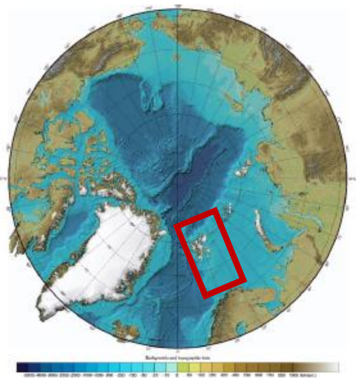
The Changing Arctic Ocean Seafloor (ChAOS)

How changing sea ice conditions impact biological communities, biogeochemical processes and ecosystems

Christian März (PI, University of Leeds) and the ChAOS Team



In this talk, we will…

… briefly introduce the ChAOS project

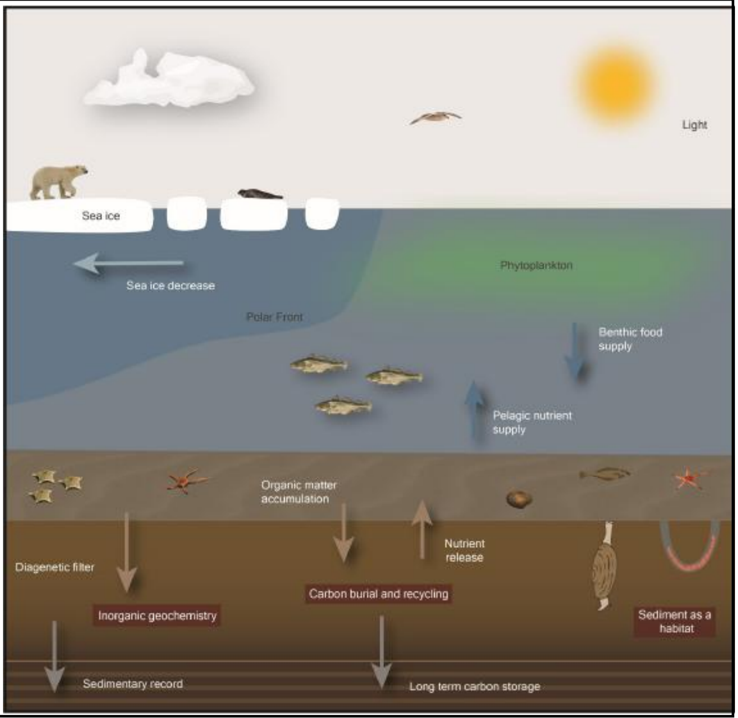
… present RRS James Clark Ross expeditions and ice conditions in summer 2017 and 2018

… show preliminary data from 2017 and 2018 expeditions:

- Macro/meiobiology → Steve Widdicombe (PML)
- Microbiology and N cycling → Karen Tait (PML)
- Nutrients → Sian Henley (Edinburgh)
- Sediment geochemistry → Johan Faust (Leeds)
- Pigments → Ruth Airs (PML)
- Modelling → Felipe Sales de Freitas (Bristol)

ChAOS will decipher how a Changing Arctic Ocean affects the shelf seafloor:

- Benthic-pelagic coupling
- Effects of multiple environmental stressors
- Recycling vs. burial of carbon and nutrients
- Benthic community structure, biodiversity and activity
- Integration of benthic processes into biogeochemical model



Physical properties of water column (Arctic PRIZE)

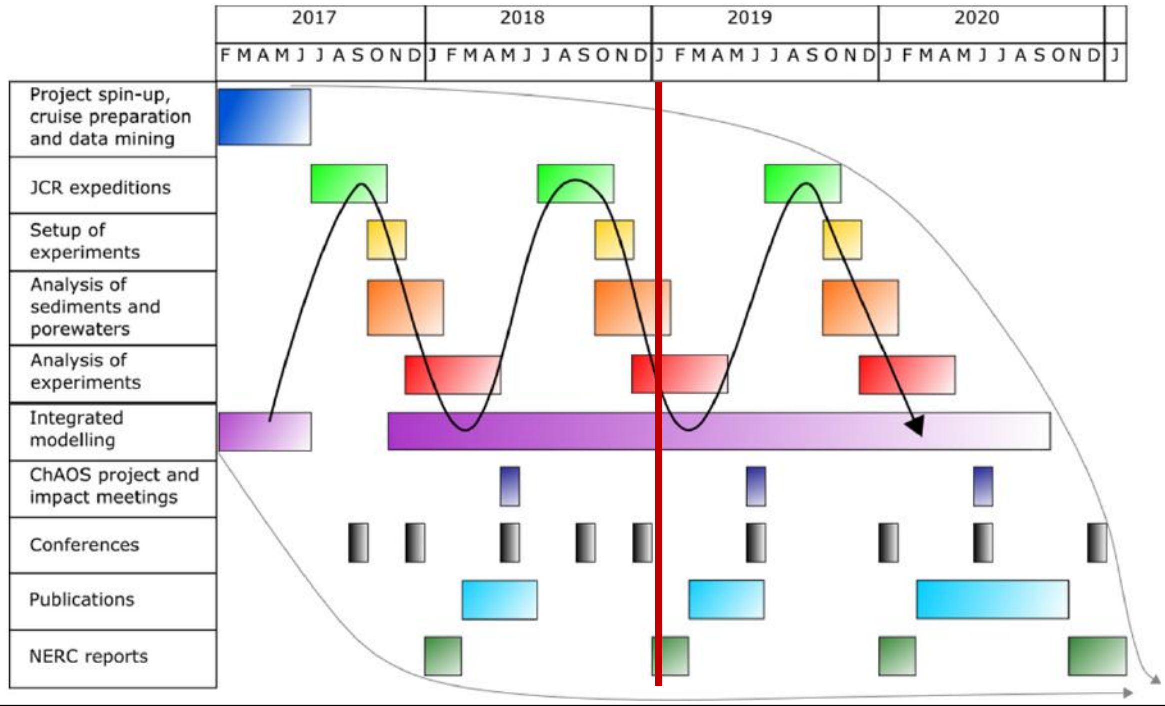
Organic matter – the food source for seafloor life
(Module 1)

Chemical and biological properties of water column (DIAPOD, ARISE)

Integrated modelling – connecting the pieces

Remineralisation – how do organisms process carbon and nutrients?
(Module 3)

Benthic community – who lives at the seafloor, what are they doing?
(Module 2)



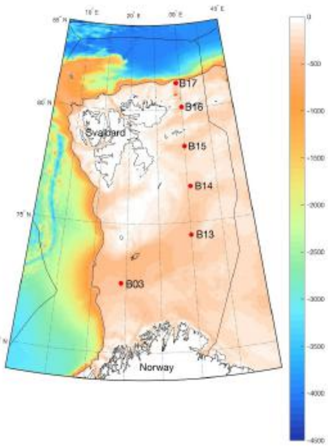
Cruises

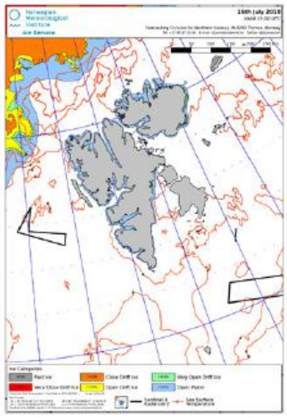
Transect across winter ice edge/polar front,
5 core stations (+ a few extras)

JR16006 (July 2017) → lots of sea ice

JR17007 (July 2018) → no sea ice

July 2019 → ???





Deployments

CTD-Rosette

Shallow Underwater Camera System (2017, 2019)

Multicorer

Boxcorers (big and small)

Agassiz trawl

Bathymetry (2019)

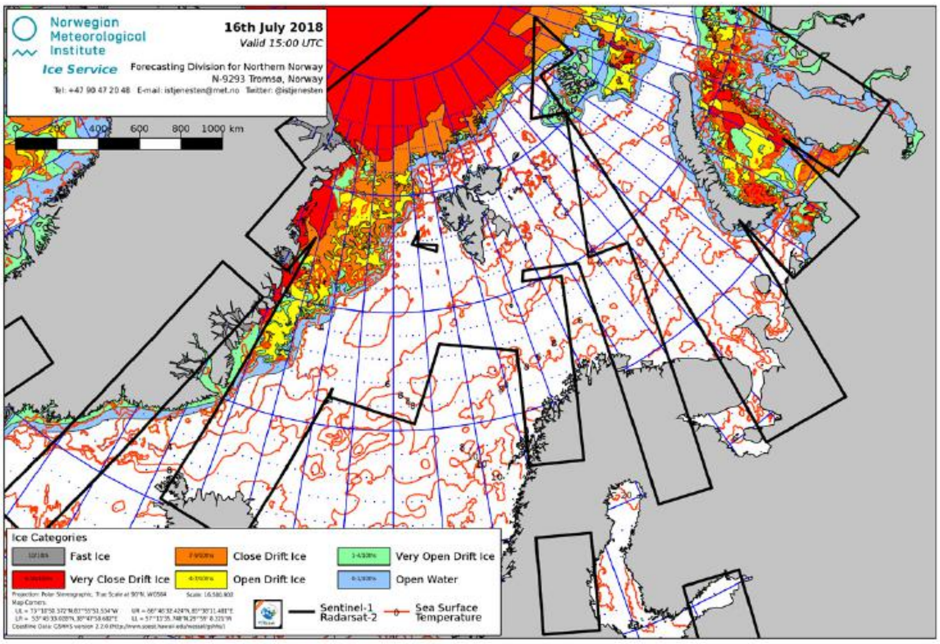
Disciplines involved

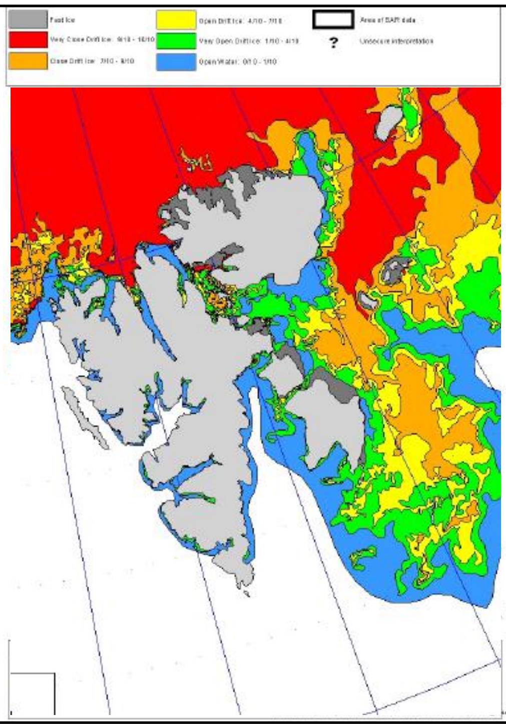
Benthic biology (macro, meio, micro, incubation experiments)

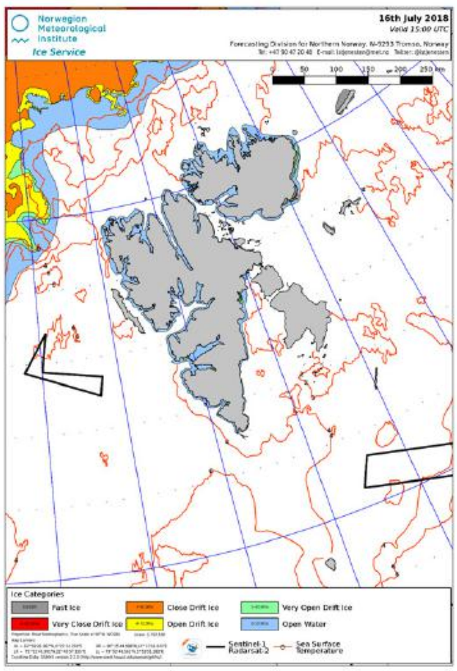
Organic geochemistry (biomarkers, radiocarbon, C isotopes, pigments)

Inorganic geochemistry (dissolved & particulate carbon, nutrients, metals)

Biogeochemical modelling (benthic-pelagic coupling, upscaling, predictions)


Norwegian Meteorological Institute
Ice Service
16th July 2018
Valid 15:00 UTC
Forecasting Division for Northern Norway
N-9293 Tromsø, Norway
400 600 800 1000 km
Ice Categories
Fast Ice
Close Drift Ice
Very Open Drift Ice
Very Close Drift Ice
Open Drift Ice
Open Water
Sentinel-1
Radarsat-2
Sea Surface Temperature

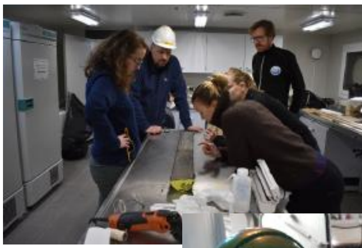

Fast Ice
Very Close Drift Ice
Close Drift Ice
Open Drift Ice
Very Open Drift Ice
Open Water
Area of SAR data
?
Uncertain interpretation


Norwegian Meteorological Institute
Ice Service
16th July 2018
Valid 15:00 UTC
Ice Categories
Fast Ice
Close Drift Ice
Very Open Drift Ice
Very Close Drift Ice
Open Drift Ice
Open Water
Sentinel-1
Radarsat-2
Sea Surface Temperature

Existing links to Nansen LEGACY

Allyson Tessin (Leeds) and Mark Zindorf (Newcastle, now Brest) on "Paleo cruise" (led by Katrine Husum, Tromsø, and Ulysses Ninnemann, Bergen)

Pore water and sediment geochemistry



Potential future opportunities

Shared meetings

Exchange of early career researchers

Nansen LEGACY members on 2019 ChAOS cruise

ChAOS members on future Nansen LEGACY cruise?

Expanding links in benthic biology/biogeochemistry, contaminants, modelling

Acknowledgements

**Captain, crew and scientists onboard RRS James Clark Ross in 2017 & 2018*

**All „honorary“ ChAOS members*

**Natural Environment Research Council*

**ARISE, Arctic PRIZE and DIAPOD teams*

**Kirsty Crocket, David Thomas, Jessica Surma and PAG for managing the program*

Changing Arctic Ocean

Natural Environment Research Council

Seabed faunal composition and function from contrasting regions of the western Barents Sea

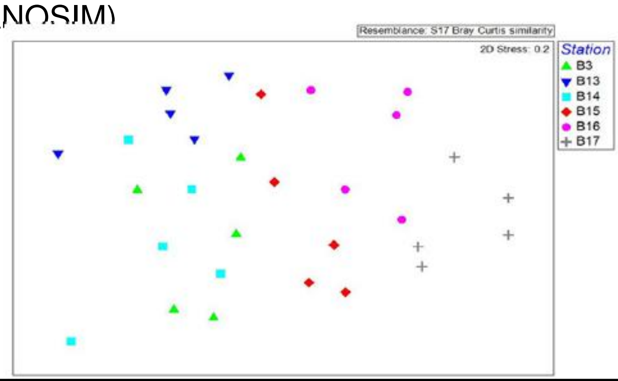
Steve Widdicombe

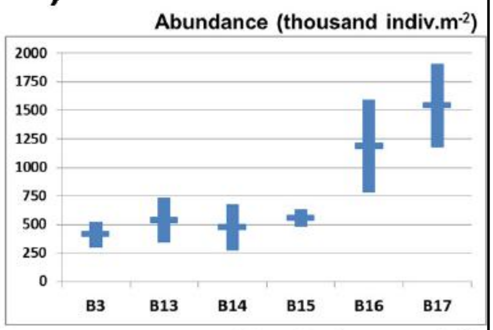
e-mail: swi@pml.ac.uk

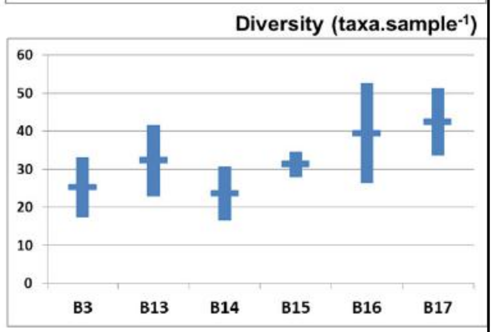
@steve_swi

Meiofauna (2017)

- There is an increase in nematode diversity and abundance from south (B3) to north (B17).
- Nematodes are particularly abundant at the most heavily iced stations, B16 and B17.
- All stations are statistically different from each other in terms of community structure (pairwise ANOSIM)

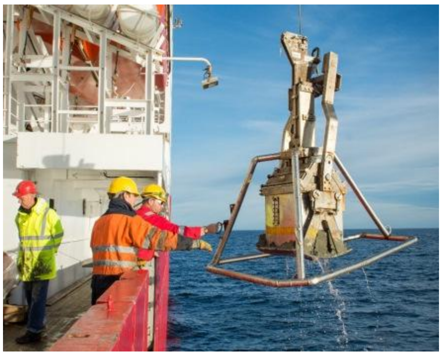






Macro-infauna

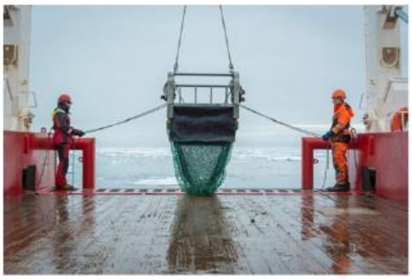
- 5 x $0.1m^2$ box core samples taken at each station (2017 and 2018).
- Sieved over 0.5mm mesh.
- Analysis underway for species composition, abundance and biomass.
- Cross-comparisons with other CAO faunal analysts would be useful.



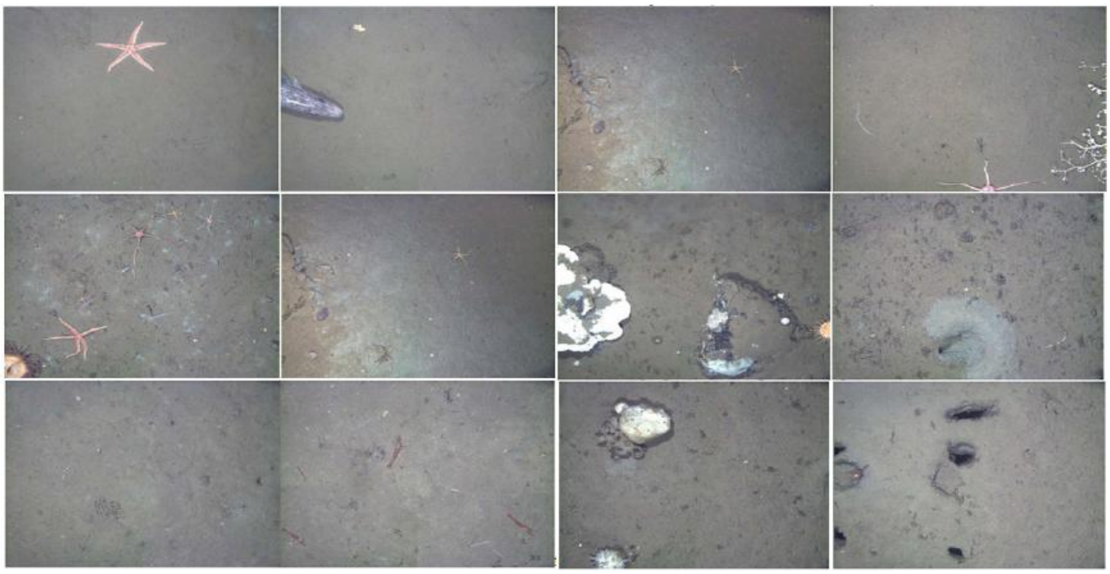
Megafauna

Shallow Underwater Camera System (SUCS)

2m Jennings trawl



SUCS (2017)



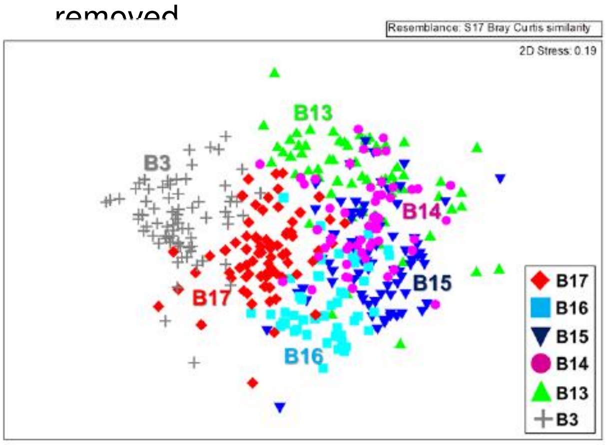
Arctic Ocean seafloor photographs ~ 200-300m depth

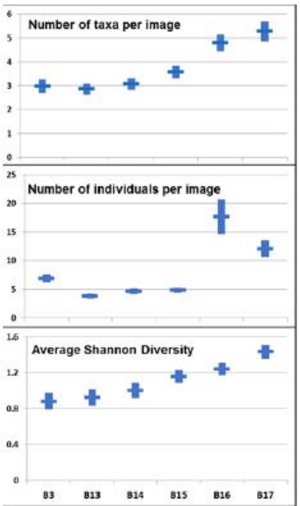
Photo credit: DKA Barnes Shallow Underwater Camera System

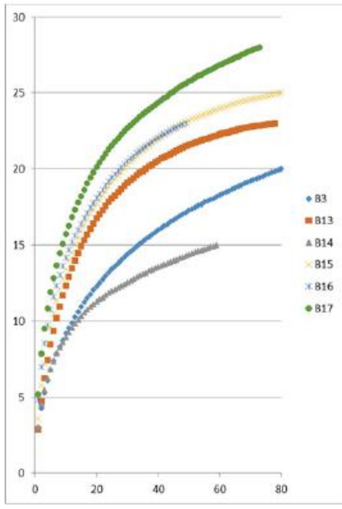
SUCS (2017)

- All stations significantly different
- Same (but weaker) pattern for transformed data
- More linear response when B3 removed

- Abundance and diversity was highest in the most northerly stations.

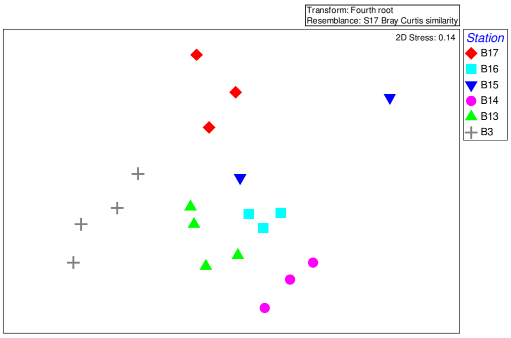


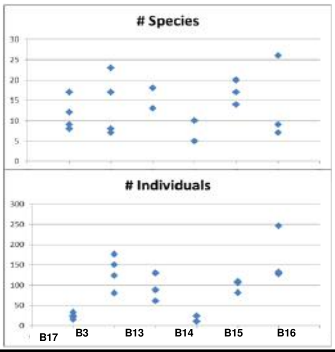




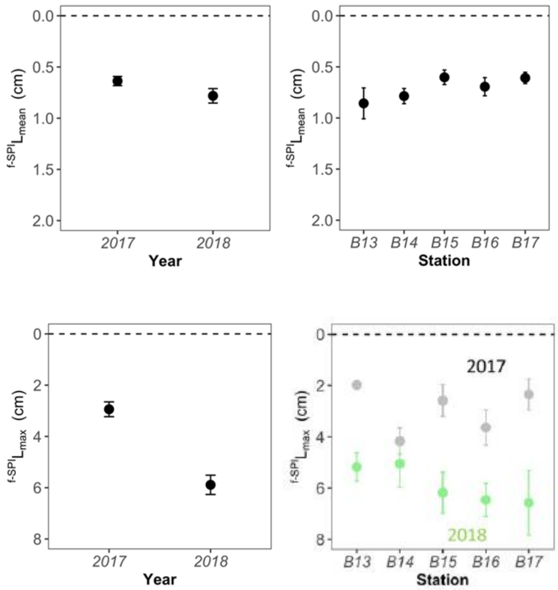
Jennings Trawls (2017)

- Stations B3 and B15 low in abundance
- No obvious N-S trend in biodiversity
- Large differences between stations in community composition
- 2018 samples yet to be fully analysed





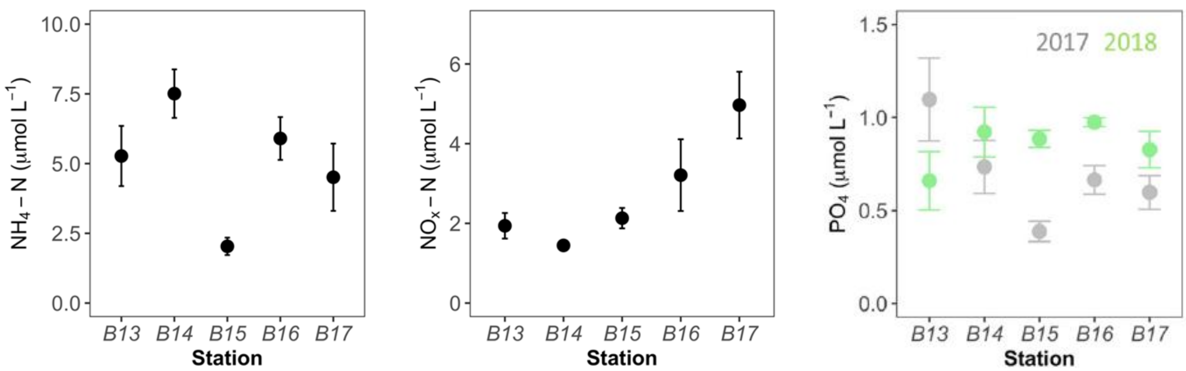
Community Function - Bioturbation



- Little difference between years in terms of the average sediment mixing activity. Activity increases from south to North
- Maximum mixing depth is significantly deeper in 2018 than in 2017.
- North-south pattern only seen in 2018.

Community Function – Nutrient Flux

- Small fluxes of nutrients (NH_4, NO_x and PO_4) from the sediment.
- Increase in NOx may indicate higher rates of nitrification, driven by greater bioturbation at higher latitudes.
- North-south pattern only seen in 2018.



ChAOS: Microbiology

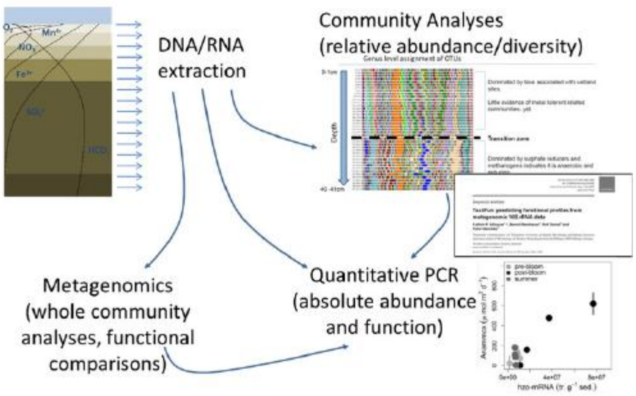
Karen Tait, Helen Parry, Jo Nunes (Plymouth Marine Laboratory)
Luiza Andrade, Peter Leary, Neil Gray, Ian Head (Newcastle University)

Changing Arctic Ocean NERC

What is the characteristic structure and function of benthic infaunal assemblages under different ice cover scenarios?

On each cruise:

- Three replicate cores (multi-cores) from each station
- Sediment is sectioned in 1 cm intervals from surface to ~25 cm
- Molecular ecology samples match geochemistry samples
- Nucleic acids extracted from each sediment layer



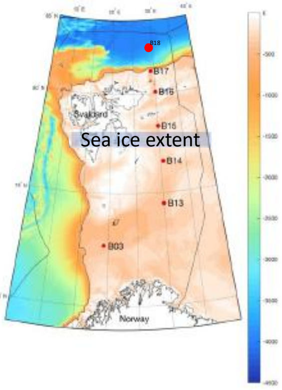
Changing Arctic Ocean NERC

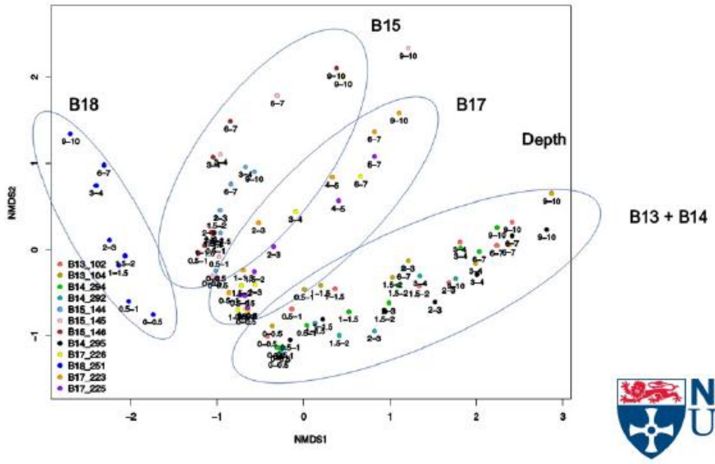
How does the activity of benthic organisms change under different ice cover scenarios?

- N cycling rates: nitrification, denitrification, anammox
- Measurement of the abundance of genes and transcripts representing key nutrient (N and S) cycling functional guilds (JR16006 data with BODC)

JR16006 sequence data:

Microbial community composition variation as a function of transect and depth

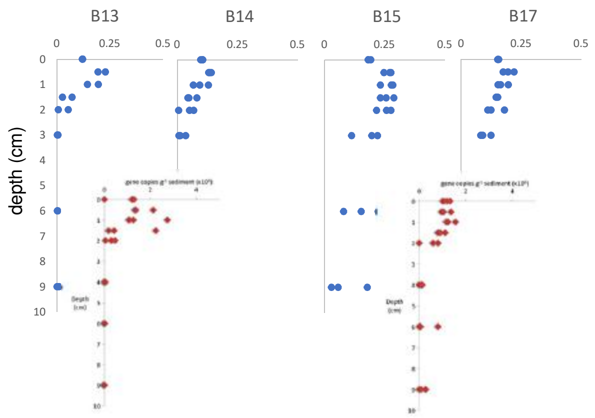




JR16006 data:

B13 and B14 = shallow transition to anaerobic conditions
B15 and B17 = deeper transition to anaerobic conditions

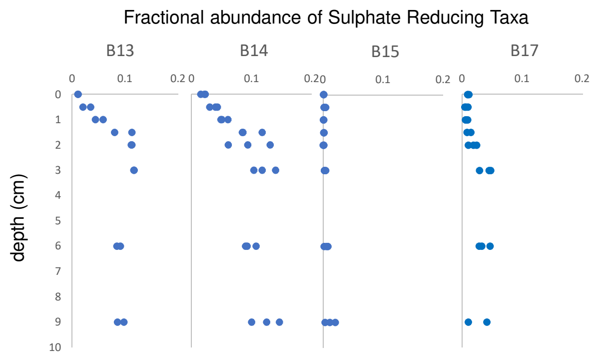
Abundance of Nitrosopumilaceae (chemolithoautotrophic aerobic ammonia oxidiser)



- ≤ 25 % of sequences were archaeal Nitrosopumilaceae – chemolithotrophic **aerobic** ammonia oxidiser
- Deeper transition into sediment confirmed using qPCR

JR16006 data:

B13 and B14 = shallow transition to anaerobic conditions
B15 and B17 = deeper transition to anaerobic conditions

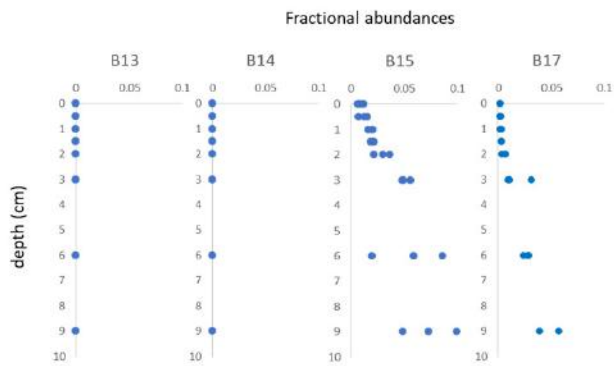


- ≤ 12 % of community at depth (B13 and B14)
- Fractional abundances of total SRB show steep increases in B13 and B14 and to a lessor extent B17.
- **LINKED TO INCREASED BIOIRRIGATION ACTIVITY AT B15?**

Newcastle University

JR16006 data:

Methylomirabilaceae wb1-A12: carries out nitrite dependent methane oxidation **via generation of molecular oxygen** and particulate methane monooxyganase



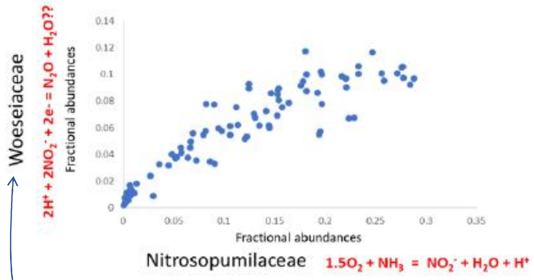
$2CH_4 + 8NO_2^- + 8H^+ = 3CO_2 + 4N_2 + 10\ H_2O$???

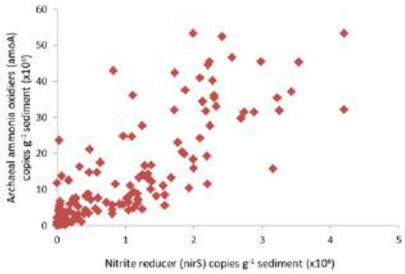
Newcastle University

JR16006 data:

Changing Arctic Ocean NERC

Tentative evidence of a tightly coupled oxidative and reductive nitrogen cycle?





Woeseiaceae: ≤ 8 % of sequences; known nitrite reducers (nirS-type)

PML Plymouth Marine Laboratory

Newcastle University

Continuing work

Changing Arctic Ocean NERC

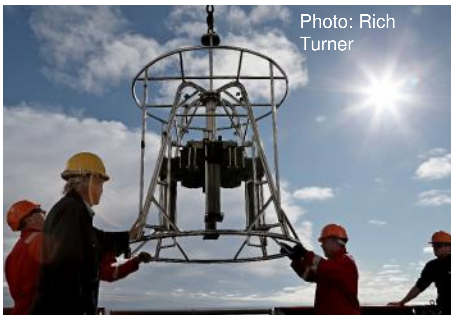
- JR17007
  - DNA extraction complete
  - Sequencing and qPCR ongoing
- Same again on cruise year, with additional work on C addition and bioturbation
- Linked GW4+ PhD student Patrick Downes: ‘The effects of changing Arctic sea ice cover on pelagic microbial organic matter utilisation: from composition to consumption’

PML Plymouth Marine Laboratory

Newcastle University

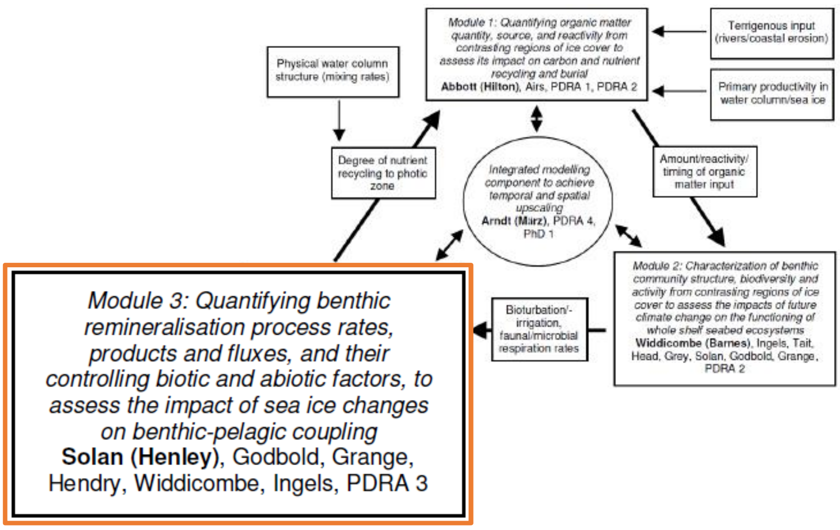
Nutrient cycling in sediment porewaters of the Barents Sea

Sian Henley, Johan Faust, Kate Hendry, Allyson Tessin,
Mark Stevenson, Tim Brand, Christian März



Acknowledgements: All willing helpers during JR16006 and JR17007
Captain, officers and crew RRS James Clark Ross

ChAOS structure



Objectives

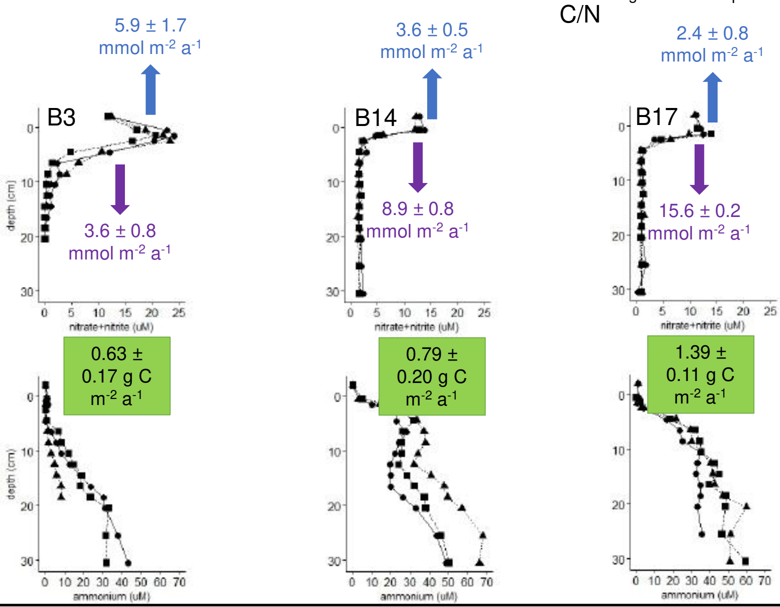
- To characterise nutrient and carbon cycling and loss processes in sediments
  - Porewater and sediment profiles, N and P speciation, $\delta^{15}N$ and $\delta^{18}O$ of nitrate and $\delta^{30}Si$ in porewaters and seawater
- To quantify macronutrient (N, P, Si) fluxes between sediments and the overlying water column, and importance for benthic-pelagic coupling
  - Porewater nutrient profiles, sediment characteristics
- To assess the most important biotic and abiotic factors driving variability with latitude and sea ice conditions
  - Physical, chemical and biological oceanographic datasets, links to other ChAOS work packages, CAO and other projects

➢ Future changes in response to environmental changes associated with ongoing sea ice declines…

Results

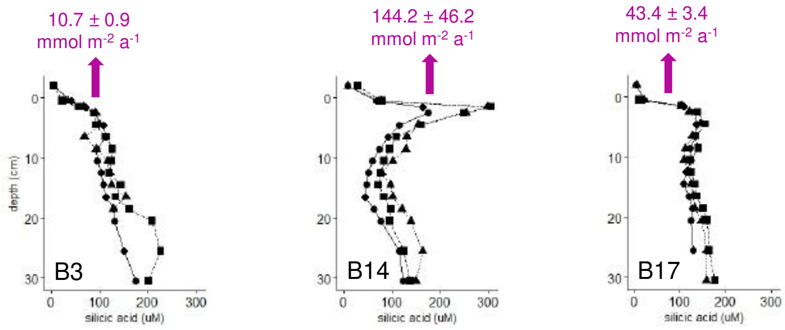
$J_{sed} = \varphi \times D_{sed} \times dC/dx$

$R_{ox.\ Corg} = J_{nitrate\ up} + J_{nitrate\ down} \times C/N$

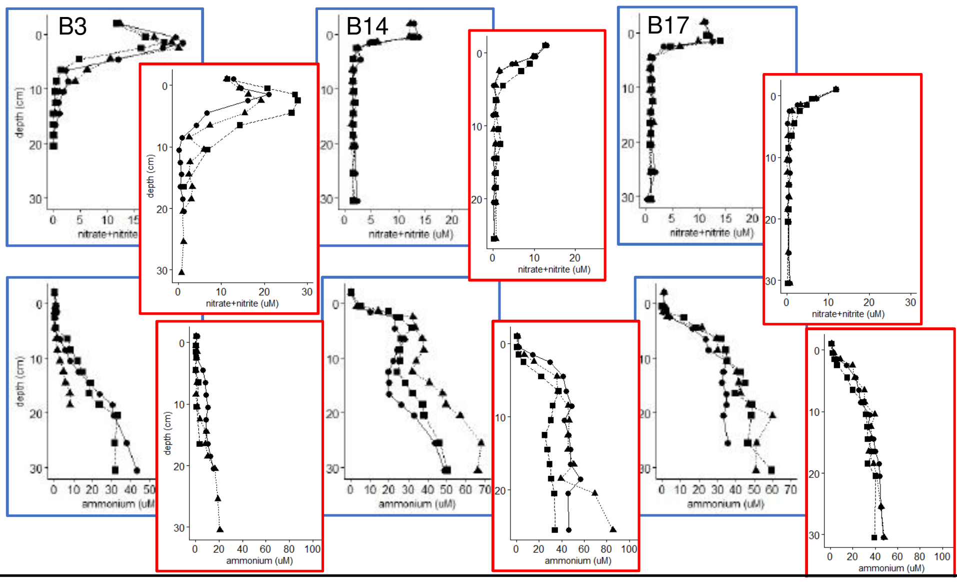


Results

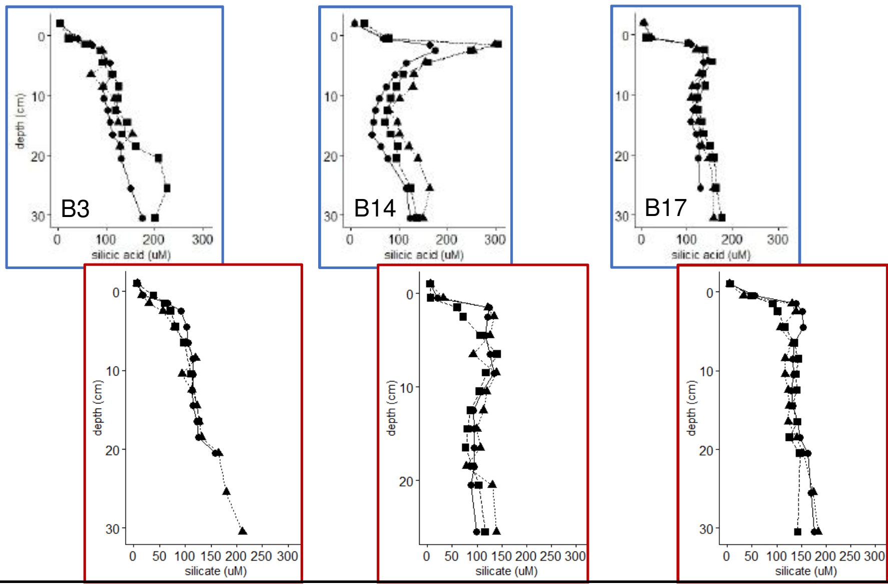
$$J_{sed} = \varphi \times D_{sed} \times dC/dx$$



Results



Results



Next steps

- To characterise nutrient and carbon cycling and loss processes in sediments
  - Porewater and sediment profiles, N and P speciation, $\delta^{15}N$ and $\delta^{18}O$ of nitrate and $\delta^{30}Si$ in porewaters and seawater
- To quantify macronutrient (N, P, Si) fluxes between sediments and the overlying water column, and importance for benthic-pelagic coupling
  - Porewater nutrient profiles, sediment characteristics
- To assess the most important biotic and abiotic factors driving variability with latitude and sea ice conditions
  - Physical, chemical and biological oceanographic datasets, links to other ChAOS work packages, CAO and other projects
- Summer 2019

Changing Arctic Ocean NERC

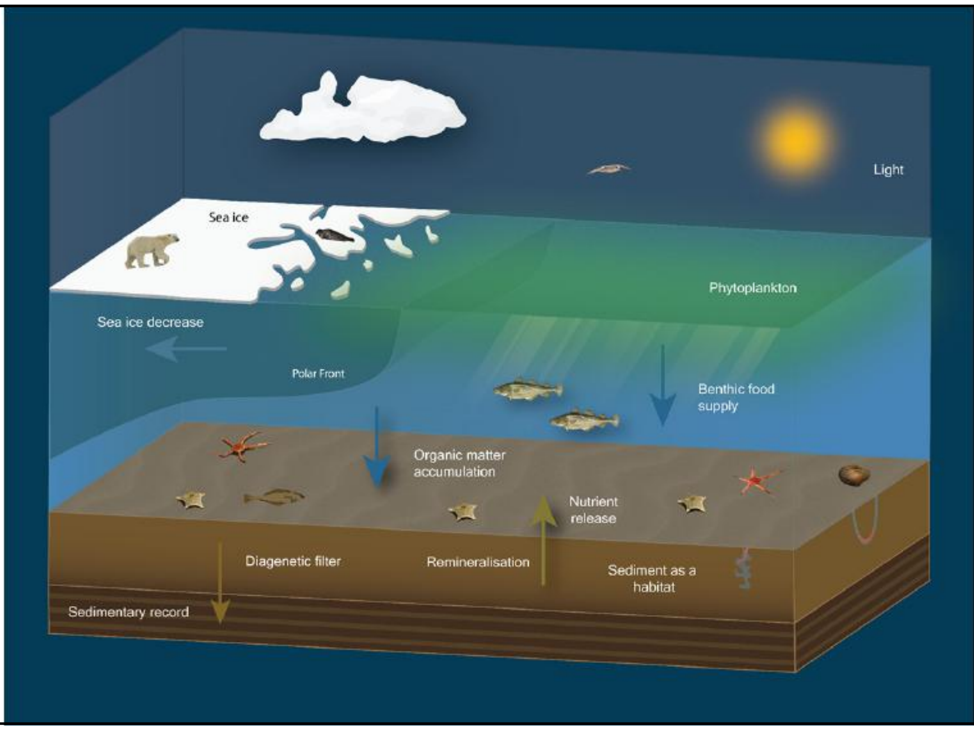
UNIVERSITY OF LEEDS

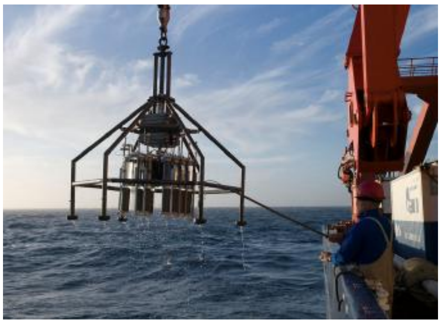
Sediment Geochemistry

Johan C. Faust and Christian Maerz

January 2019

CAO Annual Science Meeting, Birmingham

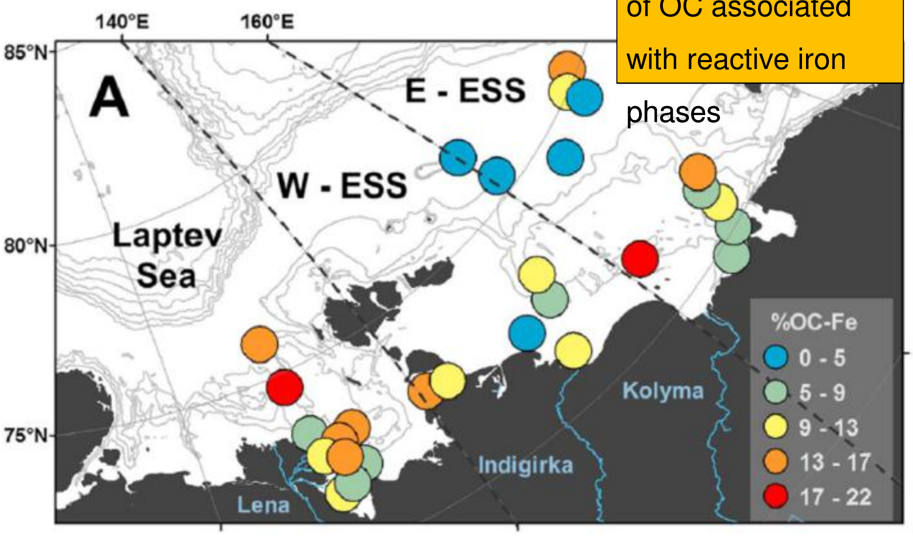




Analysis

- Elemental Composition
- ^{210}Pb and ^{14}C dating
- Grain Size
- Biogenic Opal
- C_{org} and N_{org}
- $\delta^{13}C$ and $\delta^{15}N$
- Mineralogy
- OC-Fe

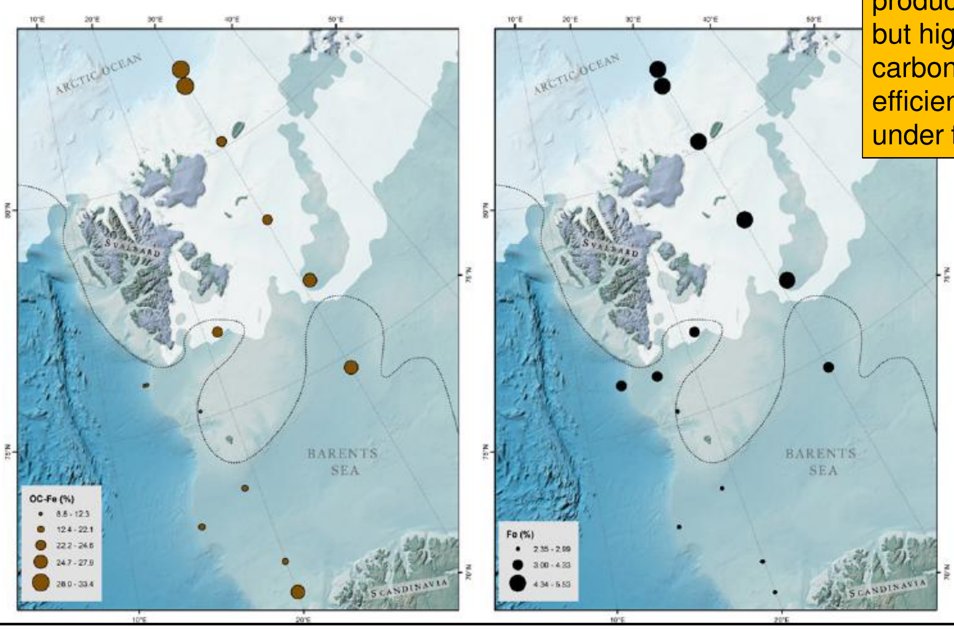
OC associated with iron oxides



Substantial fraction of OC associated with reactive iron phases

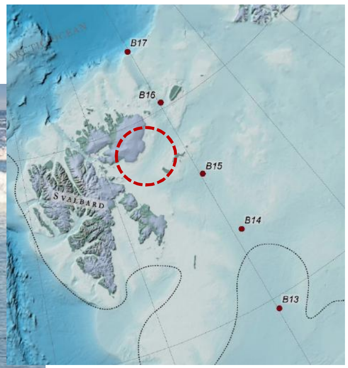
Salvadó et al. 2015

OC-Fe

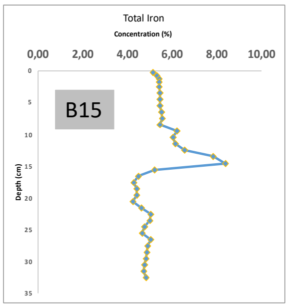


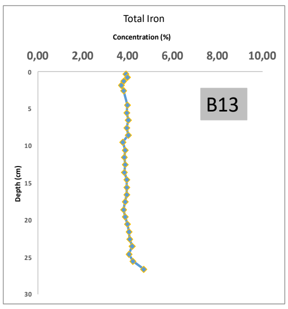
Low or slow productivity but high carbon burial efficiency under the ice?

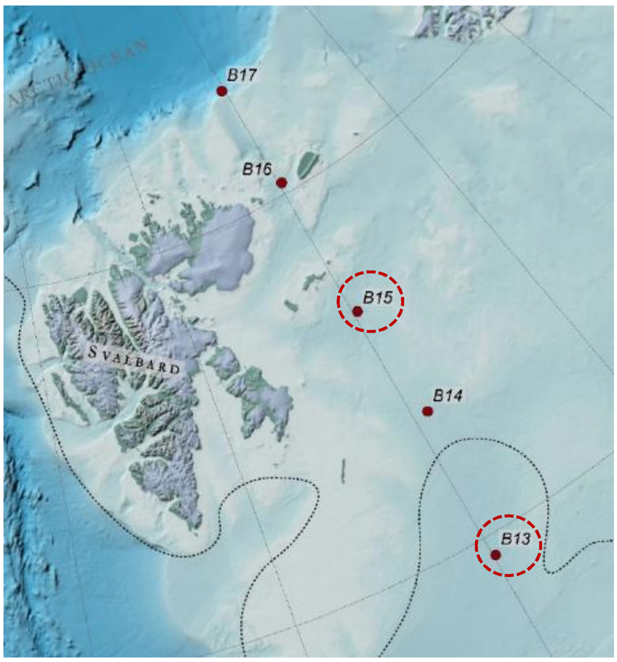
OC-Fe


B17
B16
B15
B14
B13

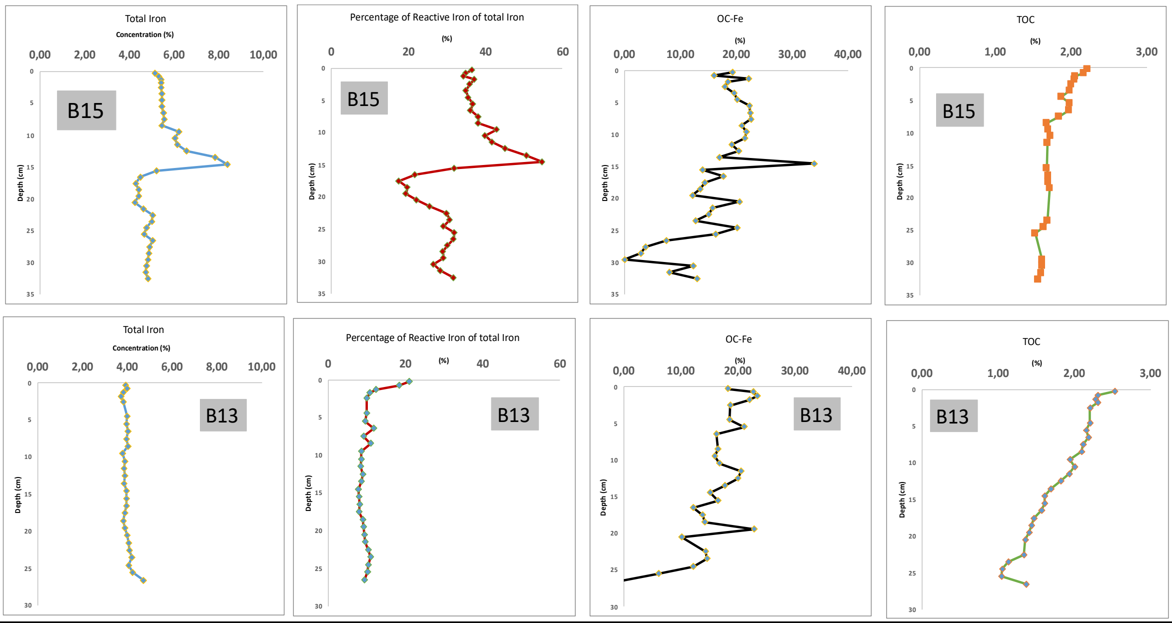
OC-Fe


Total Iron
Concentration (%)
0,00 2,00 4,00 6,00 8,00 10,00
Depth (cm)
B15

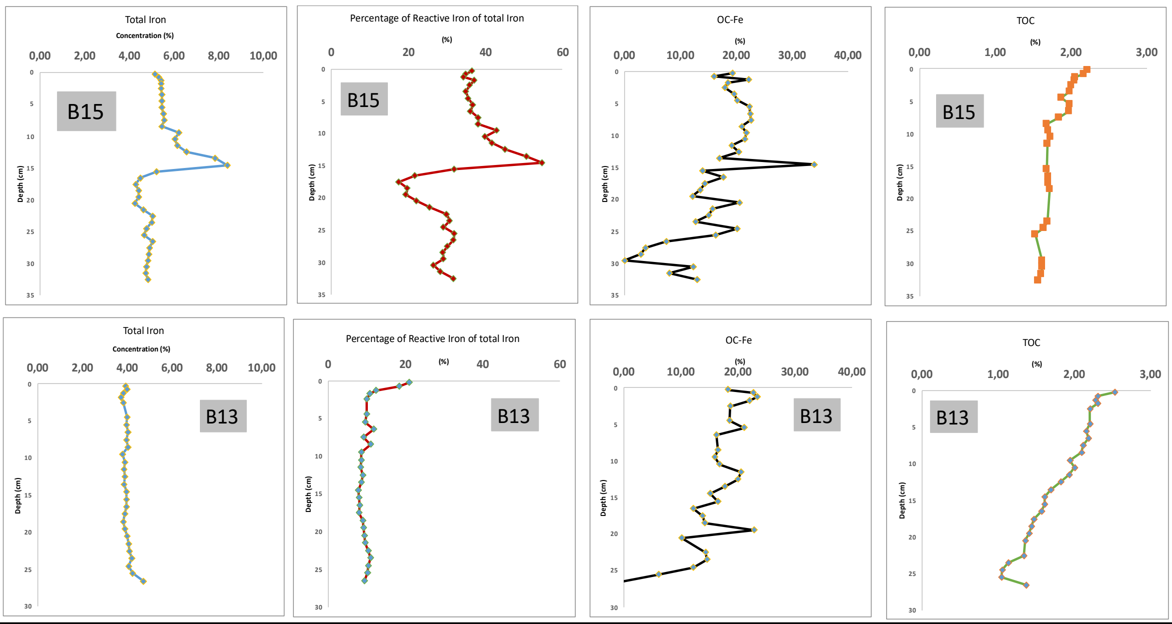

Total Iron
Concentration (%)
0,00 2,00 4,00 6,00 8,00 10,00
Depth (cm)
B13


B17
B16
B15
B14
B13
SVALBARD

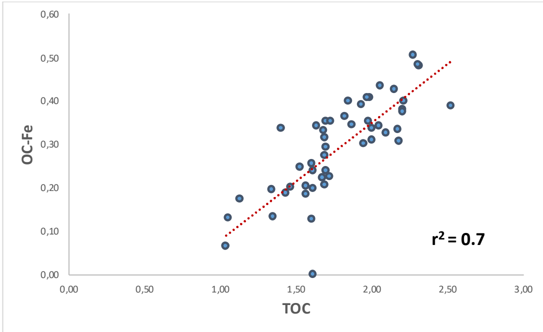
OC-Fe

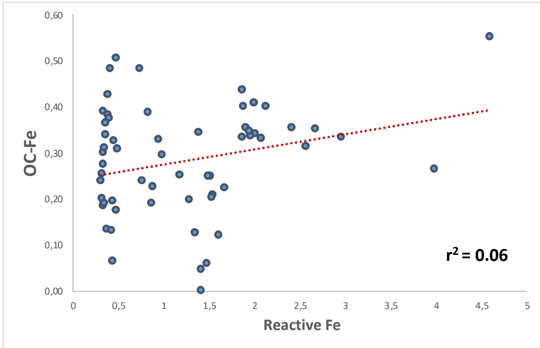

Total Iron
Concentration (%)
0,00 2,00 4,00 6,00 8,00 10,00
Depth (cm)
B15
Percentage of Reactive Iron of total Iron
(%)
0 20 40 60
B15
OC-Fe
(%)
0,00 10,00 20,00 30,00 40,00
TOC
(%)
0,00 1,00 2,00 3,00
B15
Total Iron
Concentration (%)
B13
Percentage of Reactive Iron of total Iron
B13
OC-Fe
B13
TOC
B13

OC-Fe


Total Iron
Concentration (%)
0,00 2,00 4,00 6,00 8,00 10,00
Depth (cm)
B15
Percentage of Reactive Iron of total Iron
(%)
0 20 40 60
B15
OC-Fe
(%)
0,00 10,00 20,00 30,00 40,00
TOC
(%)
0,00 1,00 2,00 3,00
B15
Total Iron
Concentration (%)
B13
Percentage of Reactive Iron of total Iron
B13
OC-Fe
B13
TOC
B13

OC-Fe





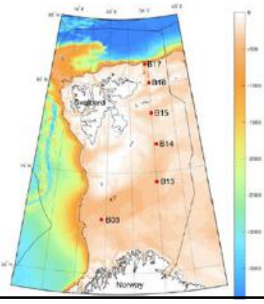
Meet at my Poster?

Sediment Pigment Analysis

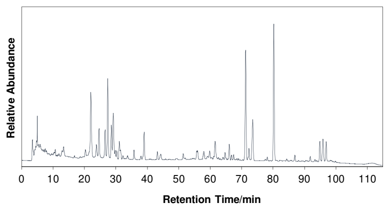
Sediment sampled: megacorer.
Stations B3, B13-B18

Surface 0.5 cm sampled for pigments, wrapped in foil, frozen at -80ºC

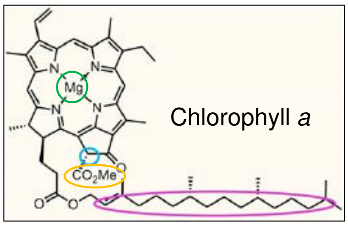
At PML, sediment thawed, pigments extracted by sonication in 100% acetone

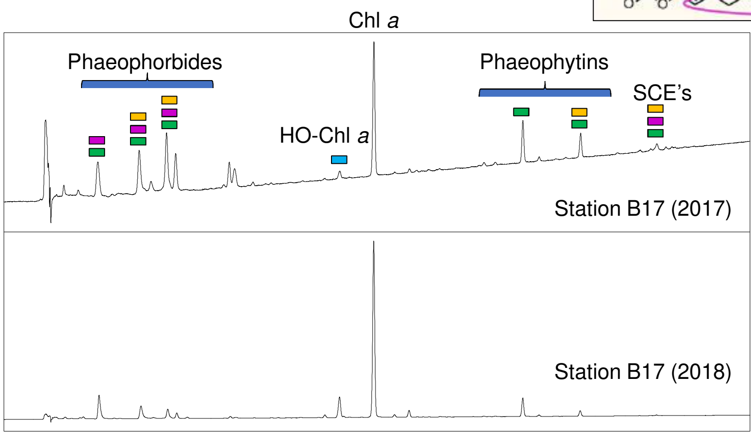


HPLC analysis; Airs et al., 2001

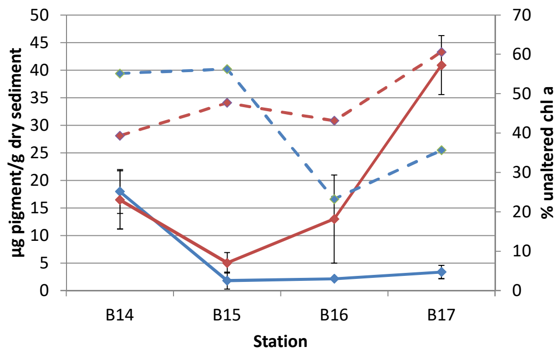


Chlorophyll alteration products



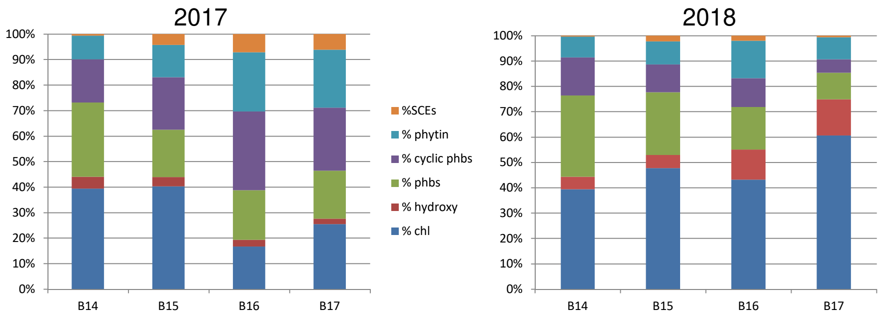


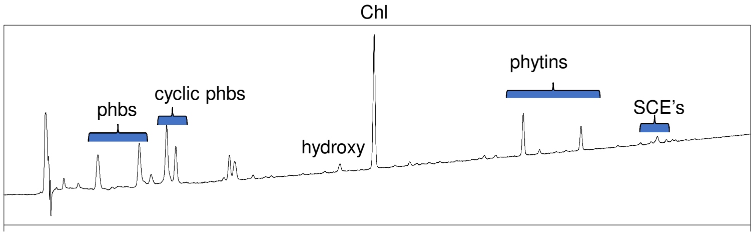
Pigment data: Stations B14-B17, 2017 and 2018

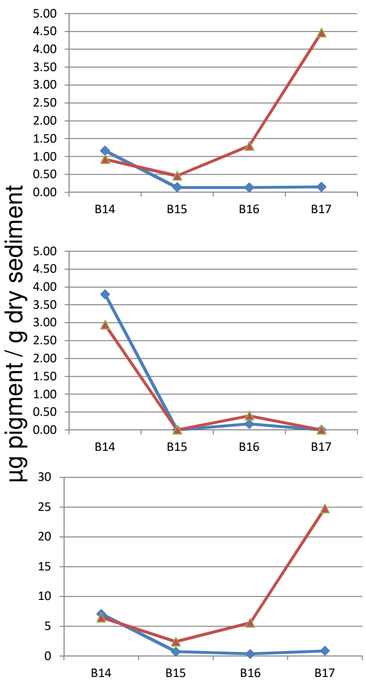


Solid line: Total chlorins (µg pigment/g dry sediment) **Blue = 2017**; **Red = 2018**
Dashed line: % unaltered chl *a*

Results: Proportion of alteration products







Blue = 2017; Red = 2018

Fucoxanthin

19'-Hexanoyloxyfucoxanthin

Chlorophyll *a*

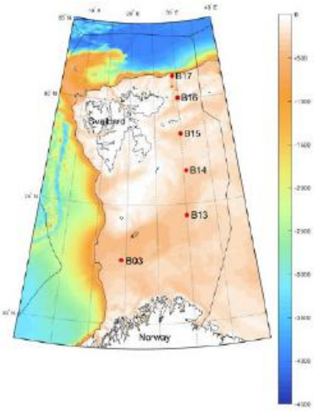
ββ-carotene (not shown) only detected at station B14

Sediment Pigment Data Summary

Marked differences observed between 2017 and 2018 for Stations B16 and B17:

- More pigment material at sediment surface in 2018, which was less degraded than in 2017.

- In 2018, 19'hex was present at B16 and B17, but the carotenoids of both stations were dominated by fucoxanthin.



University of BRISTOL

ULB UNIVERSITÉ LIBRE DE BRUXELLES

Modelling biogeochemical processes in the Barents Sea: initial findings and future directions

Felipe S. Freitas[1, 2], James Ward[1, 2], Kate Hendry[1], Sandra Arndt[2]

[1]University of Bristol, [2]Université Libre de Bruxelles

Research questions - Aims

What controls OM cycling in the Barents Sea?

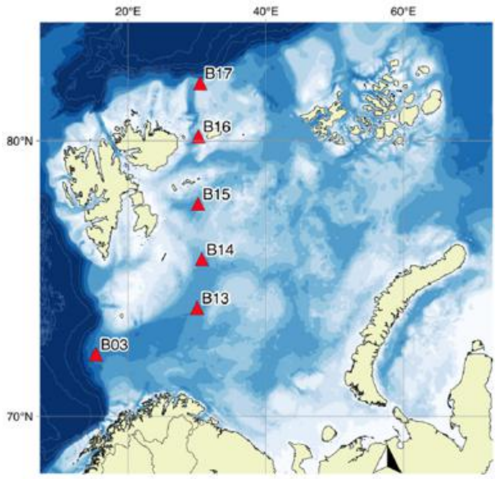
- Organic matter type and input?
- Terminal electrons availability and fluxes?
- Sedimentology: OM–matrix association?
- Microbial and macrofaunal community?

Do short- and long-time variations play a role?

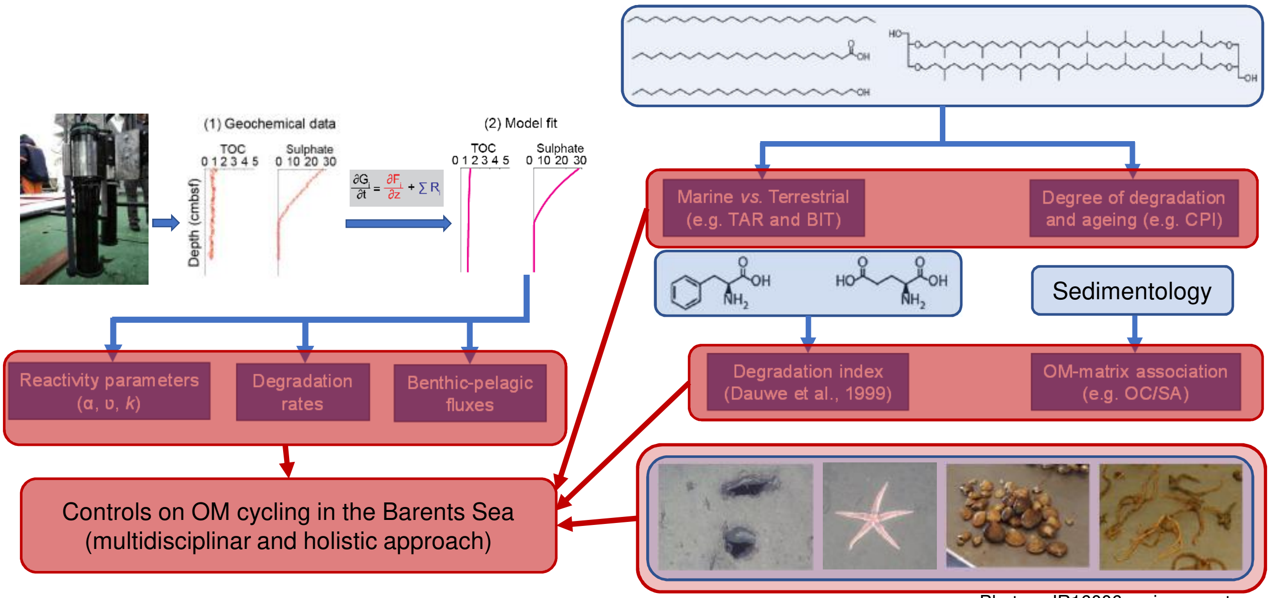
- How interannual fluctuations shape OM reactivity?
- Can we develop prognostics of future changes in the Arctic?

How is that reflected on the benthic-pelagic coupling?

- How nutrient cycling responds to changes in OM reactivity?
- Are nutrient fluxes affected at short and long time-scales?



Integrated data-model approach



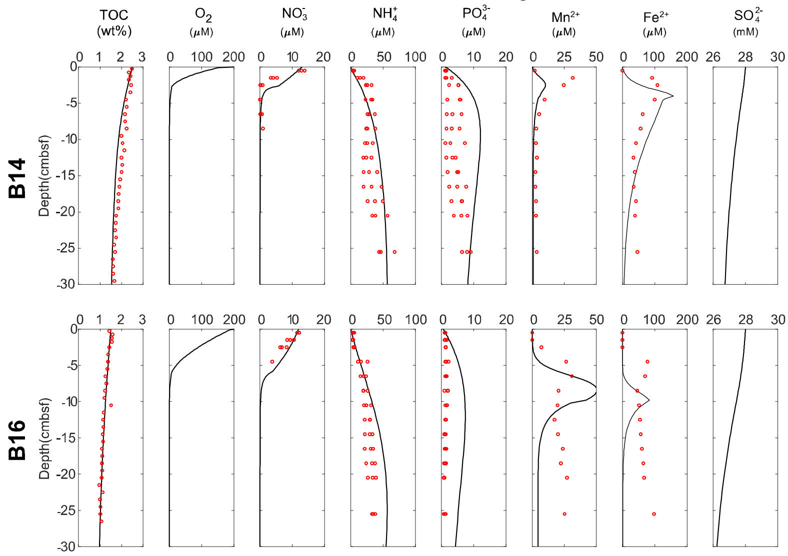
Photos: JR16006 cruise report

University of BRISTOL

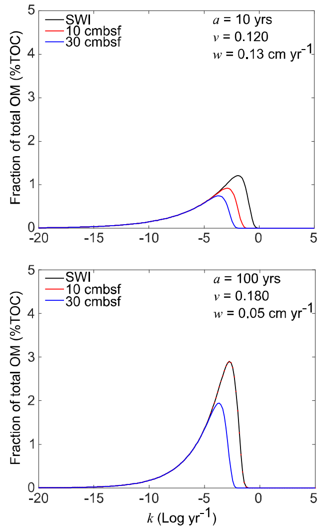
UNIVERSITÉ LIBRE DE BRUXELLES

Benthic-pelagic coupling across the sea-ice transition

Inverse modelling



OM reactivity

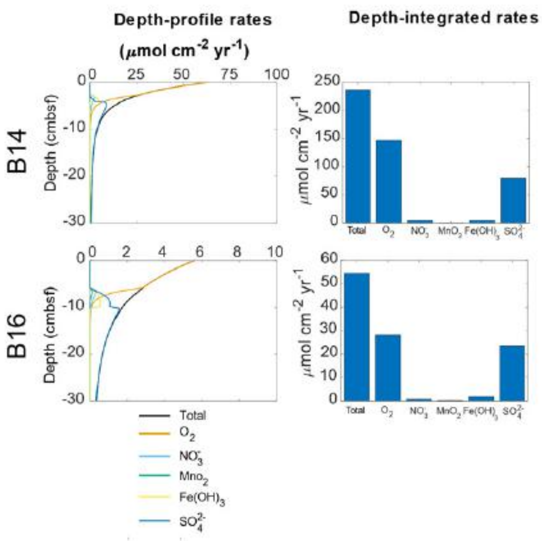


University of BRISTOL

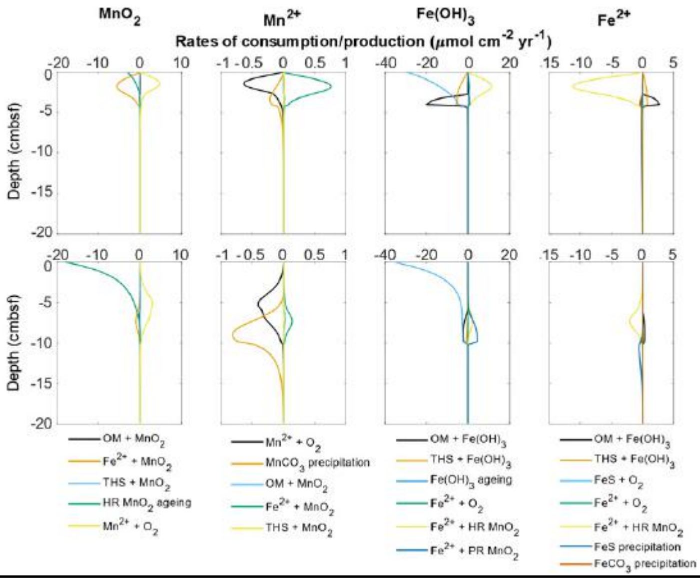
UNIVERSITÉ LIBRE DE BRUXELLES

Benthic-pelagic coupling across the sea-ice transition

OM degradation



Mn and Fe cycling



University of BRISTOL

UNIVERSITÉ LIBRE DE BRUXELLES

What's next

Complete inverse modelling for 2017 and 2018 transects

- Extract reactivity parameters
- Quantify degradation rates and nutrient fluxes
- Assess interannual variability (changes in sea ice)

Model parameters sensitivity analyses

- OM reactivity parameters
- Role of sediment biological mixing
- Mn and Fe cycling

Data integration

- OM sources (lipid biomarkers) and age
- Sedimentology
- Ecosystem structure