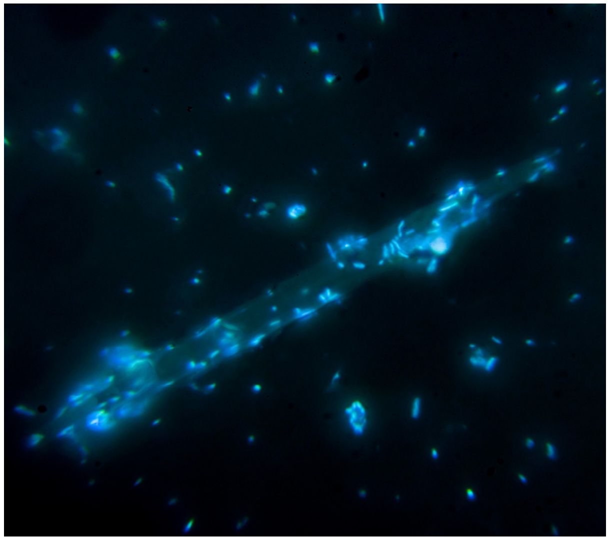
Understanding the effects of ocean acidification on sea-ice microbial eco-systems and elucidating microbial metabolic functions in a changing Arctic

Anders Torstensson

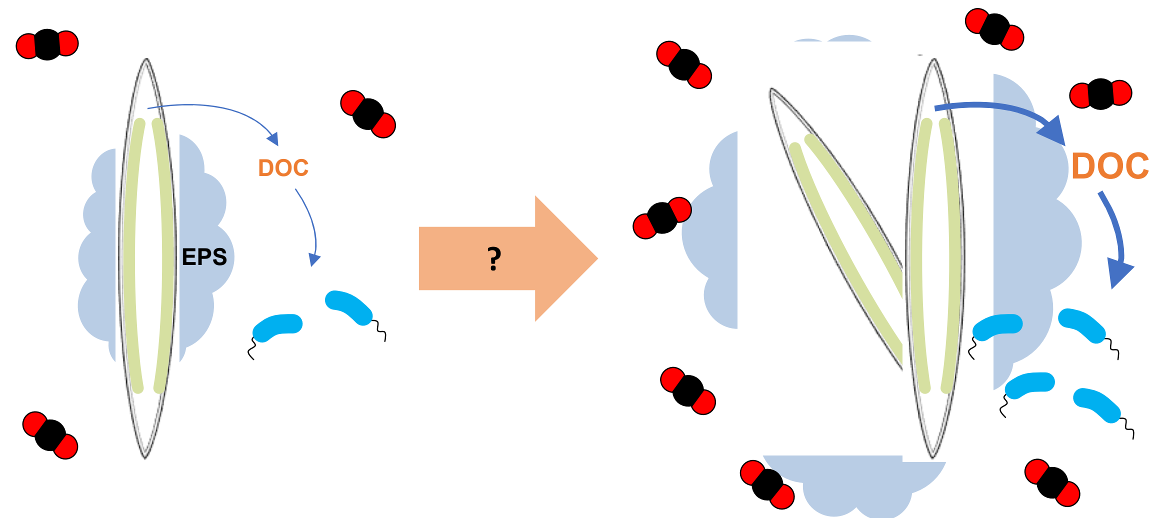


School of Oceanography
University of Washington

UPPSALA
UNIVERSITET

The effect of carbonate chemistry on the sea ice community in the High Arctic

Elizabeth Shadwick et al.



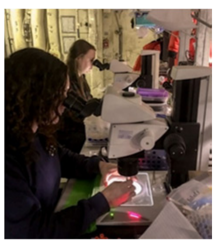
Uncovering the seasonality of sympagic and pelagic microbiomes and their metabolic functions in the Central Arctic Ocean with emphasis on carbon and nitrogen cycling

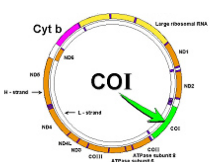
Pauline Snoeijs-Leijonmalm et al.

MOSAiC
International
Arctic Drift
Expedition

Pathways of Pelagic Connectivity:
Eukrohnia hamata (Chaetognatha) in the Arctic Ocean

DeHart, H.M., L. Blanco-Bercial, M. Passacantando, J.M. Questel, **A. Bucklin**





- Samples collected 2011 – 2016 Arctic cruises
- Species ID by morphology and COI barcodes

https://www.whoi.edu/main/topic/arctic-ocean-circulation

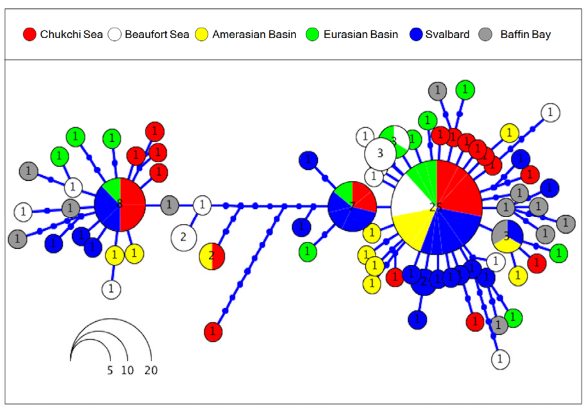
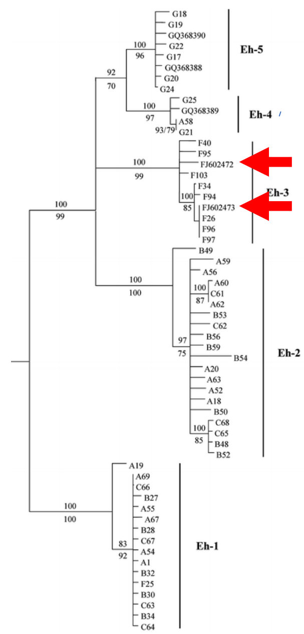
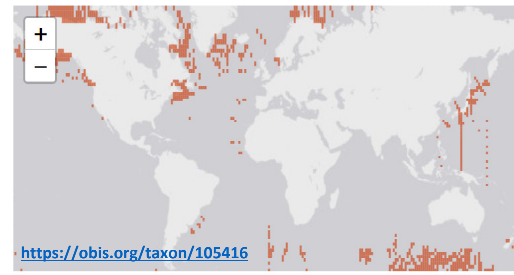
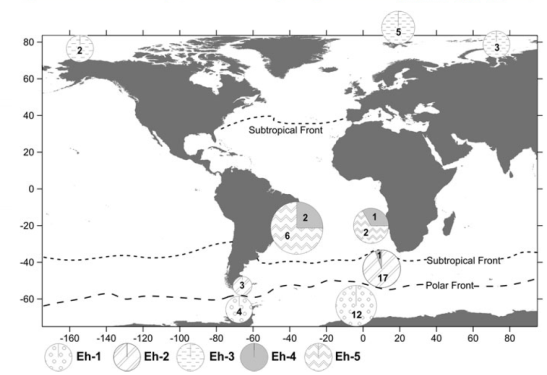


Figure 3. Haplotype network for *E. hamata*. Each circle represents a unique haplotype. Circle

- COI sequence data analyzed for diversity, structure, connectivity
- Compare global COI phylogeography (Kulagin et al., 2014, Hydrobiol.)







Kulagin, Stupnikova, Neretina, Mugue, (2014) Hydrobiologia

Pathways of Pelagic Connectivity:
Eukrohnia hamata (Chaetognatha) in the Arctic Ocean

DeHart, H.M., L. Blanco-Bercial, M. Passacantando, J.M. Questel, **A. Bucklin**

ANALYSIS of COI BARCODES

- **High haplotype diversity and low nucleotide diversity suggest recent population expansion**
- **No significant population genetic structure**
- **High levels of population connectivity**
- **Migration pathways follow major Arctic currents**

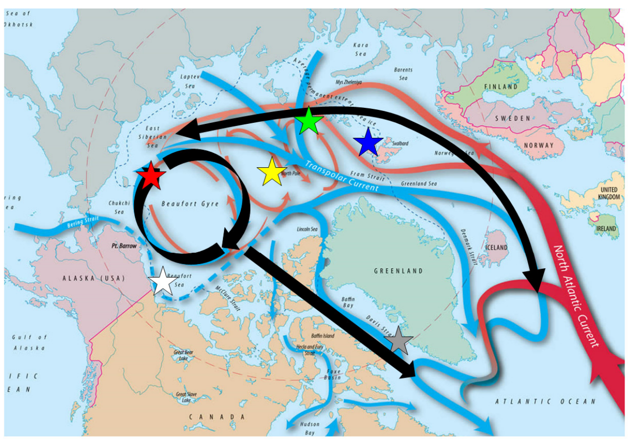
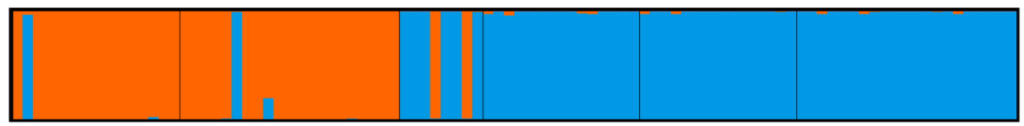


Figure 4. Schematic depicting the "Arctic Currents" population connectivity model hypothesis tested using Migrate-N.

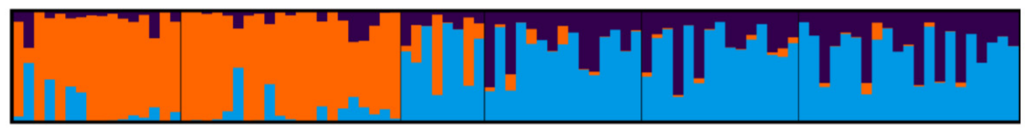
ANALYSIS of SINGLE NUCLEOTIDE POLYMORPHISMs (SNPs)

- **Analysis of 3,455 SNPs using STRUCTURE**
- **High levels of gene flow among the regions**
- **Genetic distinctiveness of Atlantic-Arctic versus Pacific-Arctic regions**
- **SNPs under selection suggest possible local adaptation of populations**

Two clusters (K=2) based on all SNPs



Three clusters (K=3) after removing SNPs under selection



1: Beaufort Sea | 2: Chukchi Sea | 3: Am Basin | 4: Eur Basin | 5: Fram Strait | 6: Labrador Sea

Recommended Reading:

- **Jennings, Bucklin, Pierrot-Bults (2010) Barcoding of arrow worms (Phylum Chaetognatha). PLoS ONE**
- **Bucklin, Hopcroft, Kosobokova, et al. (2010) DNA barcoding of Arctic holozooplankton. Deep-Sea Res. II**
- **Miyamoto, Machida, Nishida (2012) Global phylogeography of … *Eukrohnia hamata.* Progr. Oceangr.**
- **Blanco-Bercial, Bucklin (2016) New view of population genetics of zooplankton … Molec. Ecol.**

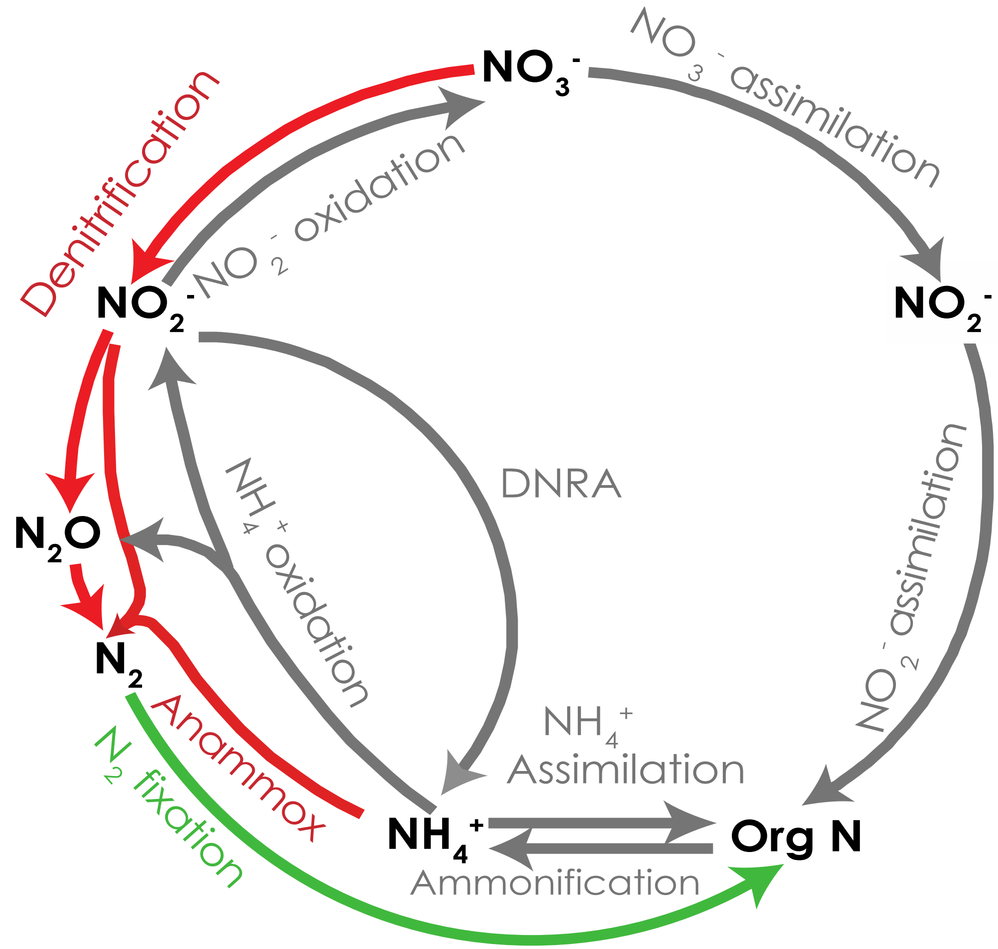
Annie Bourbonnais (University of South Carolina)
Using isotopic tracers to resolve the marine N cycle

Kinetic isotope fractionation: organisms generally assimilate lighter isotopes leaving residual substrate enriched in heavier isotopes.

NO_3^- assimilation

^{14}N (99.6%), ^{16}O (99.8%)

^{15}N (0.4%), ^{18}O (0.2%)



Distinct isotope effects for these N transformations.

Dissolved nitrogen stable isotope measurements during the SAS

Primary goal of my research: **use coupled measurements of the dissolved inorganic and organic nitrogen ($^{15}N/^{14}N$) and oxygen ($^{18}O/^{16}O$) isotope ratios of NO_3^- to:**

1) Distinguish the **dominant N transformations** contributing to N cycling among the Arctic Ocean basins.
Relevance to SAS: Ecosystem response
RQ4: How does primary production and associated availability of nutrients vary between Arctic regions

2) Assess the **contribution of water masses to reactive nitrogen reservoirs** throughout the Arctic Ocean.
Relevance to SAS: Physical drivers
RQ1: How are Arctic Ocean water circulation patterns responding to changes in sea ice properties, and atmospheric, advective and freshwater forcing?
RQ3: What are the states of, and changes in, water mass sources, sinks and transformations?

Benthic-pelagic coupling: nitrification-denitrification in sediments is the dominant N-loss process. All NO_3^- imported from the open Pacific is assimilated and recycled at least once on Bering and Chukchi shelves.

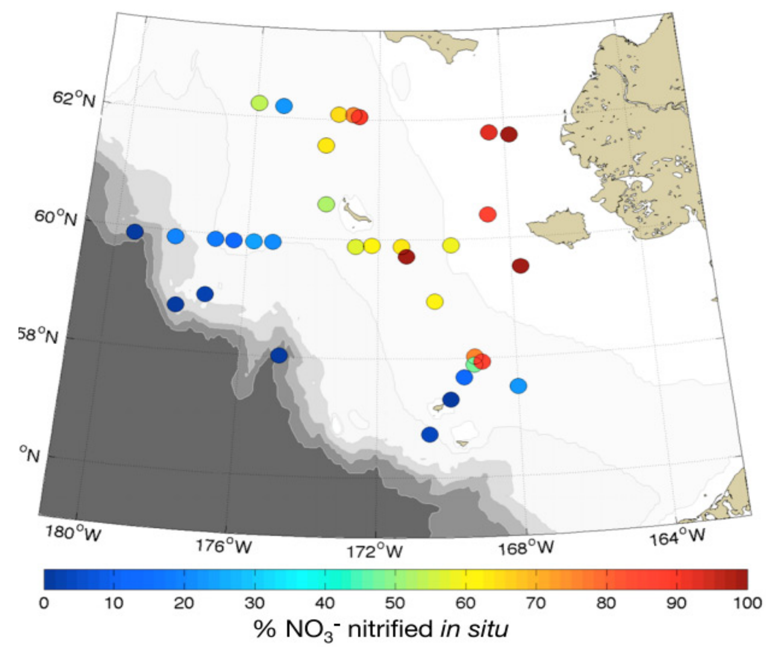


Figure 1. Proportion of nitrate remineralized *in-situ* on the Bering sea shelf (from Granger *et al.*, GBC, 2013).

Dissolved nitrogen stable isotope measurements during the SAS

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RQ1: How are Arctic Ocean water circulation patterns responding to changes in sea ice properties, and atmospheric, advective and freshwater forcing?

RQ3: What are the states of, and changes in, water mass sources, sinks and transformations?

Global Biogeochemical Cycles

Remote Western Arctic Nutrients Fuel Remineralization in Deep Baffin Bay

N. Lehmann, M. Kienast, J. Granger, A. Bourbonnais, M.A. Altabet, J.-É. Tremblay

First published: 01 May 2019 | https://doi.org/10.1029/2018GB006134

Journal of Geophysical Research: Oceans

On the Properties of the Arctic Halocline and Deep Water Masses of the Canada Basin from Nitrate Isotope Ratios

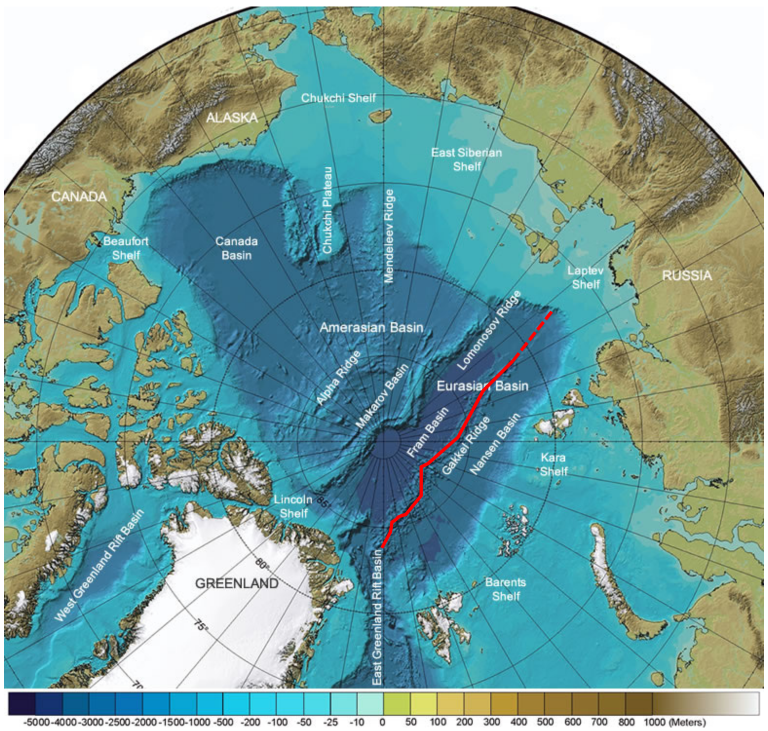
Julie Granger[1], Daniel M. Sigman[2], Jonathan Gagnon[3], Jean-Eric Tremblay[3], and Alfonso Mucci[4]

Published online 10 AUG 2018

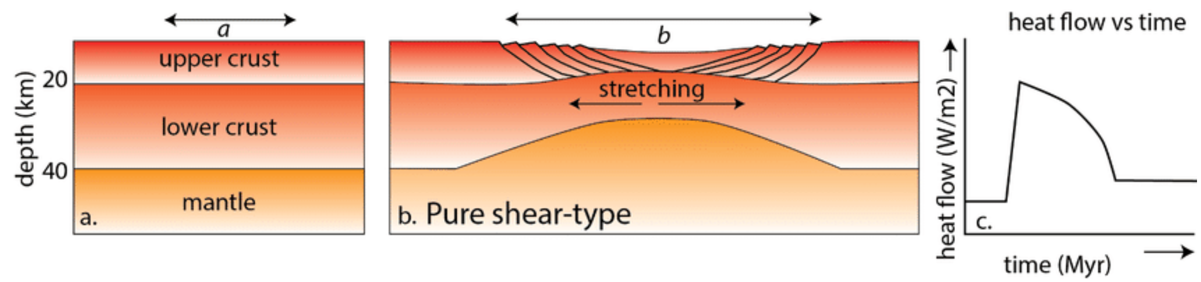
The contribution of rift tectonics to the present-day thermal state of the Arctic Oc

Anouk Beniest

Interests



Arctic Ocean Seafloor Features Map: IBCAO annotated with the names of seafloor features.



Models show surface heat flow increases during rifting. *Beniest, 2017, after McKenzie, 1978*

Two questions:

1) How much does this heat flow increase when rifting goes into break-up and spreading?

2) Does this excessive heat flow add to the thermal budget of the Arctic Ocean and if so, how much?

Anouk Beniest

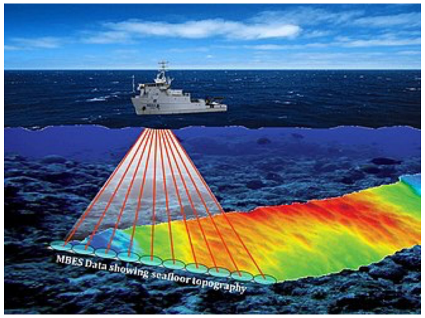
Data/methods

- Bathymetry and shallow seismics

  e.g. multi-beam, sub-bottom profilers
- Gravity

  e.g. gravimeter
- Magnetics

  e.g. mounted magnetometer

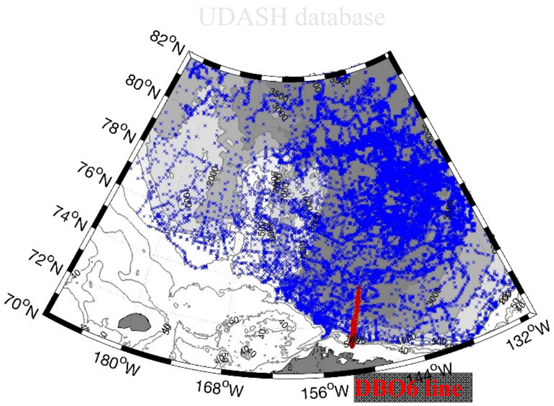


Advantages:

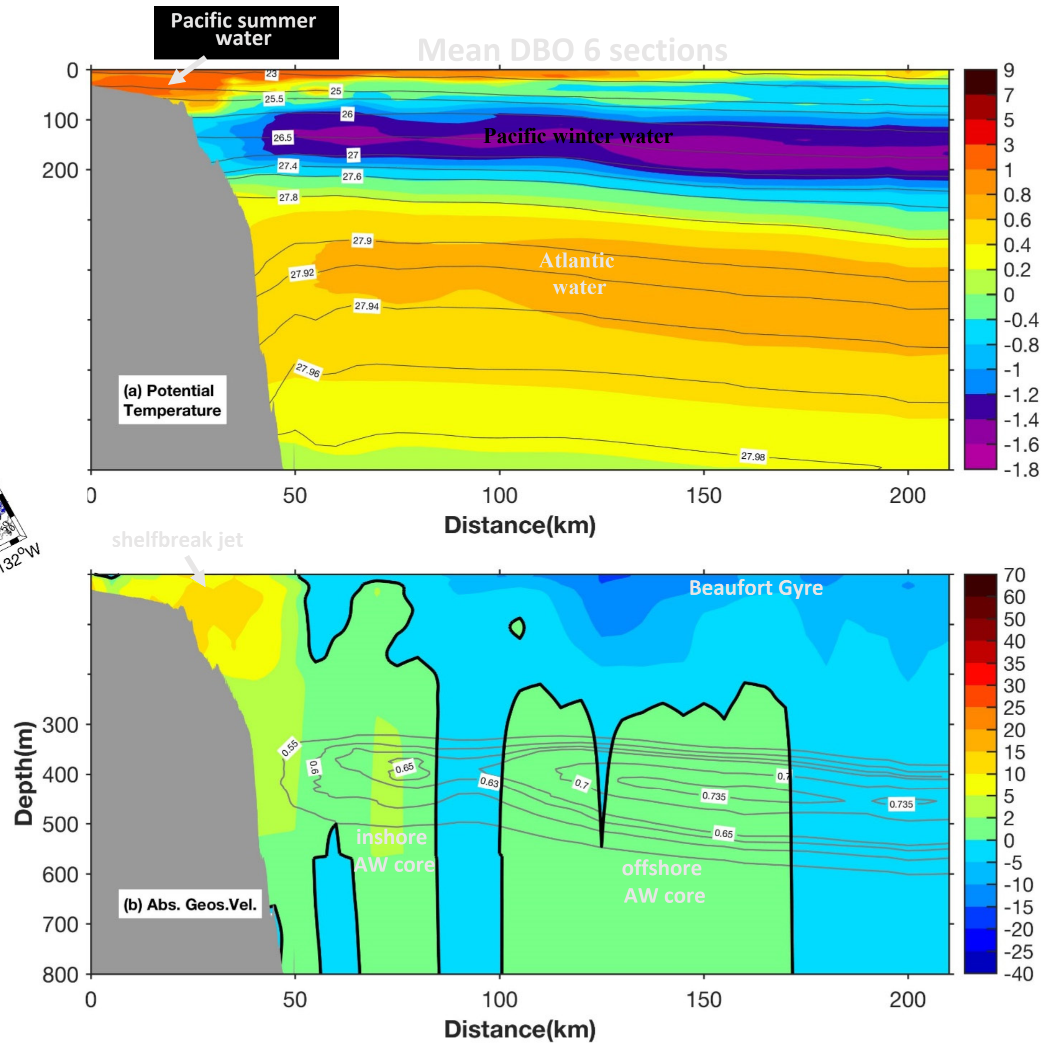
- Standard equipment on research vessels
- Data can be acquired continuously during campaigns
- No large burden, but needs to be monitored for quality and continuity
- With just slightly tweaked ship tracks more unexamined seafloor can be covered
- Important input for oceanographic studies/mapping efforts (e.g. IBCAO and AGP)/modelling studies

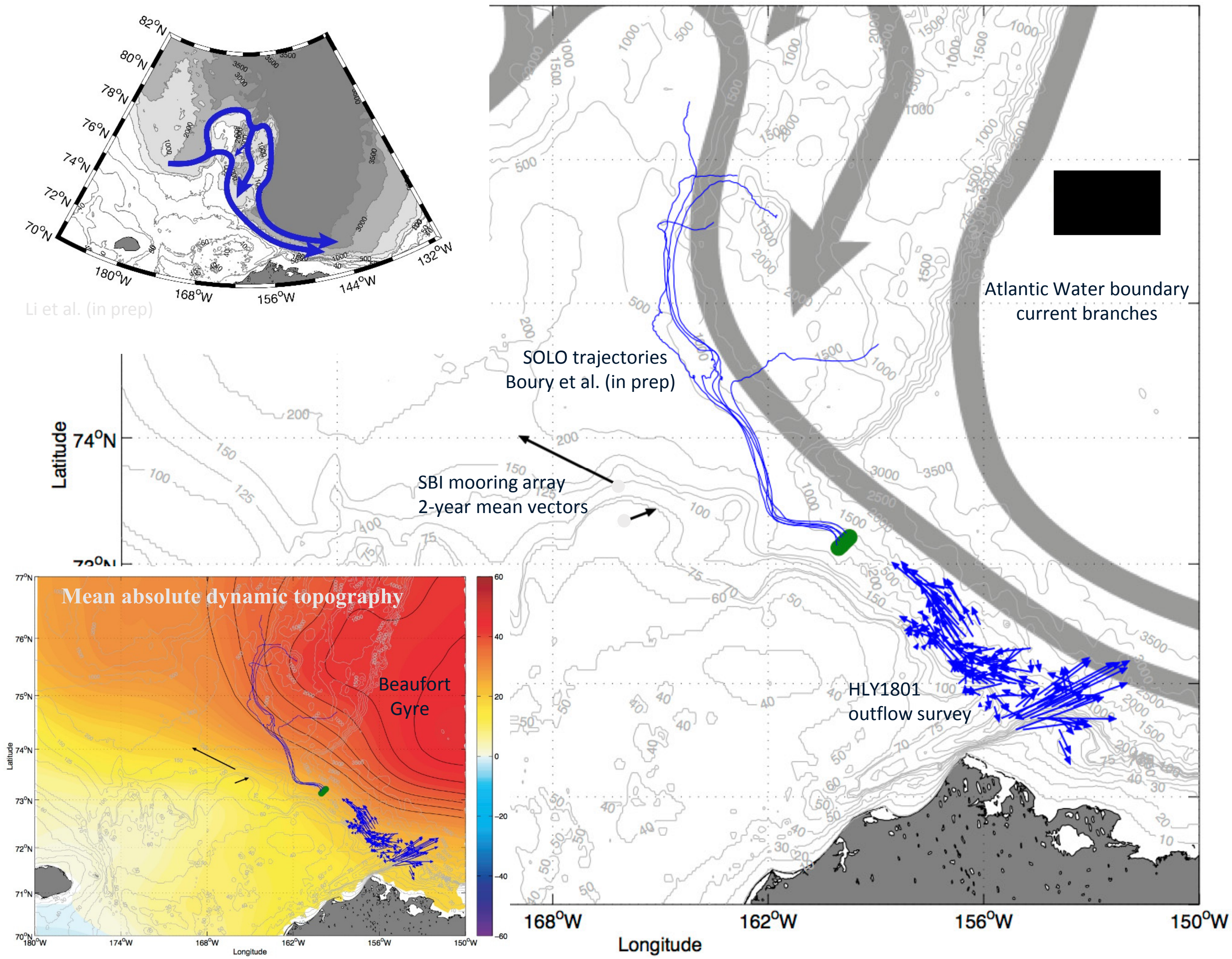
Some thoughts on the circulation of the southern Canada Basin

R. Pickart, WHOI



Li et al. (in prep)





Li et al. (in prep)
[redacted]
Atlantic Water boundary current branches
SOLO trajectories Boury et al. (in prep)
SBI mooring array 2-year mean vectors
HLY1801 outflow survey
Mean absolute dynamic topography
Beaufort Gyre
Latitude
Longitude
74°N
168°W
162°W
156°W
150°W
82°N
80°N
78°N
76°N
74°N
72°N
70°N
180°W
168°W
156°W
144°W
132°W

Improving Arctic ADCP Data

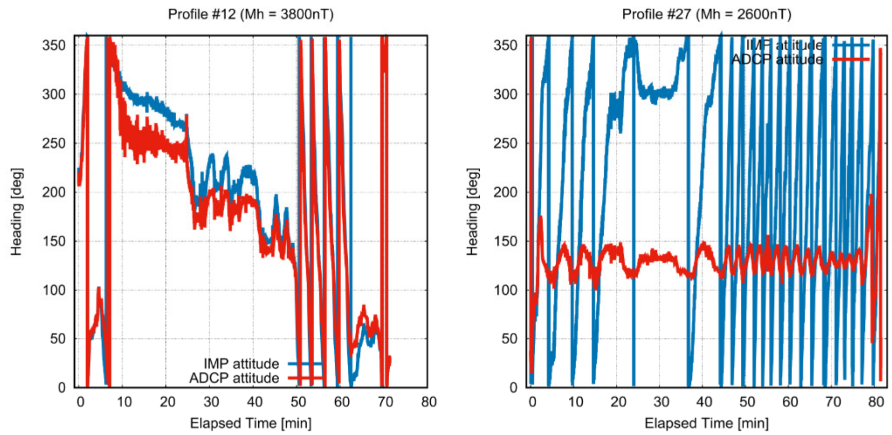
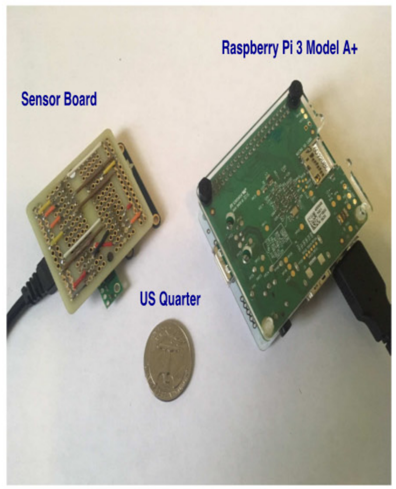


FIG. 6. Heading time series from NABOS profiles (left) 12 and (right) 27. ADCP-derived headings (red) and IMP-derived headings (blue). Horizontal geomagnetic field strength is printed above each panel; the corresponding field inclinations are 86.4° and 87.6°, respectively.

- in regions with large magnetic dip angles (weak horizontal field strength), ADCP compass performance is seriously degraded (errors $>40^\circ$ are common; compass "flat-lining" in extreme cases; *Thurnherr et al., J. Tech., 2017*)
- common accelerometer/magnetometer chips are, however, sufficiently sensitive and accurate to get good heading data for dip angles up to $\approx 88^\circ$

Independent Measurement Package



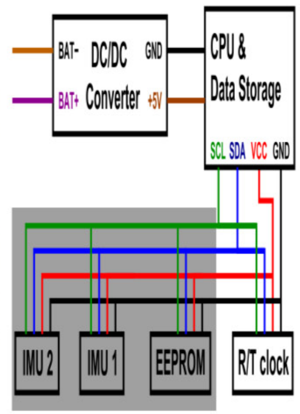


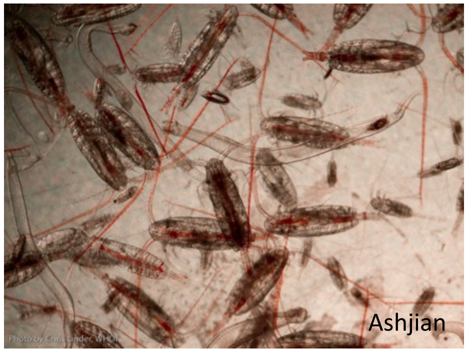
FIG. 1. Schematic of the IMP.

- electronics of the internally-recording accelerometer/magnetometer used by Thurnherr et al. (J. Tech., 2017) can be replicated for less than $200 using commonly available components; firmware is public domain
- a new prototype that may be suitable for moored deployment (low power consumption, smaller form factor) is under development
- software implementation of LADCP processing methodology described in the J. Tech. paper is available from the authors ⇒ `mailto:ant@ldeo.columbia.edu`

Carin Ashjian
Senior Scientist, Biology Department, WHOI
Biological Oceanographer focusing on Zooplankton

My Scientific Approaches

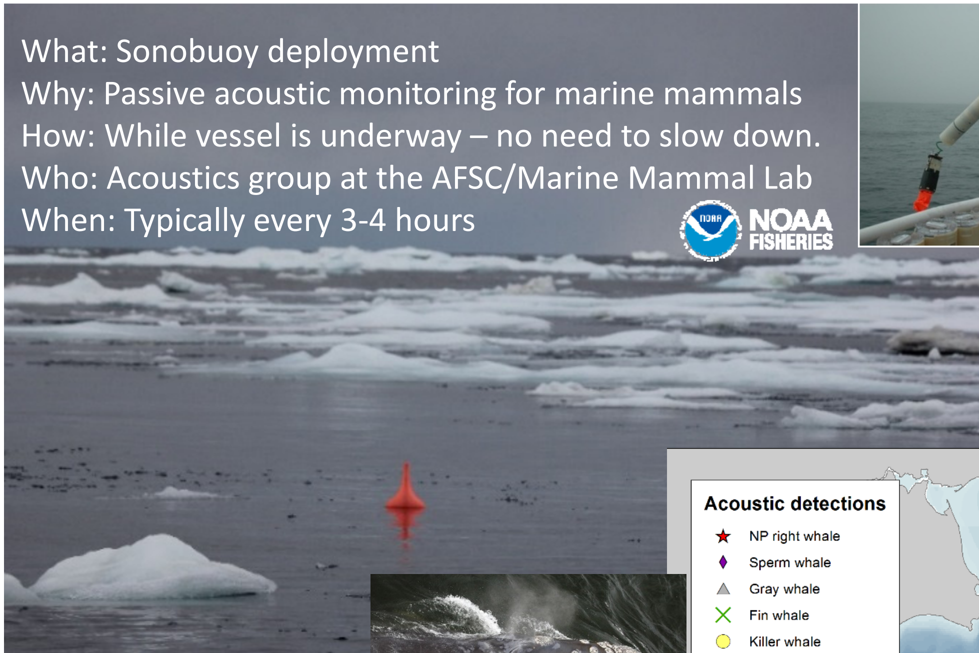
- OBSERVING– Collection of organisms (determination of species, abundances, biomass), chemical and genetic analyses, optical and acoustic observations, large ships, small boats, autonomous systems
- EXPERIMENTATION – Determination of vital rates (grazing, egg production, growth, development, primary production, respiration)
- MODELING- to understand the ecosystem and to predict future conditions - requires abundance/distribution/life history and vital rate data



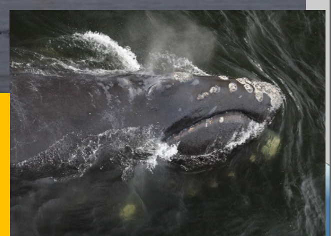
My interests in SAS:

- Zooplankton abundances/biomass and transformations to address the SAS questions:
    - Primary production: Do we seen an increase in zooplankton in response to increased PP? (if that happens)
    - Do we see persistent occurrences of subarctic species and can those species successfully recruit?
    - How do zooplankton transform carbon and does this vary across the different Pan-Arctic regions?
- How can international collaborators come together to achieve the SAS vision?

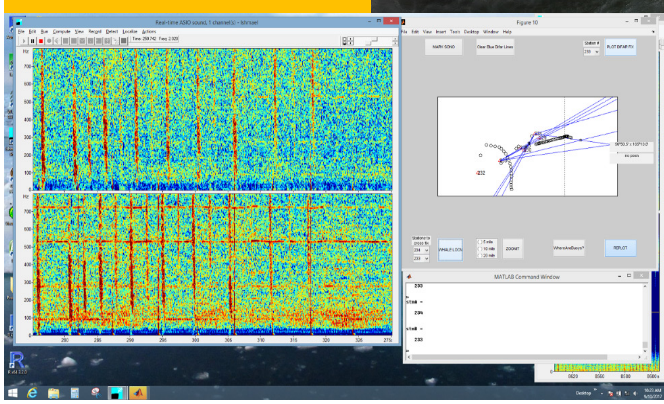
What: Sonobuoy deployment
Why: Passive acoustic monitoring for marine mammals
How: While vessel is underway – no need to slow down.
Who: Acoustics group at the AFSC/Marine Mammal Lab
When: Typically every 3-4 hours

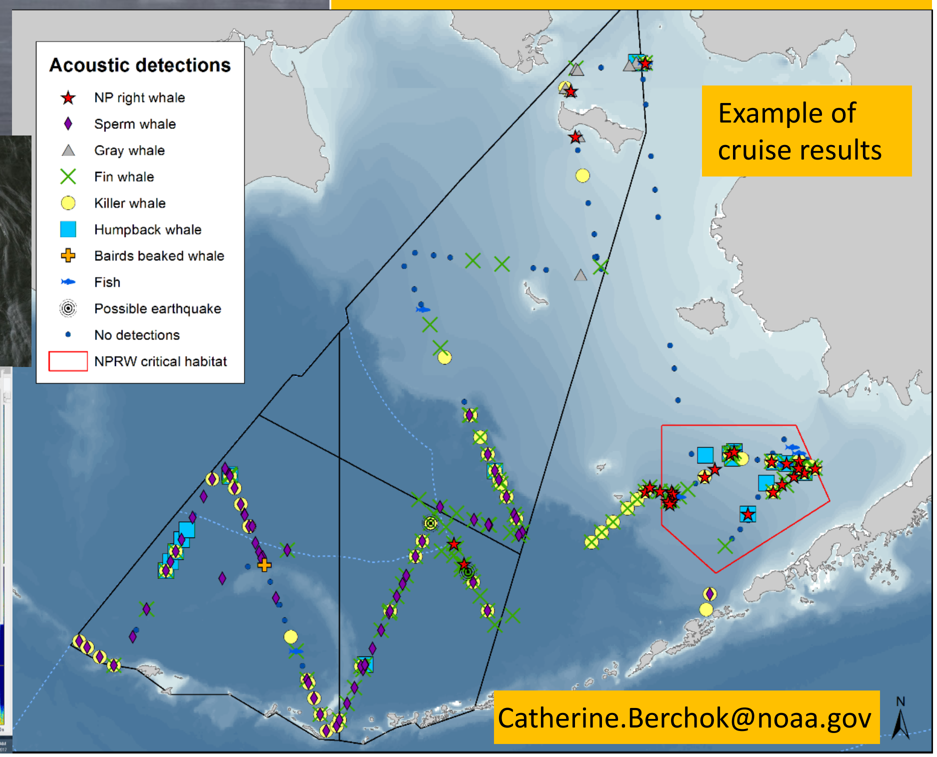


Space requirements: table for 2 laptops & some misc. gear, some space to stage prepped buoys, and a few 4’ cubed crates with buoys



We can also get localizations on sounds





Example of cruise results

Catherine.Berchok@noaa.gov

Bivalve Population Shifts and Contribution to Overall Benthic Ecosystem

Time-series analyses of abundance, biomass, and size class distributions of dominant bivalve species

Christina Goethel

University of Maryland Center for Environmental Science

- **Pacific Arctic Focus- Distributed Biological Observatory**
- **Northern Bering Sea (DBO1)**
- **Southeast Chukchi Sea (DBO3)**
- **Annual Changes**

-Changes in dominant species?

-Declining biomasses?

-Shifts in location of high biomass?

Pan-Arctic Species

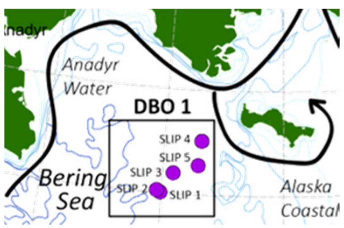
Local community implications

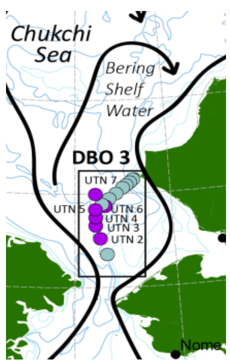
Seasonal and Annual Data compliments

Raphaelle Descoteaux

UiT, The Arctic University of Norway

- **Atlantic Arctic Focus**
- **Meroplankton**
- ***Macoma calcarea, Serripes spp.***
- **Seasonal Data**





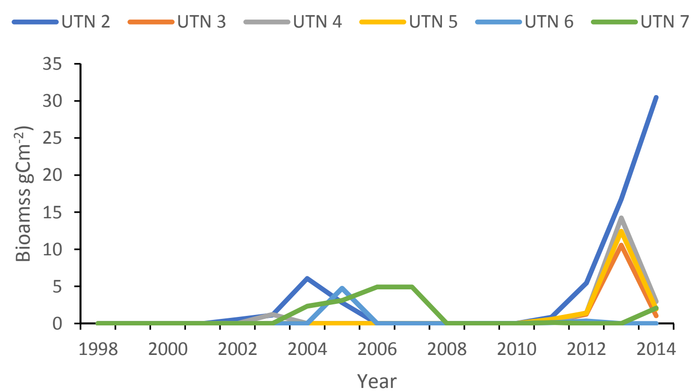
Macoma calcarea

Nuculana spp.

Serripes spp.

Example Data

Biomass of *Serripes groenlandicus* in DBO 3



Working together to try and understand a complete picture of the life cycles of these circum-Arctic bivalve species.

Ex:

What size do these bivalves settle to the benthos?

When do they settle?

-2014 increase in biomass and abundance of *Serripes* especially in southern DBO 3 sites with a crash in 2018

- *M. calcarea* abundance declining at previous hotspot UTN 5 - increasing at sites to the south

Bivalve Population Shifts and Contribution to Overall Benthic Ecosystem

Sediment oxygen utilization incubations and individual metabolic rates of dominant clam species in each DBO region- with focus on DBO 1 and DBO 3

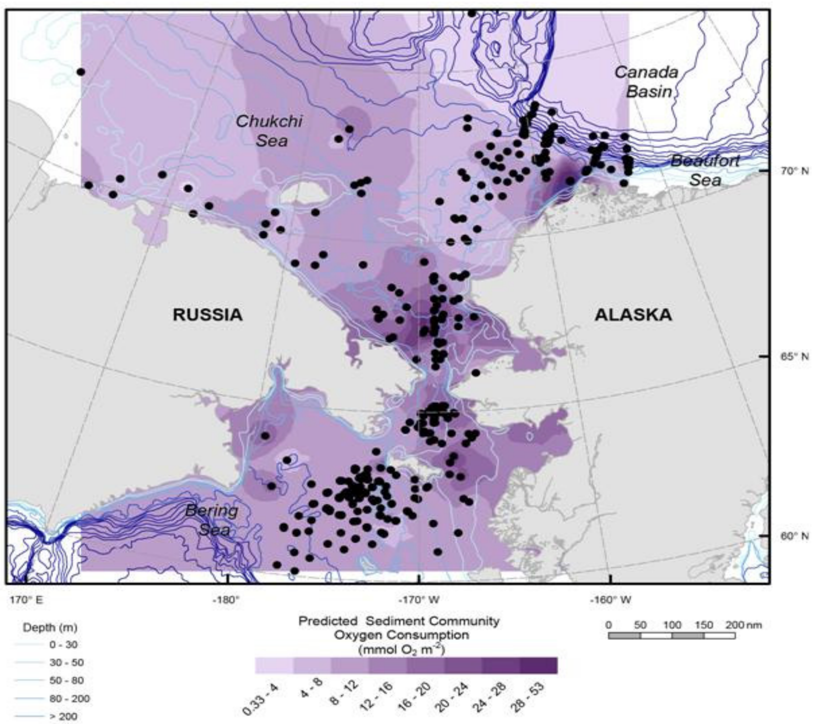


Fig. 1 Sediment Oxygen Community Consumption from 2000-2012 (Grebmeier 2012)

- Time-series analyses of changing sediment community oxygen consumption (SCOC) from 1984-2019 (Fig. 1)

- Changes in SCOC with changing environmental conditions:
    - Temperature
    - Food availability/quality
    - Food experiments started in July and August 2018
    - Temperature and food experiments scheduled for July and August 2019

- Bivalve contributions to overall community SCOC:
    - Individual metabolic rates of dominant species in each DBO region (ambient and elevated temperatures)
    - How are species shifts in bivalve communities changing the SCOC?

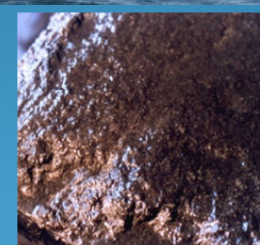
Professor Cindy Pilskaln, School for Marine Science and Technology
University of Massachusetts, Dartmouth, MA, USA

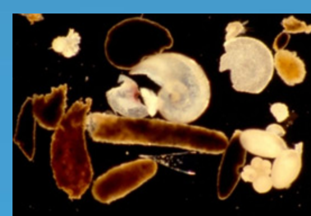
Biogeochemical Particle Flux and Sedimentation Group

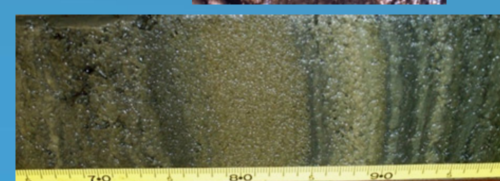
<u>Overarching Research Goals</u>:

Characterize, quantify, & model mechanisms of particle flux through the ocean and delivery to sediments.

****Primary focus on CARBON export as function of biophysical & chemical forcing on variable time scales.***







Pilskaln, 2019 SAS Planning Wkshop

Proposed Contributions to Synoptic Arctic Survey

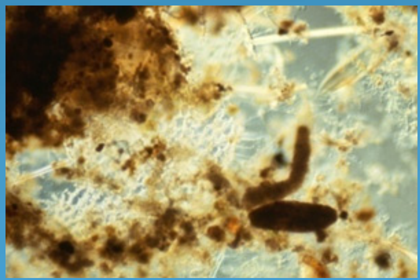
Carbon Cycle/OA Focal Area

(Science & Implementation Plan, Research Questions 7-9):

***Measurements of POC and PIC: SAS Niskin and/or pump sampling and lab-based analysis.**

***Measurements of carbon export: Short-term sediment trap deployments on SAS cruise and lab-based analysis.**

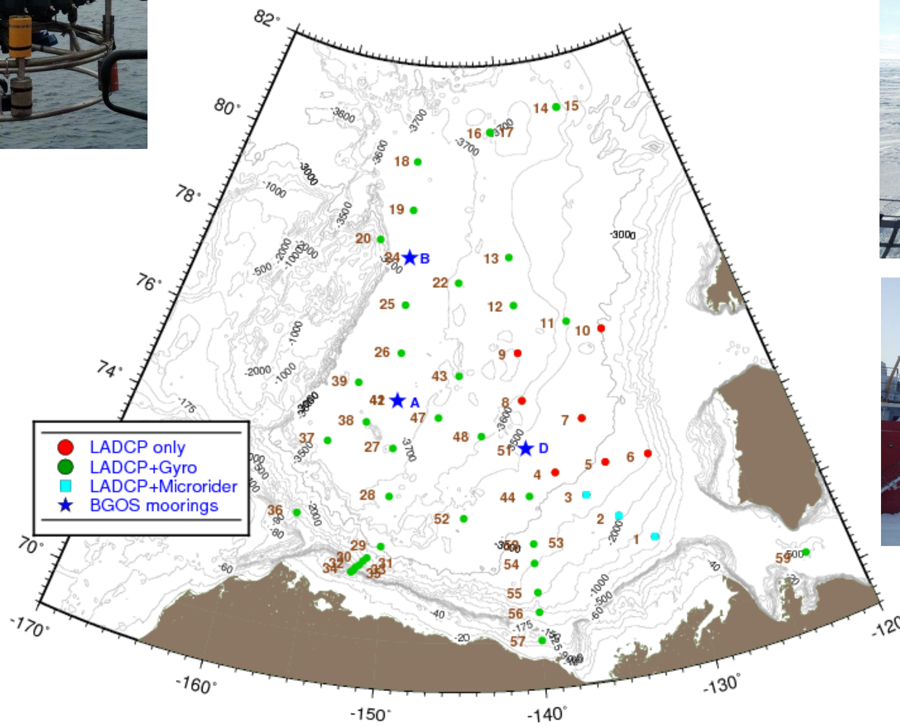
***Measurements of POC and PIC particle size, type (e.g., fecal pellets, marine snow, algal aggregates) and sinking rates: Optical instrument (e.g., VPR, LISST-HOLO2) profiling and post-cruise quantitative image analysis.**



Pilskaln, 2019 SAS Planning Wkshop

2017 Cruise SL1711
Beaufort Gyre Stations

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

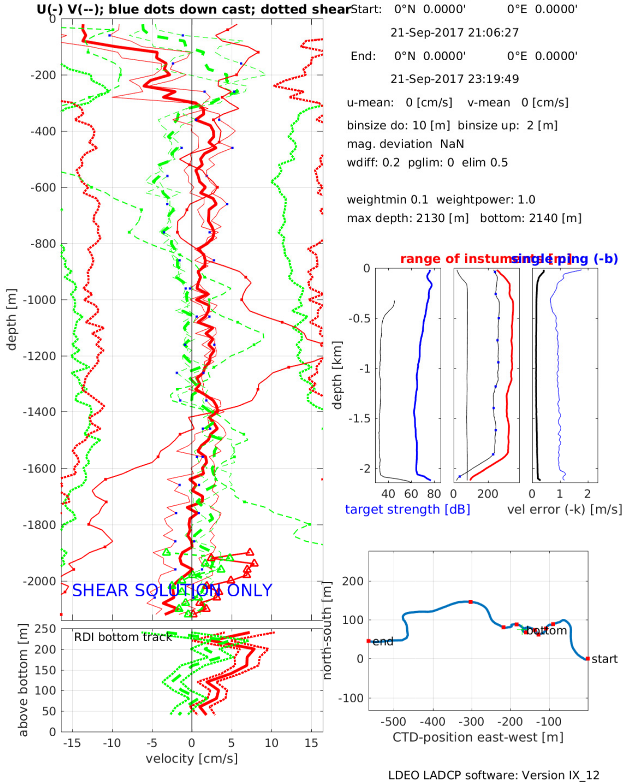


Office of Naval Research ONR Science & Technology

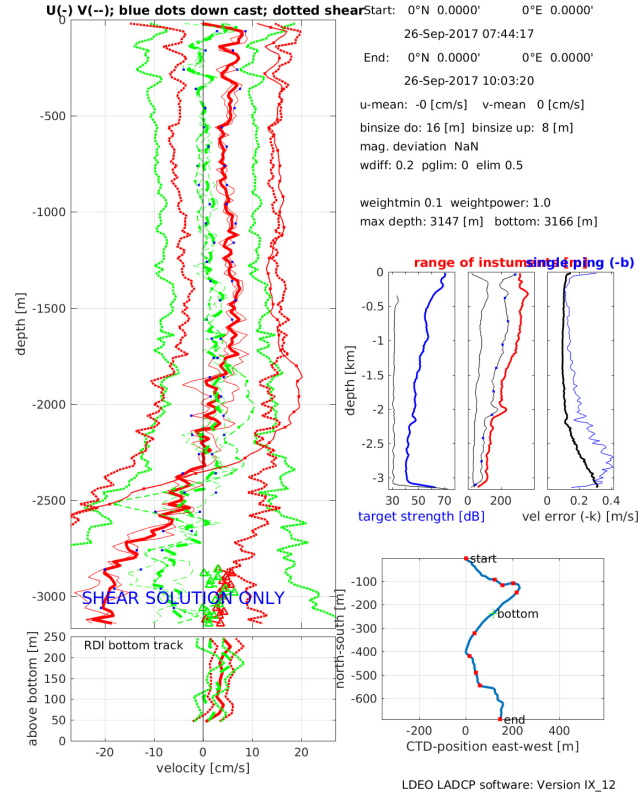
Daniel J. Torres, WHOI

Stratified Ocean Dynamics of the Arctic (SODA)

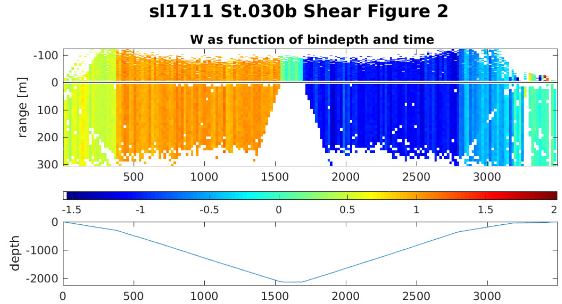
Station : sl1711 St.030b Shear Figure 1



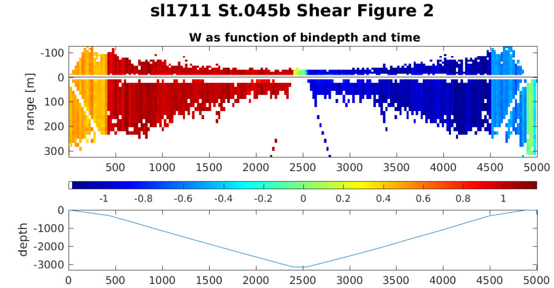
Station : sl1711 St.045b Shear Figure 1



sl1711 St.030b Shear Figure 2



sl1711 St.045b Shear Figure 2



ACIDIFICATION STATE OF THE KARA SEA

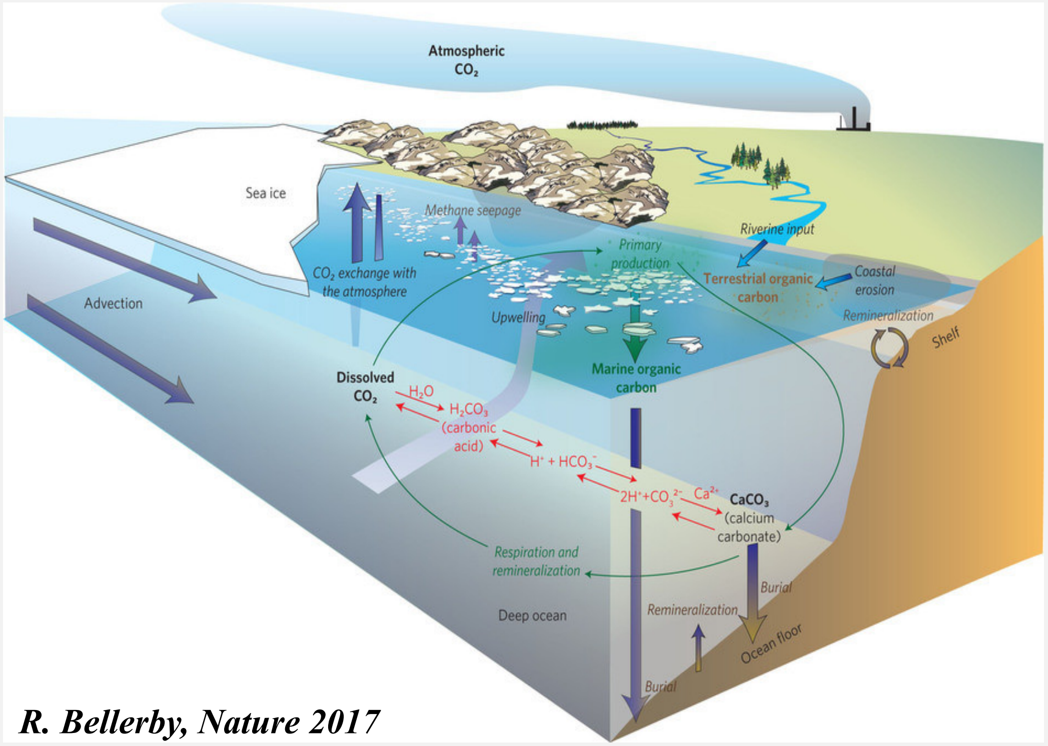
Alexander Polukhin and Julia Pronina

Shirshov Institute of Oceanology, Russian Academy of Sciences

polukhin@ocean.ru

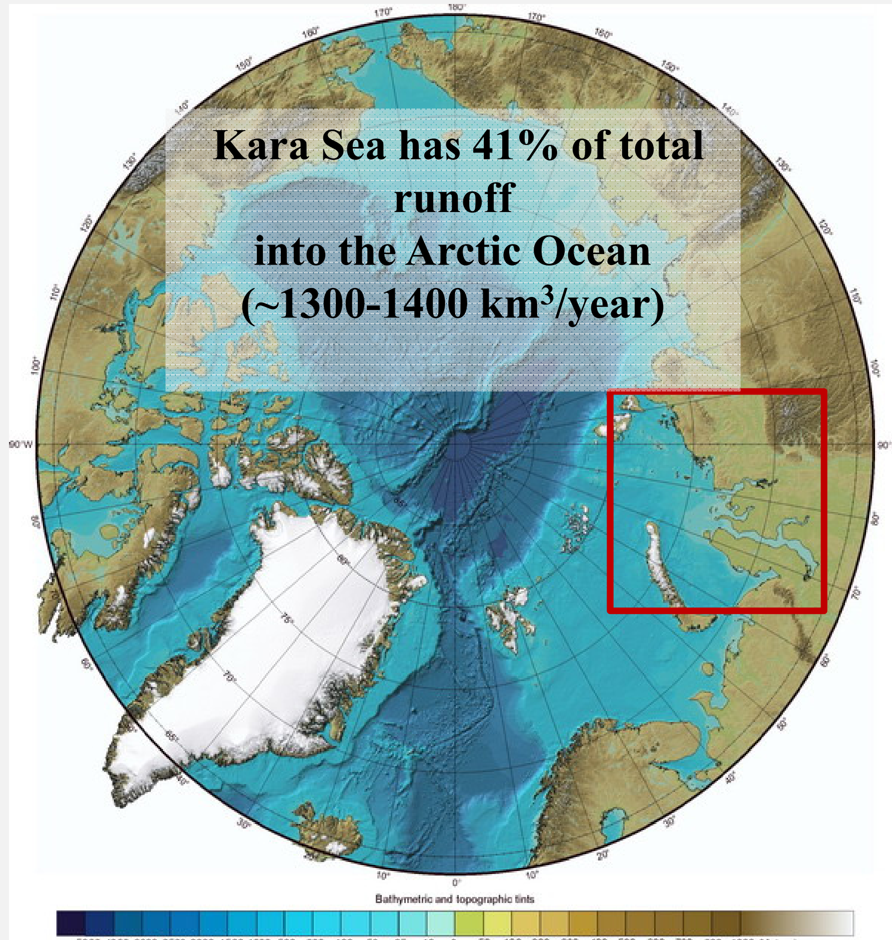
SAS International Workshop, May15-16 2019, Woods Hole, MA, USA

MOTIVATION

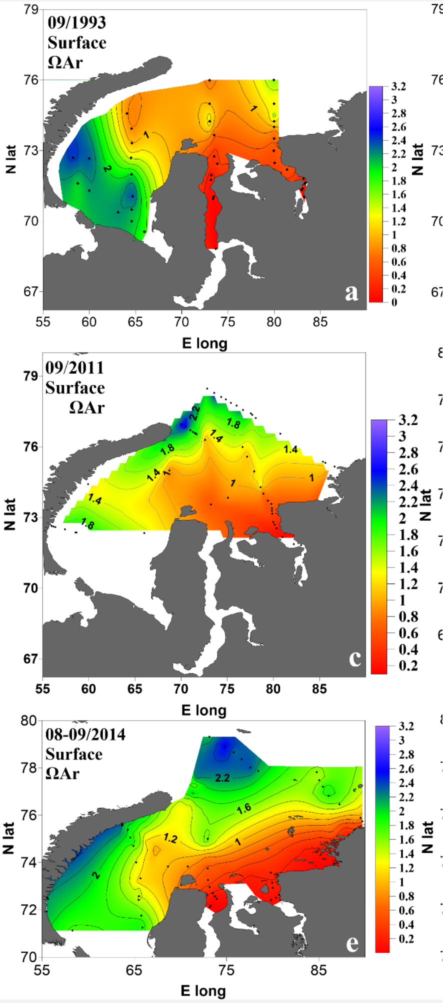


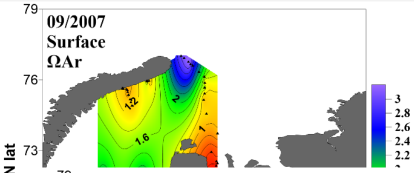
R. Bellerby, Nature 2017

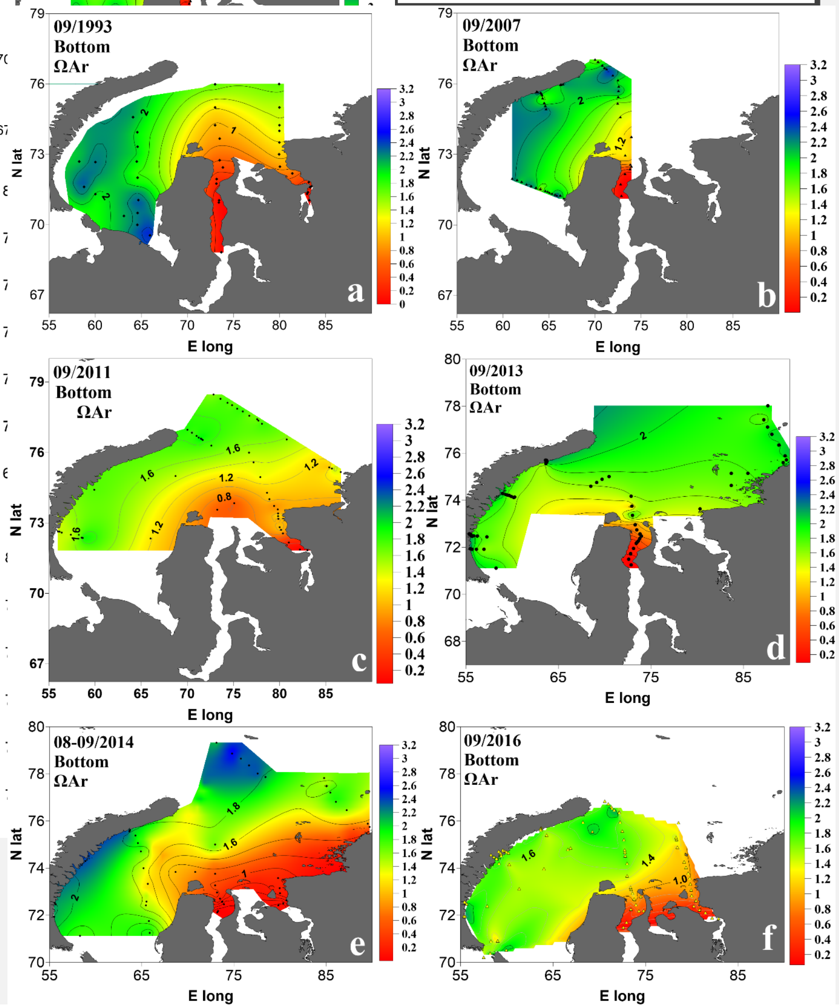
Arctic Ocean acidification is responding to changes in the marine carbon and hydrological cycles. Increases in carbon are sourced from the atmosphere, land, and advection from other oceans. Ocean acidification can be further regulated or enhanced by internal, physical, biological, and geochemical processes

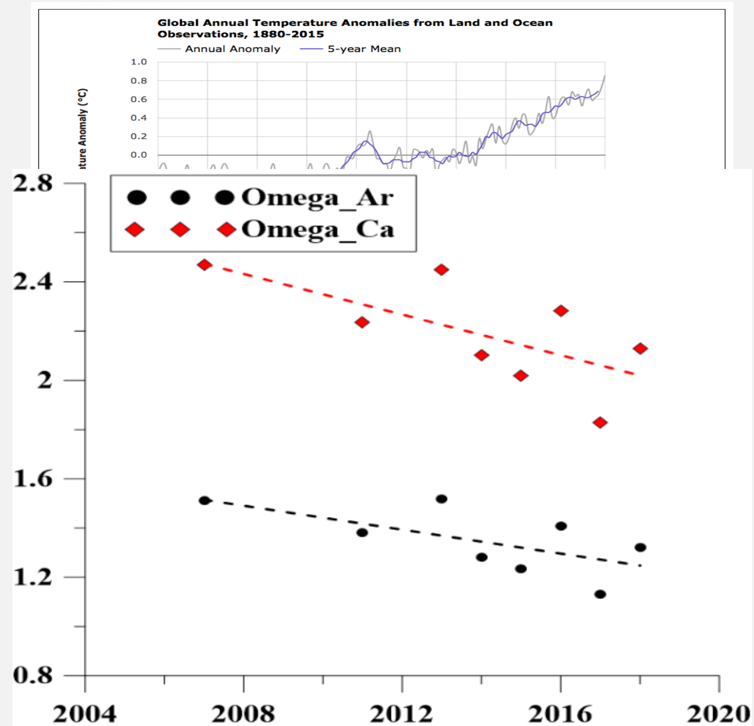


RESULTS

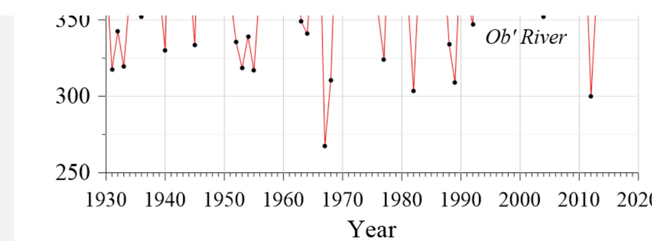








Mean Ω_{Ca} and Ω_{Ar} saturation in the surface layer of the Kara Sea for 2007-2018 period



THANK YOU FOR YOUR ATTENTION!

RUSSIAN FOUNDATION FOR BASIC RESEARCH SUPPORTED PROJECT № 18-35-00009 "INVESTIGATION OF ACIDIFICATION PROCESS OF THE KARA SEA WATERS IN THE CONTEXT OF CLIMATE CHANGES IN THE ARCTIC REGION"

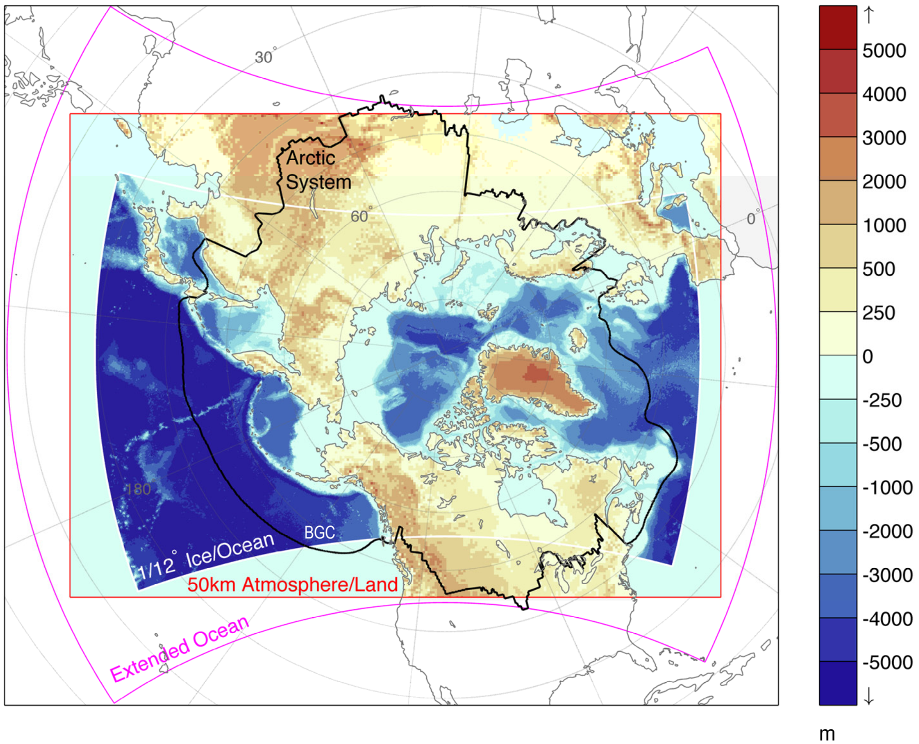
RASM

Hidden productivity: On the importance of pelagic phytoplankton blooms beneath Arctic sea ice

Jackie Clement Kinney and the RASM team

Regional Arctic System Model

- pan-Arctic, high-resolution
- ocean, ice, biogeochemistry, atmosphere, land hydrology, river routing
- Multiple configurations
  - Fully-coupled
  - ice-ocean-bgc forced with reanalysis atmospheric fields
  - Recently added JRA-55 forcing from 1950's-present
  - Plan to move to 2km for BGC



RASM

Hidden productivity: On the importance of pelagic phytoplankton blooms beneath Arctic sea ice

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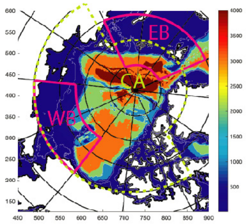
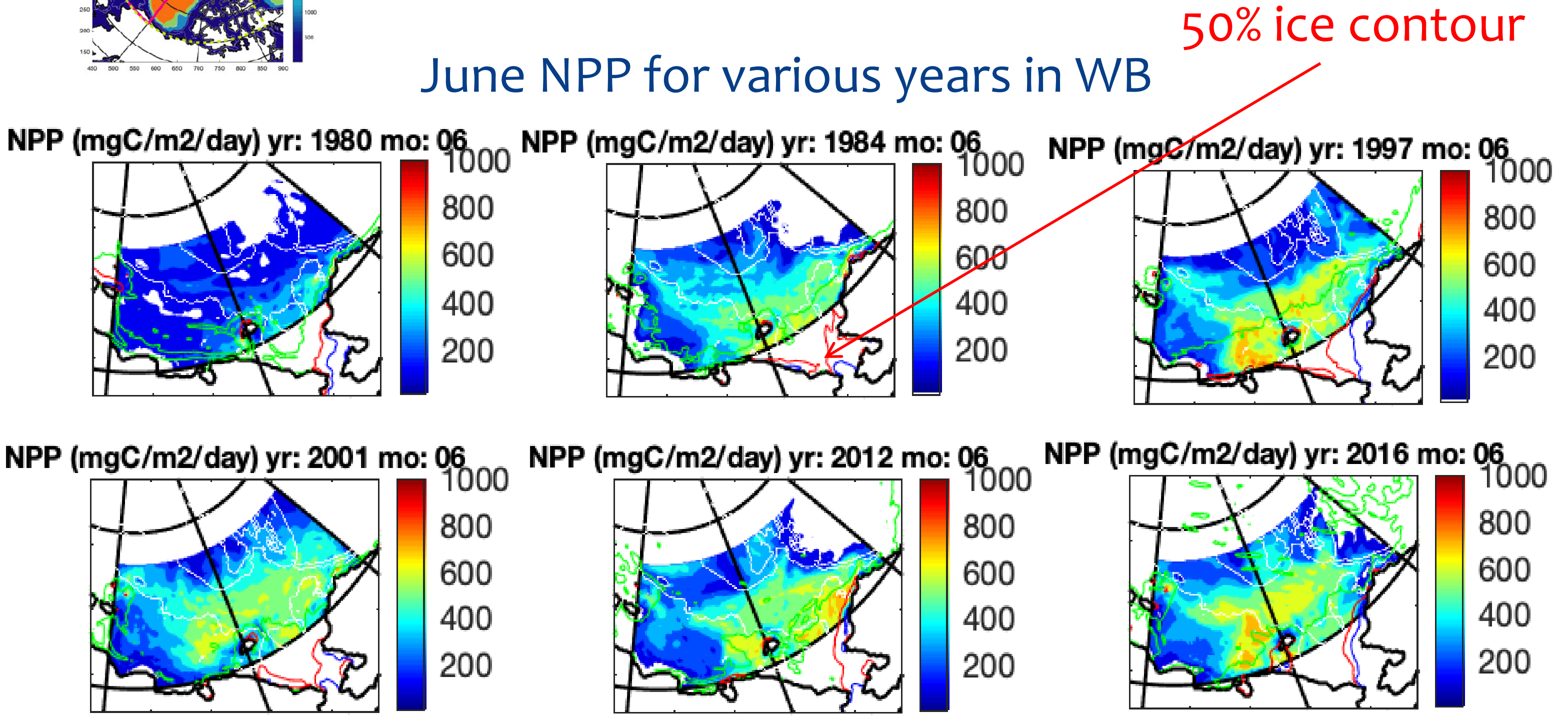


June NPP for various years in WB

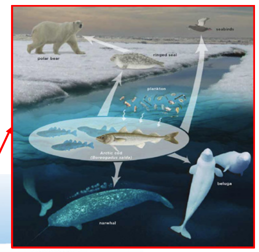


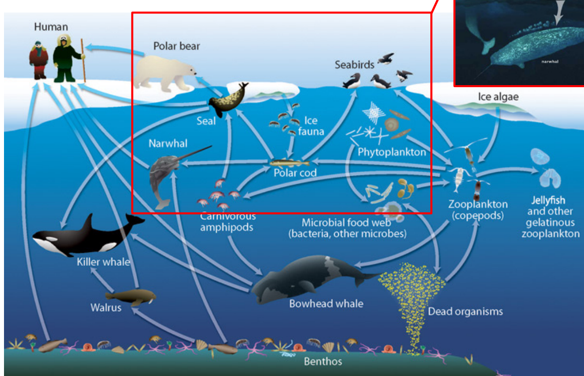
- June bloom happens every year…but a lot of interannual variability

Synoptic Arctic Survey (SAS): Proposed Biological Studies Jackie Grebmeier, Chesapeake Biological Laboratory, UMCES, Solomons, MD, USA; jgrebmei@umces.edu

Synoptic Arctic Survey

Arctic Food Web Marginal Ice Zone Regions and Upper Surface Area of the High





[Large figure: PAME 2016 Arctic MPA's. Insert: Arctic food web (Harrison et al. 2017)]


In a boon for fish stocks, the Barents Sea last year saw a steep rise in photosynthesis by phytoplankton (blue-green bloom above) and other organisms.

CLIMATE CHANGE

Nations put science before fishing in the Arctic

Historic fishing ban gives scientists time to probe ecology as northern waters warm

By Hannah Hoag

Nine nations and the European Union have reached a deal to place the central Arctic Ocean (CAO) off-limits to commercial fishers for at least the next 16 years. The pact, announced last week, will give scientists time to better understand the region's marine ecology—and the effects of climate change—before receding sea ice opens the way to widespread fishing.

"There is no other high seas area where we've decided to do the science first," says Scott Highleyman, vice president of conservation policy and programs at the Ocean Conservancy in Washington, D.C., who was part of the U.S. delegation involved in the negotiations. "It's a great example of putting

gobbled up by Arctic cod, which in turn are hunted by animals higher up the food chain, including seals, polar bears, and humans. Some parts of the Arctic Ocean's adjacent seas, such as the Barents Sea (off the northern coasts of Russia and Norway), saw steep increases in primary production—photosynthesis by plankton and other organisms—in 2016, approaching 35% above the 2003 to 2015 average, according to the U.S. National Oceanic and Atmospheric Administration.

Farther north, the state of fish stocks in the CAO is unknown, but existing international law does not prohibit fishing there. Some researchers, environmental groups, and policymakers fear unregulated commercial fishing in the CAO could harm the fragile and rapidly changing marine ecosystem. In the late 1980s, fishing trawlers from

fishing] until there was enough science and management in place," says David Balton, deputy assistant secretary for oceans and fisheries at the U.S. Department of State in Washington, D.C., who has chaired the negotiations since 2015. The deal will stand for 16 years, and will renew automatically every 5 years after that unless a country objects or until science-based fisheries quota and rules are put in place.

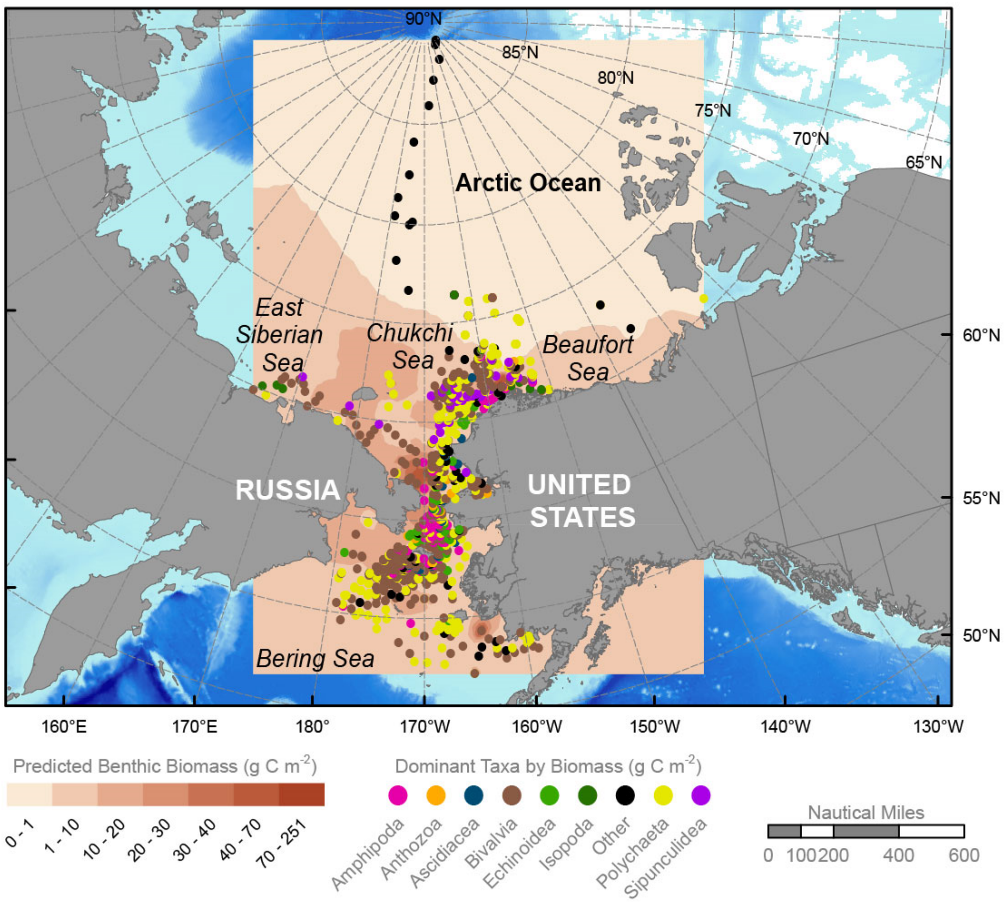
In addition to closing the area to fishing, the delegations have agreed to a research and monitoring program to identify species, their abundance, predator-prey relationships, and the pressures they face, including climate change. It hasn't been worked out yet how the program would be funded and managed, Balton says.

November 2017: Agreement between USA, Canada, Russia, Norway, Denmark, China, Japan, South Korea, Iceland & the EU: No commercial fishing in the High Sea in the coming 16 years and scientific cooperation

- evaluate shelf-basin exchange of biological and chemical component connected to the Central Arctic Ocean

http://www.synopticarcticsurvey.info/splan.html; https://web.whoi.edu/sas2019/

Distribution of macroinfaunal station biomass (g C m^{-2}) and dominant infaunal over four decades (1970-2012) in the Pacific Arctic



[Bluhm and Grebmeier 2011]

- Limited biogeochemical and biological studies on the outer continental shelf and slope regions Pacific Arctic into the Central Arctic Ocean
- Proposed subset of stations for benthic macrofaunal collections and sediment characteristics using a multi-HAPS corer
- Need for acoustic monitoring and net/trawls for plankton (prey) and fish (acoustics/science mid-water trawls)

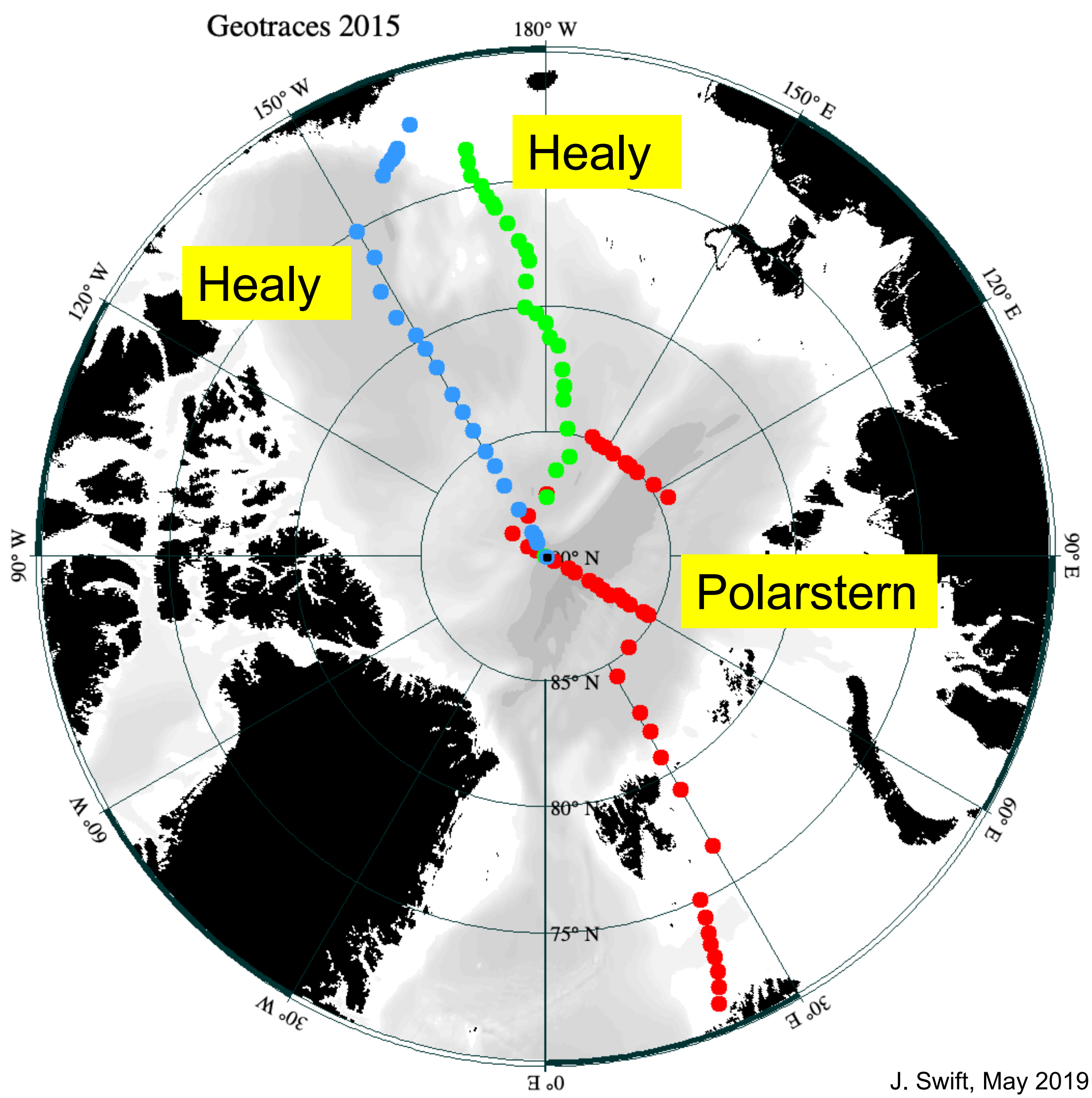
GO-SHIP Section ARC-01 and SAS

The international repeat hydrography program (now called GO-SHIP) incorporates an Arctic transect as part of its global array of ‘decadal’ reference-quality sections.

During international Geotraces Arctic in 2015, USA and German teams planned to carry out their measurements to GO-SHIP standards, though without a couple of key parameters, and in some basins with greater station spacing than optimal for GO-SHIP.

The US National Science Foundation provided added ship time & salaries (for extra stations from the Healy), broadened ocean carbon measurements (Healy), and supported CFC measurements (both ships) to bring the work significantly closer to GO-SHIP standards.

Hence a GO-SHIP 2015 trans-Arctic section can now be assembled from the Healy and Polarstern 2015 data, with choice of Makarov or Canada Basin track. (Principal exception: Nansen Basin and Barents slope spacing.)



J. Swift, May 2019

US GO-SHIP intends to propose section ARC-01, to be carried out in the first half of the 2020s from USCGC Healy or other icebreaker.

Measurements would include the complete GO-SHIP suite, to reference quality (CTDO/LADCP, S, O2, nutrients, CFCs/SF6, ocean carbon, etc.), full depth; ≤ 36 levels sampled per station; close station spacing at boundaries; ≈28 scientists, techs, and students.

ARC-01 can be run in either direction. Prefer to run the entire transect from one ship. Track does not enter the Russian EEZ. (Track shown is a preliminary schematic; actual track TBD.)

US GO-SHIP is happy to cooperate and coordinate with other programs, but there are issues to be addressed:

- extra ship time and costs of extra GO-SHIP salaries for any added time at sea
- does the repeat hydrography track (ARC-01) line up OK with SAS planned sections?
- probably prefer Makarov to Canada basin
- probably cannot do ARC-01 until after 2021

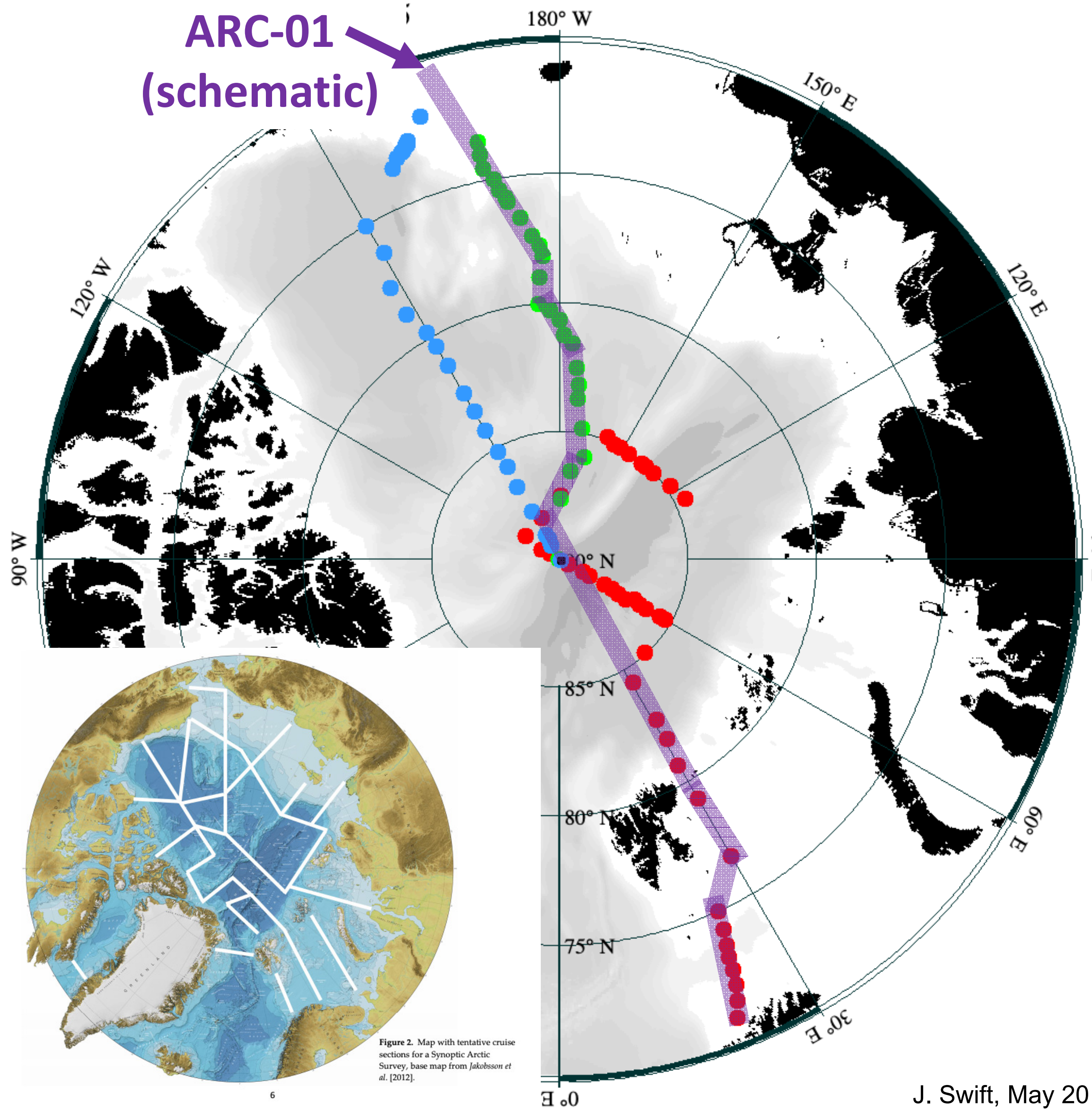
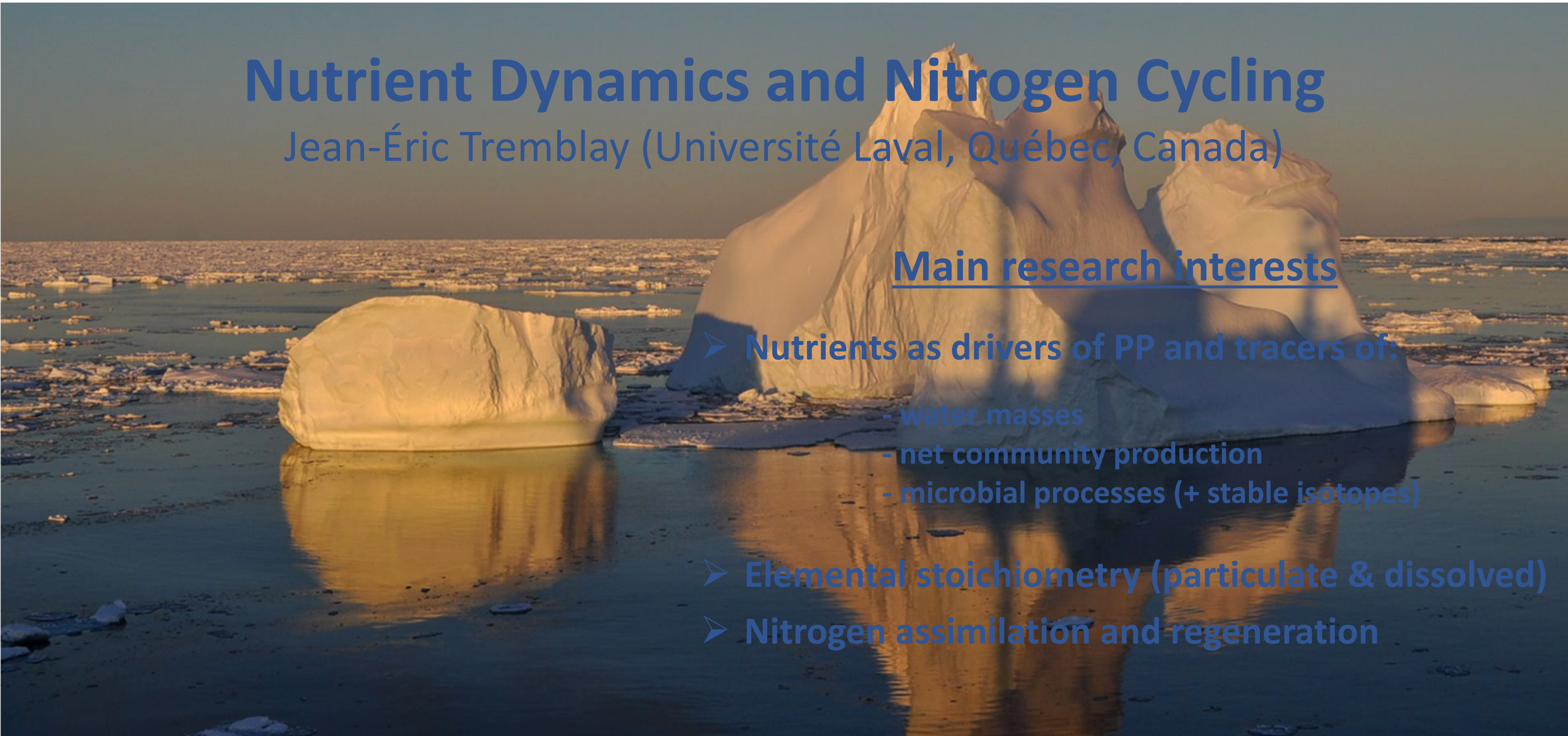


Figure 2. Map with tentative cruise sections for a Synoptic Arctic Survey, base map from *Jakobsson et al.* [2012].

J. Swift, May 2019

Nutrient Dynamics and Nitrogen Cycling

Jean-Éric Tremblay (Université Laval, Québec, Canada)



Main research interests

- Nutrients as drivers of PP and tracers of:
  - water masses
  - net community production
  - microbial processes (+ stable isotopes)
- Elemental stoichiometry (particulate & dissolved)
- Nitrogen assimilation and regeneration

ArcticNet ᐅᑭᐅᖅᑕᖅᑐᒥ ᑐᑭᓯᓂᐊᖅᑏᑦ

AMUNDSEN SCIENCE

Institut nordique du Québec
Together for the North

Québec OCÉAN

Objectives

1) Measure concentrations of macronutrients and trace metals, estimate transports
2) Evaluate how microbial processes affect and are affected by nitrogen inventories and nutrient ratios
3) Assess how the elemental composition and fatty acid profiles of microalgae are affected by physical and chemical water properties.

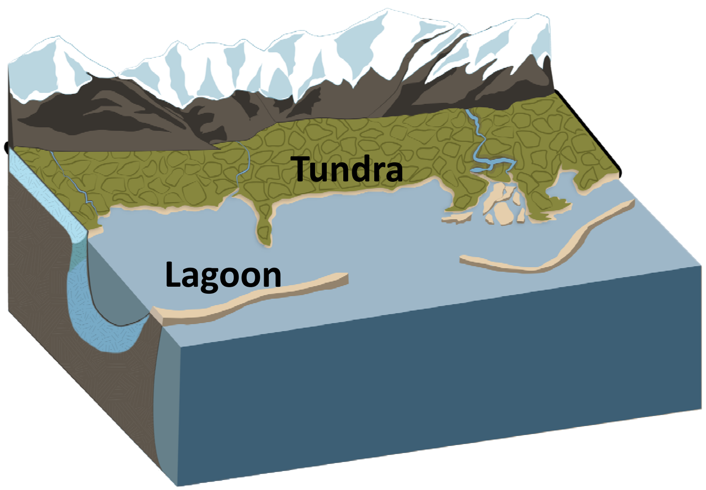
PI's: JET, Jay Cullen, Paul Myers, Chris Parrish, Connie Lovejoy

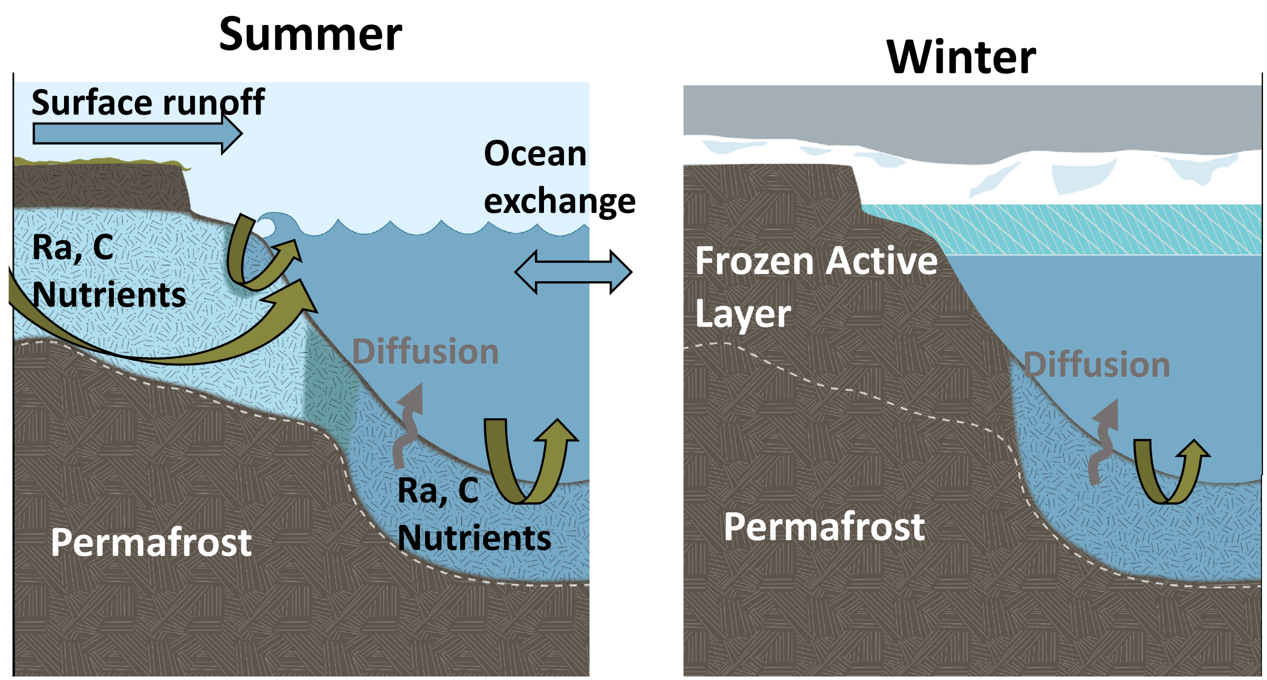
+ project led by Brent Else

Radium isotopes: Groundwater discharge

Jessica Dabrowski (MIT/WHOI, Advisor: M. Charette)

$$\frac{d(^{226}Ra)}{dt} = Runoff + Diffusion + GW \; - \text{ocean exchange}$$





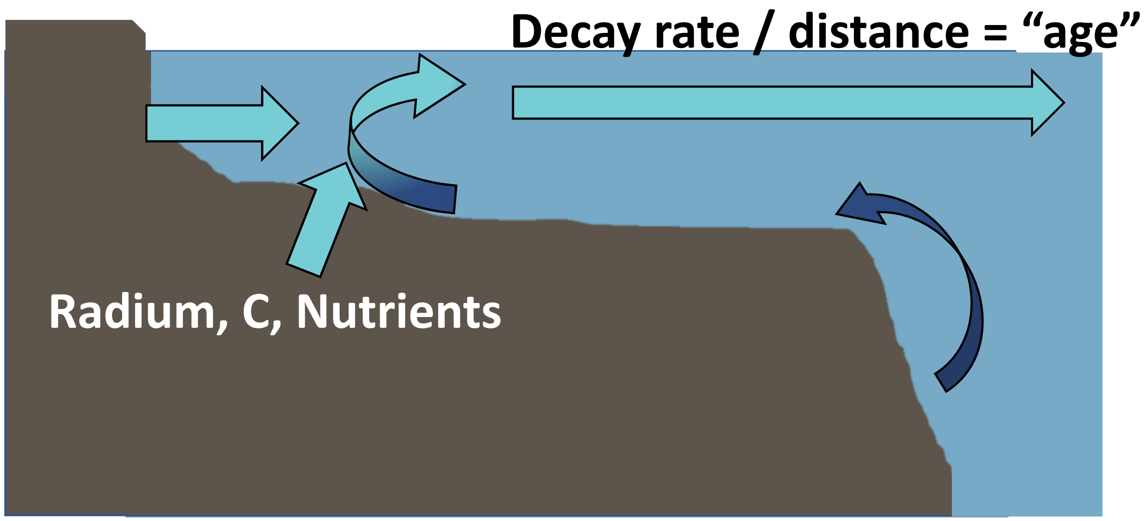
Significance:

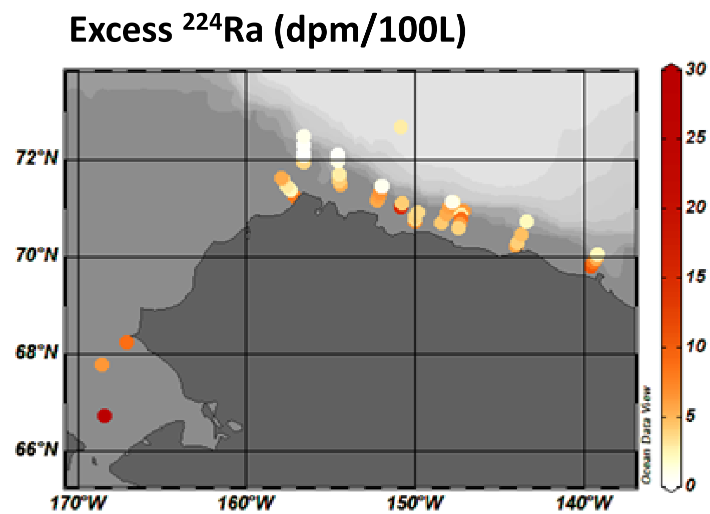
- Nutrient and carbon fluxes to productive ecosystems
- Understanding hydrology in permafrost zones
- Setting baselines

Graphics: N. Reiner, WHOI Graphics; annotated by J. Dabrowski;

Radium isotopes: **Beaufort/Chukchi Shelves**

Jessica Dabrowski (MIT/WHOI, Advisor: M. Charette)



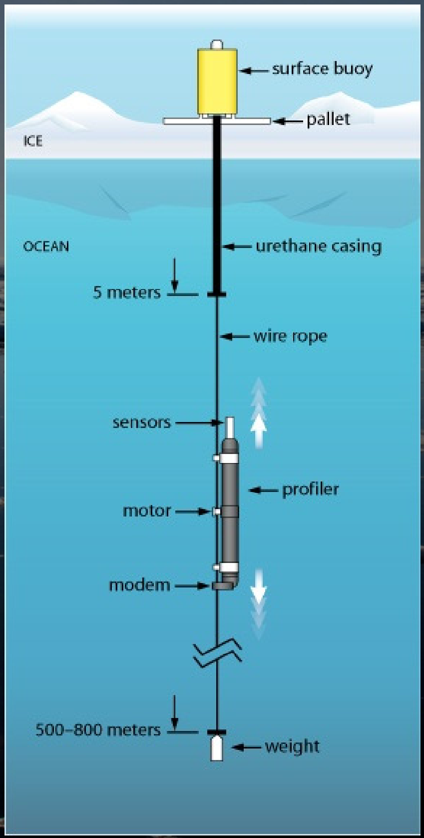


Significance:

- Short-lived and long-lived isotopes = timescales of days to seasons to years
- Benthic fluxes to productive ecosystem
- Cross-shelf transport rates and residence times in under-sampled late fall/early winter
  - Integrates heterogeneity of upwelling/downwelling
- Seasonal vs. interannual variability

Sustained observation and analysis of the Arctic upper ocean thermohaline

J. Toole,
S. Cole, R. Krishfield, S. Laney,
J. O'Brien, A. Proshutinsky,
F. Thwaites, M.-L. Timmermans,
and countless engineers and technicians



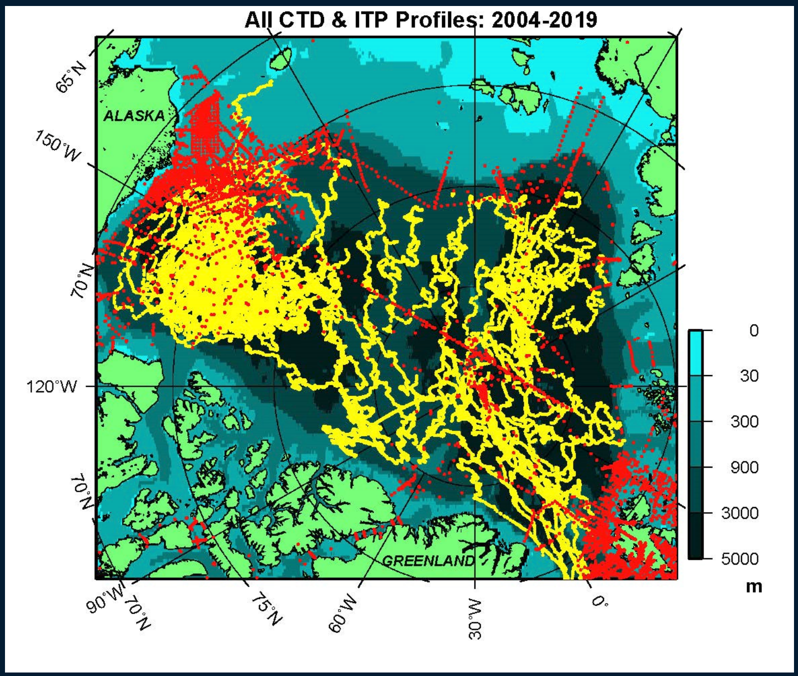
The ITP program is an international collaboration including support from:
- NSF Office of Polar Programs
- ONR Office of Naval Research
- WHOI Clark Initiative
- EU DAMOCLES Program
- UK ASBO Program
- Alfred Wegener Institute
- Ocean University of China

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

ITP deployments are from cruises of opportunity

We seek collaborations in which we send 1-2 technicians to deploy ITPs. In exchange, ITP data can provide long-time information that complements synoptic ship-based observations.

Distribution of all temperature & salinity profiles 2004-2019



Our present NSF AON and ONR SODA grants will support additional deployments in 2019 and beyond.

<u>ITP Deployment Platforms: 2004-2018</u>
CCGS Louis S. St. Laurent (Canada)
R/V Polarstern (Germany)
Ak. Federov (Russia)
Kapitan Dranitsyn (Russia, under charter to U.S. NABOS program)
RV Khromov (Russia, under charter to RUSALKA program)
MV Araon (S. Korea)
MV Xuelong (China)

Plus
Aircraft operations at North Pole (NPEO/Barneo) and in
Canada Basin (MIZ)

Fate of permafrost-derived organic carbon, bacteria, and viruses in the coastal Arctic

JP Balmonte
Uppsala University
jp.balmonte@ebc.uu.se

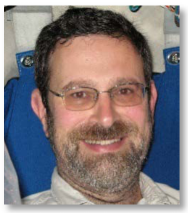
RQ6: *How does biomass flow vary across regional ecosystems of the Arctic?*
RQ7: *What is the contribution of the Arctic Ocean to maintaining the global ocean carbon dioxide reservoir and uptake?*
RQ8: *What are the input and fate of terrestrial and subsea carbon to the Arctic Ocean?*

UPPSALA UNIVERSITET

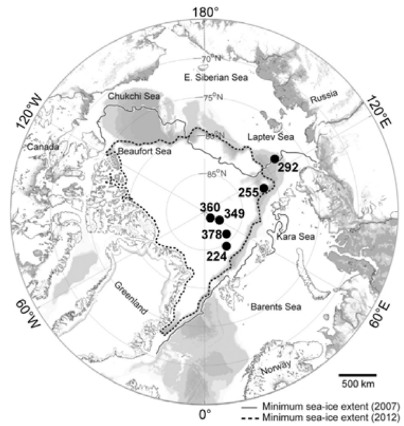
Structure and enzymatic activities of pelagic, particle-associated, and benthic bacterial communities in the central Arctic

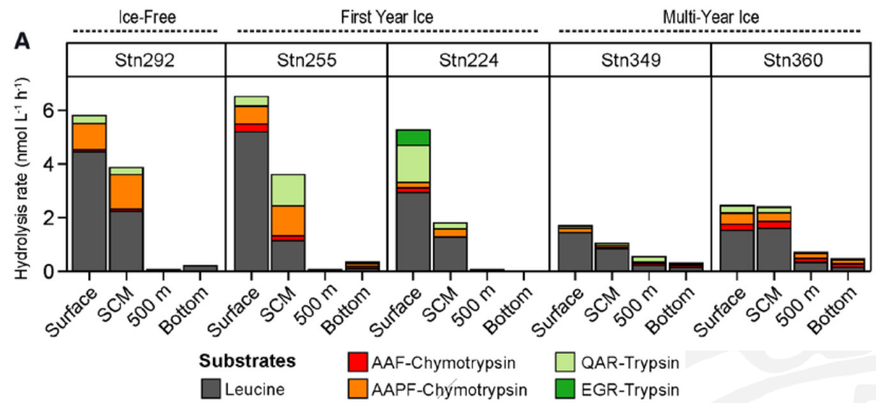
(Balmonte et al., 2018, *Environ Microbiol*)

Carol Arnosti



Andreas Teske



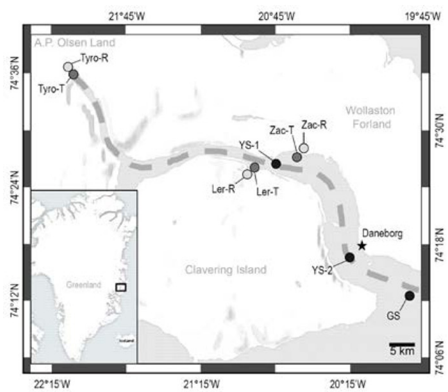


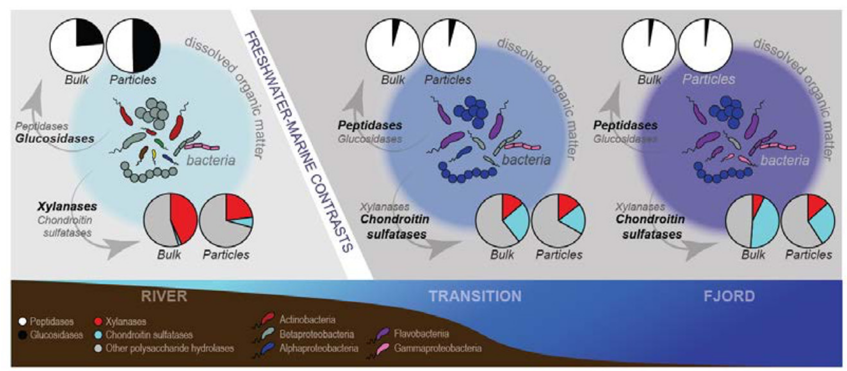
Freshwater-marine contrasts in microbial enzymatic capabilities, community structure, and DOM pools in a Greenland fjord

(Balmonte et al., in revision for *Limnol Oceanogr*)

Ronnie Glud

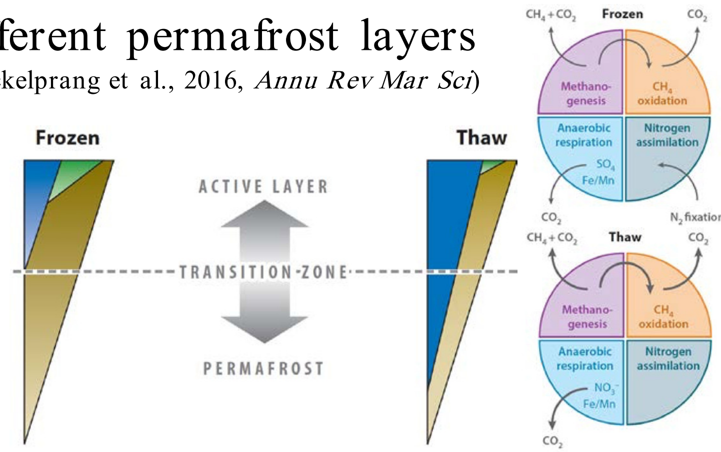
Mikael Sejr





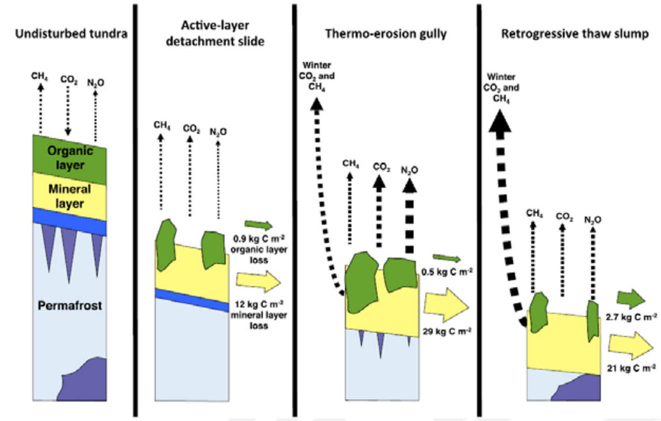
Microbial metabolic shifts in different permafrost layers

(Mackelprang et al., 2016, *Annu Rev Mar Sci*)



Carbon mobilized from permafrost thaw

(Abbott & James, 2015, *Global Change Biol*)



Mackelprang et al., 2011, *Nature* | Vonk et al., 2013, *Geophys Res Lett* | Mackelprang et al., 2017, *ISME J* | Muller et al., 2018, *Environ Microbiol* | Serikova et al., 2018, *Nature Geoscience*

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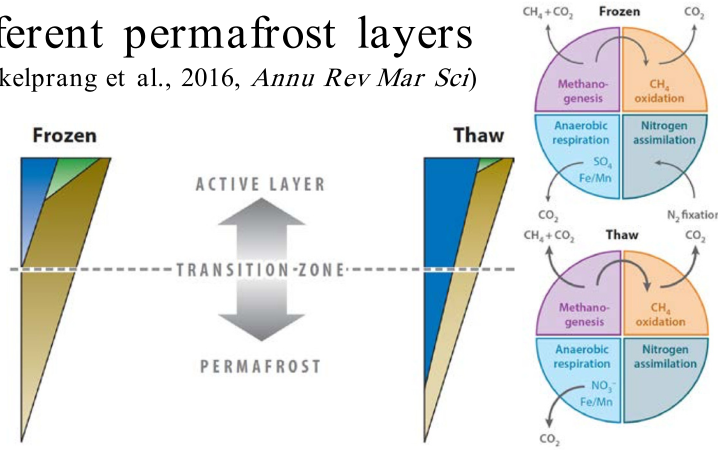

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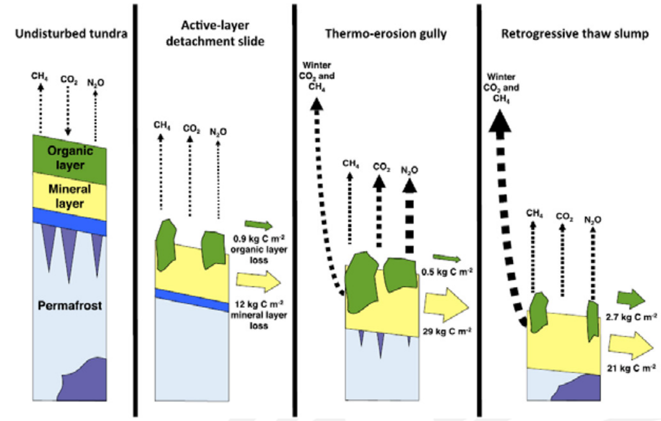
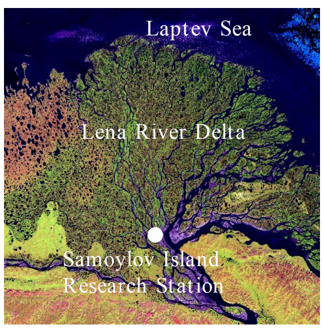


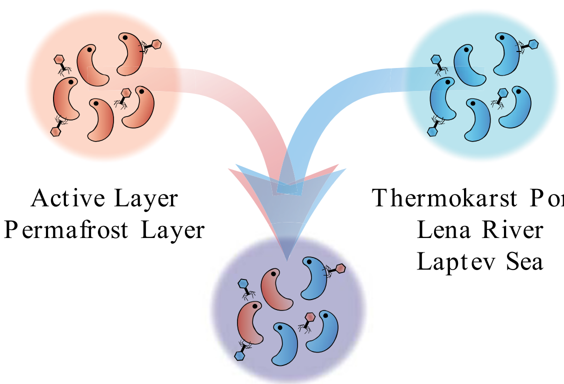
Anna Székely

Vicente Sedano

Jeffrey Hawkes

PermaCoa: *Ecological & biogeochemical consequences of **perma**frost **coa**lescing with aquatic networks*



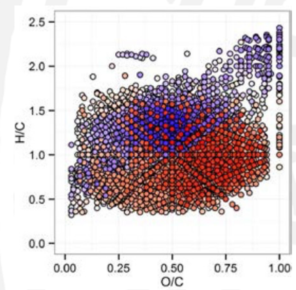


INTER ⇄ ACT

Q: Structure & function of established comm. (bacteria & viruses)?

Q: Sites of most intense OM remineralization? Compounds used?

DOM analysis
Orbitrap MS



(Hawkes et al., 2016, *Anal Chem*)

Metagenomics & metaviromics

A-T-T-C-A-G-----G-C-T-T-A
T-T-T-C-A-G-----G-C-A-A-T
A-T-T-C-A-G-----C-G-T-T-A
A-T-A-C-A-G-----G-C-T-T-A

OM Bioavailability
Bacterial respiration
Bacterial production
Enzymatic activities
Cell counts

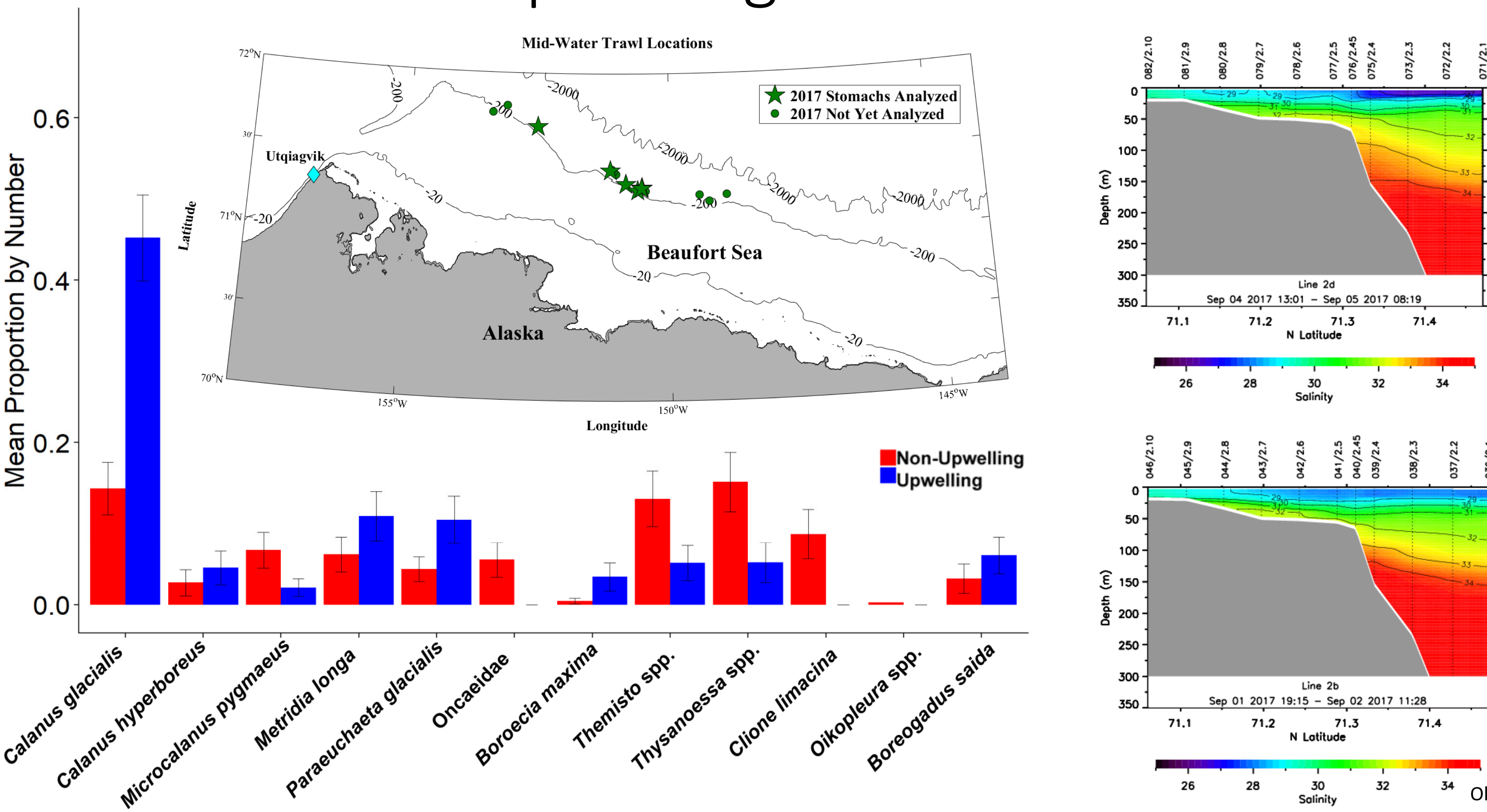
Mackelprang et al., 2011, *Nature* | Vonk et al., 2013, *Geophys Res Lett* | Mackelprang et al., 2017, *ISME J* | Muller et al., 2018, *Environ Microbiol* | Serikova et al., 2018, *Nature Geoscience*

Biophysical influences on Arctic cod (*Boreogadus saida*) feeding, growth, and distribution

Justin Suca*, Joel Llopiz*, Carin Ashjian, Stephen Okkonen,
Robert Campbell, and others

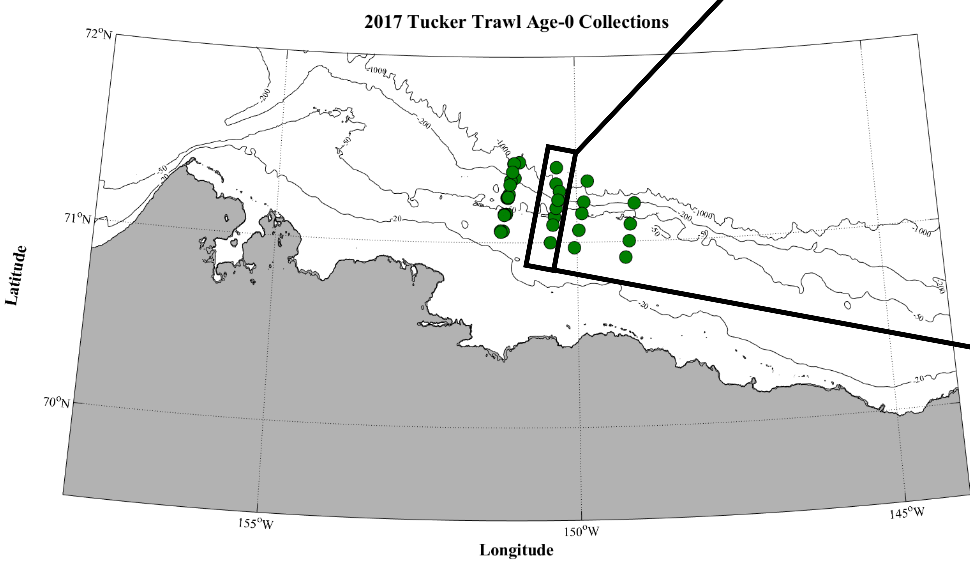
(*Llopiz Lab, Woods Hole Oceanographic Institution)

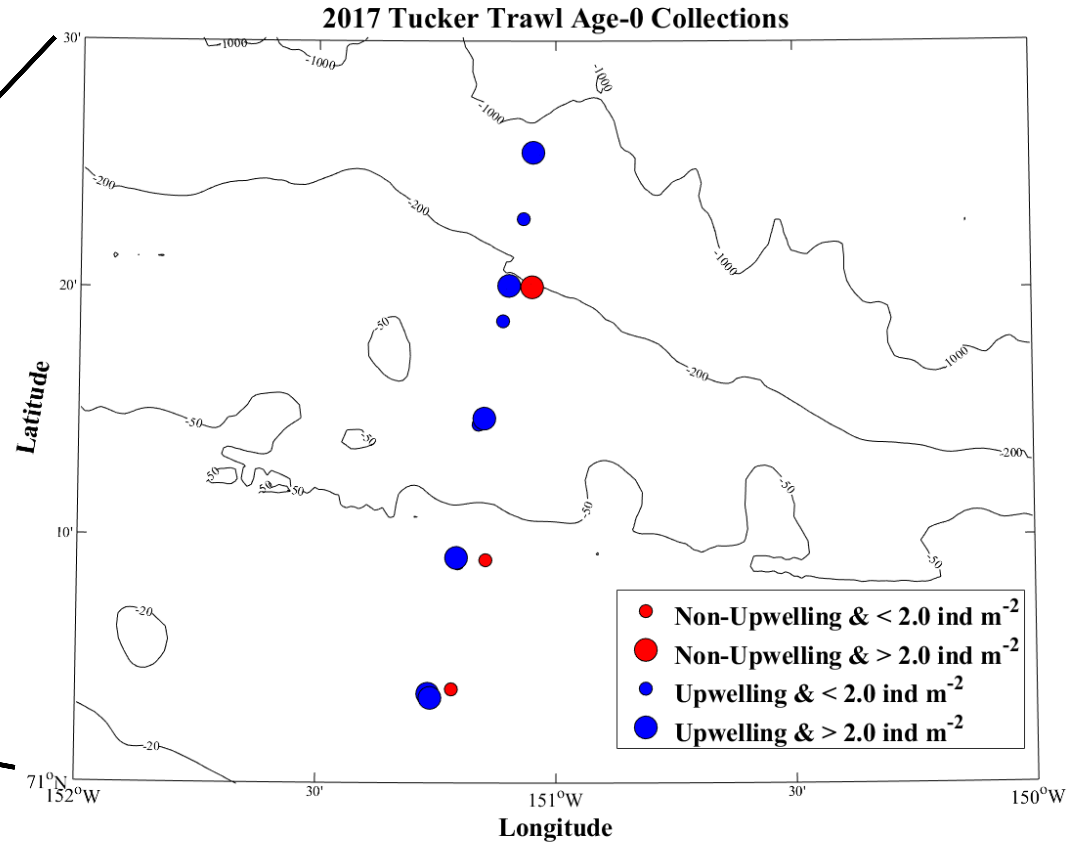
Effect of upwelling on diet of Arctic cod



Okkonen

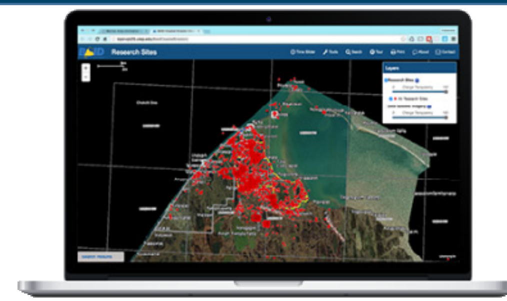
Age-0 abundance higher during upwelling





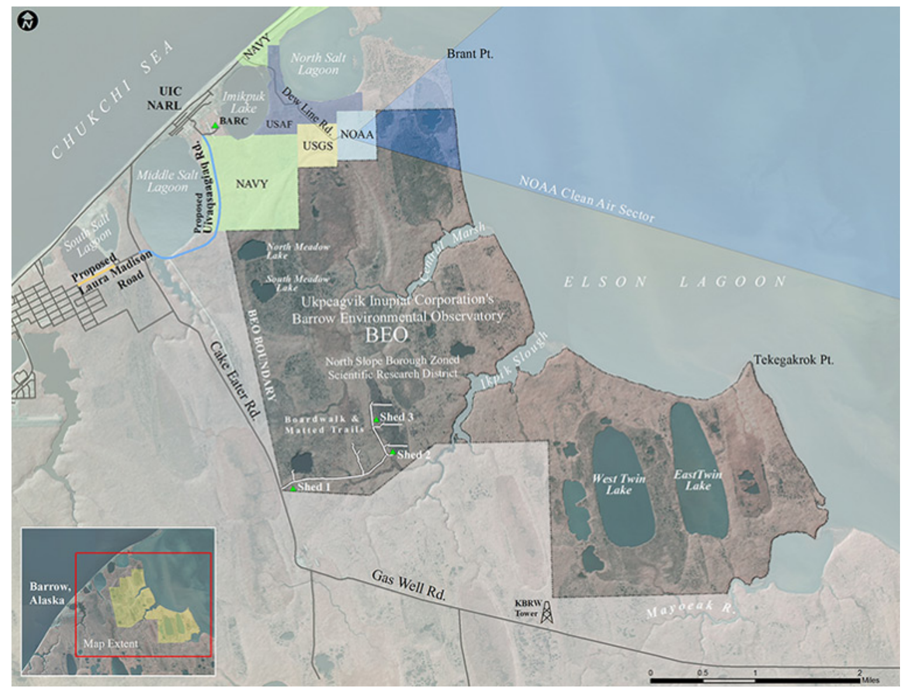
Balancing science and culture on the Arctic Coast, on a daily basis

Kaare Sikuaq Erickson



UIC
SCIENCE

Who we are:



Who we work with:

We work with all major funding agencies that conduct research in the Western Arctic.

-National Science Foundation – dozens of projects such as NEON, ITEX, LTER

-NAVY – Ice Camp

-NASA – Europa Mission testing: JPL, Winglee

-Department of Energy – ARM, NGEE

-Marine Research – Limited Cruise support, etc.

-Ice Science research – Moorings, buoys, mass-balance sites, etc.

-International Research Entities – CAS, Max Plank Institute

-Many more small projects supported throughout the year

What does engagement with indigenous communities look like?

Circumstances vary drastically from village to village and region to region

Karen Frey
Graduate School of Geography
Clark University

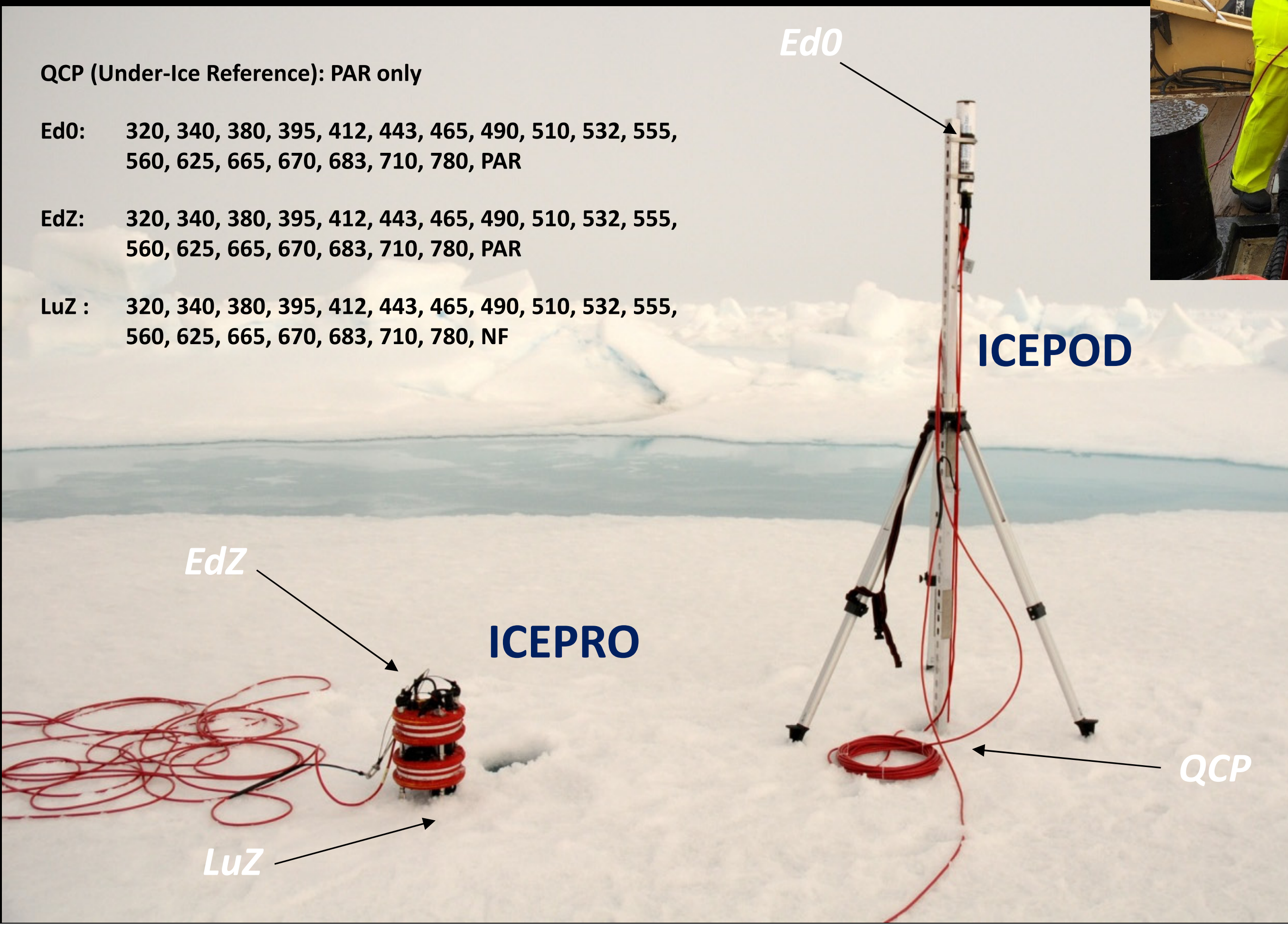
Water Column Profiling Optical Measurements

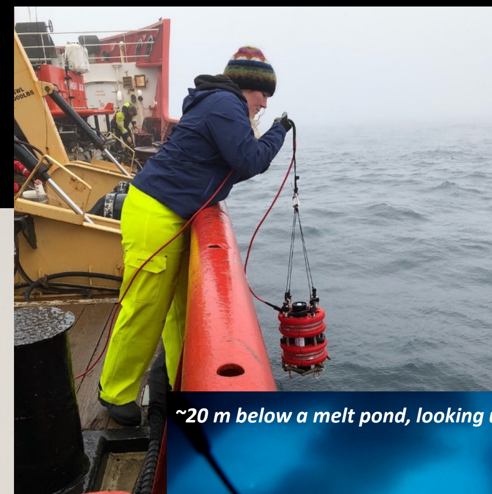
QCP (Under-Ice Reference): PAR only

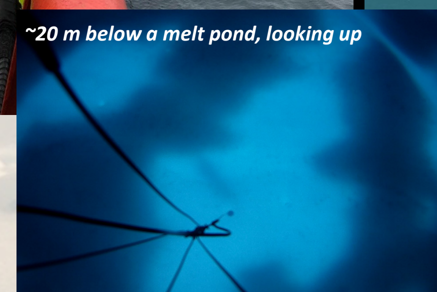
Ed0: 320, 340, 380, 395, 412, 443, 465, 490, 510, 532, 555, 560, 625, 665, 670, 683, 710, 780, PAR

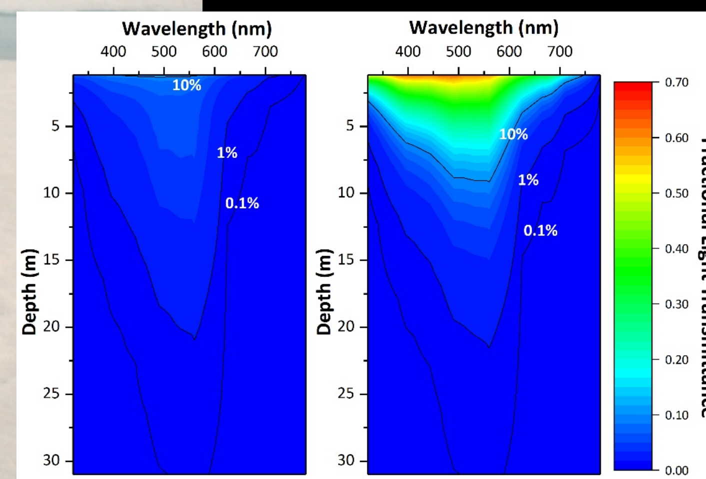
EdZ: 320, 340, 380, 395, 412, 443, 465, 490, 510, 532, 555, 560, 625, 665, 670, 683, 710, 780, PAR

LuZ : 320, 340, 380, 395, 412, 443, 465, 490, 510, 532, 555, 560, 625, 665, 670, 683, 710, 780, NF



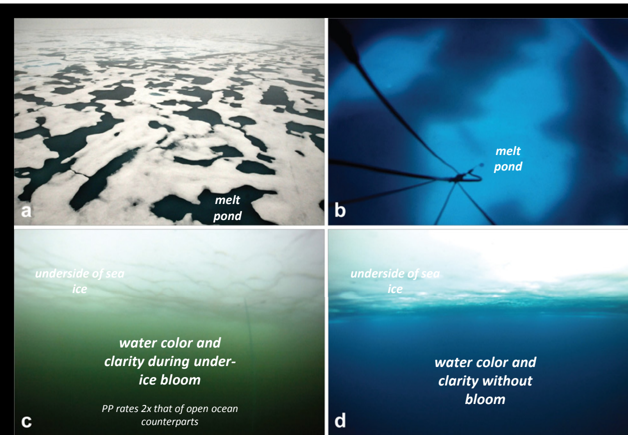




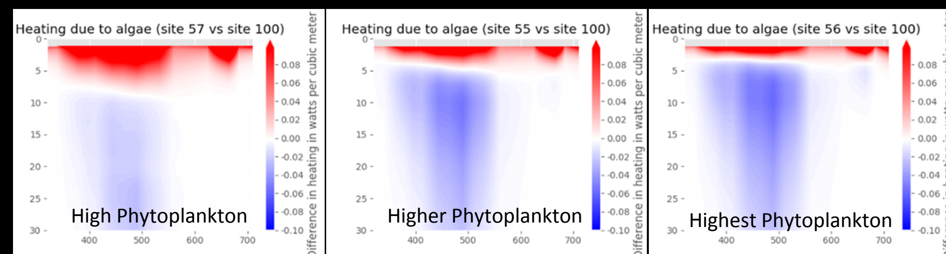


Water Column Profiling Optical Measurements

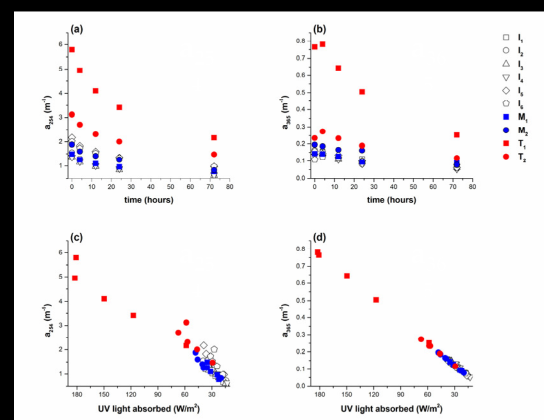
*Examples of questions to be answered by these types of measurements relate to **biological**, **physical**, and **biogeochemical** phenomena, with the hypothesis that increased melt ponding and decreased sea ice cover will bring increased light transmittance to the Arctic region:*



a) How does the transmittance and distribution of light affect rates of primary production across the Arctic?



b) How does light transmittance impact vertical heat distribution in the upper ocean water column (impacting sea ice melt and stratification, etc.)?



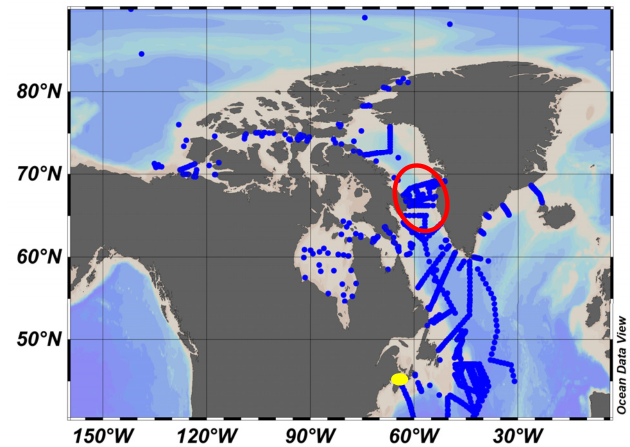
c) How does light transmittance impact the photodegradation of biogeochemical constituents (CDOM, DOC) and microplastics across the Arctic?

Fisheries and Oceans Canada   Pêches et Océans Canada

Kumiko Azetsu-Scott
Fisheries and Oceans, Canada (DFO)
Bedford Institute of Oceanography (BIO)
Dartmouth, Nova Scotia, Canada

Research interests:

- ocean carbon cycle (DIC, TA, pH and pCO_2, CH_4) and ocean acidification in the North Atlantic and the Arctic, and the interaction between two oceans
- Tracer studies - ventilation ages using CFCs and SF_6, freshwater composition and their fluxes using multiple chemical tracers ($\delta^{18}O$, salinity, nutrients, alkalinity).
- Open water, Coastal/Shelf area, Cold Seeps (methane hydrate, hydrocarbon seeps)



Canada

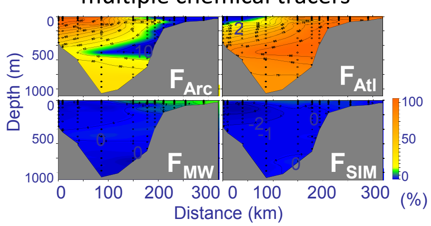
Fisheries and Oceans Canada   Pêches et Océans Canada

Davis Strait Observing System

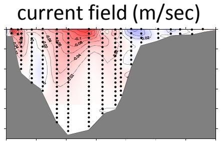
(Canada-USA-EU collaboration)

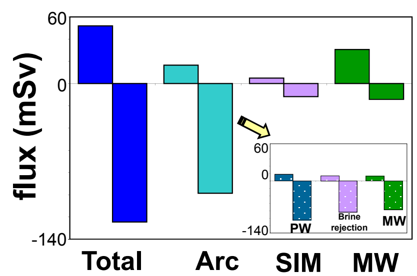
- One of two export gateways of Arctic water (both sides of Greenland, Davis Strait and Fram Strait)
- It is an ideal location to observe the propagation of changes from the Arctic to the Northwest Atlantic (integration of narrow channels in CAA)
- To monitor the intrusion of the warm and saline Atlantic water into Baffin Bay – influence the stability of glacier terminus

FW fraction estimated by multiple chemical tracers

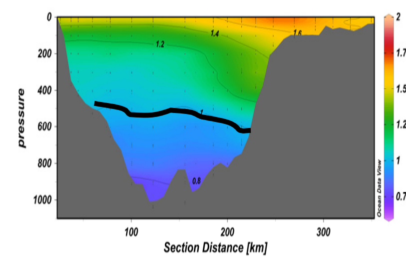


current field (m/sec)

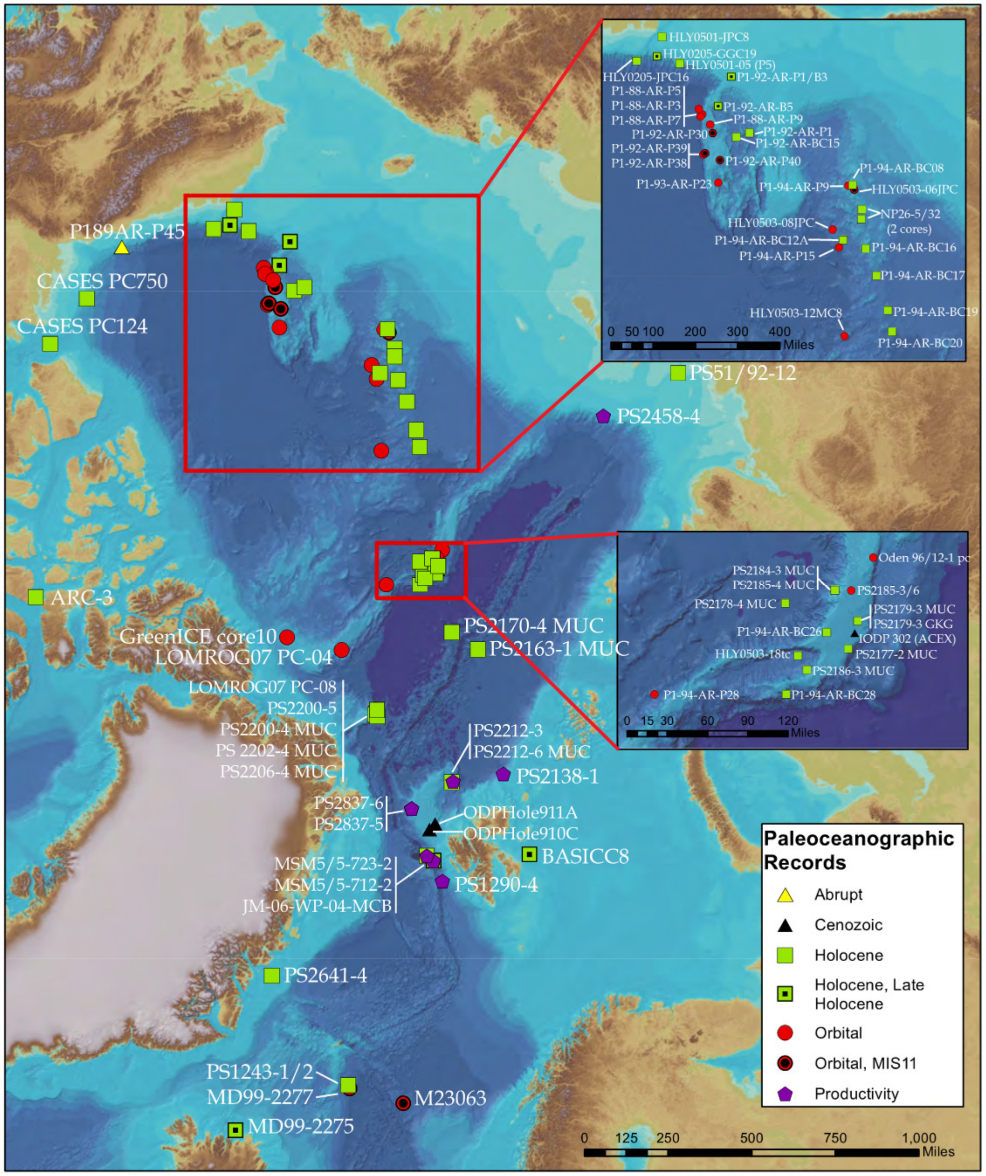




Influence of the Arctic Outflow on Ocean Acidification



Canada



Arctic Paleoceanography

Core locations with proxy records

Get new cores that bridge instrumental record to better constrain the range of natural variability during the Holocene

USGS science for a changing world
University of Maryland CENTER FOR ENVIRONMENTAL SCIENCE CHESAPEAKE BIOLOGICAL LABORATORY

Paleoceanography objectives

Establish chronology and sedimentation rate (^{210}Pb, ^{137}Cs profiles, radiocarbon dating, physical properties, astro tuning)

Gateway history and effects of Pacific/Atlantic connections

Impact of sea-level variations on Arctic marine depositional systems (paleoshelf growth)

Paleo sea-ice development in relation to climate change
Test periods of pre-anthropogenic warmth in the Arctic
(Spielhagen et al. 2011; Farmer et al., 2011; de Vernal et al., 2005, 2013 [dinocyst-based])

Identification of abrupt oceanographic events, **Holocene ocean variability and insight on benthic ecosystem changes during the Holocene and modern warming**

Paleoceanographic Proxies

1 - Foraminifera, Ostracode ecology - sea ice, AODW, AIW

2 - $\delta^{18}O_{ost}$ & $\delta^{18}O_{bf}$ - temperature and water mass

3 - Mg/Ca ratios - bottom temperature

4 – Sediment physical properties [density, color, magnetic susceptibility]

5 – IRD concentrations - past presence of ice, sea ice melt

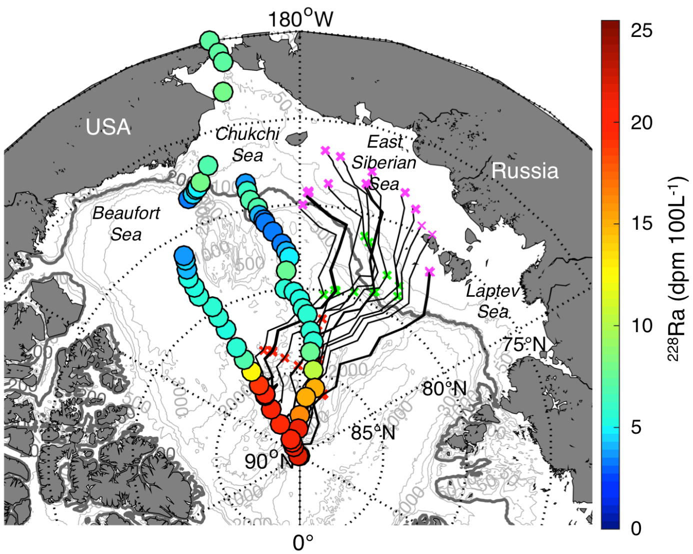
6 - Dinoflagellates, diatoms

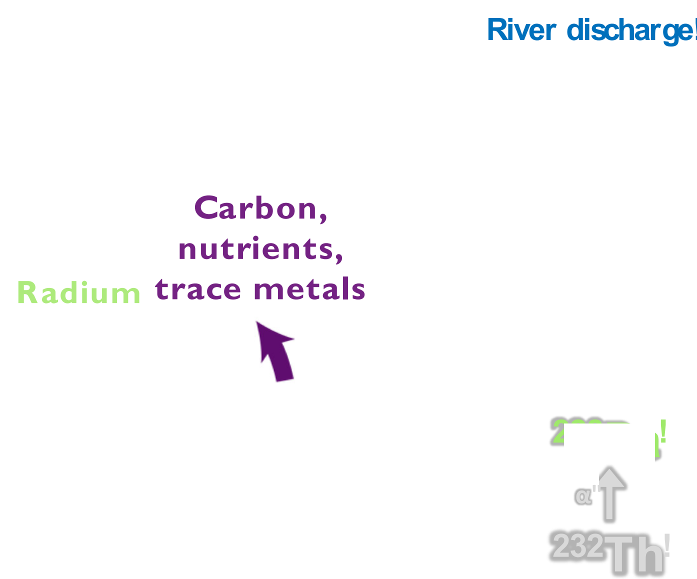
7 - IP 25 & brassicasterol biomarkers - seasonal sea-ice presence & open water phytoplankton productivity

Radium as a tool for identifying shelf-derived carbon & nutrient inputs to the central Arctic

Radium has a sediment source and is not biologically utilized, so it can be used as a tracer of terrestrial and shelf-derived nutrient inputs to the central Arctic (RQ4)

Decay of radium away from the shelf source can be used to determine timescales of organic matter degradation (RQ8)

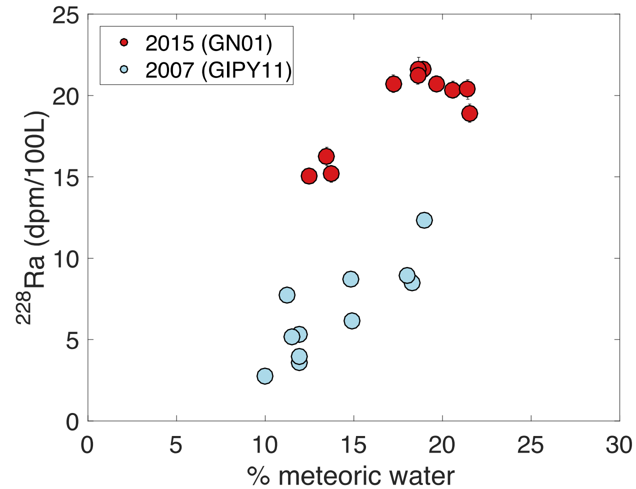


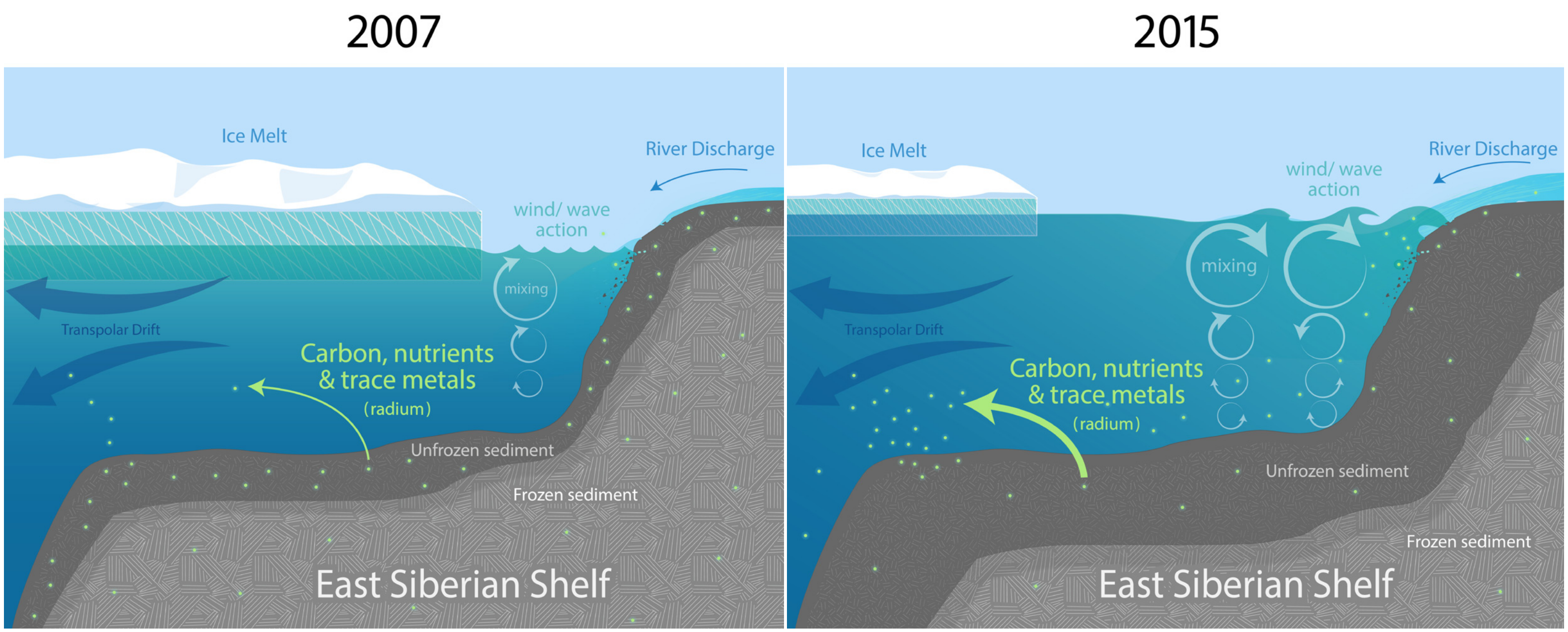


Lauren Kipp; LKipp@dal.ca
Ocean Frontier Institute Postdoctoral Fellow
(Dalhousie University/Lamont-Doherty Earth Observatory)

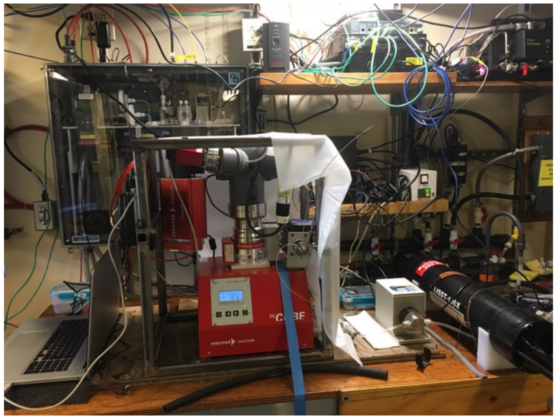
Increased ^{228}Ra levels in the TPD in 2015 imply rising fluxes of shelf-derived materials

Continuing to monitor radium in the Arctic will help elucidate the role of changing nutrient inputs vs changing light availability on primary production (RQ4)

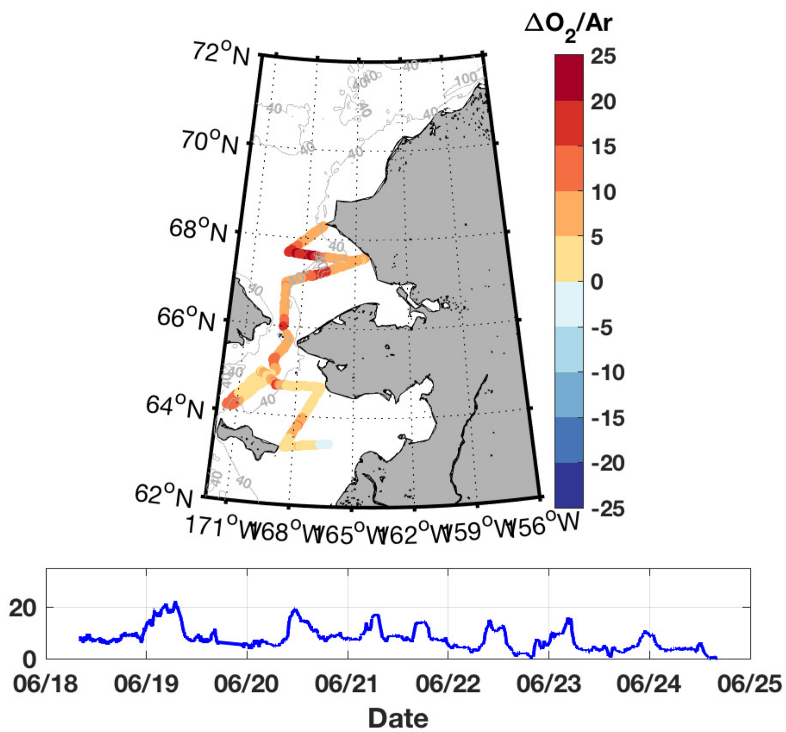




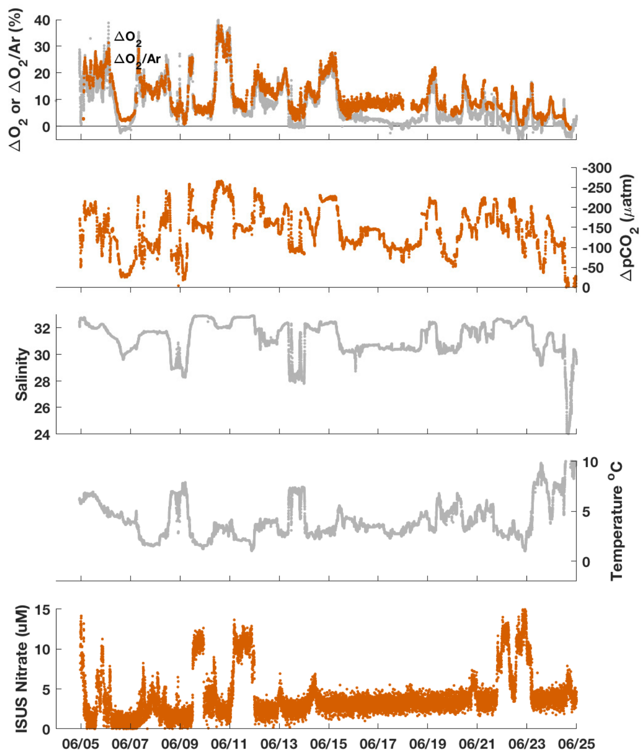

Gas-based Tracers of Biological Productivity and Metabolism
Laurie Juranek
Oregon State University



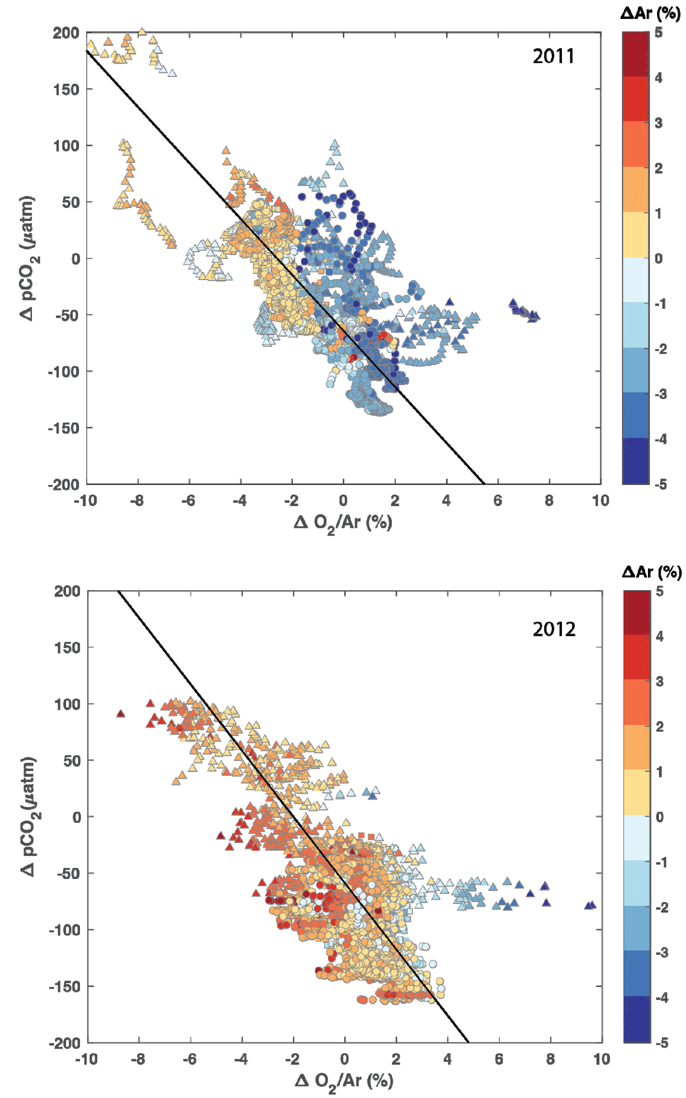
Underway Instrumentation can resolve sharp gradients in biological activity that may be missed by discrete sampling



Gives insight into physical/biological processes driving air-sea CO_2 exchange



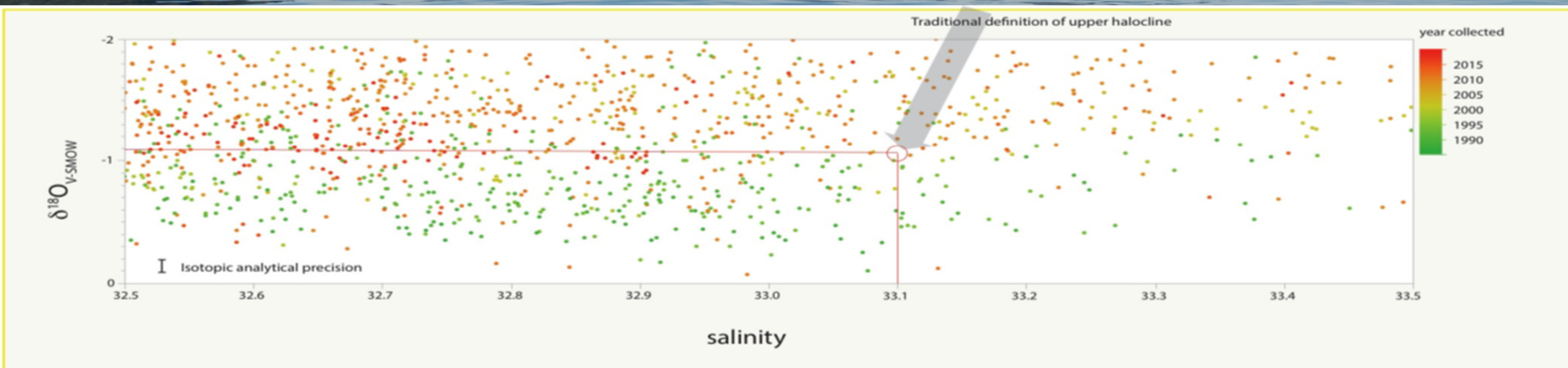
Juranek, unpublished data (NPRB 2018 ASGARD cruise)



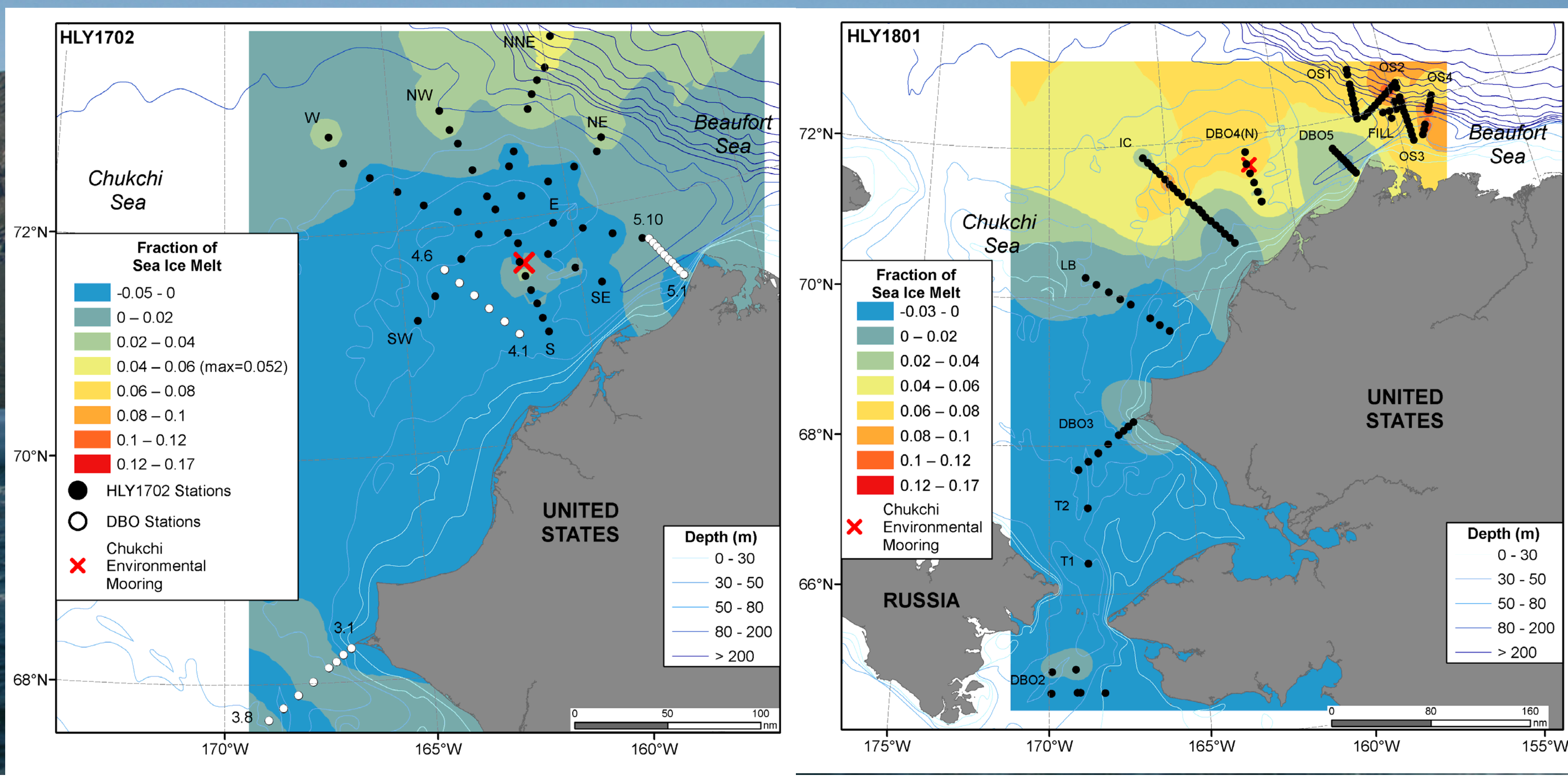
Juranek et al. (2019), JGR-Oceans

Changes in the δ^{18}O values in the upper Arctic Ocean halocline: an independent mechanism to monitor freshwater flow through Bering Strait

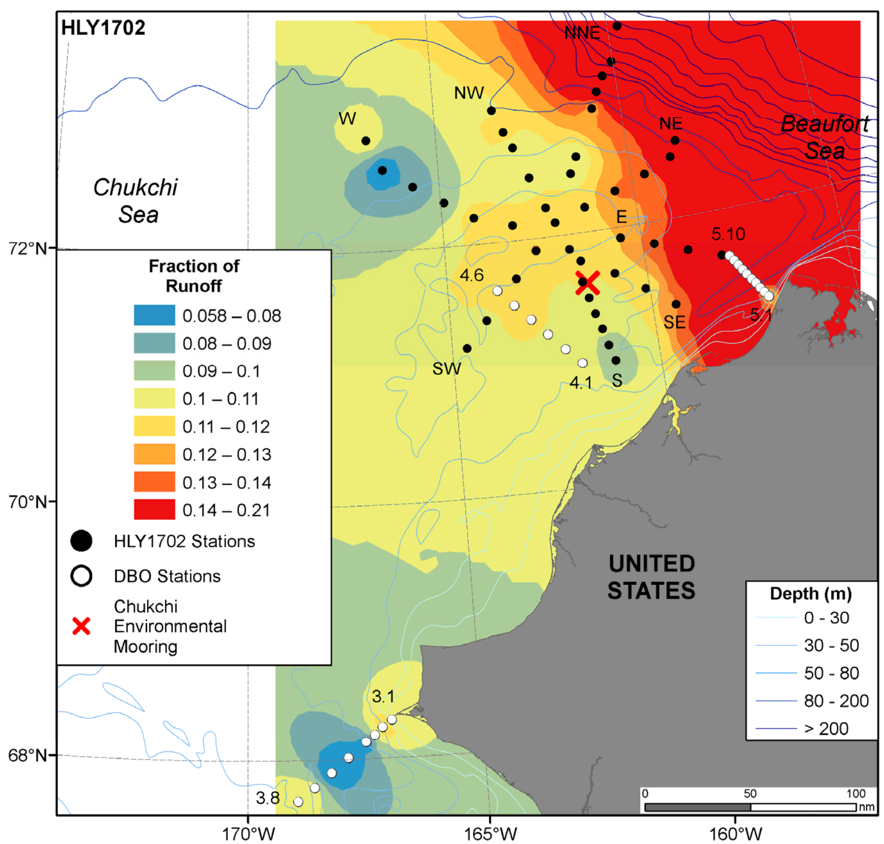
Lee Cooper, University of Maryland Center for Environmental Science, cooper@umces.edu

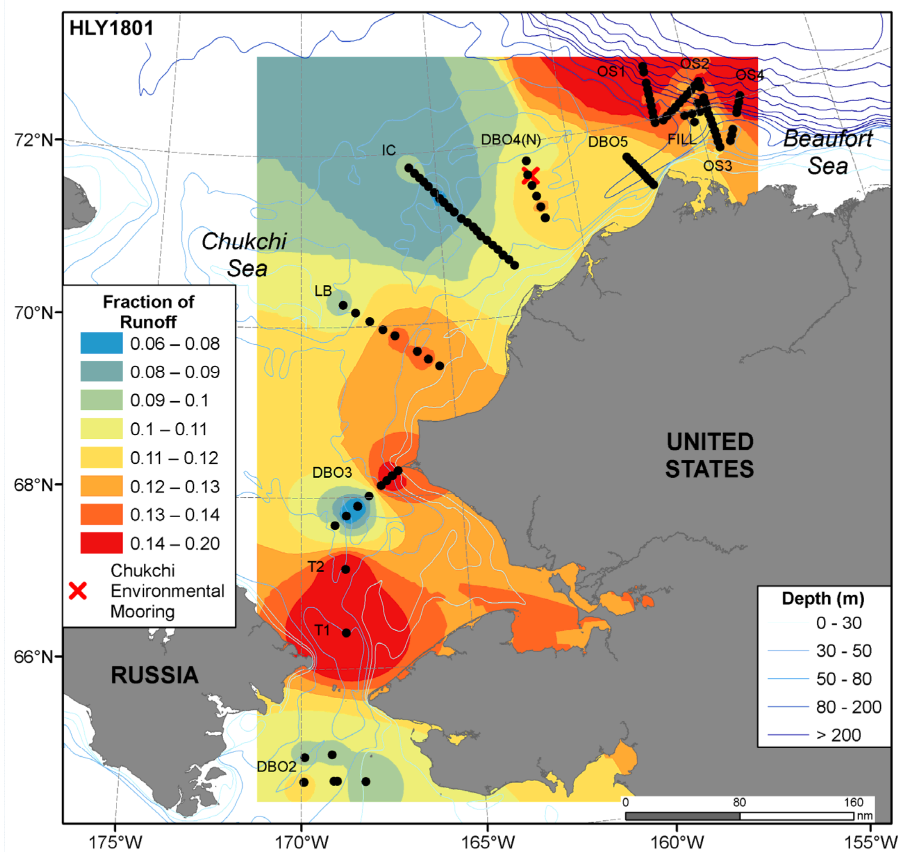


Oxygen-18/oxygen 16: following the influence of sea ice melt



Oxygen-18/oxygen 16: following the influence of river runoff





Tracing permafrost organic matter from source to (potential) sink

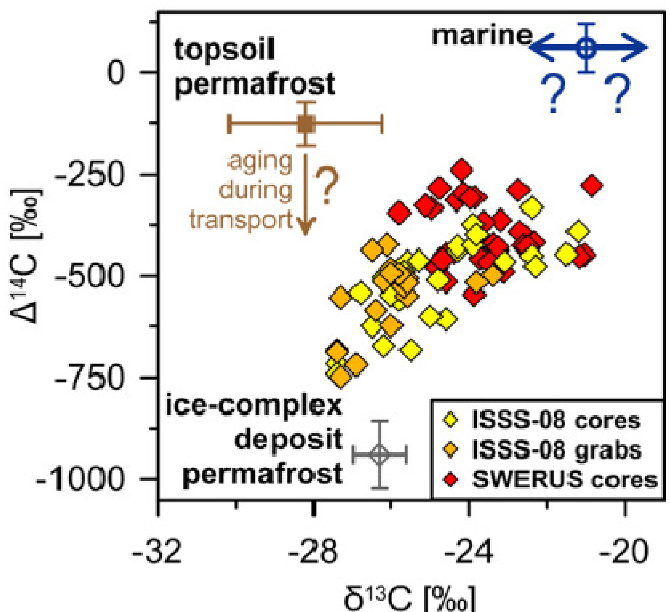
Lisa Bröder

Duvannyi Yar, Kolyma, 2018

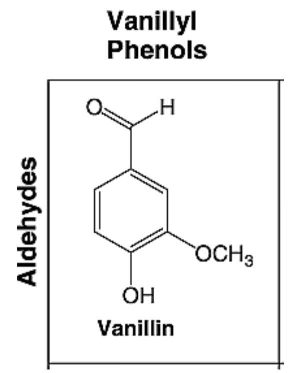
SWERUS-C3 expedition, 2014

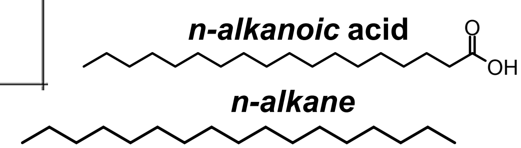
Tracing permafrost organic matter

<u>C isotopes</u> → source apportionment with 3 endmembers: topsoil/Holocene PF, ice-complex-deposit PF, marine



Bröder (2016)

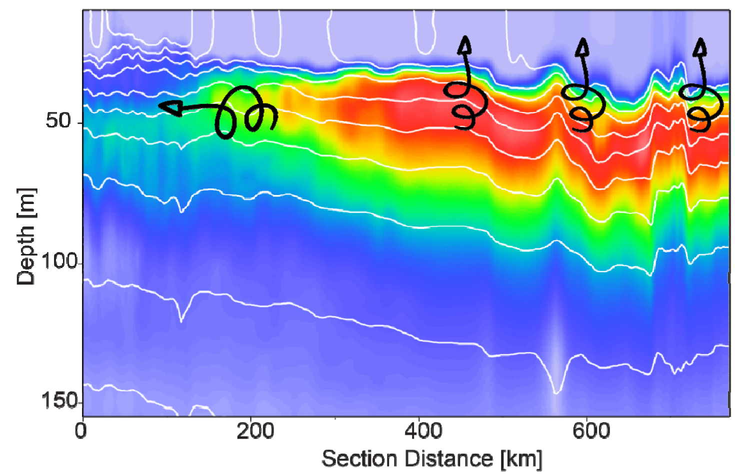




<u>Terrestrial biomarkers</u>: source-specific molecules, commonly used: lignin phenols (wood) and long-chain/high-molecular-weight *n*-alkanoic acids and *n*-alkanes (leaf waxes)

Arctic Ocean dynamics, mixing, heat, freshwater …

Mary-Louise Timmermans Yale



Research topics:

Beaufort Gyre dynamics and energetics
Arctic Ocean heat transport
Acoustic observations of Arctic layers
Arctic Ocean mixing
Formation and stability of mesoscale eddies
Sea-ice mass balance
Arctic freshwater and relationship to high-latitude climate

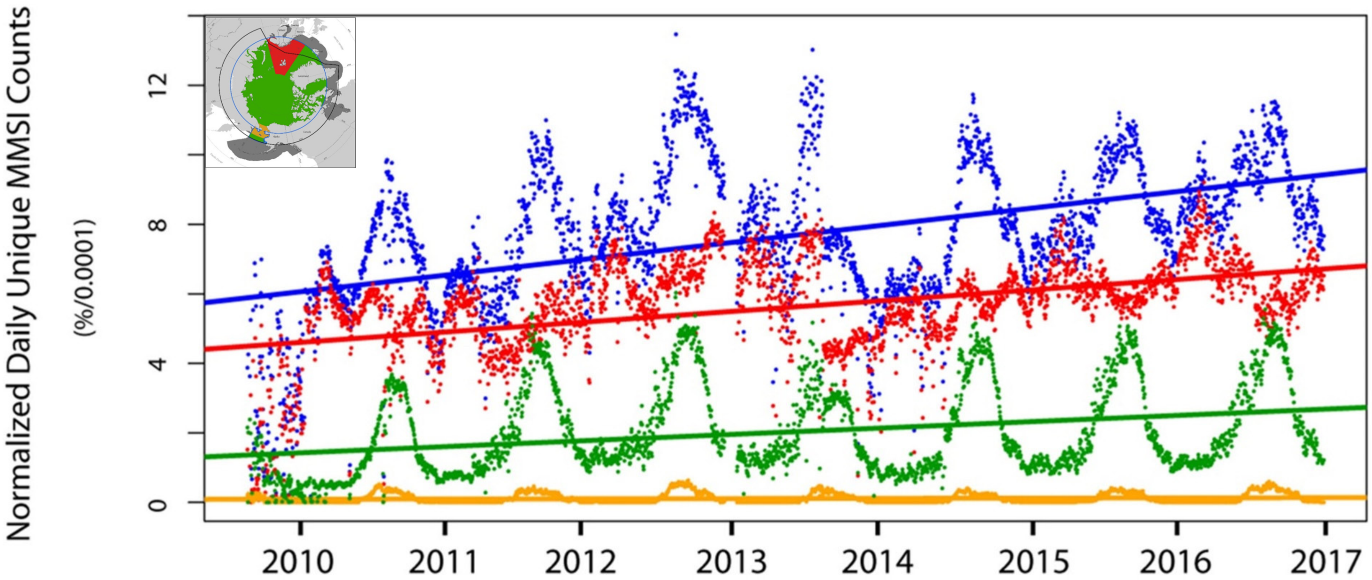
Postdoctoral positions available:

Mathematics and Data Science for Improved Physical Modeling and Prediction of Arctic Sea Ice
Multidisciplinary University Research Initiatives (MURI) Program

NYU Caltech W WISCONSIN Yale

Synoptic Surveying of Pan-Arctic Ship Traffic

Automatic Identification System (AIS) Records
Polar Orbiting Satellites
(1 September 2009 – 31 December 2016)



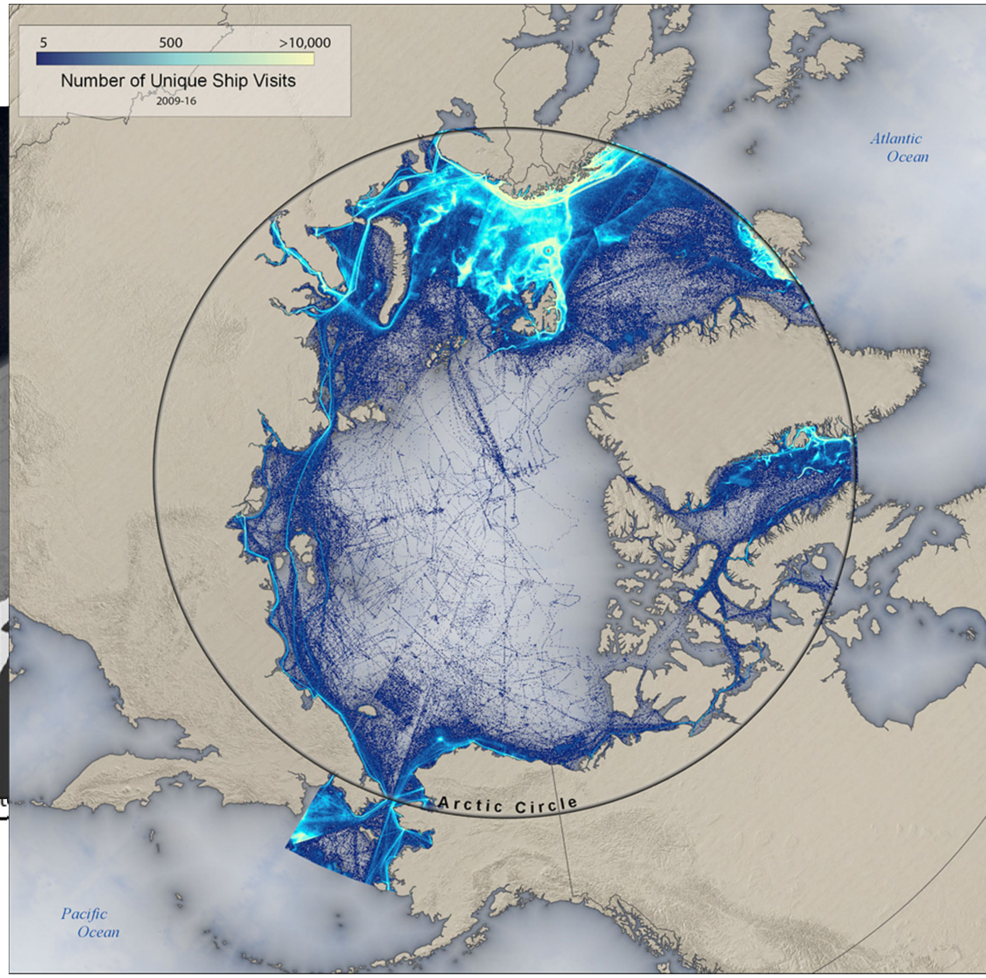
Professor Paul Arthur Berkman
Director, Science Diplomacy Center
Fletcher School of Law and Diplomacy, Tufts University
Medford, Massachusetts, United States

Science Diplomacy Center
EDUCATION ▲ RESEARCH ▲ LEADERSHIP
The Fletcher School • Tufts University

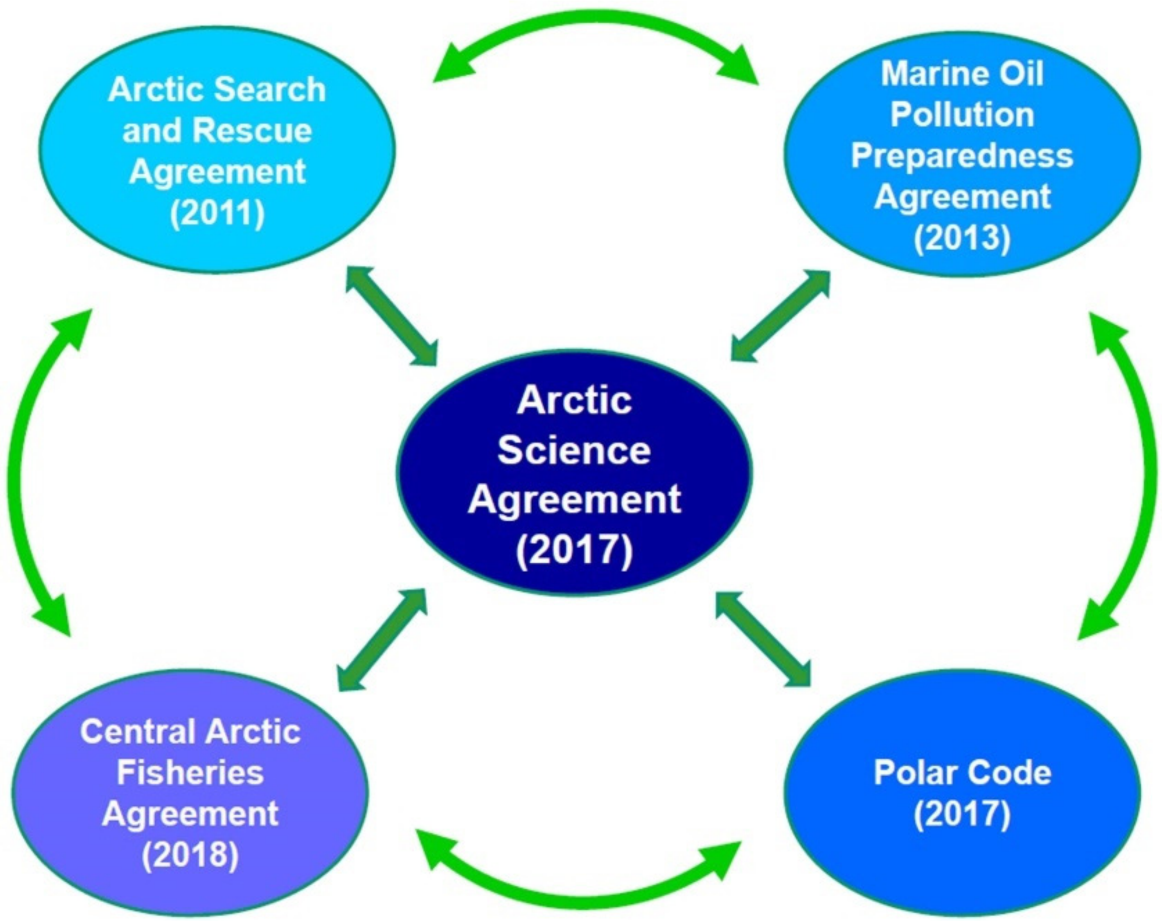
Next-Generation Arctic Marine Shipping Assessments

TABLE 11.5	
ATTR	
Sampli	
Data	Automatic rces
Observati	c
Observa	
Observatio	to decades)
Ship-Type	ations
Individual S	ve
Analytic	stions
Science- Contr	advocacy)
Informed De	and

[1] Involves Au



Science Diplomacy and Informed Decisionmaking



NOAA's Arctic Vision and Strategy

National Strategy for the Arctic Region — lines of effort —	NOAA's Arctic Vision and Strategy — strategic goals —
• Advance U.S. security interests	• Forecast sea ice
	• Improve weather and water forecasts and warnings
• Pursue responsible Arctic region stewardship	• Strengthen foundational science to understand and detect Arctic climate and ecosystem changes
	• Improve stewardship and management of ocean and coastal resources in the Arctic
	• Advance resilient and healthy Arctic communities and economies
• Strengthen international cooperation	• Enhance international and national partnerships

Renee Crain, Acting Director, Arctic Research Program
Oceanic and Atmospheric Research

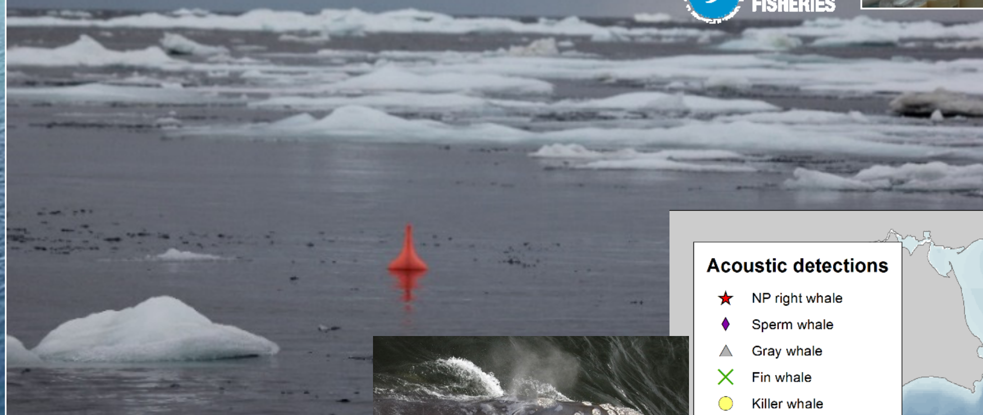
renee.crain@noaa.gov

NOAA's ARP Interest in SAS

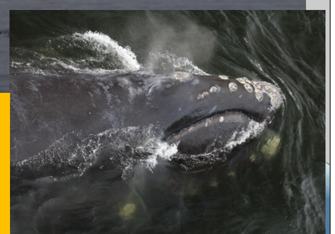
Program Priority	SAS Contributions
Observing	• Synoptic data 2020-2021 from the Arctic Ocean • Physical and biological oceanography consistent with DBO • Marine mammal observations • Fisheries observations esp. related to the moratorium on commercial fishing in the High Arctic
Modeling and Synthesis	• Advance understanding of the transport of heat and carbon through the AO • Ecosystem changes in the High Arctic
International Collaboration	• Cruise coordination • Data sharing
Outreach	• Blogs, media coverage, real-time engagement • Possible essay in the Arctic Report Card • Other publications

What: Sonobuoy deployment
Why: Passive acoustic monitoring for marine mammals
How: While vessel is underway – no need to slow down.
Who: Acoustics group at the AFSC/Marine Mammal Lab
When: Typically every 3-4 hours

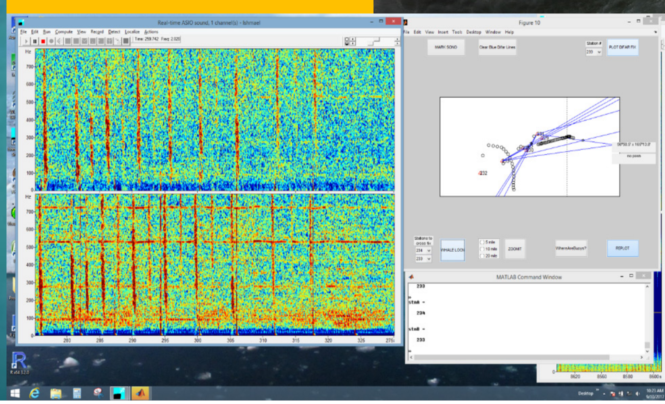
NOAA FISHERIES

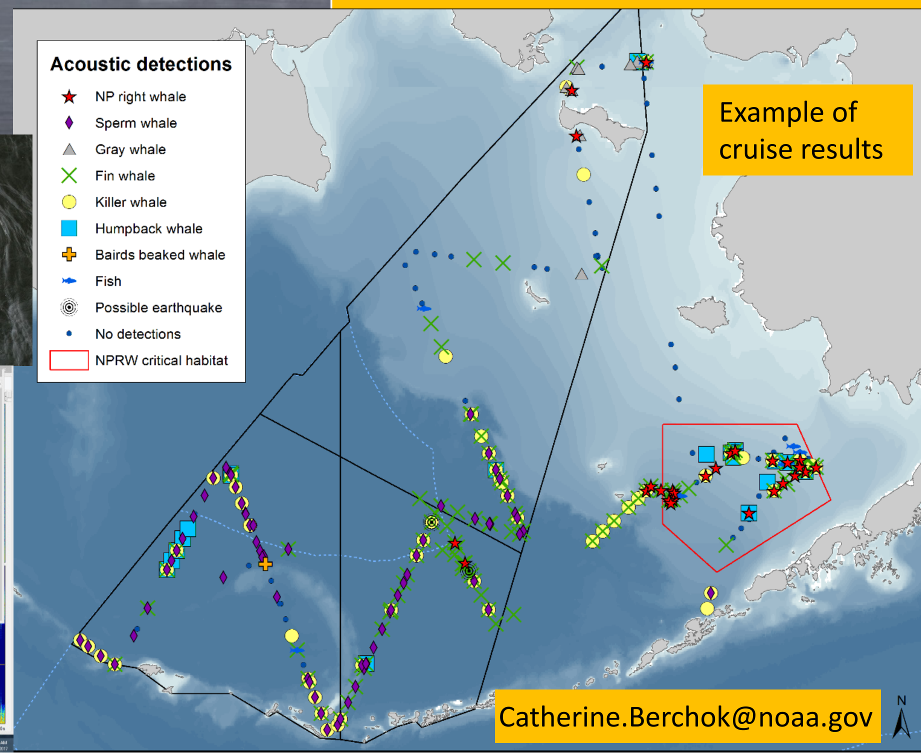


Space requirements:
table for 2 laptops & some misc. gear, some space to stage prepped buoys, and a few 4' cubed crates with buoys



We can also get localizations on sounds





Example of cruise results

Catherine.Berchok@noaa.gov

Arctic Plankton Phenology and Biogeography

Rubao Ji (WHOI)

Relevance to SAS

Ecosystem Response:

RQ4: How does primary production and associated availability of nutrients vary between Arctic regions?

RQ5: Does northward range expansion of subarctic species vary regionally and are any of these species likely to establish permanent populations in Arctic regions?

RQ6: How does biomass flow vary across regional ecosystems of the Arctic?

Collaborators and previous work (NSF OPP projects)

Ji, R., C. J. Ashjian, R. G. Campbell, C. Chen, G. Gao, C. S. Davis, G. W. Cowles, and R. C. Beardsley. 2012. Life history and biogeography of *Calanus* copepods in the Arctic Ocean: An individual-based modeling study. *Progress in Oceanography,* 96(1):40–56

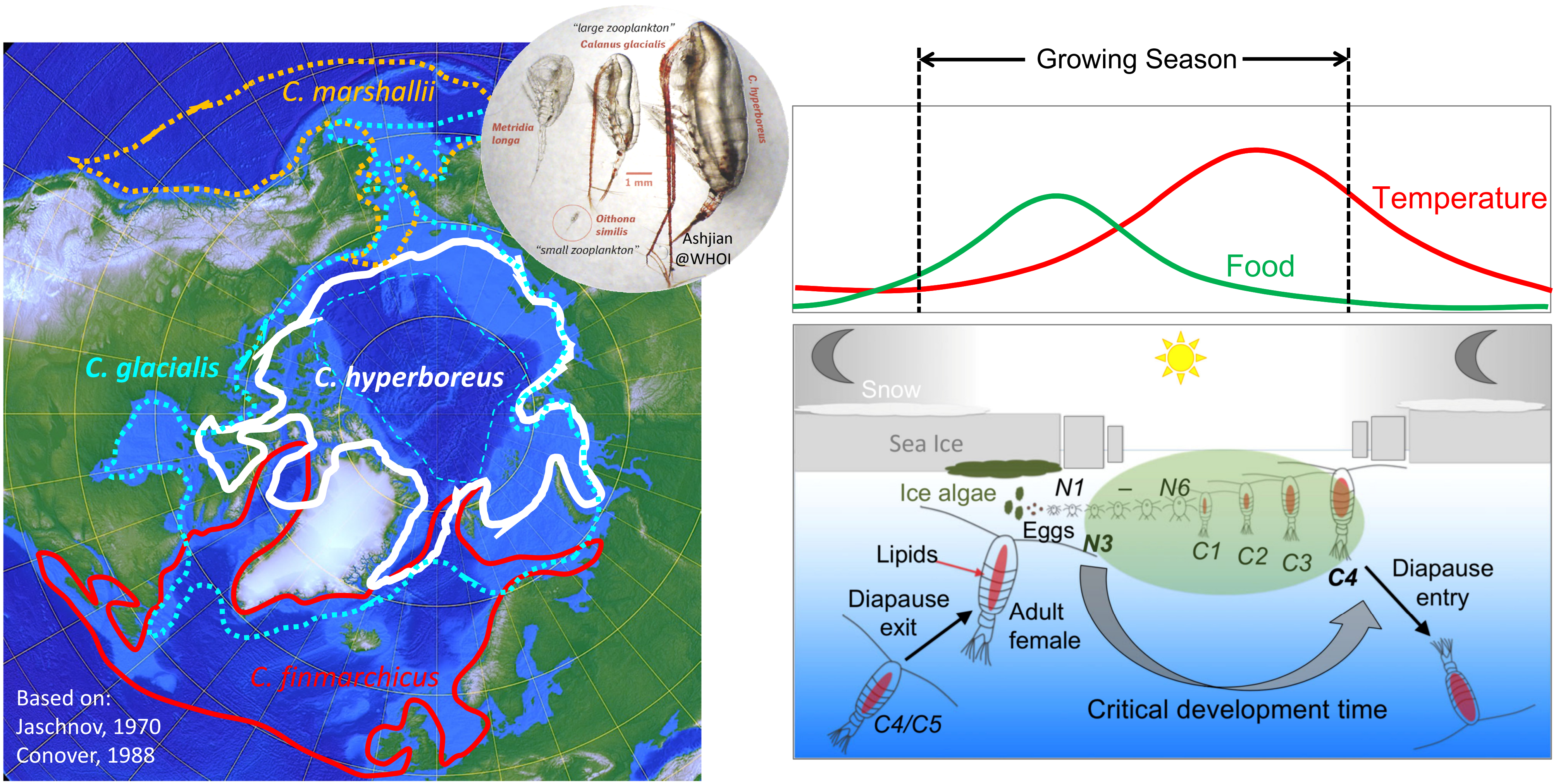
Ji, R., Jin, M., Varpe, Ø., 2013. Sea ice phenology and timing of primary production pulses in the Arctic Ocean. *Global Change Biology* 19, 734–741.

Feng, Z., R. Ji, R. G. Campbell, C. J. Ashjian, and J. Zhang. 2016. Early ice retreat and ocean warming may induce copepod biogeographic boundary shifts in the Arctic Ocean. *J. Geophy. Res.: Oceans.* Doi:10.1002/2016JC011784

Feng, Z., R. Ji, C. Ashjian, R. Campbell, and J. Zhang. 2018. Biogeographic responses of the copepod *Calanus glacialis* to a changing Arctic marine environment. *Global Change Biology,* 24(1):e159–e170

Kvile, K. Ø., C. Ashjian, Z. Feng, J. Zhang, and R. Ji. 2018. Pushing the limit: Resilience of an Arctic copepod to environmental fluctuations. *Global Change Biology,* 24(11):5426–5439.

Linking biogeography and phenology



Marine pelagic primary productivity and nutrient dynamics in the Canadian and Alaskan Arctic: Over a decade of studies under the umbrella of the Canada's Three Oceans, Distributed Biological Observatory, and GEOTRACES programmes

Shea Wyatt

University of Victoria, BC, Canada

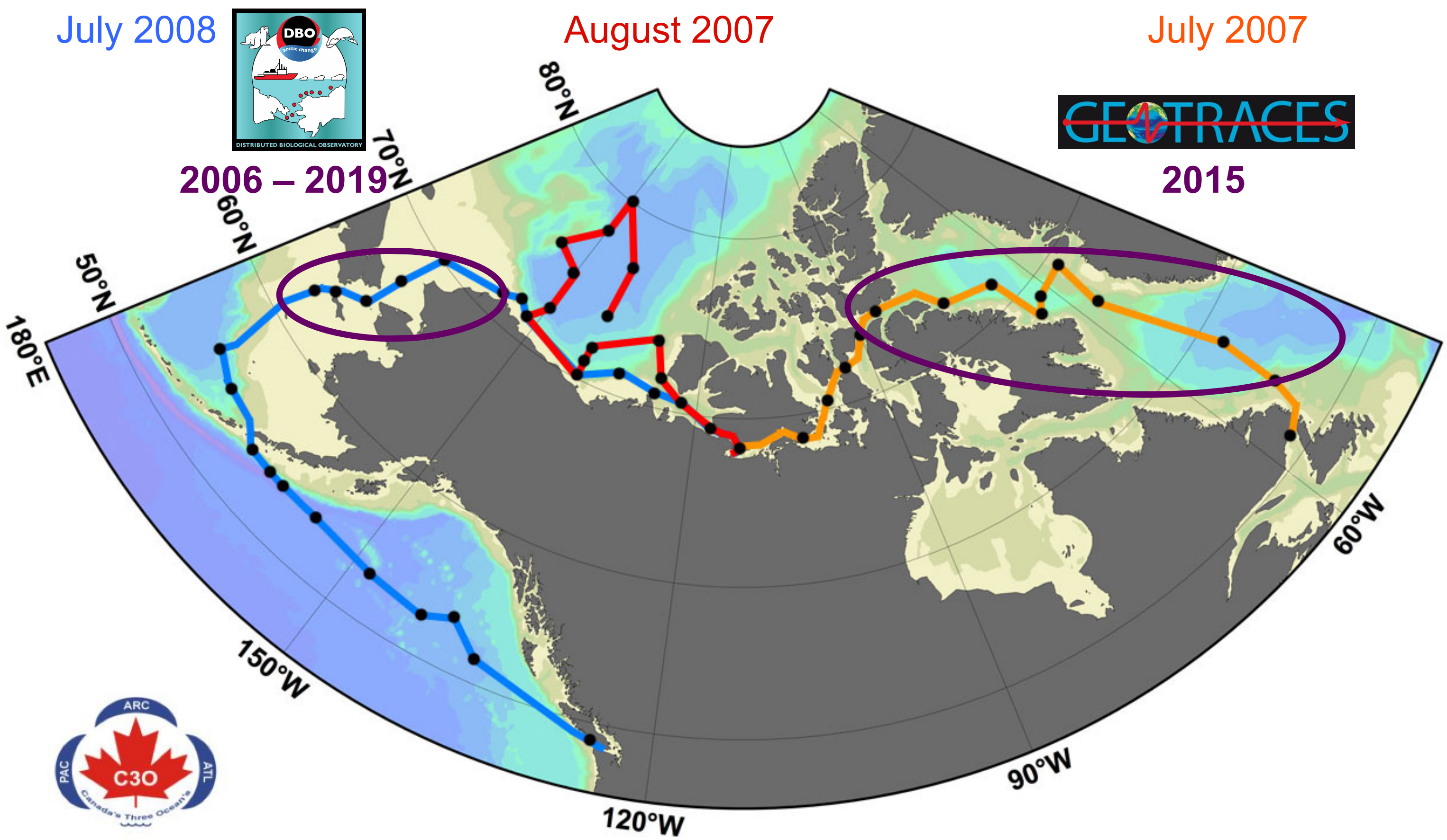
SAS Workshop 2019 – May 15, WHOI

University of Victoria

NSERC CRSNG

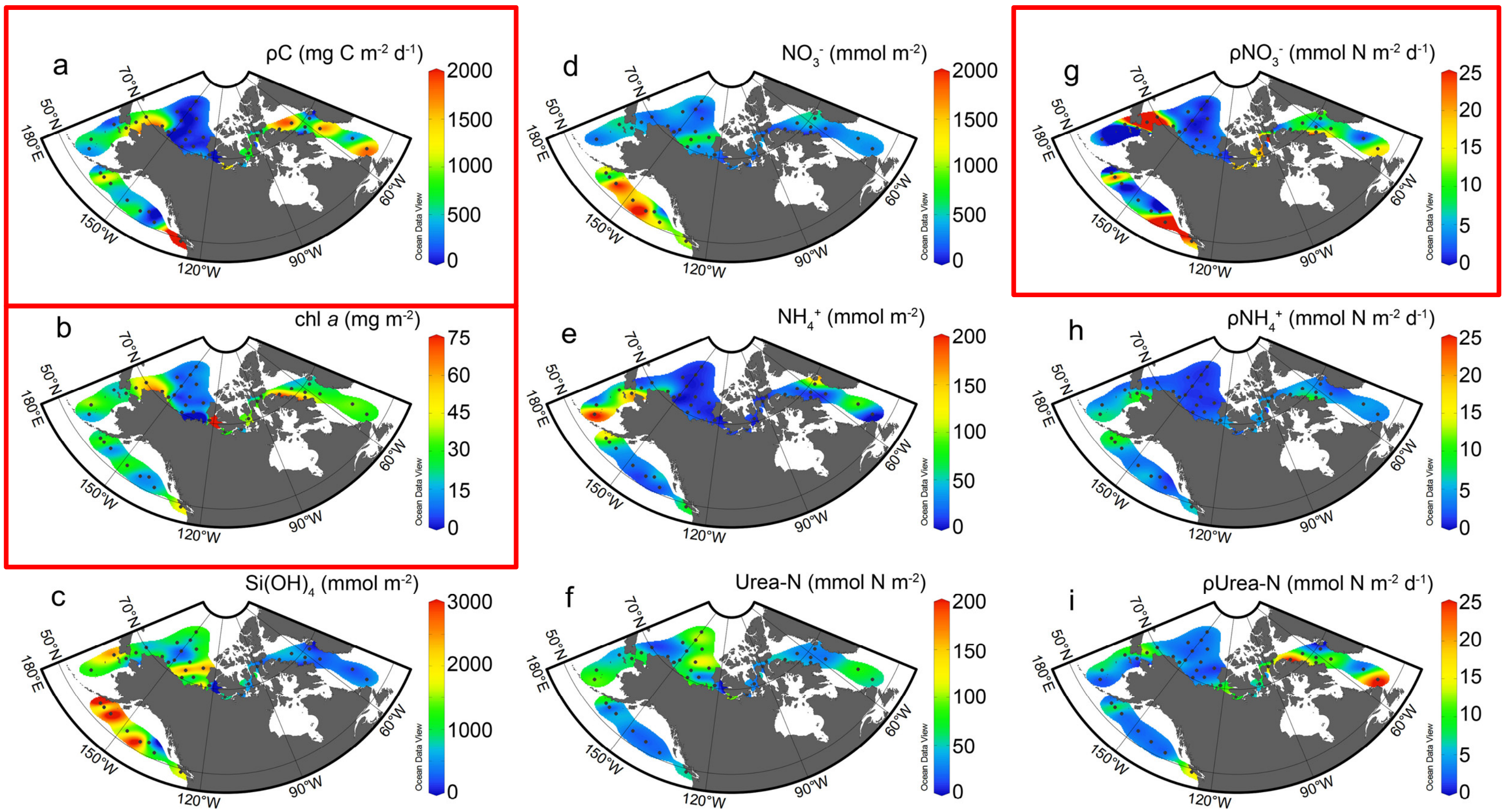
PHYTOPLANKTON ECOPHYSIOLOGY

UVic



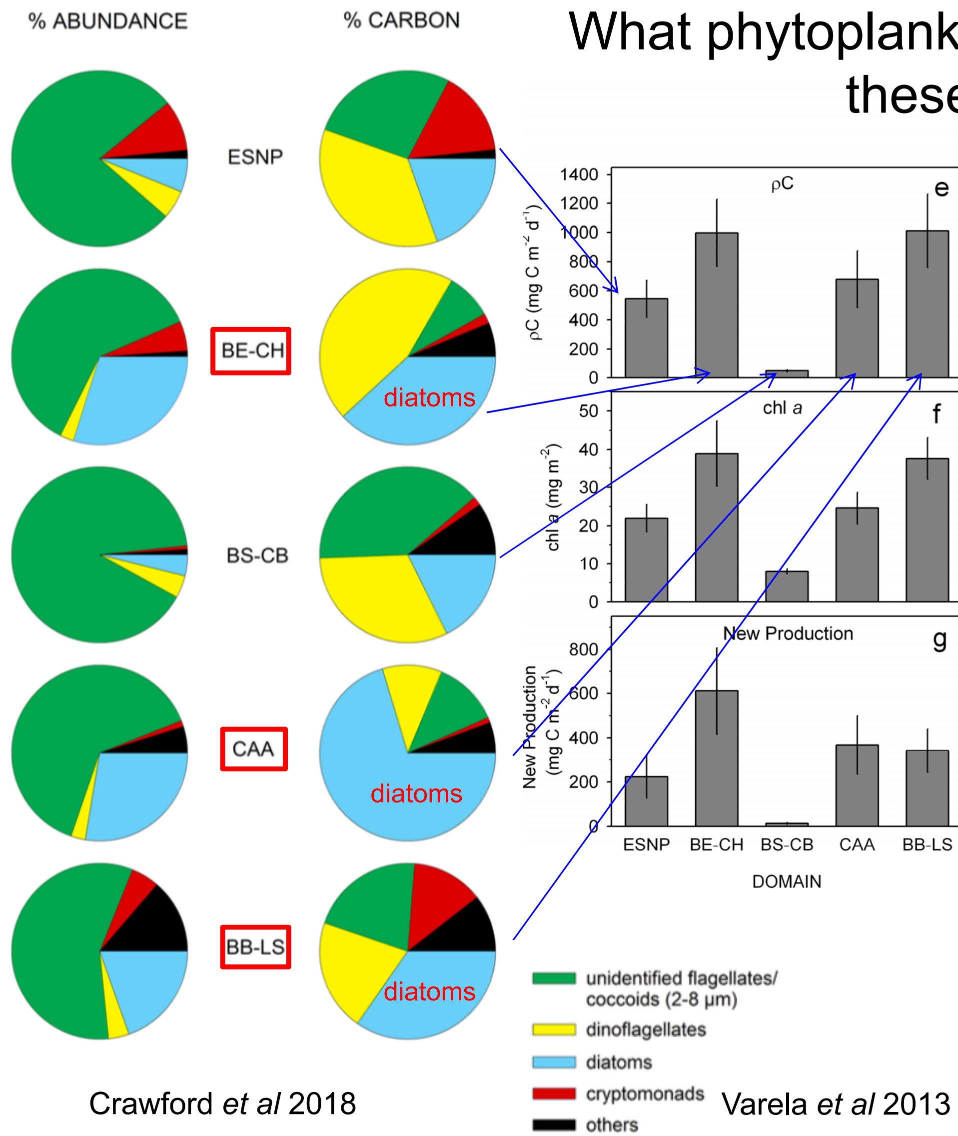
July 2008
August 2007
July 2007
DBO
DISTRIBUTED BIOLOGICAL OBSERVATORY
2006 – 2019
GEOTRACES
2015
80°N
70°N
60°N
50°N
180°E
150°W
120°W
90°W
60°W
ARC
PAC
ATL
C3O
Canada's Three Oceans

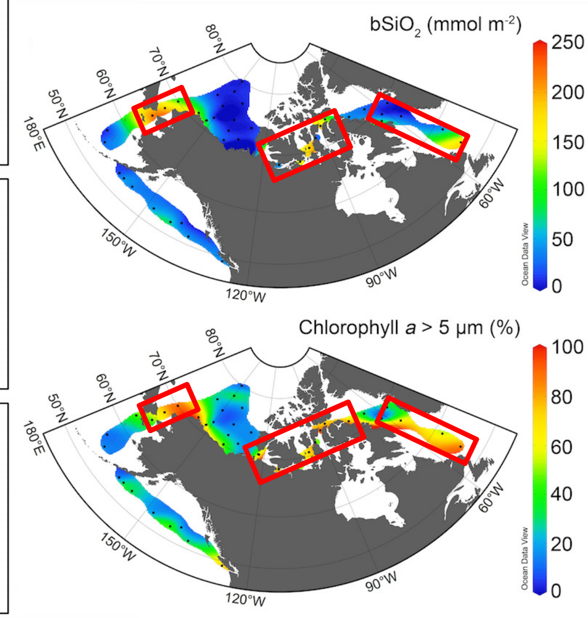
Spatial distributions of phytoplankton production and biomass & nutrient concentrations



Varela, Crawford, Wrohan, Wyatt and Carmack. 2013.
Pelagic primary productivity and upper ocean nutrient dynamics across Subarctic and Arctic Seas.
Journal of Geophysical Research: Oceans 118, 7132-7152.

What phytoplankton are responsible for these patterns?





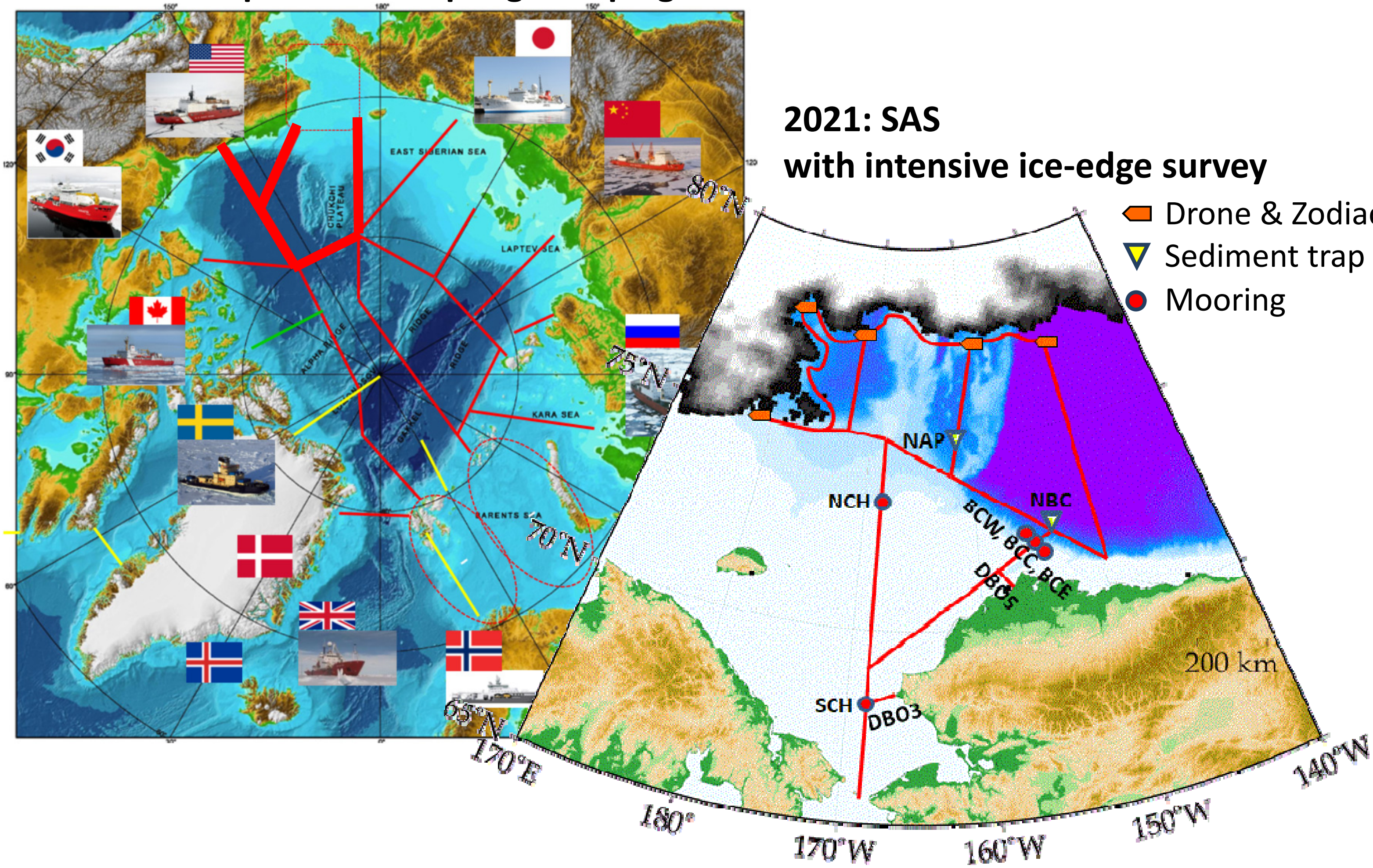
Crawford *et al* 2018

Varela *et al* 2013

Wyatt *et al* 2013

Planned R/V *Mirai* Arctic Ocean cruises in 2020 and 2021

2020: SAS ship-based sampling campaign



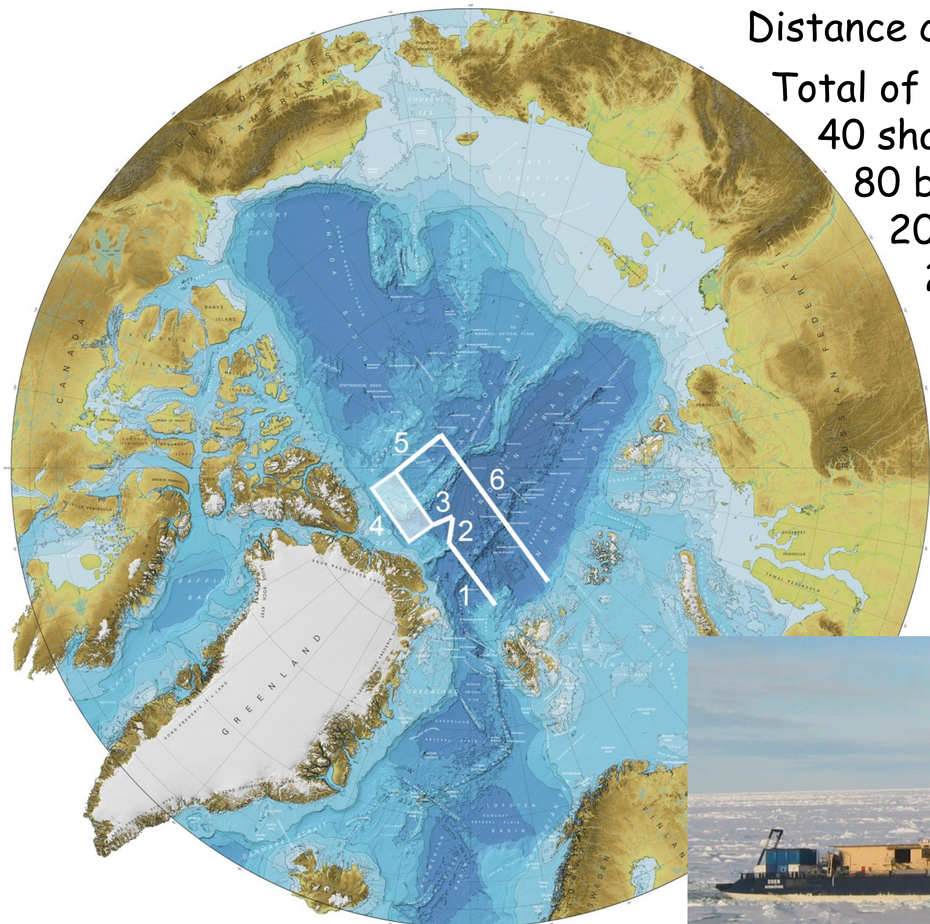

Snow
Ice
Nutrients
Dark
Pre-bloom,
net heterotrophic
No interaction
Sea ice a
net ph
Limited ice
Late Sprin
Early Summ
Strong ice-pelag
-benthic
couplin

[SWIPA, 2017]

UNIVERSITY OF GOTHENBURG

The Swedish contribution to SAS

A 6-7 week cruise in August-September 2020



Distance covered, about 1600 nm

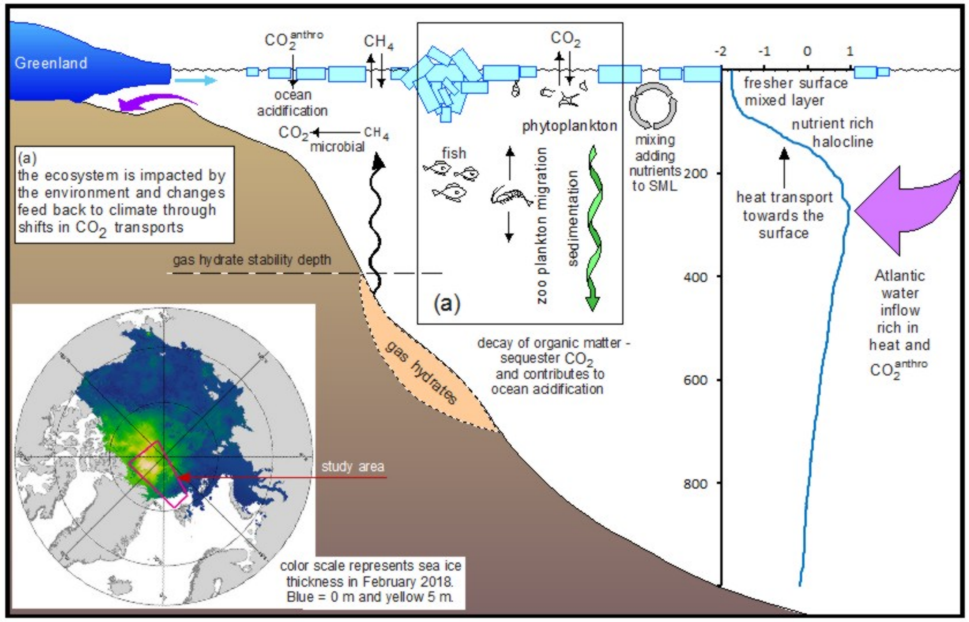
Total of 80 stations for CTD-water
- 40 shallow CTD for biology
- 80 bongo nets
- 20 multi nets
- 20 Tucker trawls
- 20 box cores
- 10 AUV/ROV missions
- Fish trawling

Ferry box - continuous
Plans are also for several sea ice stations

The Swedish contribution to SAS

25 scientists from 7 universities and one institute are committed to participate

Preliminary manning;
17 oceanography and chemistry, 22 pelagic and epontic ecosystem, and 2 benthic ecosystem, and 2 for atmospheric measurements and remote sensing



Also modelling and remote sensing are essential to the science goals and are included in the synthesis

An application has been submitted to the Knut and Alice Wallenberg Foundation with Pauline Snoeijs Lejonmalm (SU) as lead

Massive melting of Arctic ice: Implications for the Central Arctic Ocean ecosystem and feedbacks to global warming

Impact of ice retreat on biological pump and carbon sink in the western Arctic Ocean

based on Chinese Arctic cruises

Xiaobo Ni **Jianfang Chen**

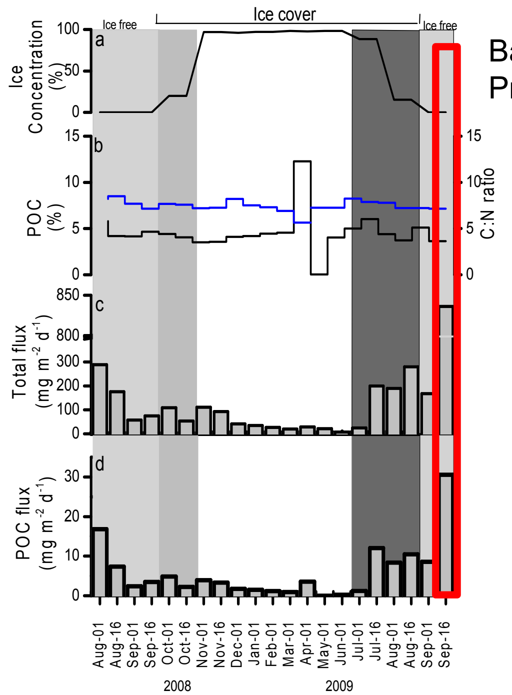
Key Laboratory of
Marine Ecosystem and Biogeochemistry
Second Institute of Oceanography, MNR

Chinese Arctic Research Expedition 1999-2018

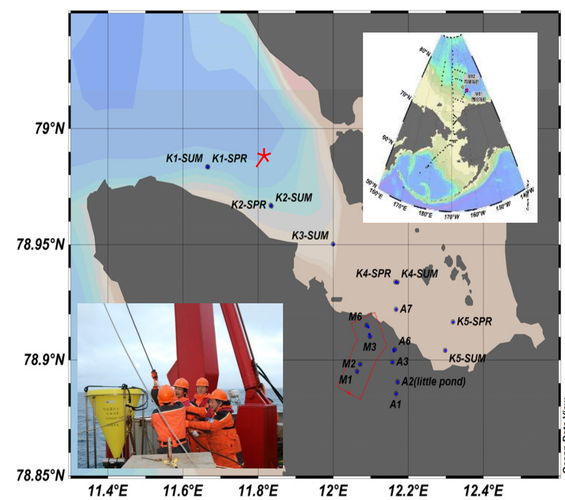
<u>Profiling, ocean/ice sampling</u>: Oxygen, chl-a, nutrients, POC, PN, BSi, pigments , $\delta^{13}C$, $\delta^{15}N$, etc.

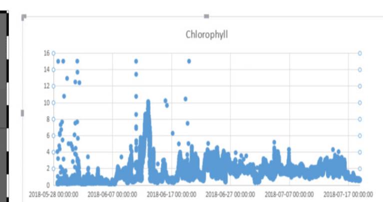
<u>Primary production</u>: carbon/nitrogen uptake, oxygen release

<u>Particle fluxes</u>: sediment traps



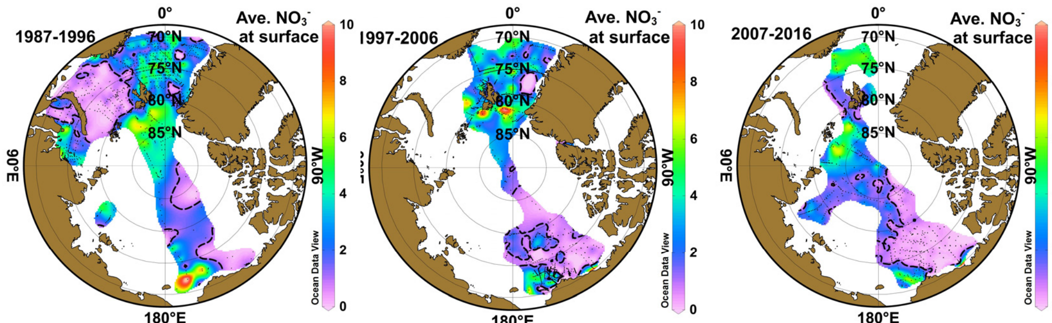
Bai & Chen et al., 2019
Progress in Oceanography





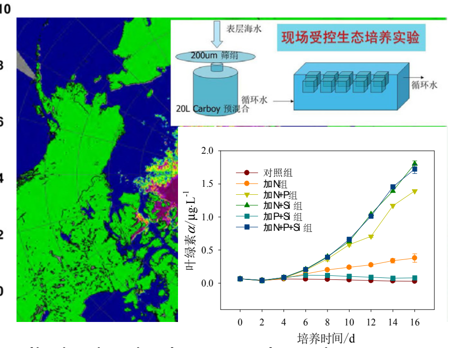
Enhanced biological pump, Oligotrophic trend in surface water and subsurface ocean acidification

N limitation in the Arctic Ocean

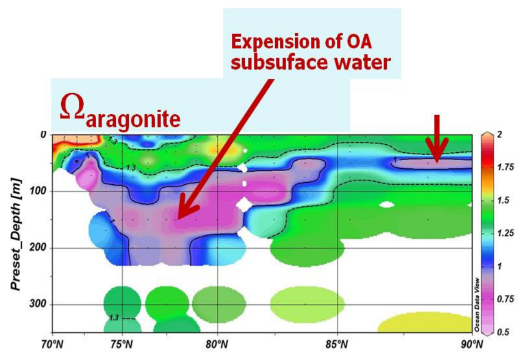


http://www.chinare.org.cn/en/index/;https://www.nodc.noaa.gov/cgi-bin/OC5/WOD;
http://cdiac.ornl.gov/oceans/datmet.html ; http://manida.awi.de/

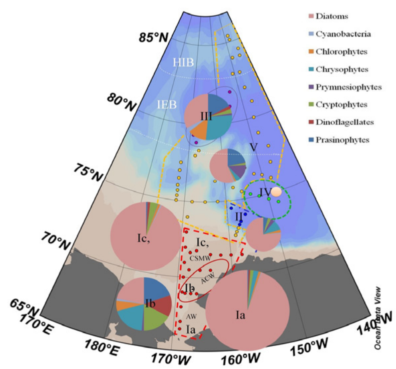
Average nitrate concentration (μM) of top 30 m water column in the Arctic Ocean, Zhuang et al., 2019 submitted



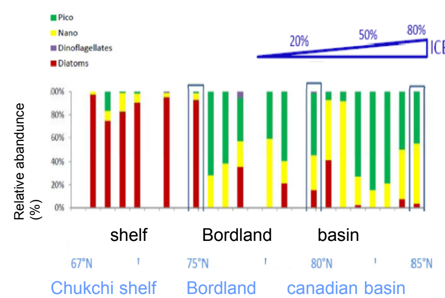
N limitation in the central Arctic,
Li et al., AOS, 2014;



Expension of OA in subsurface water Qi et al., NCC2017;

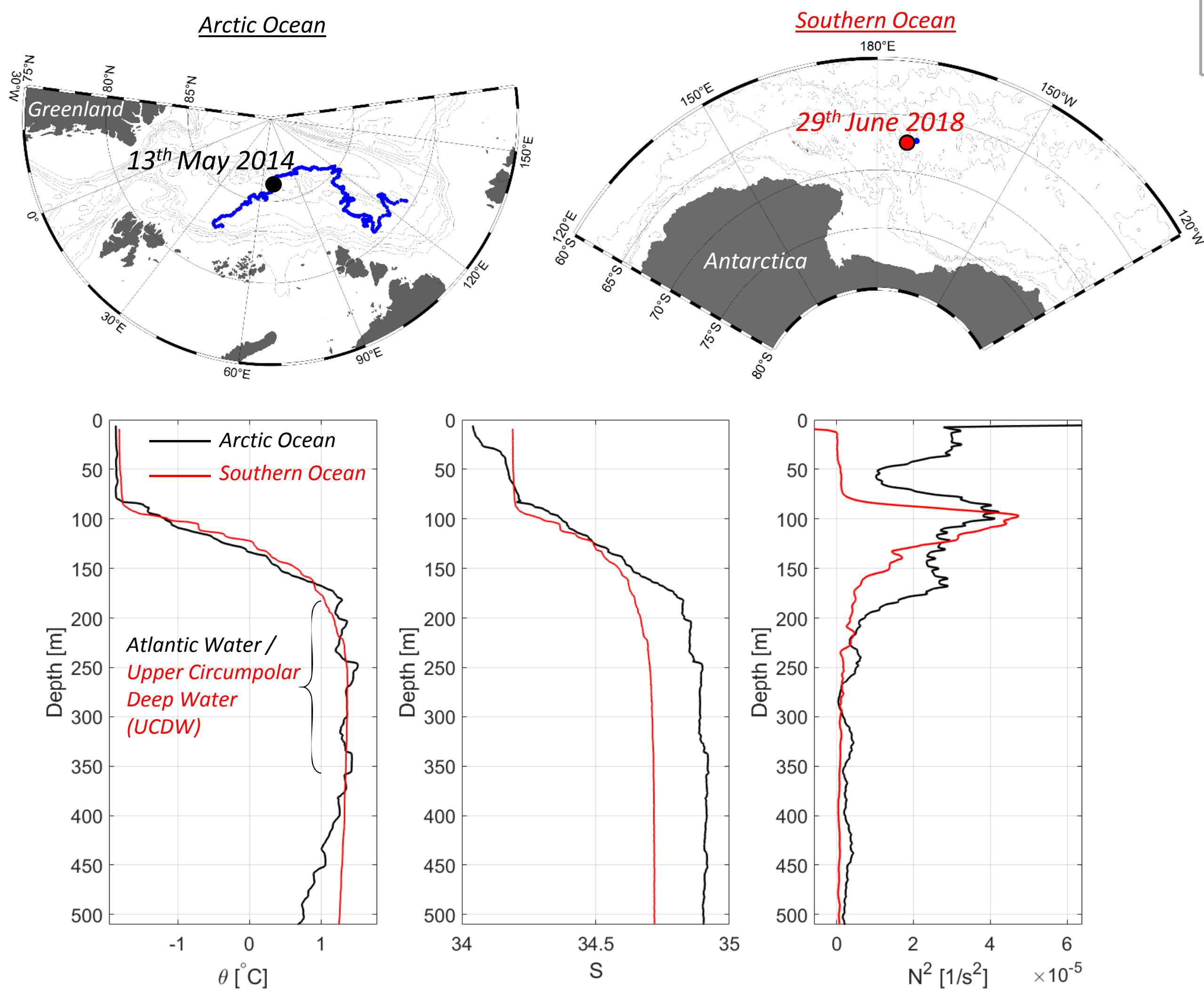


Phytoplankton communities : pigment analysis



Couple et al., Biogeosciences,2012,2015;
Jin et al., AOS,2017;
Zhuang et al., Continental Shelf Research, 2016;
Zhuang et al., Deep Sea Research, 2018:
Zhuang et al., Polar Science, 2018

What can we learn from the Southern Ocean?



GEOPHYSICAL FLUID DYNAMICS INSTITUTE
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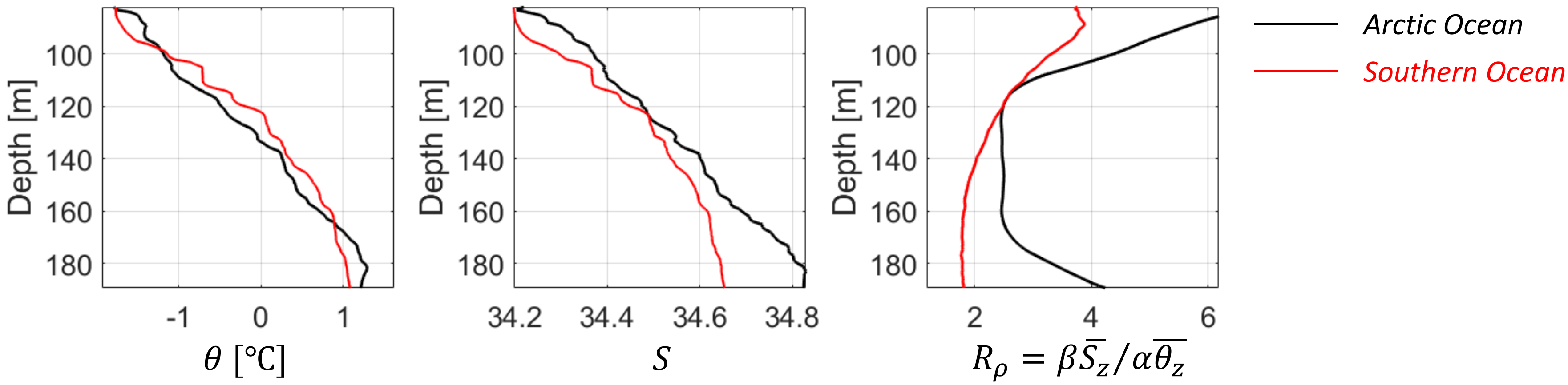
Findings from the Southern Ocean:

- Double-diffusive staircases are observed within the main pycnocline underlying the surface mixed layer
- The presence of a double-diffusive staircase structure enhances sea ice formation and UCDW entrainment by suppression of upward heat fluxes
- Vertical heat flux suppression may produce a feedback that maintains staircase structure

Will the Eurasian Basin's stratification become similar to that of the Southern Ocean?

What can we learn from the Southern Ocean?

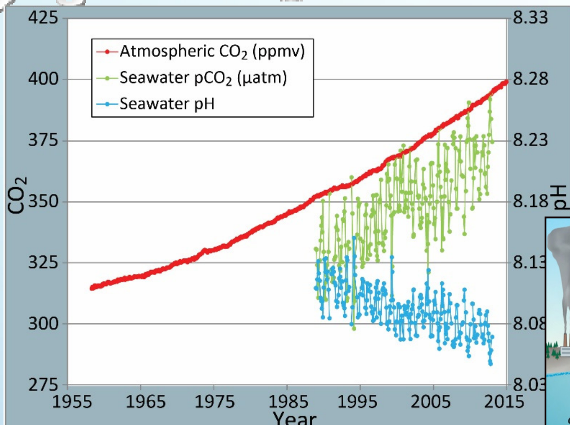


Questions to explore:	How can GFDI be involved?	Other potential involvement:
• Does reduced stratification necessarily mean enhanced vertical mixing in the Eurasian Basin? • What processes will be dominant in controlling sea ice thickness and ventilation of the Atlantic Water layer? • How does brine rejection interact with the layered stratification?	Floats Lab experiments	- Use floats to study 3D picture of the intrusions - Inverse box modeling to help validating numerical models

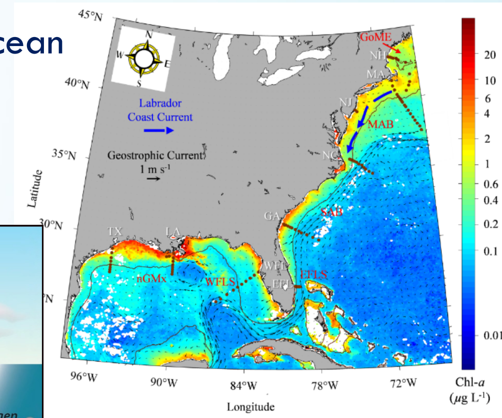
High-resolution studies of the seawater CO_2 system and ocean acidification using in situ sensors

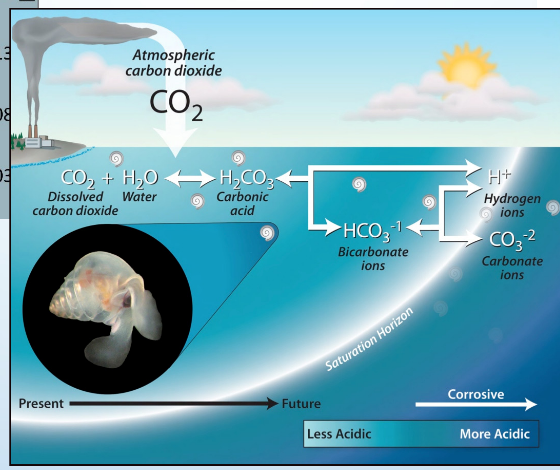
Z. Aleck Wang
Marine Chemistry and Geochemistry
WHOI

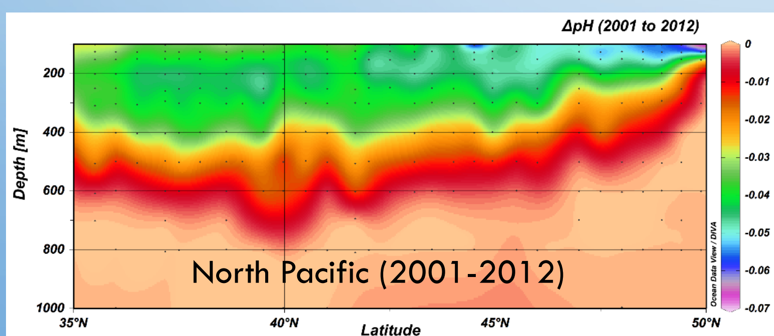
Ocean Acidification and Marine Carbon Cycle

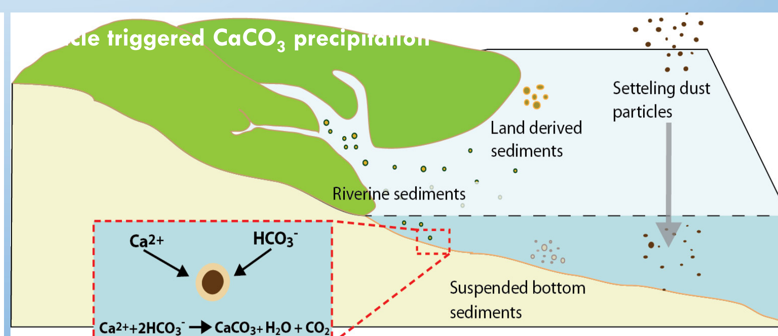


Coastal Ocean



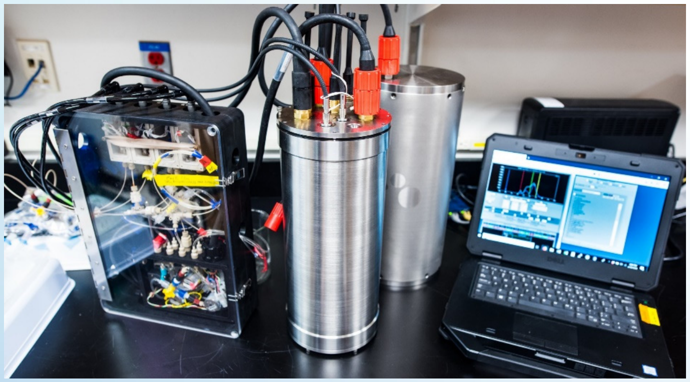


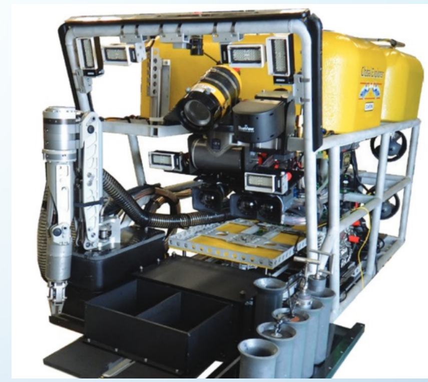


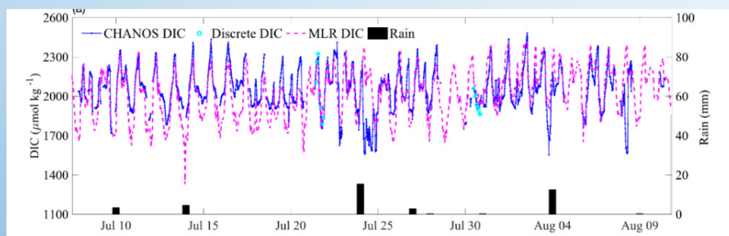


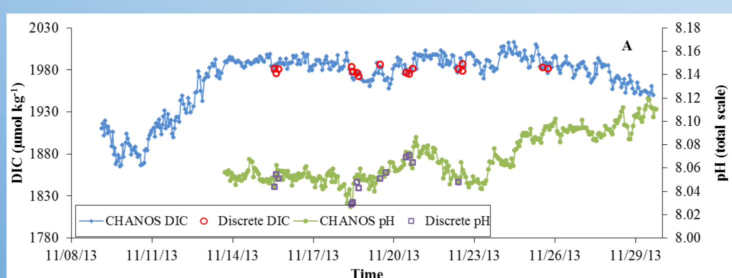
In-situ Sensors: CO_2 parameters

Channelized Optical System II (CHANOS II): Total CO_2, *p*CO_2, pH







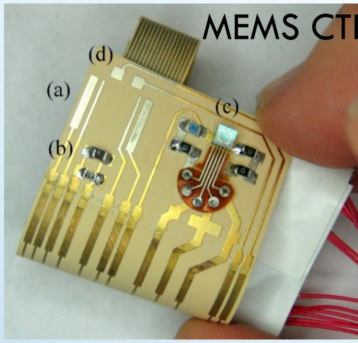


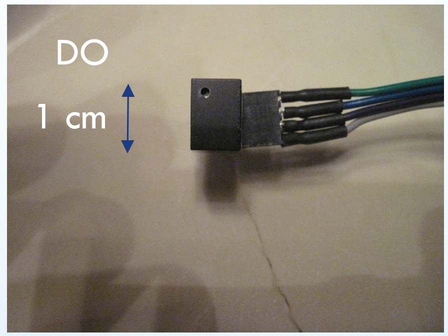
Methodology:

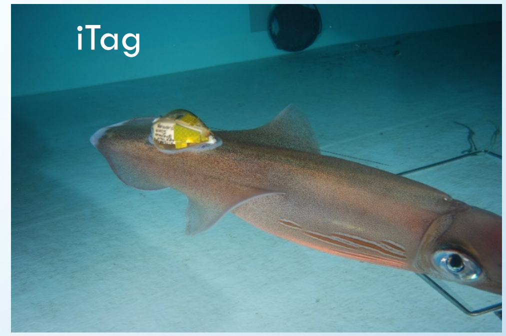
- ✓ Simultaneous, in-situ spectrophotometric measurements of DIC & pCO_2 or DIC & pH
- ✓ High-frequency (~1 Hz), in situ measurements up to 3000m; versatile for various platforms, particularly mobile platforms (CTDs, AUVs, ROVs)

In-situ Sensors: O_2, salinity

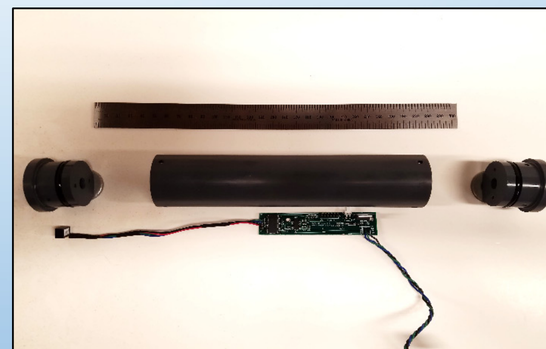
Compact, low cost sensors <u>for ALL</u>: O_2, salinity, pH and others







Low-cost Conductivity/Salinity Sensor

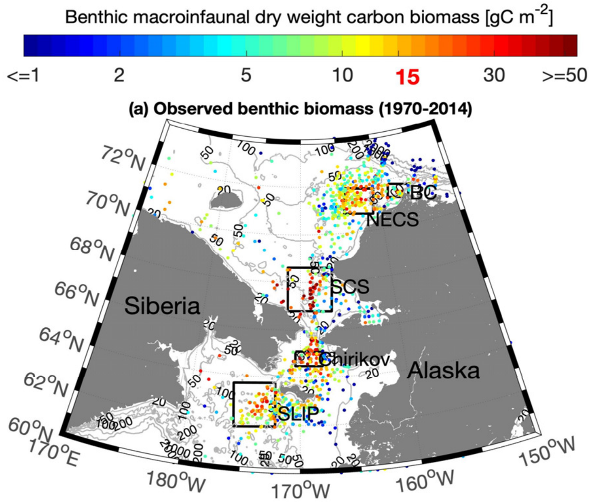


Low-cost DO optode

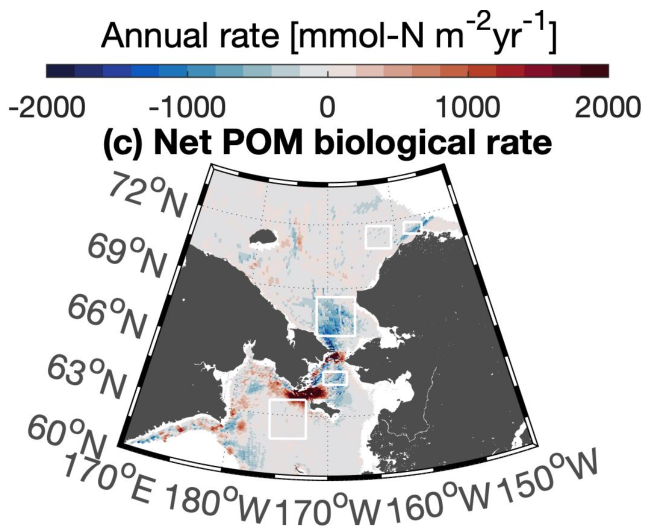
Mechanisms for the Formation of Benthic Hotspots in the Pacific Arctic

Zhixuan Feng (WHOI)

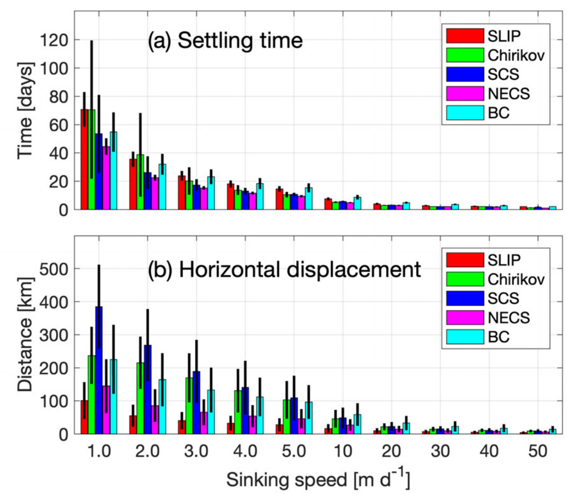
Collaborators: Rubao Ji, Carin Ashjian, Jinlun Zhang, Robert Campbell & Jackie Grebmeier



Ice-Ocean-BGC model results



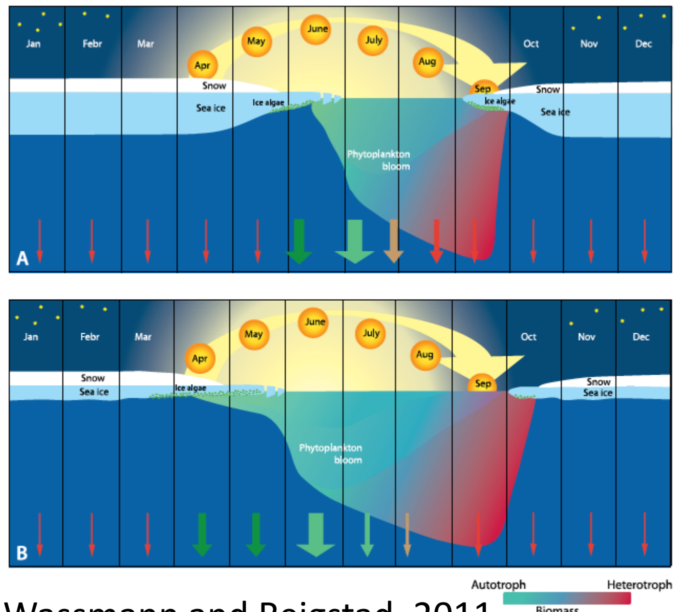
Particle tracking model results



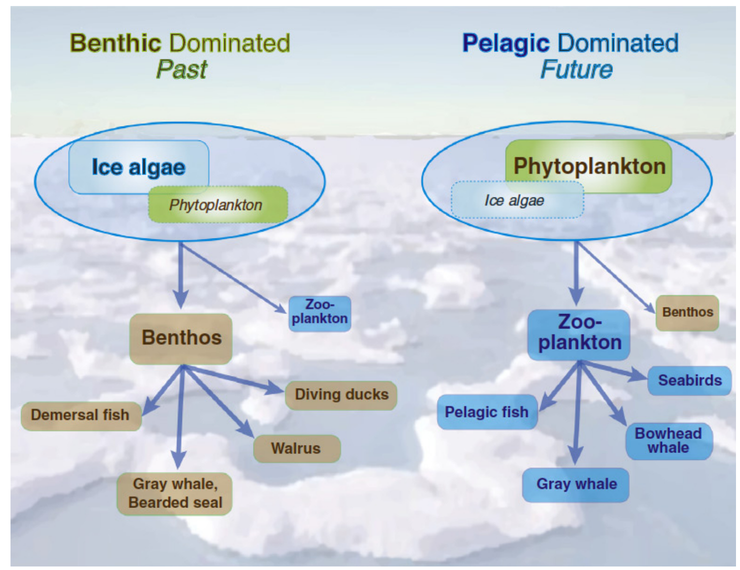
Data-model synthesis reveals 2 contrasting regimes and food supply mechanisms:

- Retentive: SLIP and NECS.
- Advective: Chirikov, SCS & Barrow Canyon.

Benthic-pelagic coupling in a pan-arctic scale



Wassmann and Reigstad, 2011



Moore and Stabeno, 2015

- What key processes and parameters are needed to have a better pan-arctic understanding of the benthic-pelagic coupling?