

## ANNUAL REPORT ON GEOTRACES ACTIVITIES IN CANADA

May 1, 2018 – April 1, 2019

### *Accomplishments*

Canadian GEOTRACES activities continue to be organised around the 2015 multi-leg expedition in the Arctic Ocean and ongoing process study work in the northeast subarctic Pacific through the Line P Time Series Program. Canadian PI's continue to work closely with US colleagues on Arctic GEOTRACES synthesis projects and a number of jointly authored manuscripts are planned, in progress or published at this point. The Canadian GEOTRACES community continues to support an ongoing process study making observations of bioactive trace elements and trace element-microbe interactions on time-series cruises completed along Line P in the northeast Pacific. The September expedition of 2018 was extended using a NSERC Ship Time grant to Roberta Hamme (UVic) and colleagues to allow support of the US EXPORTS project at Ocean Station PAPA. Cullen is coordinating US colleagues to qualify the trace element sampling program for EXPORTS as a GEOTRACES compliant activity.

Our new scientific results, publications and presentations are summarized by Individual Investigator below.

Jay T. Cullen, University of Victoria

### *Refereed Journal Publications (\* denotes HQP)*

- Schlitzer, R., et al. (2018) The GEOTRACES Intermediate Data Product 2017. Chemical Geology.
- \*Jackson, S.L., J. Spence, \*D.J. Janssen, A.R.S. Ross and J.T. Cullen. (2018) Determination of Mn, Fe, Ni, Cu, Zn, Cd and Pb in seawater using offline extraction and triple quadrupole ICP-MS/MS. Journal of Analytical Atomic Spectroscopy, DOI: 10.1039/C7JA00237H
- Nixon, R.L., S.L. Jackson, J.T. Cullen, A.R.S. Ross (in review). Distribution of copper-complexing ligands in the Canadian Arctic waters as determined by immobilized copper(II)-ion affinity chromatography. Marine Chemistry.
- Whitby H., E. Bucciarelli, G. Sarthou, N. Cassar, C.L. Osburn, \*D.J. Janssen, J.T. Cullen, A. Gonzalez, M. Tonnard, H. Planquette. (2018). Relationship between -HS functional groups and iron in the northeast Pacific. Nature Geoscience.
- \*Janssen D.J., W. Abouchami, S. Galer, J.T. Cullen. (in press). Particulate cadmium stable isotopes in the subarctic northeast Pacific reveal dynamic Cd cycling and a new isotopically light Cd sink. Earth and Planetary Science Letters
- Rosario Lorenzo M., M. Segovia, J.T. Cullen, M.T. Maldonado MT. (in press). Particulate trace metal dynamics in response to increased CO<sub>2</sub> and iron availability in a coastal mesocosm experiment. Biogeosciences.

### ***Research Activities***

- We have analyzed several thousand bottle cast samples for a number of conservative and non-conservative tracers (e.g., S, T,  $\delta^{18}\text{O}(\text{H}_2\text{O})$ ,  $\delta^{13}\text{C}(\text{DIC})$ , TA) and combined those with data (e.g., nitrate, SRP,  $\text{O}_2$ ) acquired by collaborators to identify the properties of source-water types in the study area (Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay/Davis Strait) and estimate the relative contribution of these throughout the water column. These water-mass reconstructions are used by our Canadian Geotraces collaborators to interpret the vertical and horizontal distributions of trace elements and their isotopes (e.g., Varela et al., 2016).
- We have been tracking the temporal evolution of the aragonite compensation depth (ACD) in the waters of the study area over the past decade. Our observations reveal that the surface waters in the eastern Beaufort Sea (Mackenzie Shelf and Amundsen Gulf), part of the Canada Basin and the Queen Maud Gulf are already undersaturated with respect to aragonite, this may have deleterious effects on marine ecosystems, particularly organisms that secrete  $\text{CaCO}_3$  skeletons/exoskeletons and shells. The Aragonite Compensation Depth in the Canada Basin and Beaufort Sea is shoaling as Atlantic waters, acidified by uptake of anthropogenic  $\text{CO}_2$  in the North Atlantic, intrude at depth in the Arctic Ocean (Luo et al., 2016). Atlantic waters enter the Arctic Ocean through Fram Strait and Norwegian Sea/Barents Sea and reach the Canada Basin in about 20 years.

### ***Refereed Journal Publications (HQP in Bold)***

- Wang K., Munson K.M., Beupr -Laperri re A., Mucci A., Macdonald R.W. and Wang F. (2018) Subsurface methylmercury maximum explains biotic mercury levels in the Canadian Arctic. *Nature Scientific Reports* 8: 14465, pp. 1-5. doi.org/10.1038/s41598-018-32760-0
- Granger J., Sigman D.M., Gagnon J., Tremblay J.- . and Mucci A. (2018) On the properties of the Arctic Halocline and deep water masses of the Canada Basin from nitrate isotope ratios. *JGR-Oceans* 123: 5443-5458. doi.org/10.1029/2018JC014110
- Mol J., Thomas H., Myers P.G., Hu X. and Mucci A. (2018) Inorganic carbon fluxes on the Mackenzie Shelf of the Beaufort Sea. *Biogeosciences* 15: 1011-1027. <https://doi.org/10.5194/bg-15-1011-2018>.
- Beupr -Laperri re A. and Mucci A. (in preparation) The state and variability of the carbonate system of the Canadian Arctic in the context of ocean acidification: 2003 – 2016.

### ***Conference Presentations***

- Wang K., Munson K., Beupr -Laperri re A., Mucci A., Macdonald R. and Wang F. (2018) Methylmercury distribution in the sub-surface seawater explains the spatial trend of biotic mercury in the Canadian Arctic Ocean. Contributed oral presentation. ASLO Meeting, June 10-15, 2018, Victoria, BC.
- Beupr -Laperri re A., Mucci A. and Thomas H. (2018) Time series of ocean acidification in the Canadian Arctic Ocean. Contributed poster. Joint CMOS-MEOPAR Meeting, June 10-14, 2018, Halifax, NS.

- Mol J., Thomas H., Myers P.G., Hu X. and Mucci A. (2018) Inorganic carbon fluxes on the Mackenzie Shelf of the Beaufort Sea. Contributed poster. EGU General Assembly, April 8-13, 2018, Vienna, Austria.
- Mol J., Thomas H., Myers P.G., Hu X. and Mucci A. (2018) Inorganic carbon fluxes on the Mackenzie Shelf of the Beaufort Sea. Contributed poster. EGU General Assembly, April 8-13, 2018, Vienna, Austria.

### ***Thesis***

- Beaupré-Laperrière A. (2019) The state and variability of the carbonate system of the Canadian Arctic in the context of ocean acidification. M.Sc. Thesis, McGill University, 101 pp.

### ***Other tangible results***

- Based on measured conservative (e.g.,  $\delta^{18}\text{O}(\text{H}_2\text{O})$ , SP, TA) and non-conservative (DIC, dissolved oxygen, nutrients) tracers we have reconstructed the structure of the water column based on the properties of the source-water types delivered at the study sites. This product was delivered to our collaborators and partners, which allowed them to more readily interpret the vertical and horizontal distributions of the geochemical and isotopic tracers measured throughout the water column at the Canadian Geotraces sampling sites (Thomas, Wang, Granger, Oriens, Maldonado). In one case (Wang et al., 2018), we have been able to explain the differential bioaccumulation of Hg in marine mammals between the eastern and western Canadian Arctic and identify the probably source of the sub-surface methyl-mercury in the Canada Basin and eastern Beaufort Sea.
- In collaboration with Prof. Helmuth Thomas, we measured 3 of the measurable carbonate system parameters (TA, DIC, pH) throughout the water column in the study area in order to investigate carbon export, estimate  $\text{CO}_2$  fluxes at the air-sea interface, as well as determine the loci and progressive acidification of the water column.

### ***Training of Highly Qualified Personnel***

- Alexis Beaupré-Laperrière was an undergraduate student in the Department of Earth and Planetary Sciences at McGill University and processed (carbonate chemistry and quality control) and mined the data collected prior to, during and after the Canadian Geotraces/ArcticNet cruise. He started this work in the context of an “Introduction to Research” course-for-credit in January 2016. He pursued this work and initiated the source-water mass OMP analysis during the summer of 2016 while he held an NSERC SURA. He pursued this work on an ad-hoc basis during the fall of 2016 until he was admitted to the M.Sc. graduate student in the summer of 2017. During his M.Sc., he synthesized 13 years of data and documented the temporal, vertical migration of the aragonite compensation depth and the acidification of Arctic waters by absorption of anthropogenic  $\text{CO}_2$  from the atmosphere as well as the lateral intrusion below the surface of pre-acidified waters (Pacific and Atlantic) into the Canada Basin, the eastern Beaufort Sea and the Canadian Arctic Archipelago.

Paul Myers, Department of Earth and Atmospheric Sciences, University of Alberta

### ***Refereed Journal Publications***

- Grivault N., X. Hu, P.G. Myers. (2018). Impact of the Surface Stress on the Volume and Freshwater Transport Through the Canadian Arctic Archipelago From a High Resolution Numerical Simulation. *Journal of Geophysical Research: Oceans* 123 (12), 9038-9060
- Dmitrenko I.A., S. A. Kirillov, P.G. Myers, A. Forest, B. Tremblay, J. V. Lukovich, Y. Gratton, S. Rysgaard, D.G. Barber. (2018). Wind-forced depth-dependent currents over the eastern Beaufort Sea continental slope: Implications for Pacific water transport. *Elem Sci Anth* 6 (1)
- Hu X., J. Sun, T. O. Chan, P. G. Myers. (2018). Thermodynamic and dynamic ice thickness contributions in the Canadian Arctic Archipelago in NEMO-LIM2 numerical simulations. *Cryosphere* 12 (4)
- Mol J., T. Helmuth, P. G. Myers, X. Hu, A. Mucci. (2018). Inorganic carbon fluxes on the Mackenzie Shelf of the Beaufort Sea. *Biogeosciences* 15 (4), 1011

### ***Thesis***

N. Grivault PhD September 2018

Dr. Andrew R.S. Ross, Research Scientist, Institute of Ocean Sciences, Fisheries and Oceans Canada (DFO), Assistant Adjunct Professor, Biochemistry and Microbiology, University of Victoria (UVic)

### ***Publications (in review)***

- Nixon, R.L, Jackson, S.L, Cullen, J.T., Ross, A.R.S. Distribution of copper-complexing ligands in the Canadian Arctic as determined using immobilized copper(II)-ion affinity chromatography. *Marine Chemistry* (submitted November 27, 2018; revisions due April 30, 2019).

### ***Presentations***

- Ross, A.R.S., Janssen, D.J., Cullen, J.T., Spence, J., Simpson, K., Robert, M. Nemcek, N., Pena, A. 2018. Depletion of micronutrient trace metals in Line P surface waters during the 2014 warming anomaly: implications for marine ecosystems and climate change. North Pacific Marine Science Organization (PICES) 2018 Annual Meeting, Yokohama, Japan, 25 October-4 November.
- Ross, A.R.S., Nixon, R.L. 2018. Characterization of marine organic ligands using Cu(II)-IMAC and mass spectrometry. 53rd Canadian Trace Organics Workshop, Vancouver BC, 14-15 May.

### ***HQP Training***

- 1 PhD student (Richard Nixon; University of Victoria Department of Biochemistry and Microbiology)
- 1 BSc co-op summer student (Jacob Davies; University of Victoria Department of Chemistry)

***Refereed Journal Publications***

- Nina Schuback and Philippe D. Tortell. 2019. Diurnal regulation of photosynthetic light absorption, electron transport and carbon fixation in two contrasting oceanic environments. *Biogeosciences*, in press
- Alysia Herr, John W. Dacey, Ron Kiene and Philippe D. Tortell. 2019. Patterns and drivers of dimethylsulfide concentrations in the northeast Subarctic Pacific across multiple spatial and temporal scales. *Biogeosciences*, In press
- Hermann W. Bange, Damian L. Arévalo-Martínez, Mercedes de la Paz, Laura Farias, Jan Kaiser, Annette Kock, Cliff S. Law, Andrew Paul Rees, Gregor Rehder, Philippe D. Tortell, Robert C. Upstill-Goddard, Samuel T Wilson. 2019. A harmonized nitrous oxide (N<sub>2</sub>O) ocean observation network for the 21st century. *Frontiers in Marine Science*, in press
- William J. Burt and Philippe D. Tortell. 2018. Observations of Zooplankton Diel Vertical Migration from High-Resolution Surface Ocean Optical Measurements. *Geophysical Research Letters*, 45. <https://doi.org/10.1029/2018GL079992>
- Samuel Wilson, Hermann Bange, Damian Arévalo-Martínez, Jonathan Barnes, Alberto Borges, Ian Brown, John Bullister, Macarena Burgos, David Capelle, Michael Casso, Mercedes de la Paz, Laura Farias, Lindsay Fenwick, Sara Ferrón, Gerardo Garcia, Michael Glockzin, David Karl, Annette Kock, Sarah Laperriere, Cliff Law, Cara Manning, Andrew Marriner, Jukka-Pekka Myllykangas, John Pohlman, Andrew Rees, Alyson Santoro, Mabel Torres, Philippe Tortell, David Wisegarver, Robert Upstill-Goddard, Guiling Zhang, and Gregor Rehder. 2018. An intercomparison of oceanic methane and nitrous oxide measurements. *Biogeosciences*, Volume: 15 Issue: 19 Pages: 5891-5907
- WJ Burt, Z. Chen, T Westberry, M Behrenfeld, J Graff, B Jones, and PD Tortell. 2018. Carbon to Chlorophyll ratios and net primary productivity of Subarctic Pacific surface waters derived from autonomous shipboard sensors. *Global Biogeochemical Cycles*, Volume: 32 Issue: 2 Pages: 267-288, [doi.org/10.1002/2017GB005783](https://doi.org/10.1002/2017GB005783).
- Jarnikova T., Dacey J., Lizotte M., Levasseur, M. and P. Tortell. 2018. The distribution of methylated sulfur compounds, DMS and DMSP, in Canadian Subarctic and Arctic waters during summer, 2015. *Biogeoscience*. 15, 2449–2465, [doi.org/10.5194](https://doi.org/10.5194)
- Izett R., C. Manning, R. Hamme and PD Tortell. 2018. Refined estimates of net community production in the Subarctic Northeast Pacific derived from  $\Delta\text{O}_2/\text{Ar}$  measurements with N<sub>2</sub>O-based corrections for vertical mixing. *Global Biogeochemical Cycles*. [doi:10.1002/2017GB005792](https://doi.org/10.1002/2017GB005792)
- Chen Zeng, Sarah Z. Rosengard, William Burt, Angelica Peña, Nina Nemcek, Tao Zeng, Kevin R. Arrigo, and Philippe D. Tortell. 2018. Optically-derived estimates of phytoplankton size class and taxonomic group biomass in the Eastern Subarctic Pacific Ocean. *Deep-Sea Research Part I* 136 (2018) 107–118
- Fenwick, L. and P. Tortell. 2018. Methane and nitrous oxide distributions in coastal and open waters of the Northeast Subarctic Pacific during 2015-2016. *Marine Chemistry*, volume 200 (20) Pages 45-56

- Capelle, D. W., Hallam SW and P. Tortell. 2018. A Multi-year time-series of N<sub>2</sub>O dynamics in a seasonally anoxic fjord: Saanich Inlet, British Columbia. *Limnology and Oceanography*, Volume 63 (2), Pages 524-539
- Hoppe, CJM; Schuback, N; Semeniuk,; Giesbrecht, K; Mol, J; Thomas, H; Maldonado, MT; Rost, B; Varela, DE; Tortell, PD. 2018. Resistance of Arctic phytoplankton to ocean acidification and enhanced irradiance. *Polar Biology* Volume 41(3) p. 399-413.
- Hoppe, C, Schuback, N, Seminuik D., Giesbrecht K., Mol J., Thomas H., Maldonado M., Rost B., Tortell P. Compensation of Ocean Acidification effects in Arctic phytoplankton assemblages. 2018. *Nature Climate Change*, accepted, NCLIM-17081528B

### ***Conference Presentations***

- 2019, European Geophysical Union General Assembly. Repeat measurements of methane and nitrous oxide distributions across the North American Arctic Ocean from 2015–2018. Cara C Manning, Zhiyin Zheng, Victoria L Preston, Annie Bourbonnais, Kevin Manganini, Anna PM Michel, David P Nicholson, Scott D Wankel, and Philippe D Tortell
- 2018, ArcticNet Conference, (Ottawa) Characterisation of a High Arctic seabed hydrocarbon seep at Scott Inlet, Baffin Bay. Margaret Cramm et al., including Robert Izett and Philippe Tortell.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Influence of mixing dynamics on net community production and CO<sub>2</sub> uptake in Canadian Arctic and Subarctic ocean waters: P D Tortell, R Izett, M Chanona, J L Thibault, P G Myers.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Biogeochemical and physical controls on interannual and spatial variability in CH<sub>4</sub> and N<sub>2</sub>O distributions across the North American Arctic Ocean: C C Manning, D W Capelle, L Fenwick, E Damm, P D Tortell.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Carbon : Chlorophyll ratios and net primary productivity of Subarctic Pacific surface waters derived from autonomous shipboard sensors: W Burt, T Westberry, M Behrenfeld, C Zeng, R Izett, P D Tortell.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Refined estimates of net community production in the Subarctic Northeast Pacific derived from  $\Delta$ O<sub>2</sub>/Ar measurements with N<sub>2</sub>O-based corrections for vertical mixing: R Izett, C C Manning, R C Hamme, P D Tortell.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Diurnal variability in surface chlorophyll-a, phytoplankton carbon and particle size distribution in two contrasting biomass regimes of the coastal Northeast Pacific Ocean: S Rosengard, P D Tortell, N Schuback, W Burt, C Zeng.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). The Biogeochemistry of Methanethiol in Nearsurface Waters of the Northeastern Pacific Ocean: T E Williams, R P Kiene, K Esson, P D Tortell, J W H Dacey.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Examining the concentrations and dynamics of DMS, DMSP and DMSO across oceanographic regimes of the subarctic Pacific: A E Herr, P D Tortell.
- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). Extremely Fast Turnover of Dissolved Dimethylsulfoniopropionate (DMSP) Sustains High

Concentrations of Dimethylsulphide and Methanethiol in the NE Subarctic Pacific: R P Kiene, K Esson, T E Williams, P D Tortell, J W H Dacey.

- 2018, ALSO / AGU Ocean Sciences Meeting (Portland, Oregon). From Fjords to Open Seas: A Decade of Geochemical and Multi-Omic Time Series Observations From the Saanich Inlet Redoxcline: S J Hallam, A K Hawley, M Torres-Beltrán, S Crowe, F A Whitney, P D Tortell.
- 2018, American Society of Mass Spectrometry (San Diego) Ross D McCulloch, Alysia Herr, John H Dacey, Phillippe D Tortell. An Automated, Sea-going Purge & Trap APCI-MS/MS for the Detection of Trace Dimethyl Sulfide in Ocean Waters.

### ***HQP trained***

- Zarah Zang, B.Sc.
- Alysia Herr, M.Sc.
- Nina Schuback
- Ana Franco
- Cara Manning
- Sarah Rosengard
- William Burt

Feiyue Wang, University of Manitoba

### ***List of publications***

- Wang K., Munson, K.M., Beaupré-Laperrière A., Mucci A., Macdonald R.W., and Wang F. 2018. Subsurface seawater methylmercury maximum explains biotic mercury concentrations in the Canadian Arctic. Sci. Rep. 8:14465, doi: 10.1038/s41598-018-32760-0.
- Wang K. 2019. Methylmercury in Seawater and Its Bioaccumulation in Marine Food Webs of the Canadian Arctic. Ph.D. Dissertation, University of Manitoba, Winnipeg, MB.

### ***Presentations***

- Munson, K.M., Singer, J. Gao Z., Chaudhuri P., Huyghe S., Ciastek S., Kuzyk Z.Z., Stern G.A., and Wang F. 2018. Mercury and methylmercury in the Hudson Bay system: an update. ArcticNet Annual Scientific Meeting, December 9–14, 2018, Ottawa, ON.
- Wang K., Munson K., Beaupré-Laperrière A., Mucci A., Macdonald R., and Wang F. 2018. Subsurface seawater methylmercury maximum explains biotic mercury levels in the Canadian Arctic. Association for the Sciences of Limnology and Oceanography (ASLO) 2018 Summer Meeting. June 10–15, 2018, Victoria, BC.

### ***Media & Outreach***

- Wang F. 2018. How we solved an Arctic mercury mystery. The Conversation. October 18, 2018. <https://theconversation.com/how-we-solved-an-arctic-mercury-mystery-103963>.

### ***HQP Training***

- Kang Wang, Ph.D. Thesis defended in March 2019.
- Kathleen Munson.