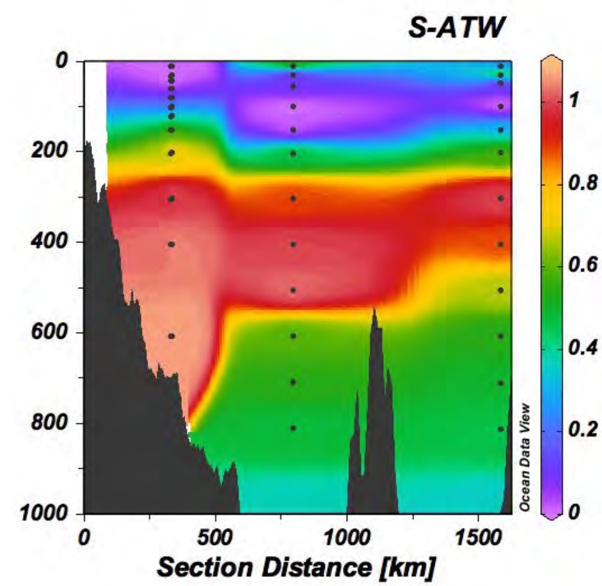






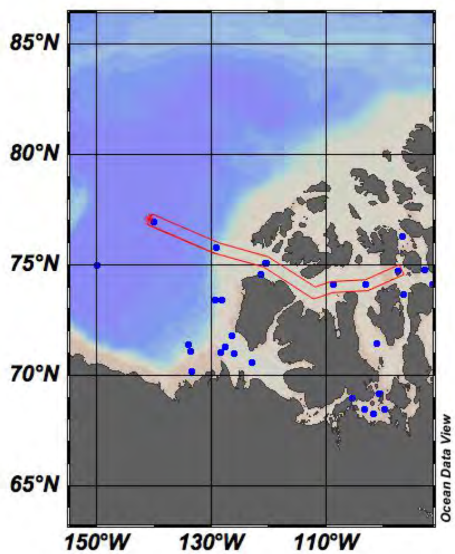
Baffin Bay Arctic Water

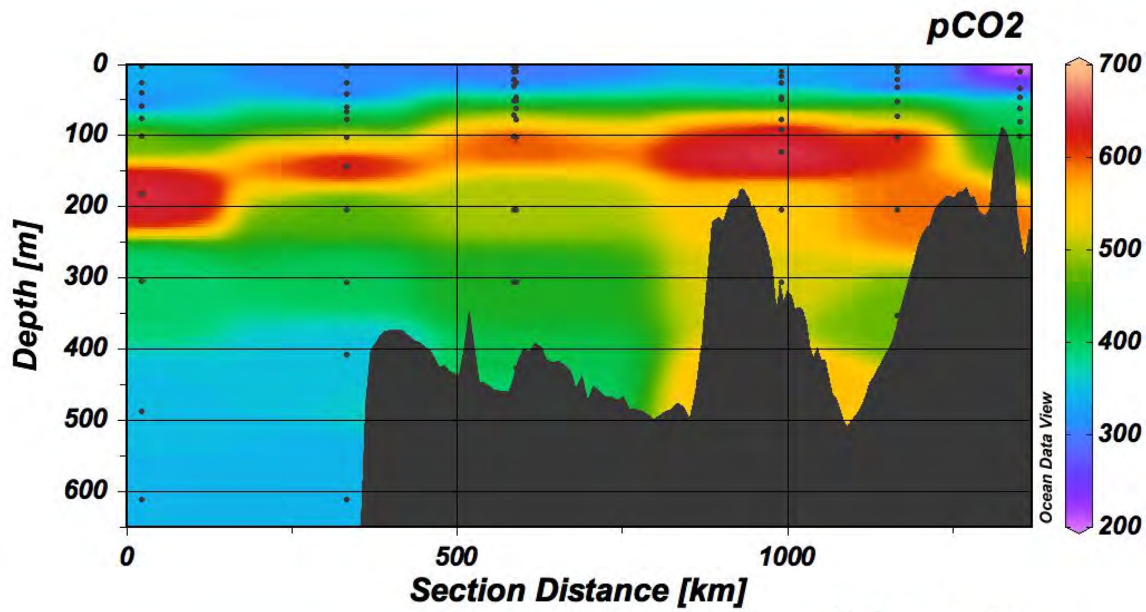


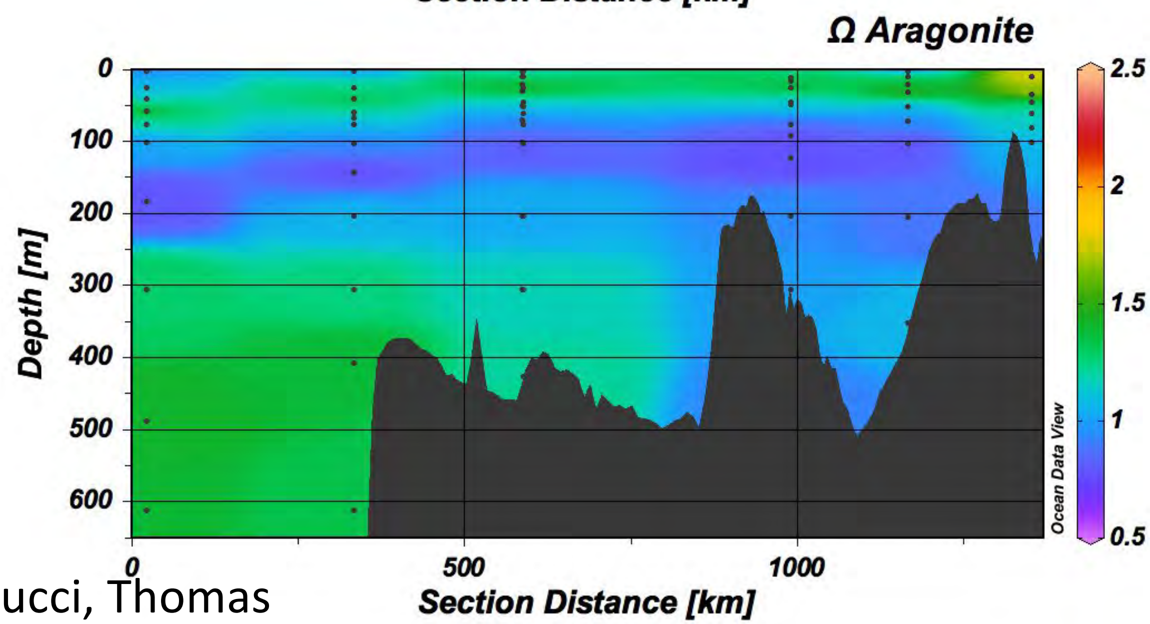


Southern Atlantic Water (from Lab Sea)

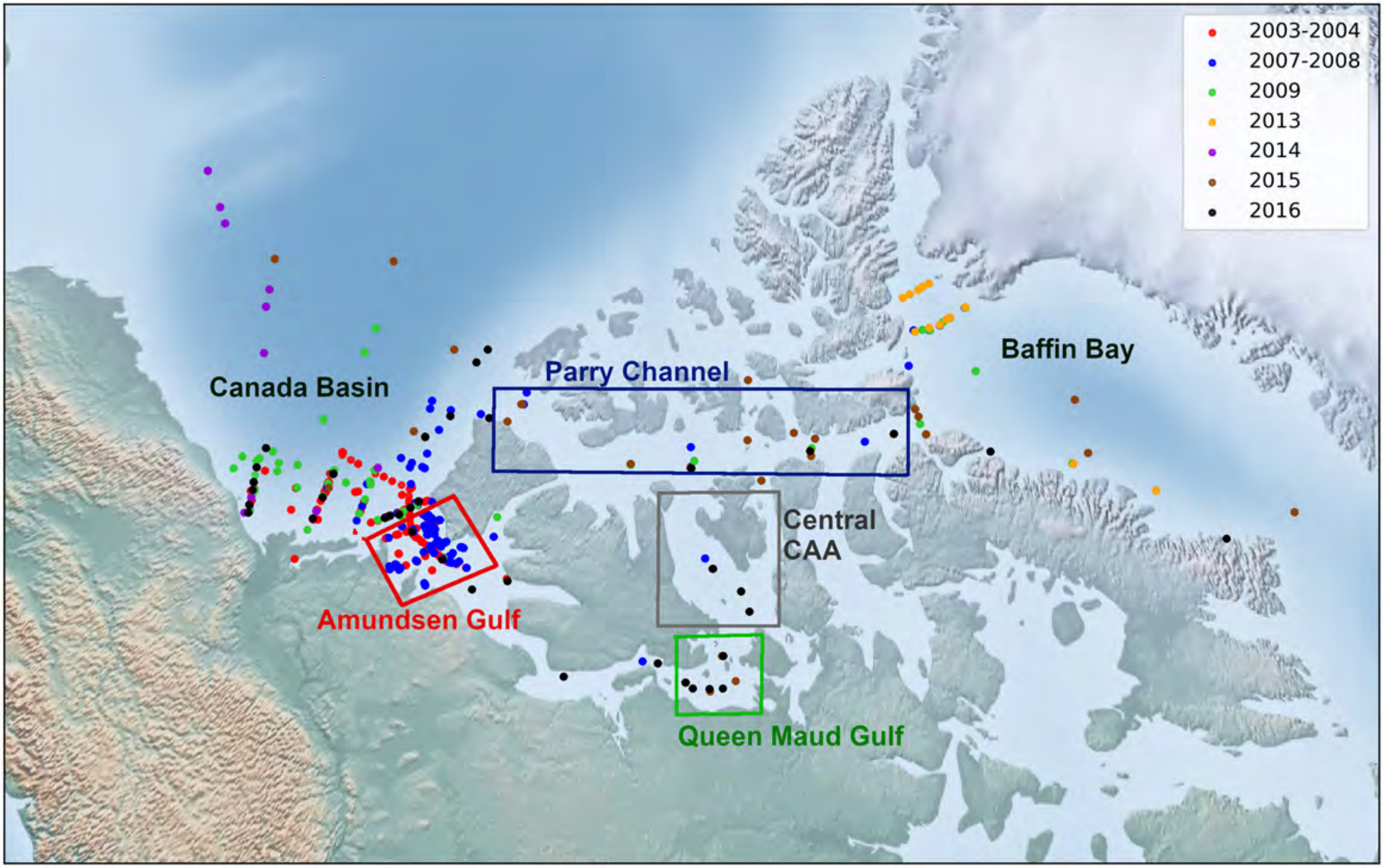
Computed pCO_2 and saturation state with respect to aragonite in the water column of the western Canadian Arctic: from the Canada Basin to Barrow Strait.







Alexis Beaupré-Laperrière, Mucci, Thomas

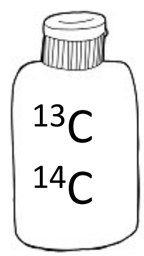


Geographical location of the oceanographic stations covered by the dataset, color-coded according to the year of sampling, with the approximate boundaries of the main areas mentioned in the text.

Comparison of primary production and carbon export methods

In vitro | **In situ**

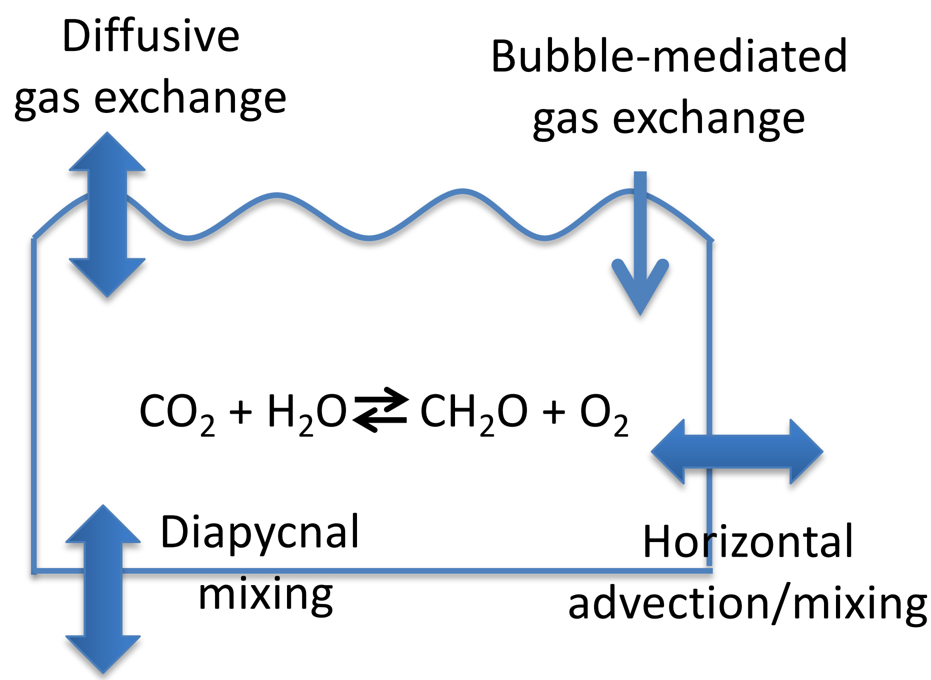
Primary production



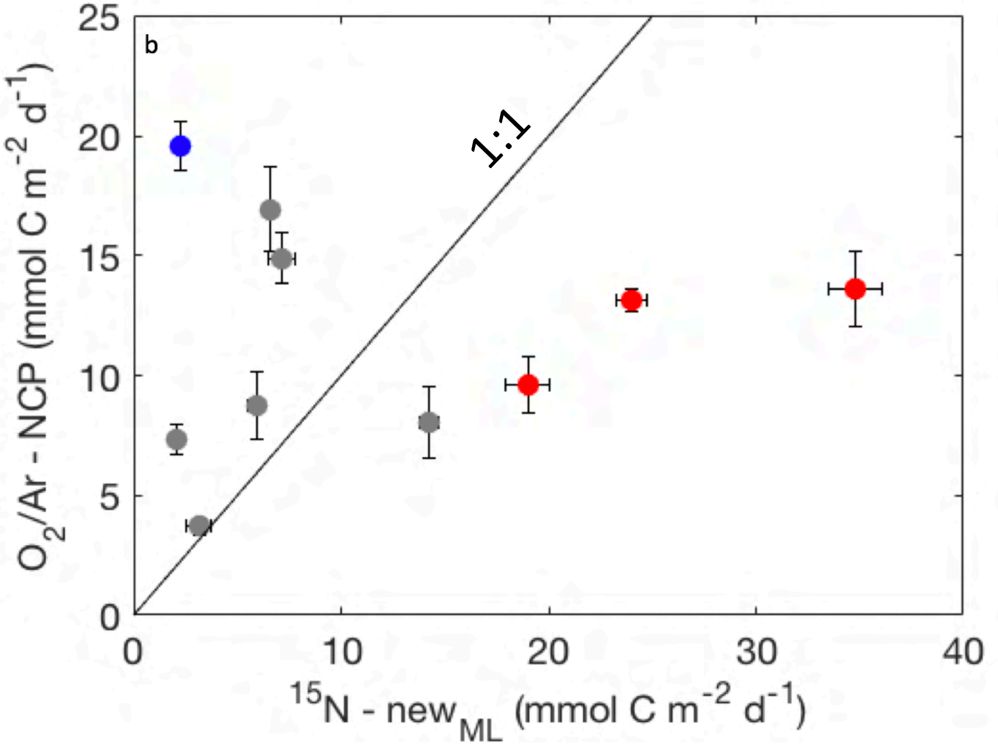
Gross oxygen production

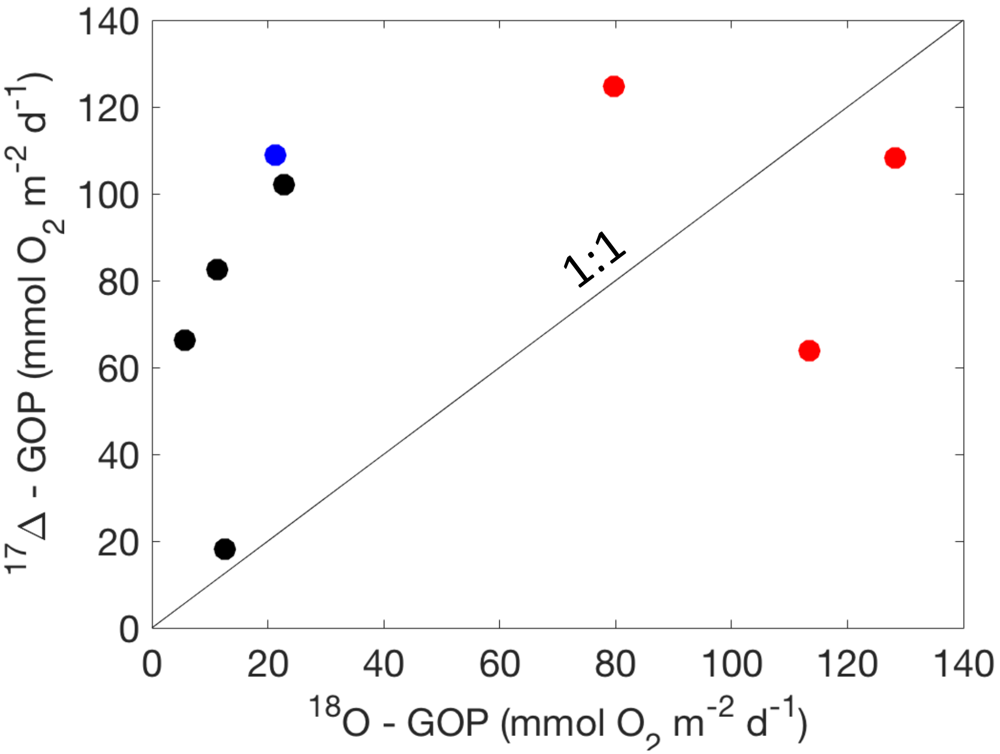
Carbon export

Recycled production



Integration: 24 hours | Residence time of O_2 in mixed layer





Generally near 1:1 except several outliers

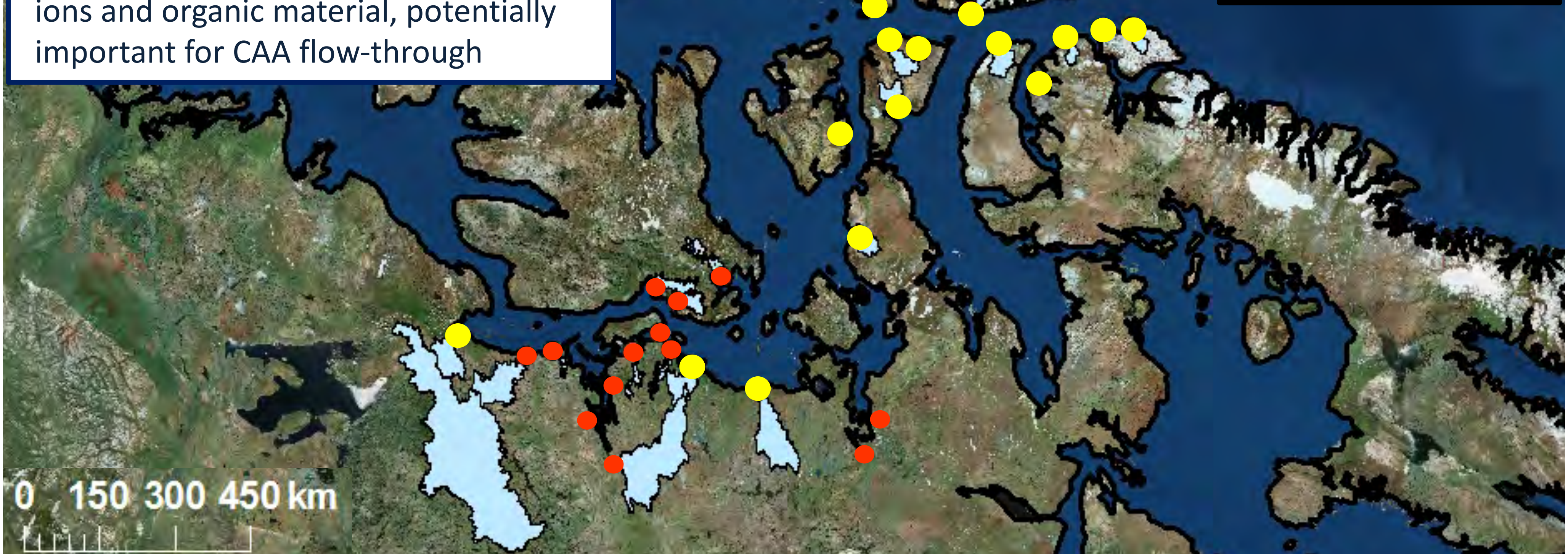
- **Episodic events**
- **Recently shoaled mixed layer**
- Mixing at the base of the mixed layer
- Methodological issues

Canadian Arctic GEOTRACES River Sampling

- collected samples from 15 rivers along the cruise track, Leg 2 (yellow)
- rivers sampled for: inorganic ions, water isotopes, carbon (organic, inorganic), sediments, trace metals (M. Colombo), isotope tracers (^{13}C, ^{15}N, ^{14}C, $^{87/86}Sr$), Pb-isotopes (J. De Vera), Si-isotopes (K. Giesbrecht)
- combined w Canadian Arctic Archipelago Rivers Study data (red)

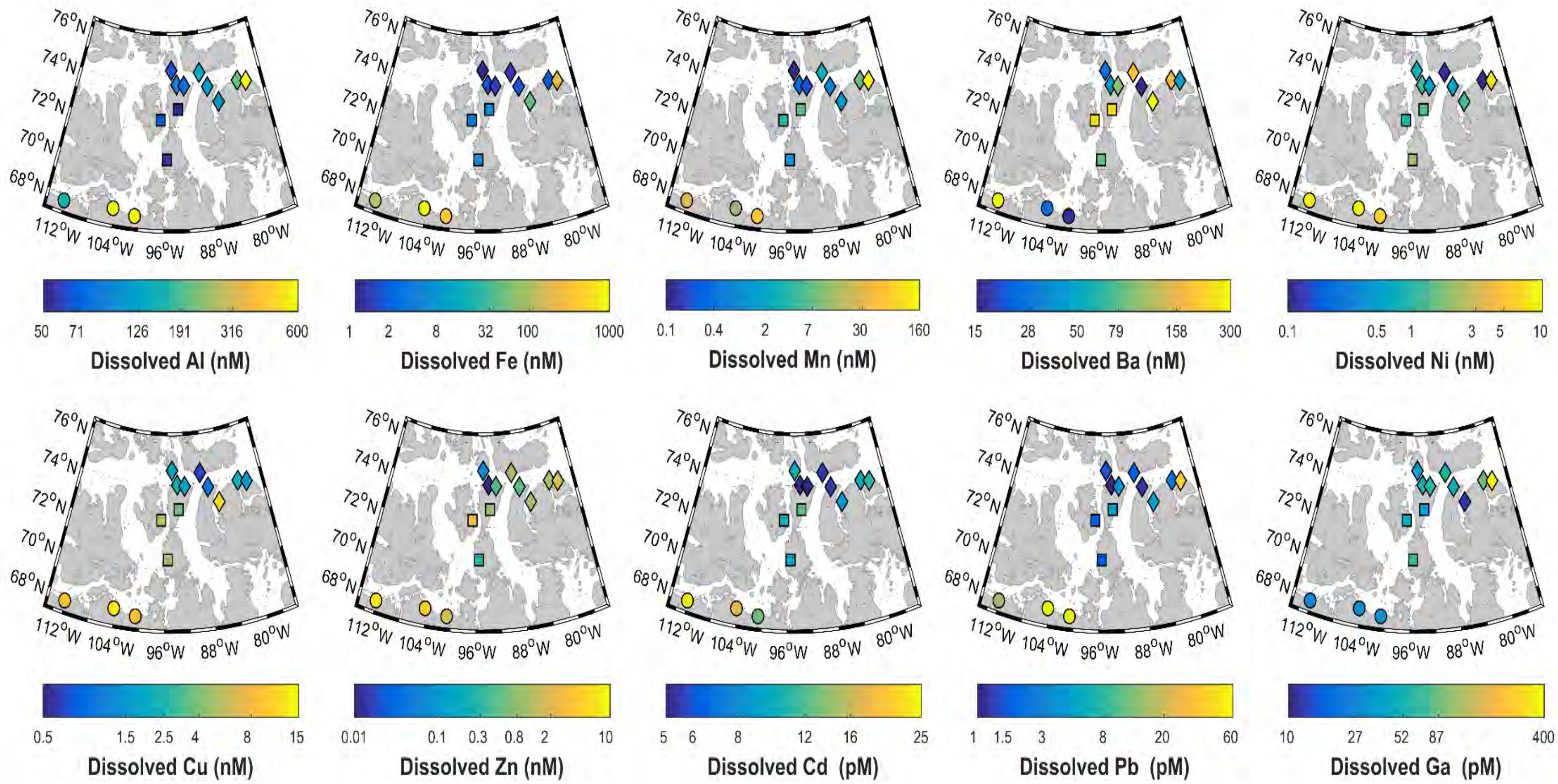
Key Findings:

- river geochemical characteristics reflect gradients in geology and hydrology across the CAA
- rivers can be local sources of inorganic ions and organic material, potentially important for CAA flow-through

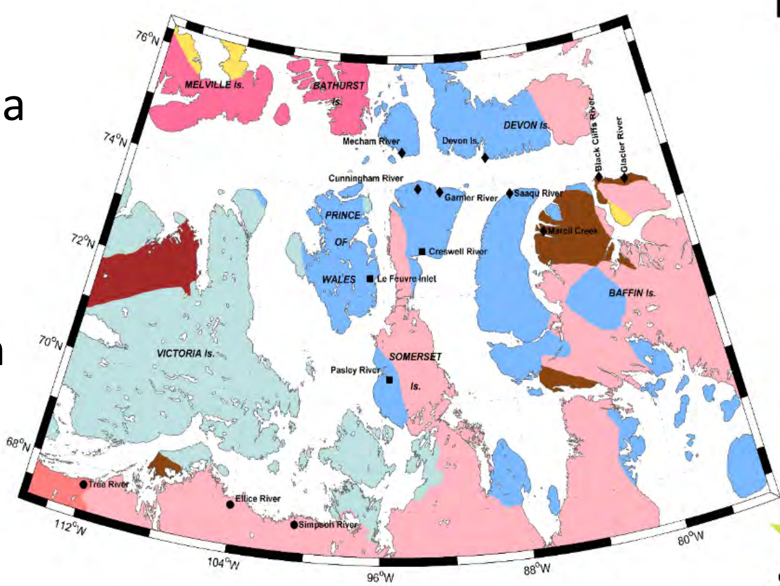


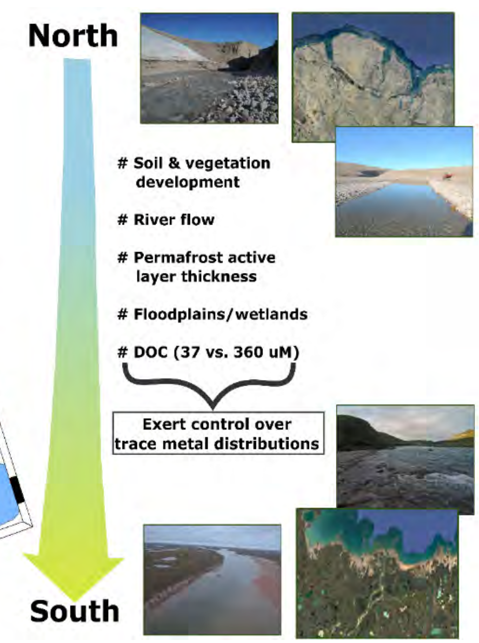
Brown, K. A., Williams, W. J., Carmack, E. C., Fiske, G., François, R., McLennan, D., & Peucker-Ehrenbrink, B. (2020). Geochemistry of small Canadian Arctic Rivers with diverse geological and hydrological settings. *JGR: Biogeosci.*, 125

Small CAA rivers



Colombo, Manuel, Brown, Kristina A., De Vera, Joan, Bergquist, Bridget A. and Orians, Kristin J., 2019. Trace Metal Geochemistry of Remote Rivers in the Canadian Arctic Archipelago. Chemical Geology, 525, 479-491.





Cullen (w/ Sarah Jackson and Dave Janssen)

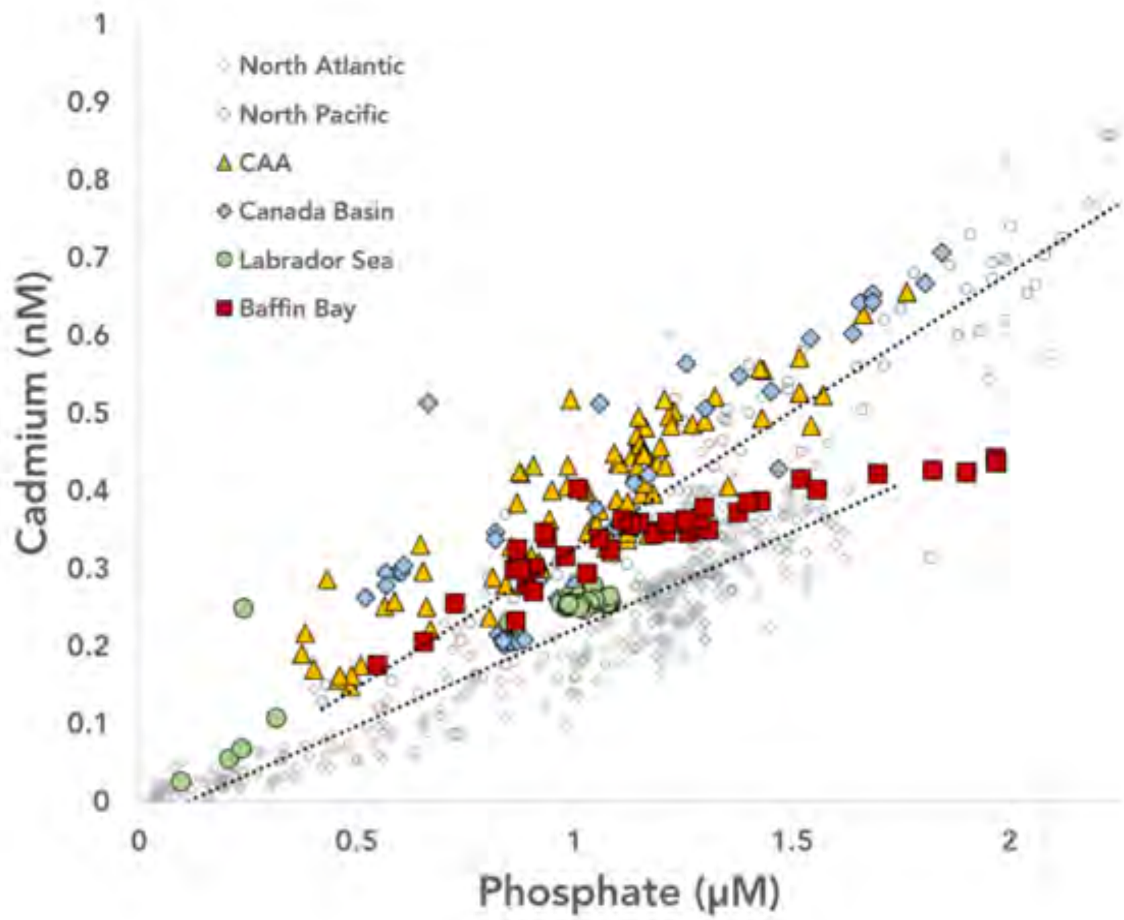
Collected filtered seawater samples for dissolved TM at all stations using TMR

- Analysis complete for Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb
  - Data sets merged with Orians (UBC) for Mn and Fe
  - Data will be be submitted for IDP2021
- Intercompared ”cross over” for Mn, Fe (Fitzsimmons/Jensen) want to talk to others here
- Al intercalibration samples from Measures/Hatta

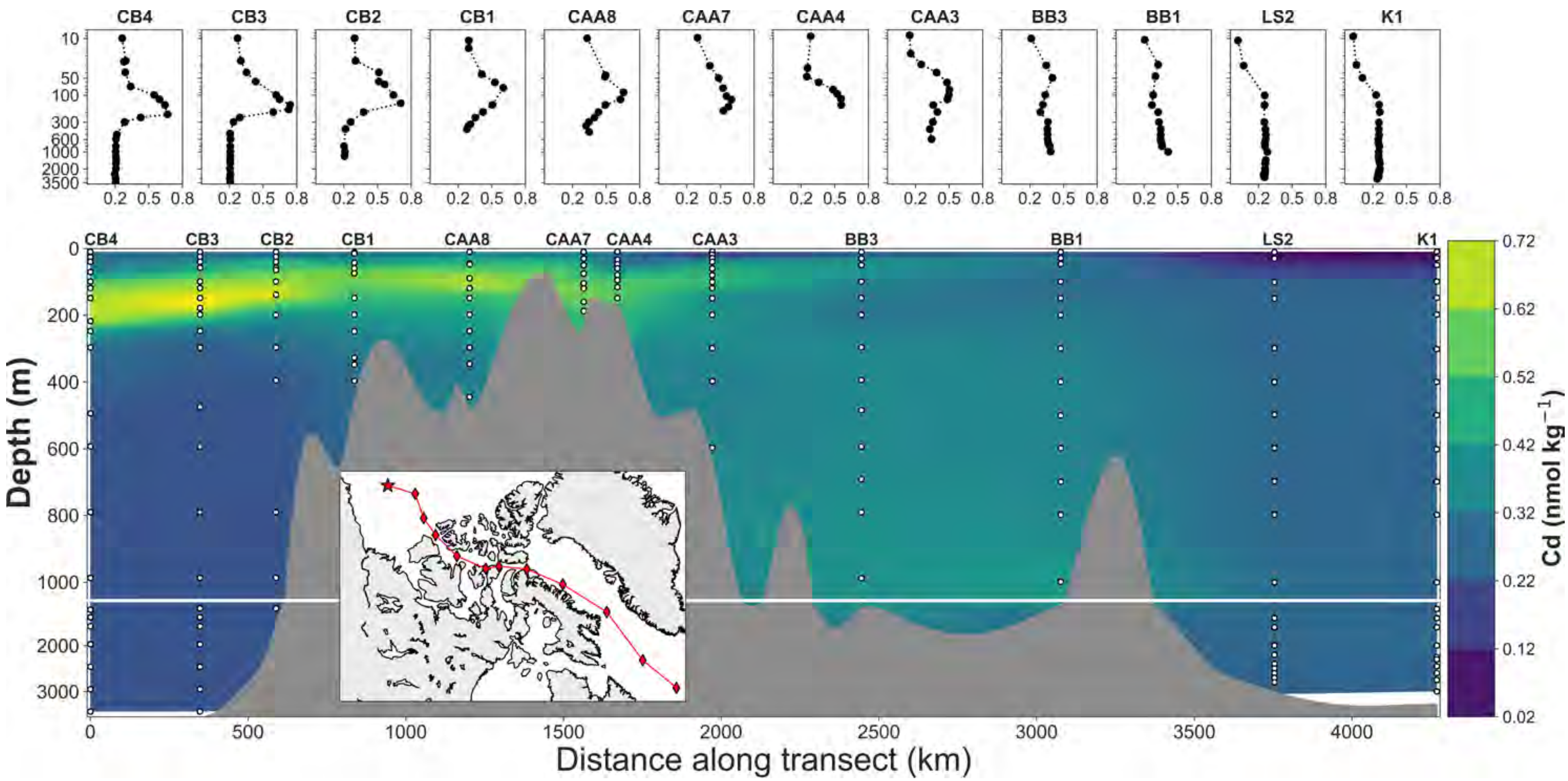
Publications (Jackson MSc 2018)

- Fe and Mn (Orians Colombo) in revision, 2020 GCA
- Cd (in prep)

dissolved Cd vs Phosphate GN02 & GNO3



Arctic dissolved Cd Section



Kristin Orians (w/ Manuel Colombo)

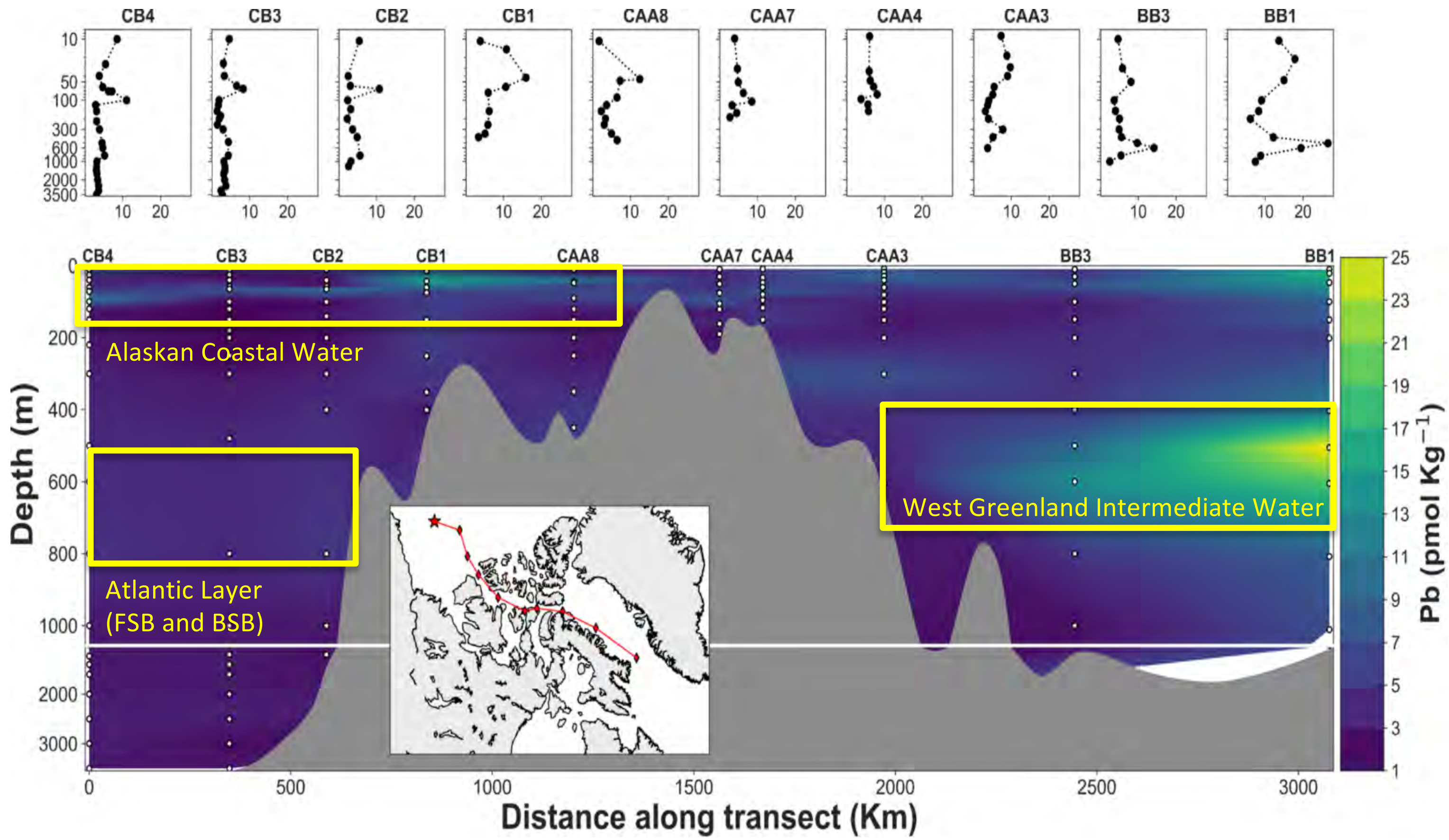
Collected filtered seawater samples for dissolved TM at all stations using TMR

- Analysis complete for Pb, Mn, Fe, & Ga
  - Data sets merged with J. Cullen (U Vic) for Mn and Fe
  - Intercalibrated with US colleagues
  - To be submitted to GEOTRACES data base soon
- Set of samples provided to A. Shiller for V analysis
- Analyzed TMs (diss. and part. Al, Fe, Mn, Ba, Ni, Cu, Zn, Cd, Pb, Ga) in small CAA rivers (collected by K. Brown).

Publications (all in M. Colombo UBC PhD thesis, 2019)

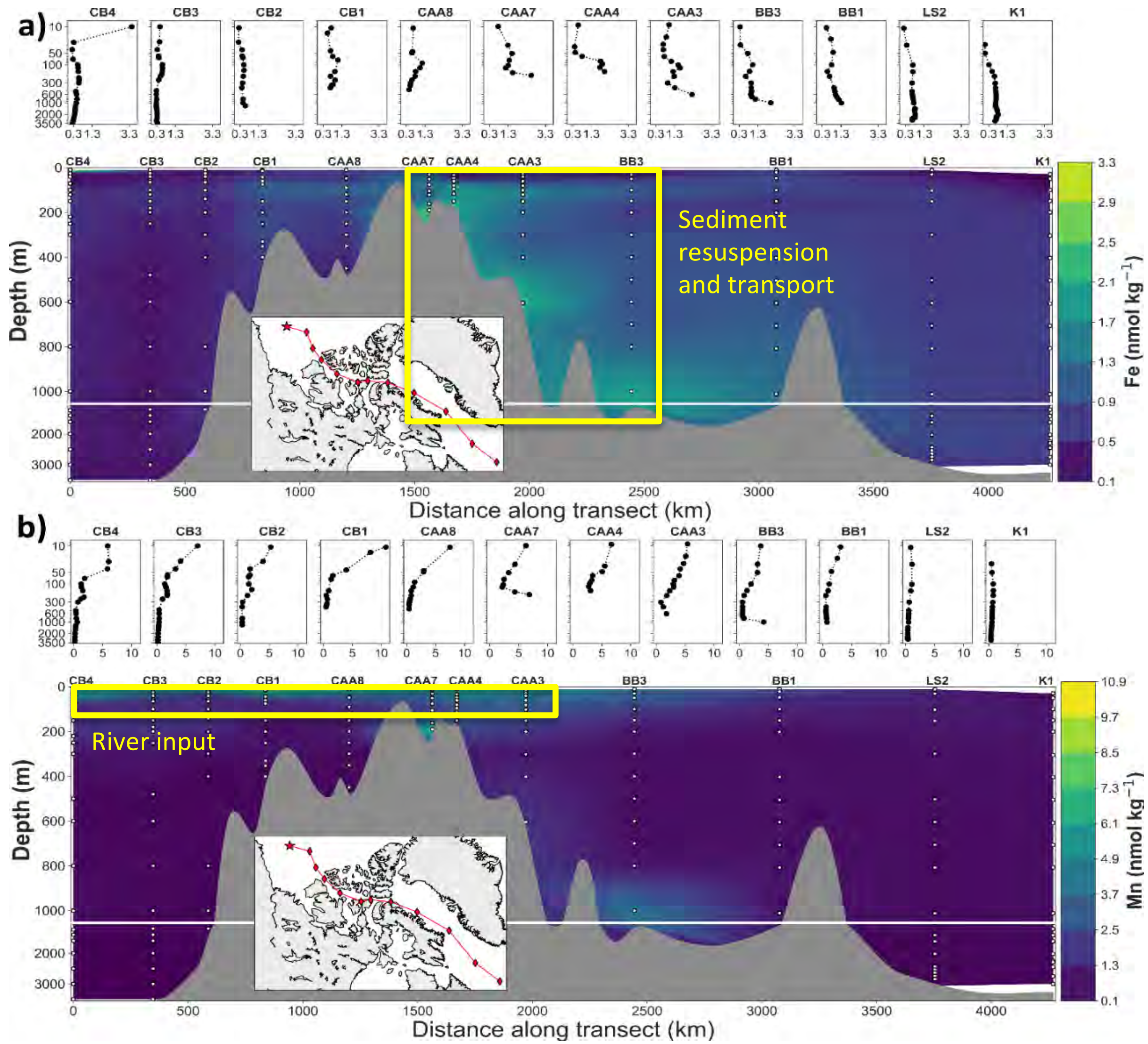
- Rivers (w/ K. Brown, B. Bergquist and others) 2019 Chemical Geology, 525, 479-491.
- Pb (w/ S. Allen and others) 2019 *ACS Earth Sp. Chem.* **3**, 1302–1314.
- Fe and Mn (w/ J. Cullen and others) in revision, 2020 GCA
- Ga (in prep)

Dissolved Pb



Lowest in the Canada Basin → → → Higher in Baffin Bay / Labrador Sea

Dissolved Mn and Fe



Joan De Vera & Bridget Bergquist, University of Toronto

Collaborators: Dr. P. Chandan, Dr. A. Steffen, G. Stupple, Dr. W. Landing, S. Jackson, Dr. J. Cullen, Dr. P. Pinedo-Gonzales and Dr. S. John

Overall Goal: Tracing the Distribution of Pb and Trace Elements (TEs) in the Canadian Arctic from the Atmosphere to the Ocean

Projects:

1. Pb isotopes and TEs in aerosols including dissolution experiments

- complete and near submission (by March 2020)

2. Tracing Pb in Canadian Arctic waters using Pb isotope measurements in seawater

- complete and near submission (by March 2020)

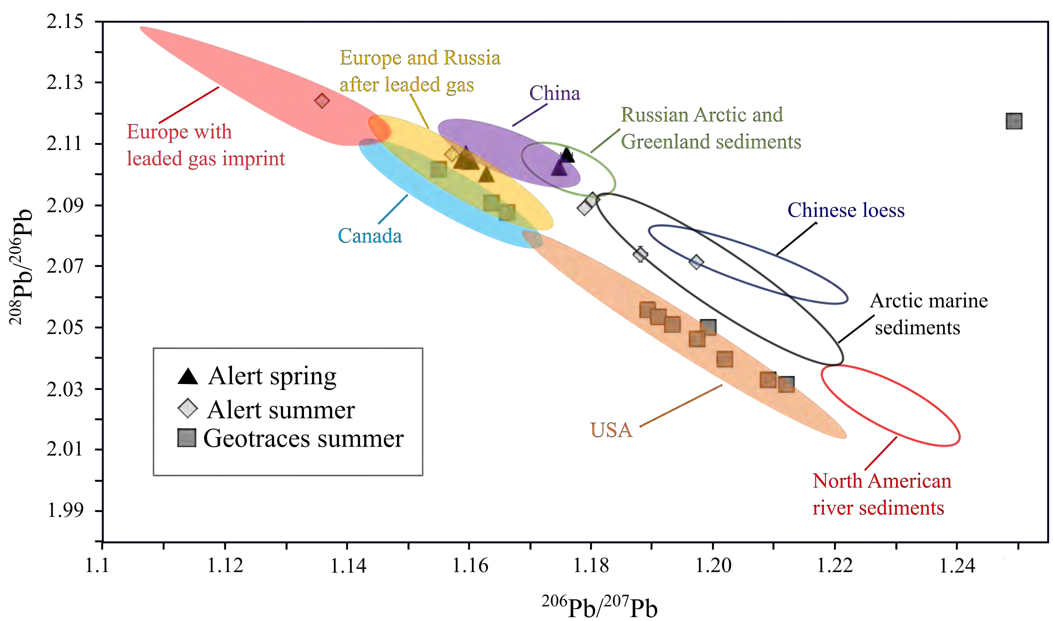
3. Fe isotopes in Canadian Arctic waters

- samples prepped, but technical difficulties in r

https://www.geospatialworld.net/blogs/arctic-sea-ice-falls-to-record-low-in-june/

1. Pb isotopes and TEs in aerosols

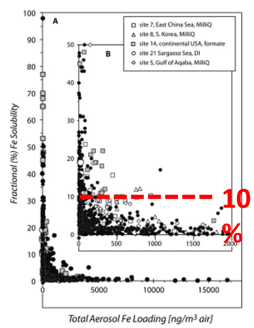
Europe and Russia (Eurasia) are the likely source of the anthropogenic Pb in aerosols during Arctic Haze



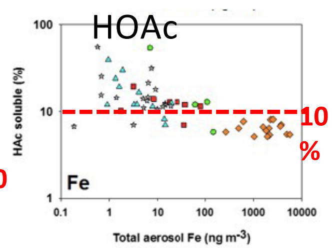
- Spring aerosols
  - Clustered together indicating a dominant source
  - Likely sources are Europe and Russia consistent with Arctic Haze pattern
- Summer aerosols
  - Scattered indicating mix of different sources
  - Lithogenic and North American sources

Arctic aerosols have high fraction of dissolvable Fe

UPW & seawater (instantaneous)

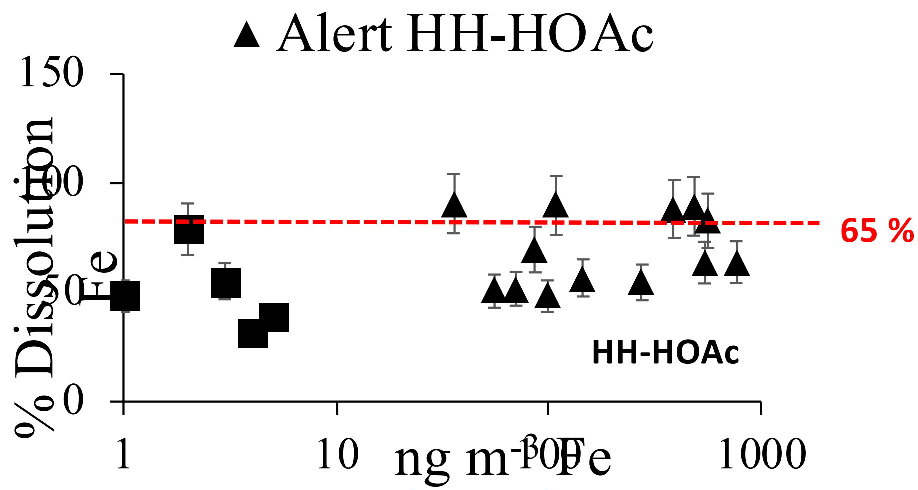


Sholkovitz et al. 2012



Shelley et al 2018

Other studies

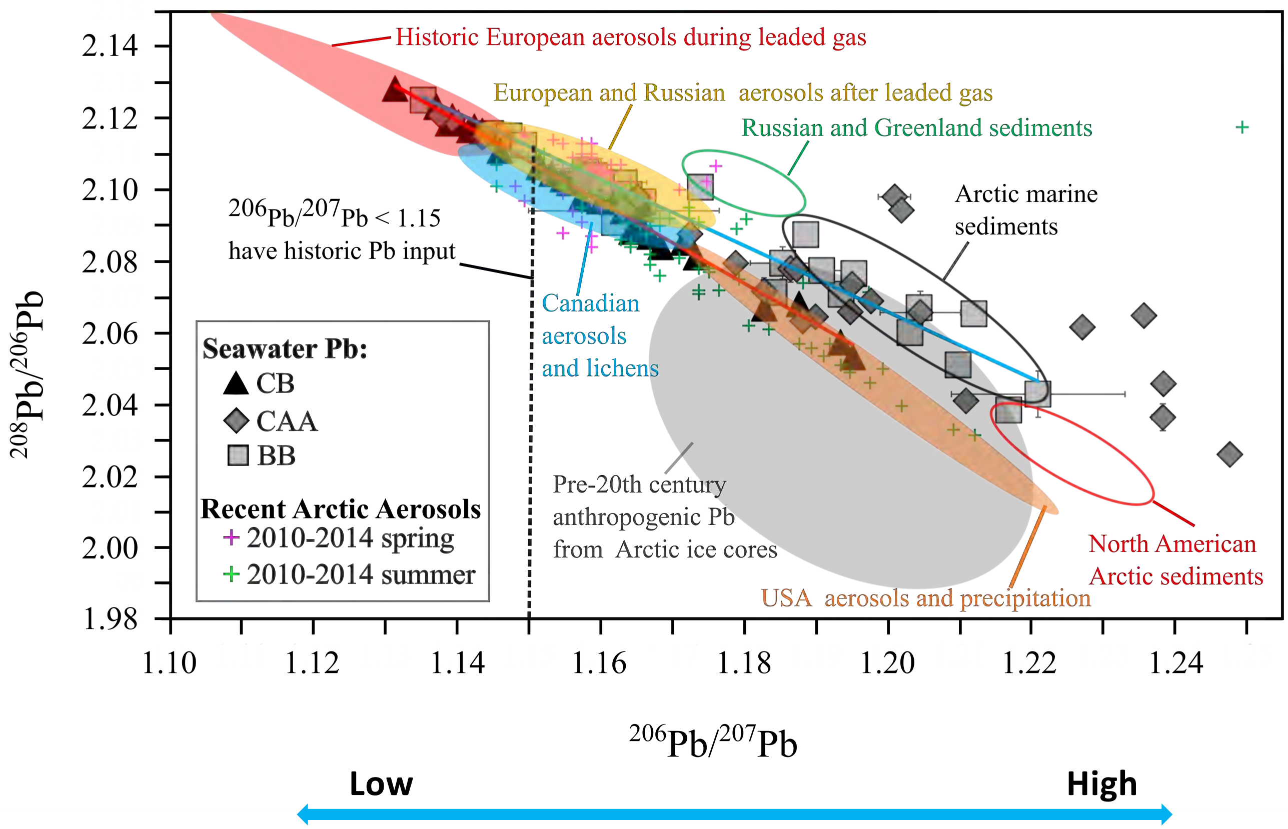


This study

Trend: Low dissolution (<u><</u>10%) in aerosols with high Fe concentrations

This trend is not observed in the Arctic where the average maximum dissolution is **65 ± 18 %**

2. Tracing Pb in Canadian Arctic waters using Pb isotope measurements in seawater



Sources:

Low $^{206}Pb/^{207}Pb$

1. Historic Europe + Russian (Eurasian) Pb

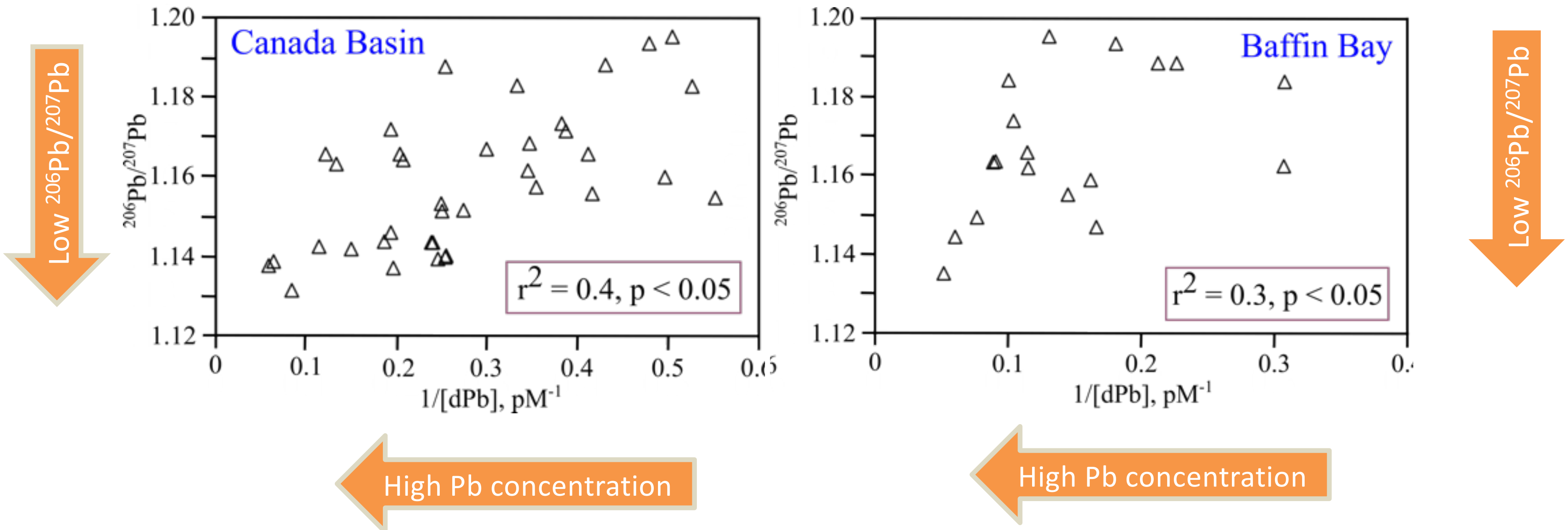
High $^{206}Pb/^{207}Pb$

2. Natural Pb
3. US aerosols
4. Pre-20th century anthropogenic Pb

Intermediate $^{206}Pb/^{207}Pb$

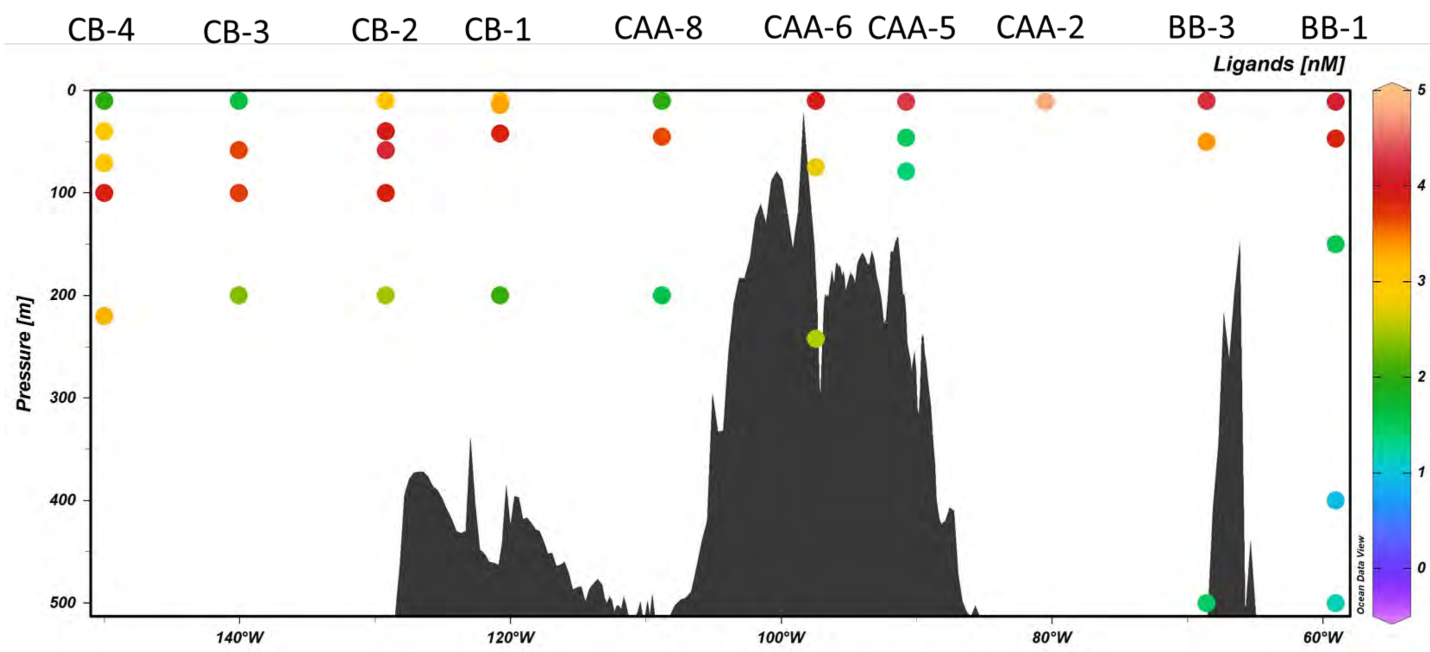
5. Modern Arctic aerosols

Historic Eurasian Pb (low $^{206}Pb/^{207}Pb$) is an important source of dissolved Pb in the Arctic waters



Low $^{206}Pb/^{207}Pb$ ratios (<1.15) are associated with elevated Pb concentrations (as high as 17 pM).

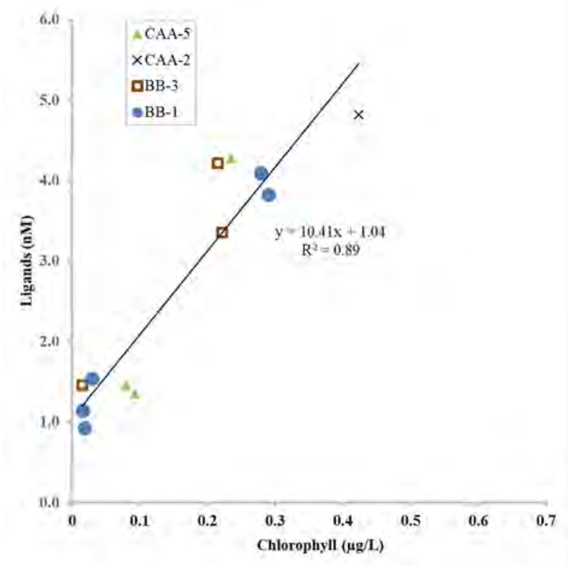
Distribution of Copper Ligands

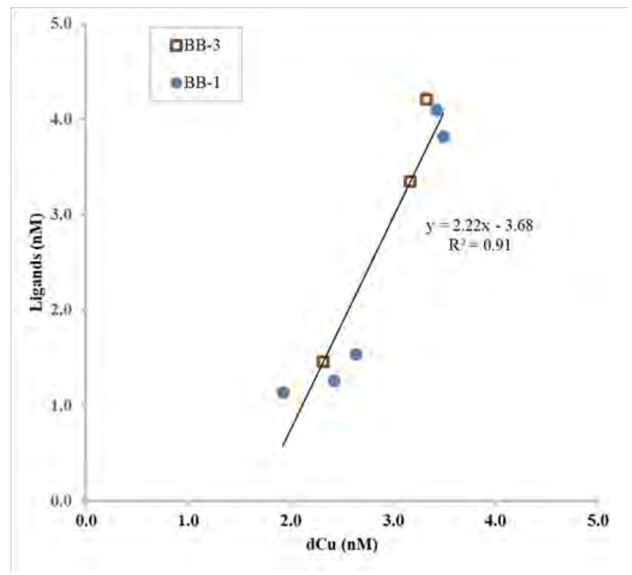


- Cu ligands are concentrated near the chlorophyll maximum and where markers of terrestrial DOM are most abundant.

Nixon et al. (2019) Marine Chemistry: doi 10.1016/j.marchem.2019.103673

Ligands vs. Chlorophyll and dCu



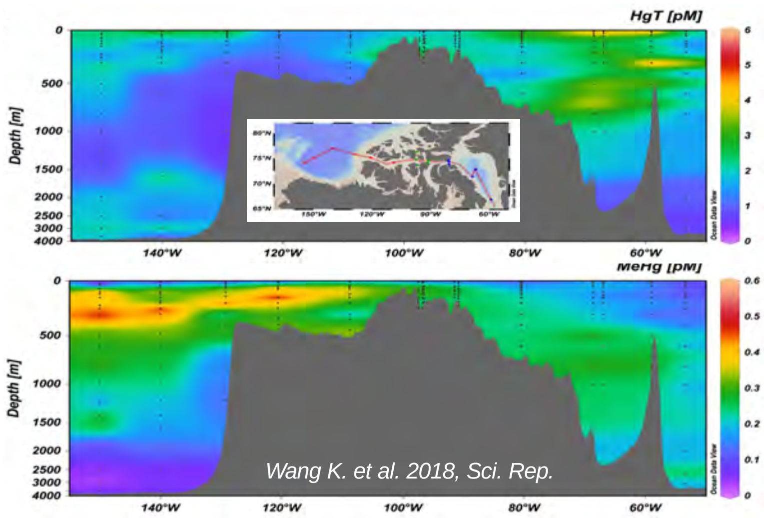


- Cu ligand concentration is correlated with chlorophyll and dCu, suggesting that phytoplankton are a source of ligands and may produce some of them in response to Cu exposure

Nixon et al. (2019) Marine Chemistry: doi 10.1016/j.marchem.2019.103673

Total and Methylated Mercury in Canadian Arctic seawater – Fei Wang @ U Manitoba

- **Main Results & Conclusion**
  - Total Hg and MeHg distributions in seawater are de-coupled.
  - MeHg shows a distinct enrichment in the shallow subsurface (100-300 m), and the peak concentrations are much higher in the western Canadian Arctic than in the east.
  - The subsurface MeHg enrichment explains very well the spatial trend of Hg in marine animals in the Canadian Arctic



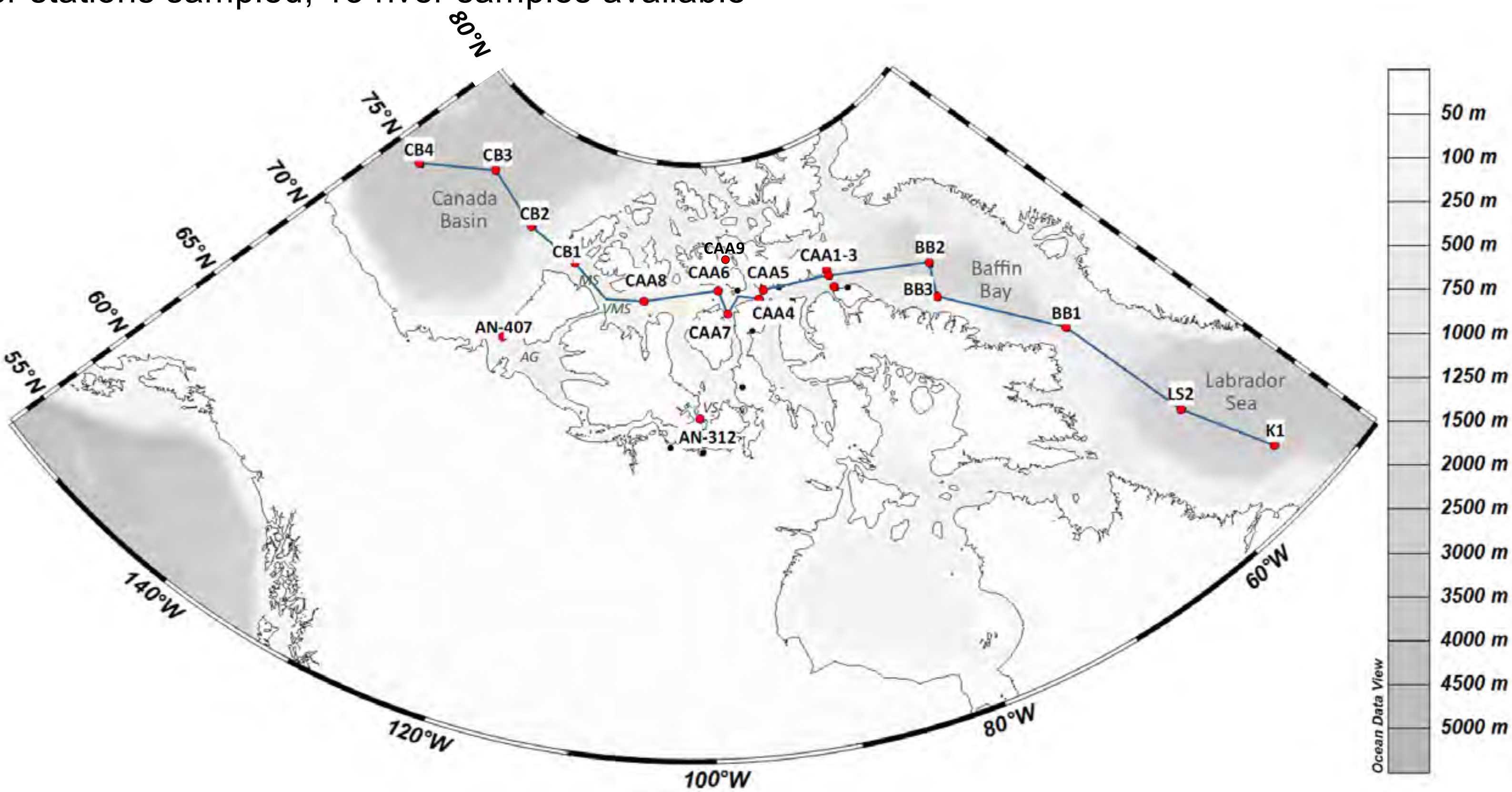
- **Potential for integration in pan-Arctic synthesis?**
  - Yes
  - Carl Lamborg / Cahd Hammerschmidt (US)
  - Lars-Eric Heimburger-Boadvida (France)

Measurement of ƐNd, ^{230}Th – ^{231}Pa and REE concentration

M. Grenier, I. Baconnais, C. Holmden, R. François, M. Soon, C. Jeandel

2015 ArcticNet – Canadian Arctic Geotraces (transects GN02-GN03)

20 seawater stations sampled, 13 river samples available



Measurement of ƐNd, ^{230}Th – ^{231}Pa and REE concentration

M. Grenier, I. Baconnais, C. Holmden, R. François, M. Soon, C. Jeandel

2015 ArcticNet – Canadian Arctic Geotraces (transects GN02-GN03)

20 seawater stations sampled, 13 river samples available

	LABRADOR SEA	BAFFIN BAY	CAA	CANADA BASIN	RIVERS	TOTAL
ƐNd	28 data available TBP	31 data available TBP	79 data available TBP	36 data available Published	13 data available	187 data to be submitted to GDAC
^{230}Th – ^{231}Pa	26 data available TBP	23 data available TBP	9 data available TBP	36 data available Published		94 data to be submitted to GDAC
REE concentration	NA	NA	NA	NA	NA	NA

TBP = To Be Published

NA = Not Available (not measured yet)

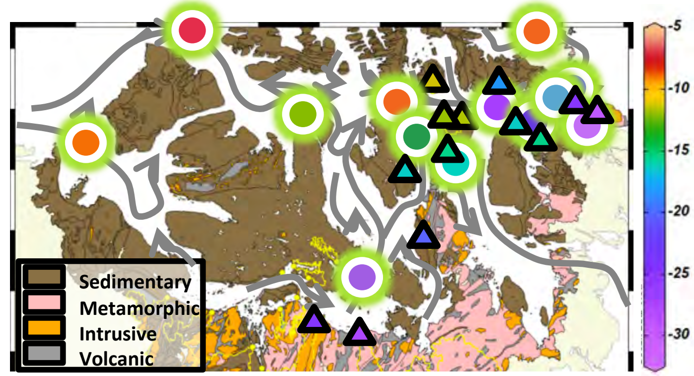
GEOTRACES HORIZON 2020 LEGOS THE UNIVERSITY OF BRITISH COLUMBIA UNIVERSITY OF SASKATCHEWAN

Measurement of ƐNd, ^{230}Th – ^{231}Pa and REE concentration

M. Grenier, I. Baconnais, C. Holmden, R. François, M. Soon, C. Jeandel

KEY RESULTS:

- Only the surface layer [0-100 m] clearly circulates between Canada Basin to the Labrador Sea.
- Strong influence of margin processes from the Canada Basin to Baffin Bay through particle resuspension and lateral transport. Using ƐNd, they can be traced back to the source.
- Strong vertical processes seen in Baffin Bay are dominant in Labrador Sea: the discrimination between particle scavenging, particle composition and deep convection is in progress.



ƐNd in CAA (triangles for river data and dots for seawater data): from -32 to -6

PAPERS IN PREPARATION:

GEOTRACES
THE UNIVERSITY OF BRITISH COLUMBIA
UNIVERSITY OF SASKATCHEWAN

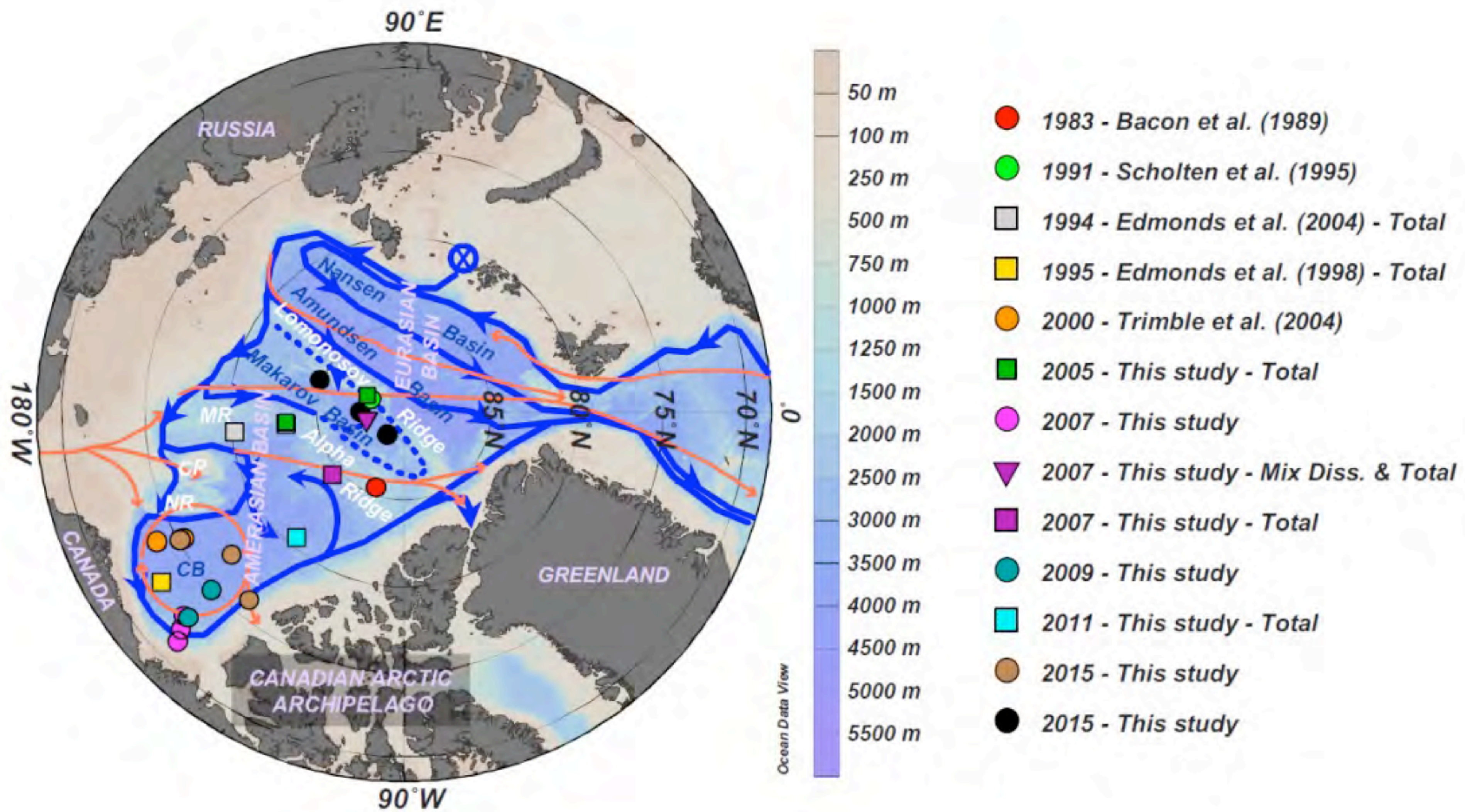
Changes in Circulation and Particle Scavenging in the Amerasian Basin of the Arctic Ocean over the Last Three Decades Inferred from the Water Column Distribution of Geochemical Tracers

JGR Oceans

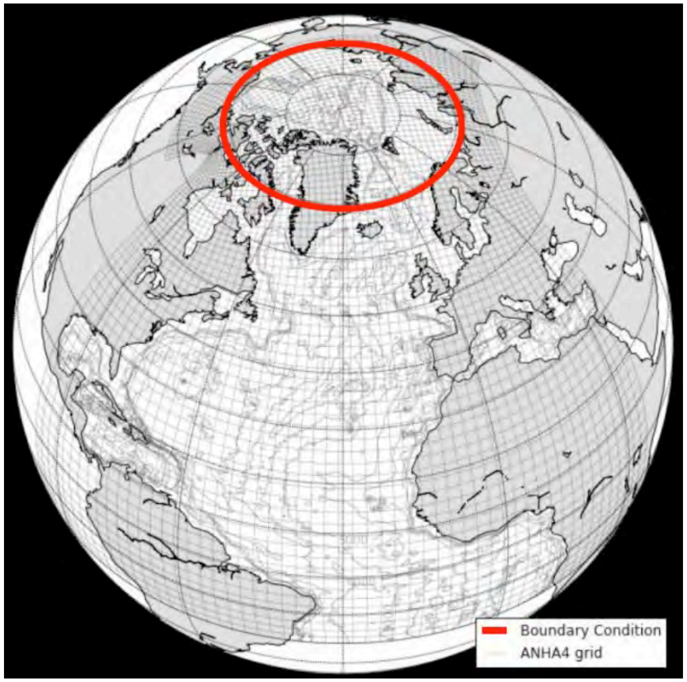
RESEARCH ARTICLE

10.1029/2019JC015265

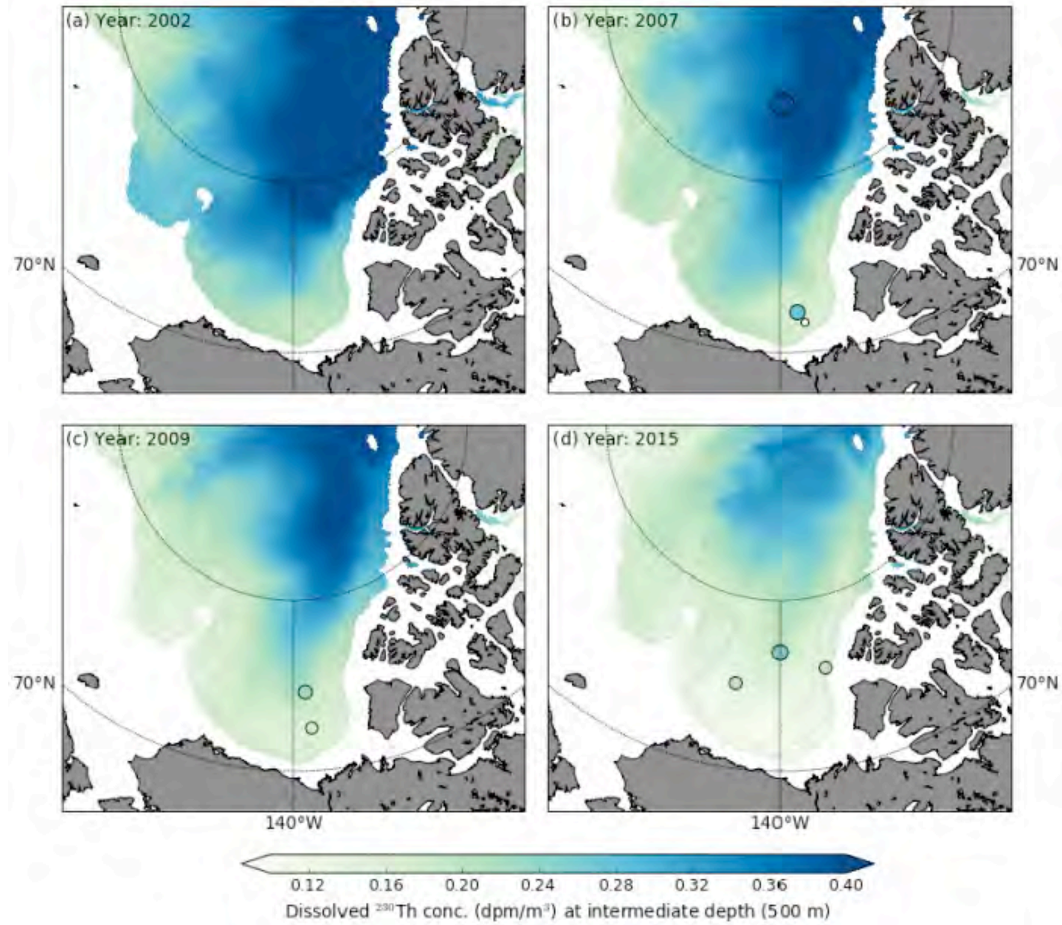
Melanie Grenier[1], Roger François[1], Maureen Soon[1], Michiel Rutgers van der Loeff[2], Xiaoxin Yu[1], Ole Valk[2], Christelle Not[3], S. Bradley Moran[4], R. Lawrence Edwards[5], Yanbin Lu[5], Kate Lepore[6], and Susan E. Allen[1]



Dissolved ^{230}Th concentration at 500m depth



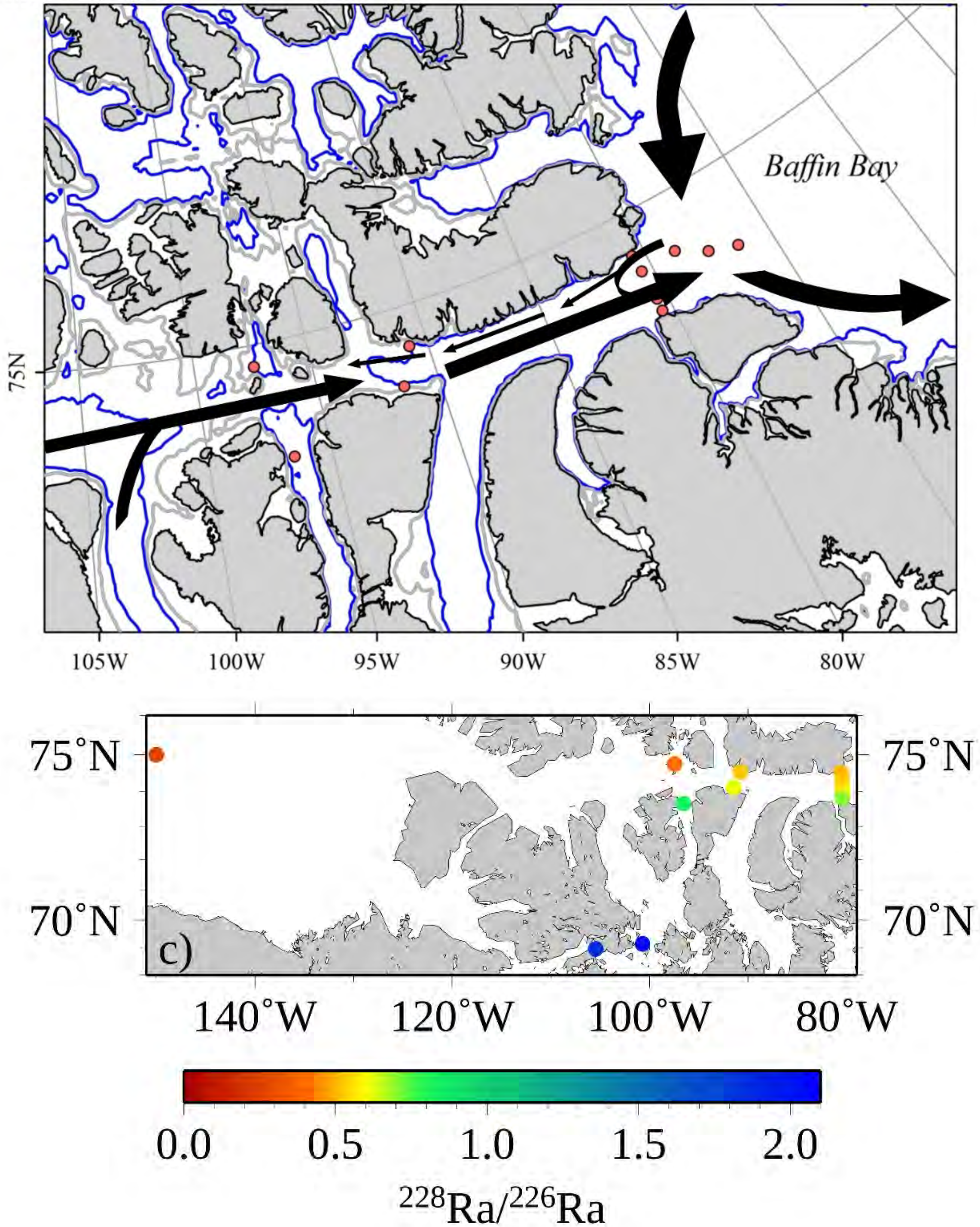
Arctic Northern Hemisphere Atlantic (ANHA4) configuration of the Nucleus for European Modeling of the Ocean (NEMO) model

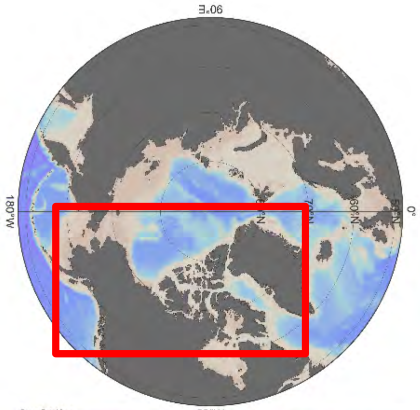


Modeling dissolved and particulate ^{230}Th in the Canada Basin: Implications for recent changes in particle flux and intermediate circulation

Xiaoxin Yu[1], Susan E. Allen[1], Roger François[1], Mélanie Grenier[1], Paul G. Myers[2] and Xianmin Hu[2*]

Mears et al., Figure 14



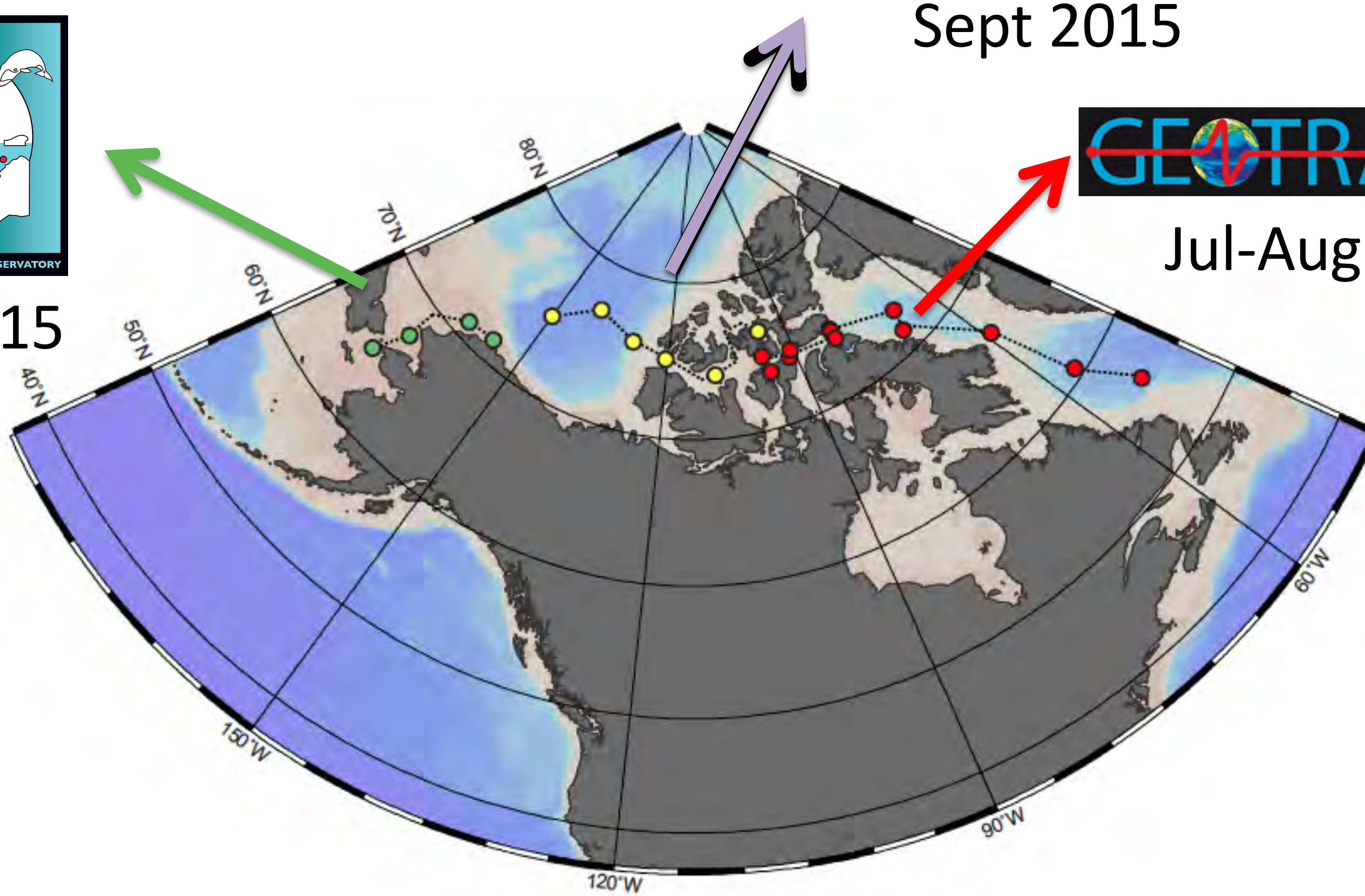


Natural variations in $\delta^{30}Si(OH)_4$ across Arctic and Subarctic seas

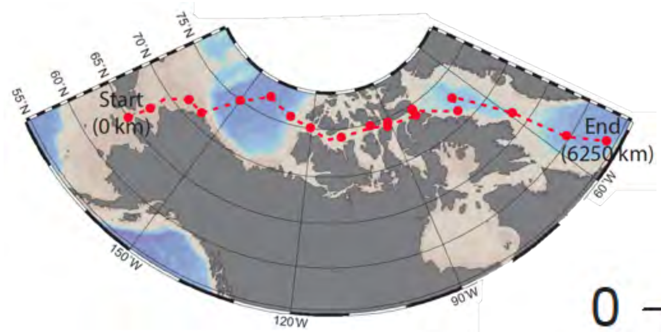
Sept 2015

Jul-Aug 2015

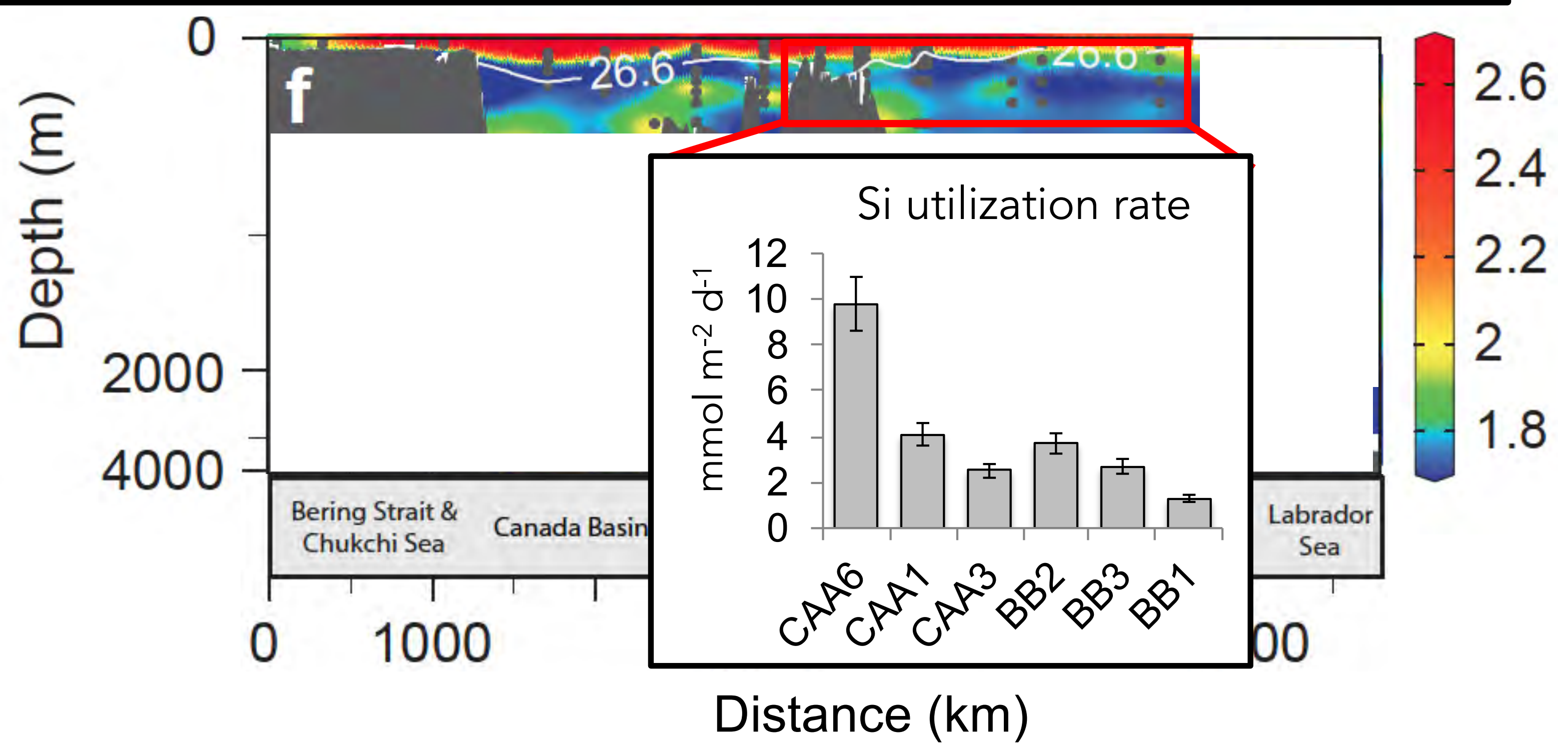
July 2015

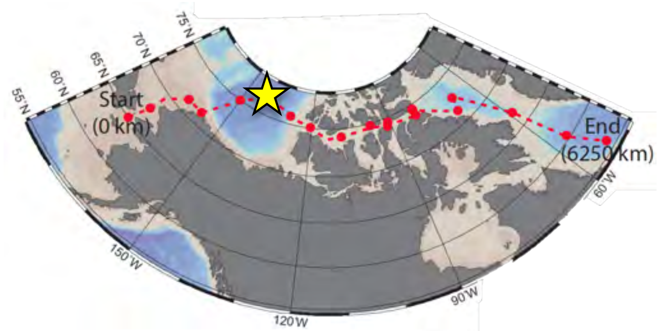


Variations in dissolved silica and $Si(OH)_4$ isotopes

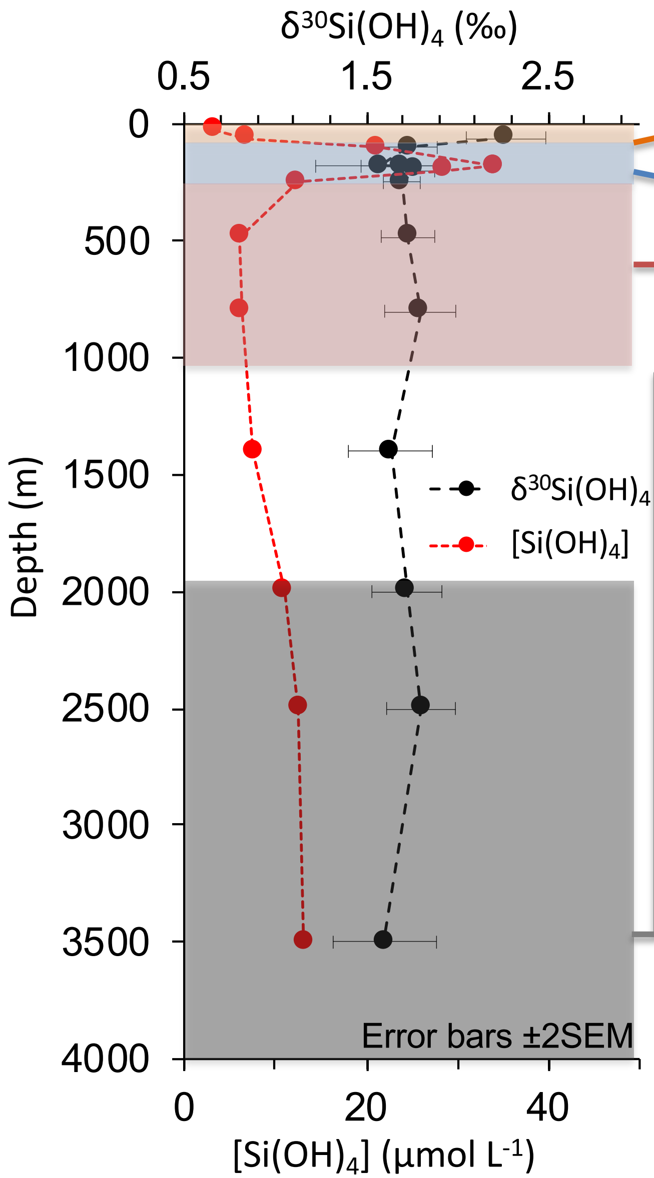


Si isotopes track modification of nutrient-rich Pacific-origin waters on their transit from west to east through the Arctic





Silicon isotopes reflect water mass composition



Surface waters

Modified Pacific waters

Modified Atlantic waters

Canada Basin Deep Water

Water mass $\delta^{30}Si(OH)_4$ signals agree with previous measurements

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

10.1002/2015GB005277

Key Points:
- Deep Arctic silicic acid isotopic signals are the heaviest of all ocean basins
- Riverine inputs decrease the surface Arctic silicic acid isotopic composition
- Silicon isotopic distribution in the Arctic follows that of major water masses

Supporting Information:
- Supporting Information S1

Heavy silicon isotopic composition of silicic acid and biogenic silica in Arctic waters over the Beaufort shelf and the Canada Basin

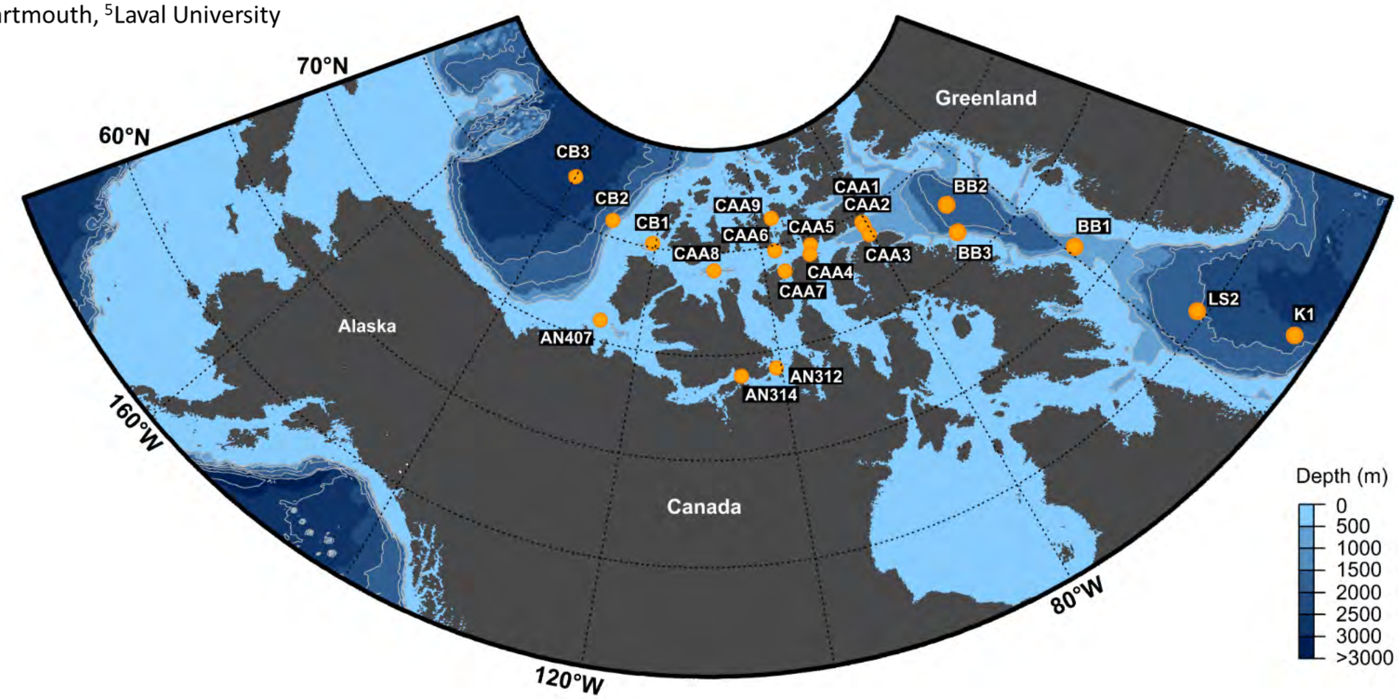
D. E. Varela[1,2], M. A. Brzezinski[3,4], C. P. Beucher[2,3], J. L. Jones[3], K. E. Giesbrecht[2], B. Lansard[5,6], and A. Mucci[5]

[1]Department of Biology, University of Victoria, Victoria, British Columbia, Canada, [2]School of Earth and Ocean Sciences, University of Victoria, Victoria, British Columbia, Canada, [3]Marine Science Institute, University of California, Santa Barbara, California, USA, [4]Department of Ecology Evolution and Marine Biology, University of California, Santa Barbara, California, USA, [5]GEOTOP and Department of Earth and Planetary Sciences, McGill University, Montréal, Quebec, Canada, [6]Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, Gif-sur-Yvette, France

CANADIAN ARCTIC GEOTRACES UPDATE: NITRATE (AND N_2O) N AND O ISOTOPE RATIOS

N. Lehmann[1], M. Kienast[1], J. Granger[2], A. Bourbonnais[3,4], A. Altabet[4], J.-É. Tremblay[5]

[1]Dalhousie University, [2]University of Connecticut, [3]University of South Carolina, [4]University of Massachusetts Dartmouth, [5]Laval University



- Data collected:
  1. Nitrate $\delta^{15}N$ and $\delta^{18}O$
  2. N_2O $\delta^{15}N$ and $\delta^{18}O$, isotopomer abundance, site preference

DATA COLLECTED

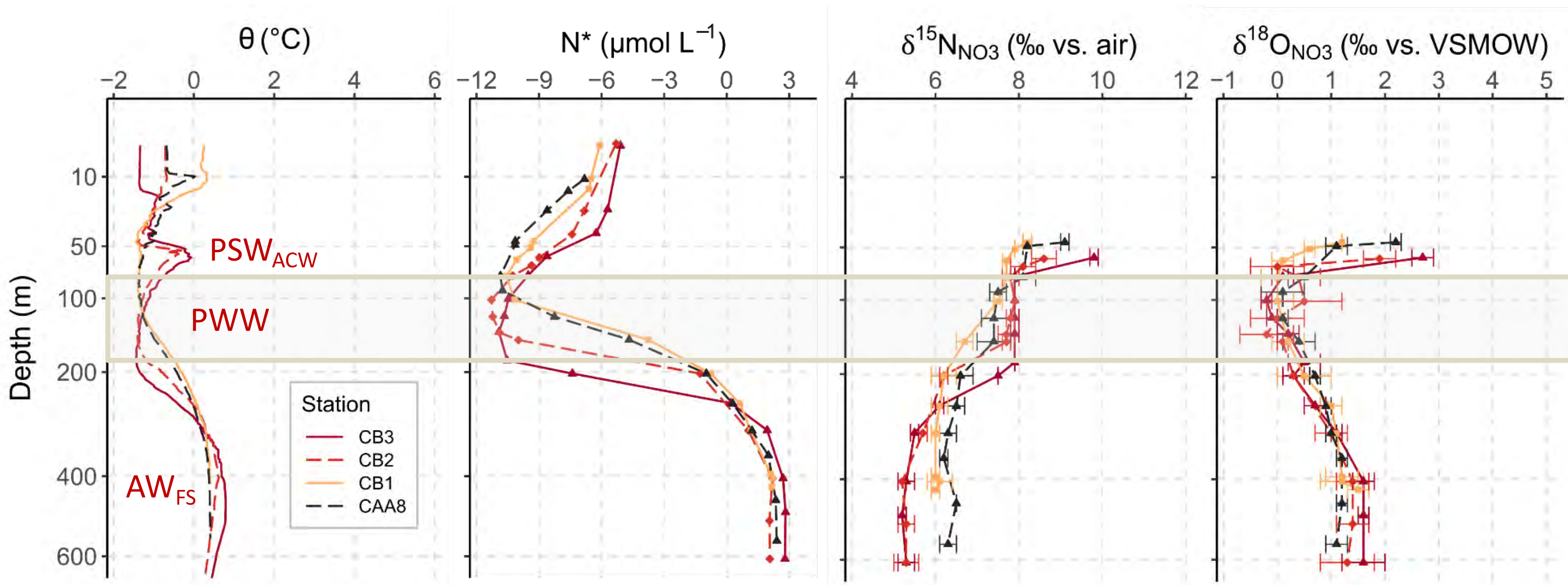
NITRATE δ15N and δ18O						N2O δ15N and δ18O			
Leg	Station	collected	analyzed	published*	to be included in IDP21	collected	analyzed	published*	to be included in IDP21
Leg 2	K1	yes	yes	yes	yes	yes	yes	yes	-
Leg 2	LS2	yes	yes	yes	yes	-	-	-	-
Leg 2	BB1	yes	yes	yes	yes	yes	yes	-	-
Leg 2	BB2	yes	yes	yes	yes	yes	yes	yes	-
Leg 2	BB3	yes	yes	yes	yes	yes	yes	-	-
Leg 2	CAA1	yes	yes	-	yes	yes	yes	-	-
Leg 2	CAA2	yes	yes	-	yes	yes	yes	-	-
Leg 2	CAA3	yes	yes	yes	yes	yes	yes	-	-
Leg 2	CAA4	yes	yes	-	yes	yes	yes	-	-
Leg 2	CAA5	yes	yes	-	yes	yes	yes	-	-
Leg 2	CAA6	yes	yes	-	yes	yes	yes	-	-
Leg 2	CAA7	yes	yes	-	yes	yes	yes	-	-
Leg 2	AN312	yes	yes	-	-	-	-	-	-
Leg 2	AN314	yes	yes	-	-	-	-	-	-
Leg3	AN407	yes	yes	-	-	-	-	-	-
Leg3	CAA8	yes	yes	-	yes	-	-	-	-
Leg3	CAA9	yes	yes	-	yes	-	-	-	-
Leg3	CB1	yes	yes	-	yes	-	-	-	-
Leg3	CB2	yes	yes	-	yes	-	-	-	-
Leg3	CB3	yes	yes	-	yes	-	-	-	-

*published in: Lehmann, N., Kienast, M., Granger, J., Bourbonnais, A., Altabet, M. A., & Tremblay, J. É. (2019). Remote Western Arctic Nutrients Fuel Remineralization in Deep Baffin Bay. *Global Biogeochemical Cycles*, *33*(6), 649-667.

BACKGROUND

$N^* = [DIN] - 16^*[PO_4^{3-}] + 2.9$

- **Canada Basin**: Distinct isotopic signatures for Pacific- and Atlantic-derived nutrients



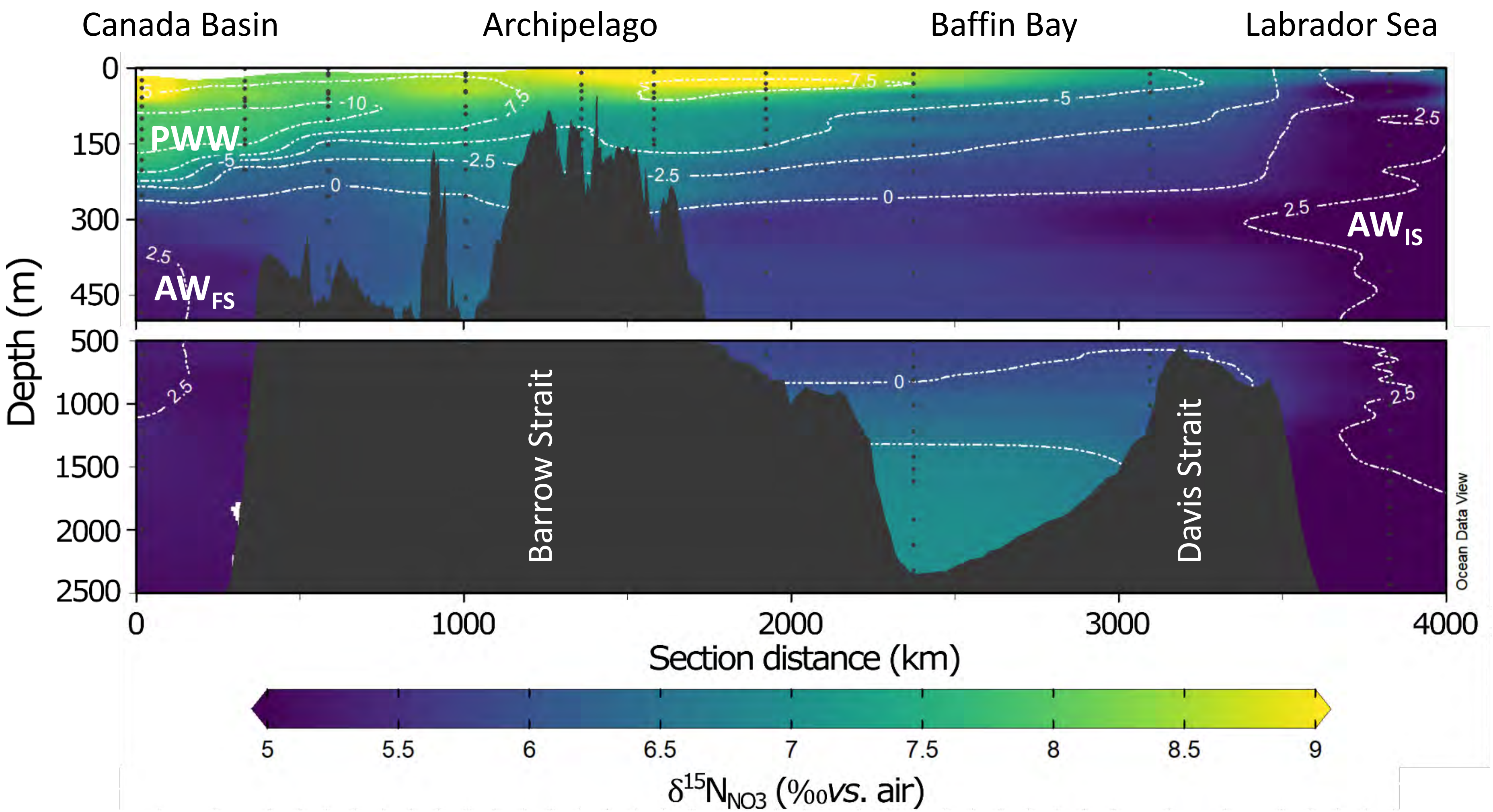
- **Pacific Winter Water (PWW):**

1. Elevated $\delta^{15}N_{NO3}$ as a result of benthic coupled nitrification-denitrification on the Bering and Chukchi shelves
2. Low $\delta^{18}O_{NO3}$ indicative of substantial remineralization in transit (Chukchi shelf)

Granger et al., 2011, 2018; Brown et al., 2015

Key findings

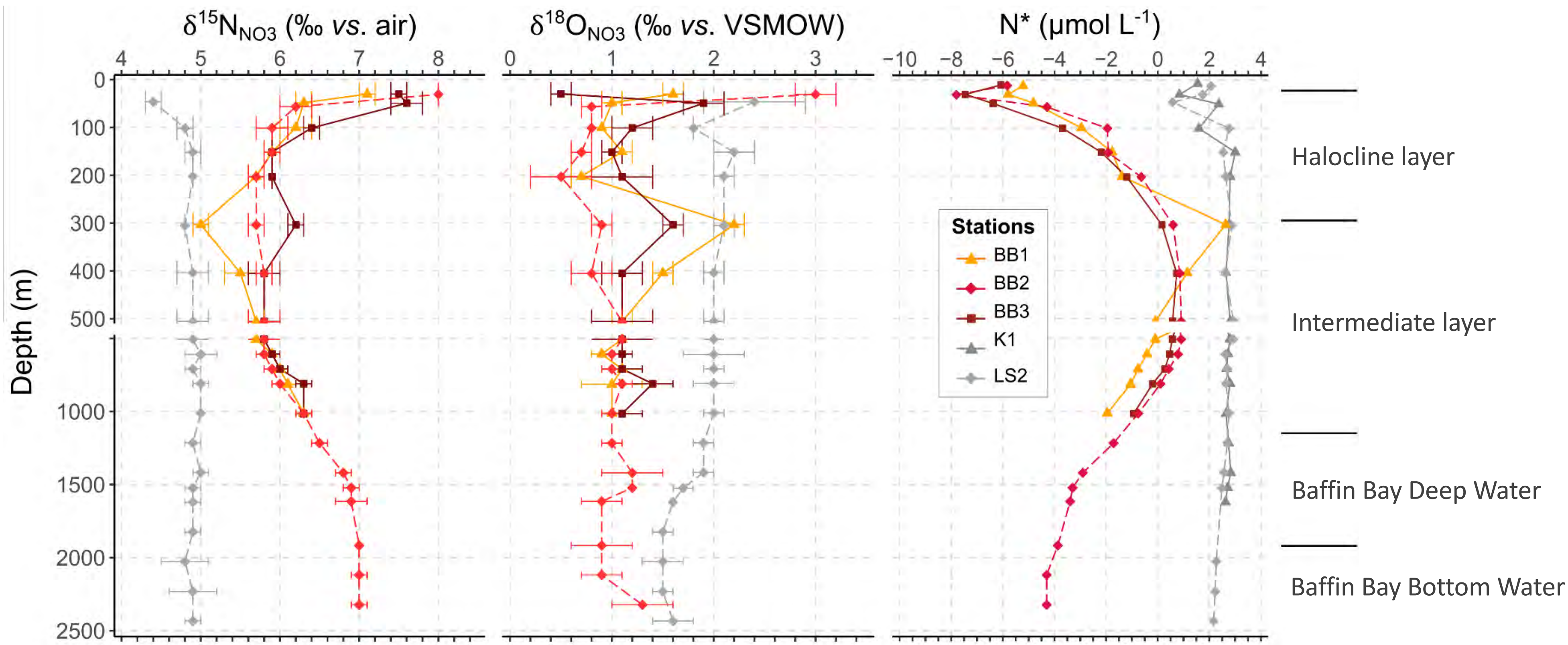
- Elevated $\delta^{15}N_{NO3}$ indicative of Pacific-derived nutrients traceable at subsurface (50-150m) throughout Archipelago and Baffin Bay



Contours: N* (µmol L^{-1})

Key findings

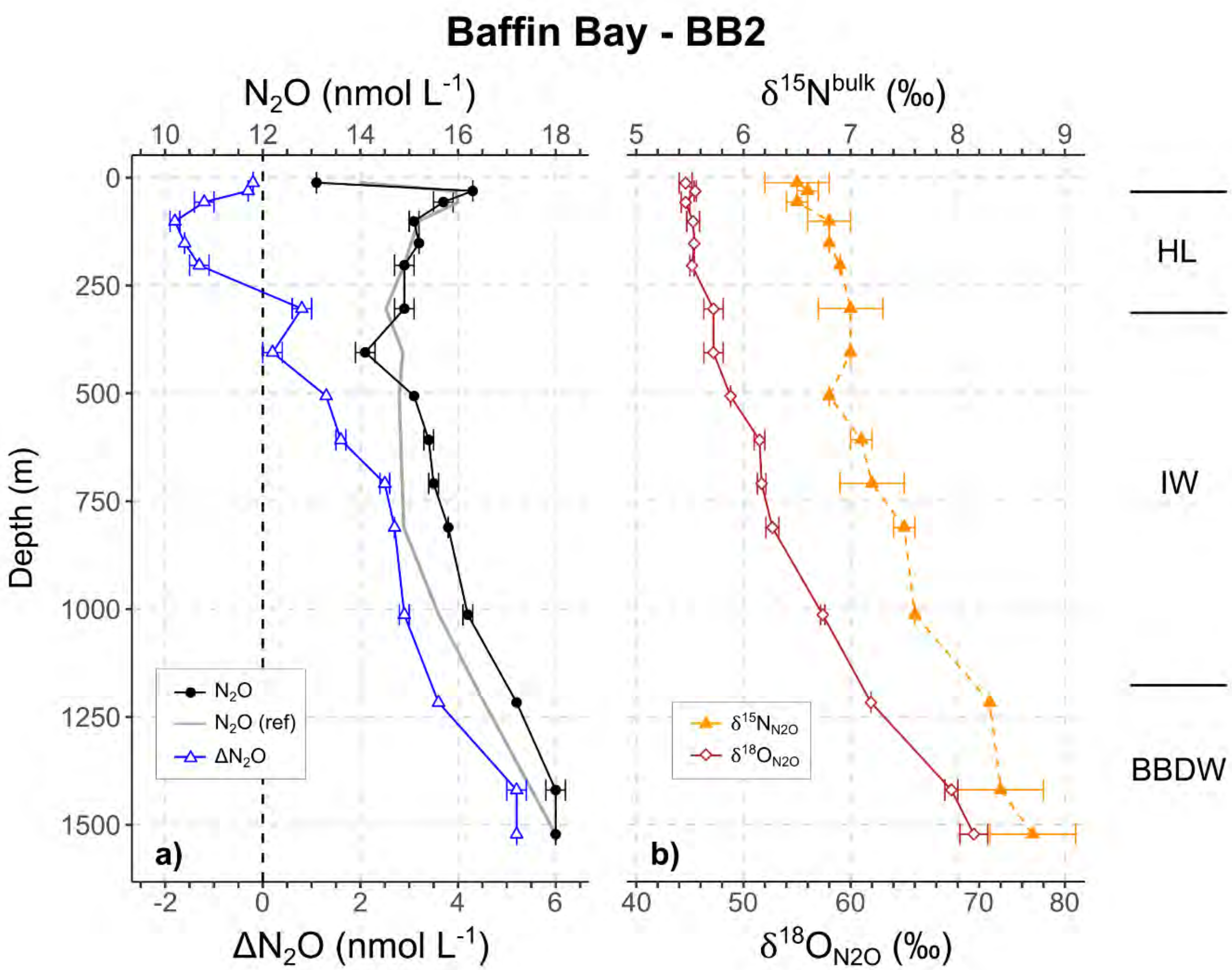
- **Baffin Bay**: ^{15}N-enrichment and N* minima in upper halocline and bottom waters



- Elevated $\delta^{15}N_{NO3}$ and concurrently low $\delta^{18}O_{NO3}$ in deep/bottom water indicate:
  1. Substantial remineralization of ^{15}N-enriched organic matter in deep and bottom water
  2. Export production largely fueled by Pacific-derived nutrients

KEY FINDINGS

- **Baffin Bay**: Distinct supersaturation of N_2O in Baffin Bay Deep Water



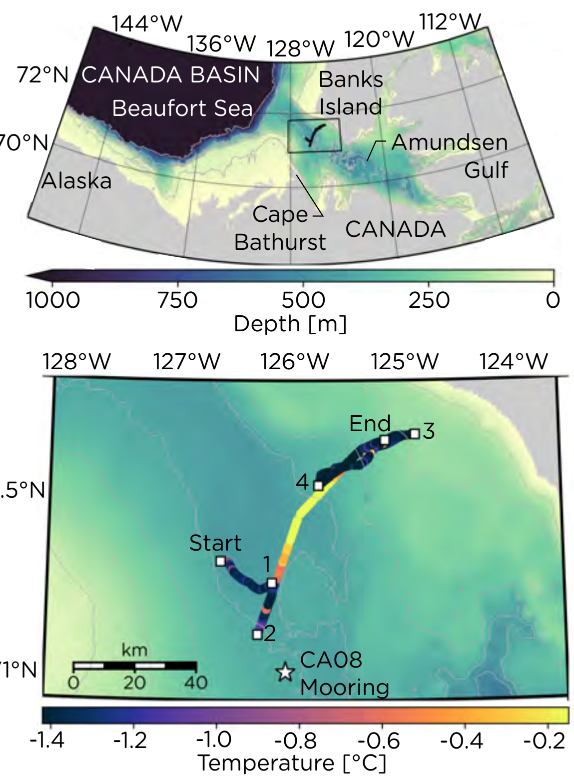
- Concurrent enrichment in N_2O $\delta^{15}N$ and $\delta^{18}O$ suggests:
  1. Predominant sedimentary source of N_2O in well oxygenated water column
  2. Sedimentary denitrification acts as potential source of N-deficiency in deep Baffin Bay

Stephanie Waterman (swaterman@eoas.ubc.ca)

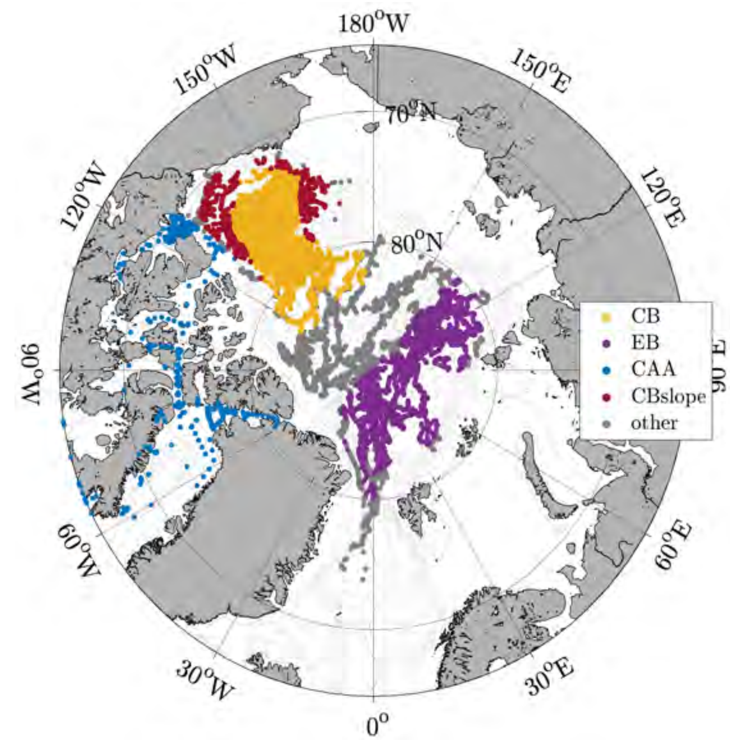
Our group has been working to quantify ocean mixing rates and mechanisms first in Canadian Arctic shelf and shelf slope waters, and later Arctic-wide.

Methods

1. glider-based CTD & turbulence measurements collected during the Canadian program in Amundsen Gulf in Aug 2015 [Schefiele et al 2018; Scheifele et al in review]
2. indirect methods applied to historical data to infer turbulence and mixing rates that span space & time more broadly [Chanona et al 2018, Chanona et al submitted, Dosser et al. in prep]



[Scheifele et al in review]



[Dosser et al. in prep]

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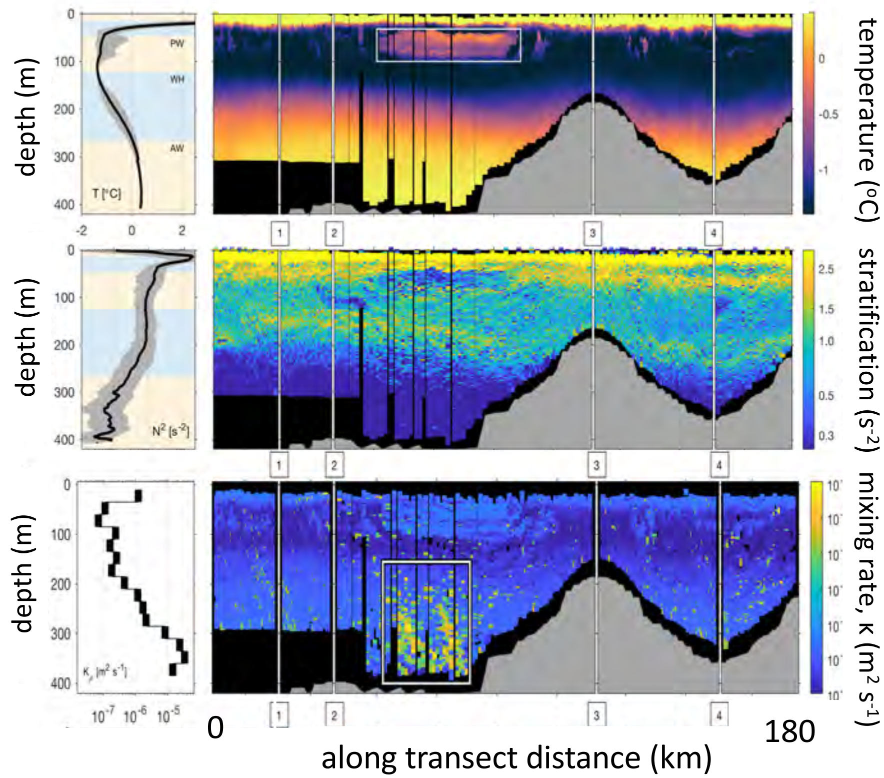
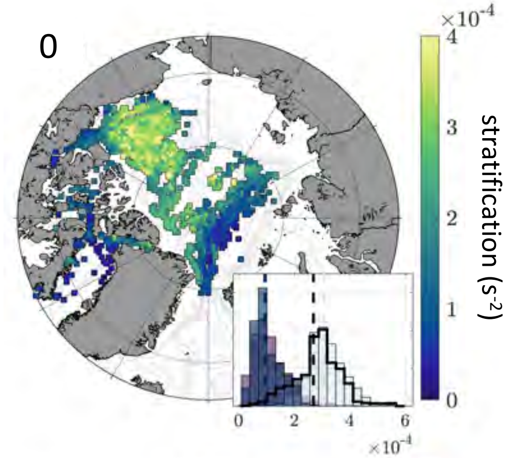
Data Products

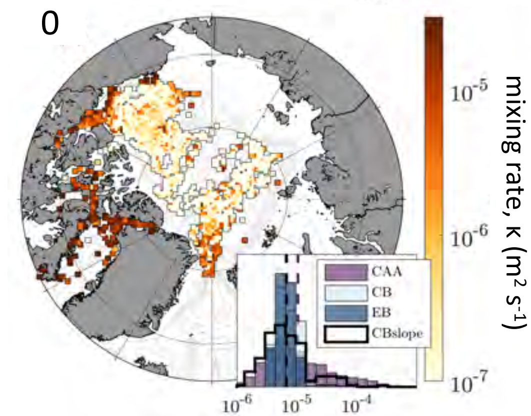
1. highly-resolved sections of T, S & derived products (stratification *etc.*) + direct turbulent dissipation rate & inferred mixing rate estimates in Amundsen Gulf in August 2015
2. spatial maps + multi-year timeseries of stratification + indirect estimates of turbulent dissipation & mixing rate

Glider Data in Amundsen Gulf in 2015



[Scheifele et al in review]



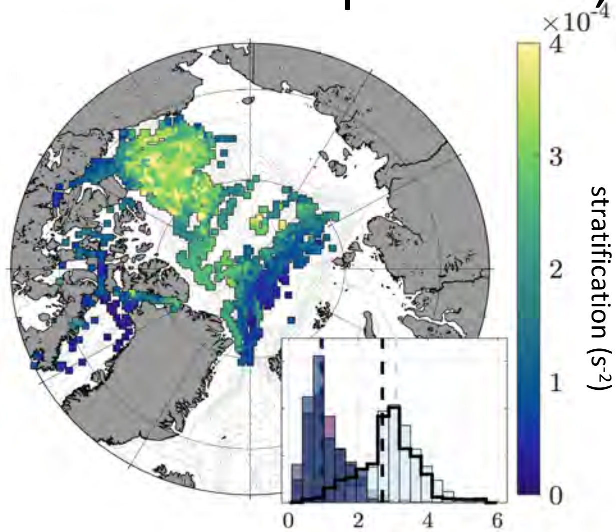


[Dosser et al. in prep]

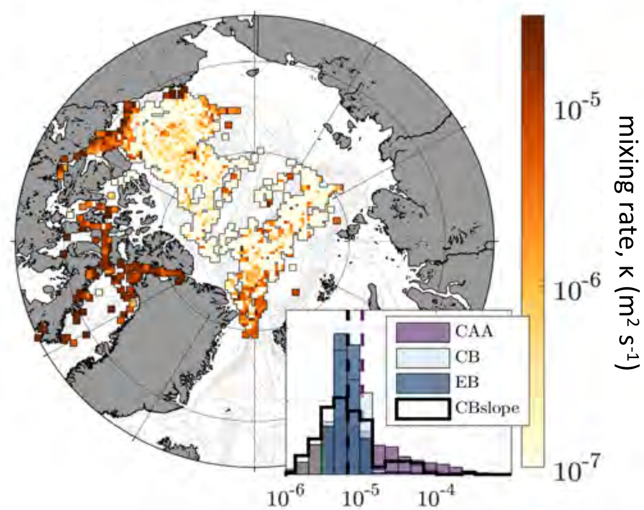
Our group has been working to quantify ocean mixing rates and mechanisms first in Canadian Arctic shelf and shelf slope waters, and later Arctic-wide.

Take Home Messages:

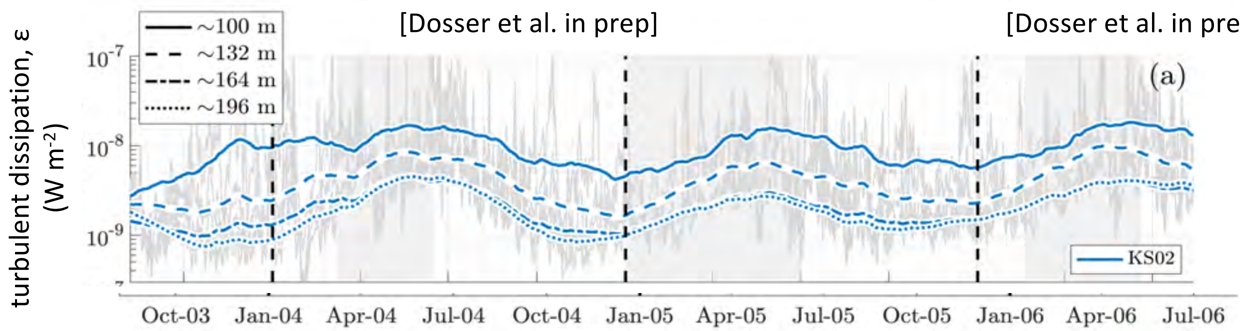
- ocean mixing rates are exceptionally variable in space & time, but do show large-scale patterns in mixing regimes and mixing rates
- these large-scale patterns could be useful for providing a "mixing map" and/or representative seasonal cycle for upper ocean mixing rates to be applied in budget studies of GEOTRACES researchers



[Dosser et al. in prep]



[Dosser et al. in prep]



[Chanona et al. submitted]