Feedbacks between wintertime sea ice and summertime heat content and phytoplankton bloom strength in a 20-year Antarctic time series

Hugh Venables

Mike Meredith, Alex Brearley, Oliver Legge, Patrick Rozema

Many other collaborators and wintering Marine Assistants

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC SCIENCE OF THE ENVIRONMENT

Rothera Time Series (RaTS)

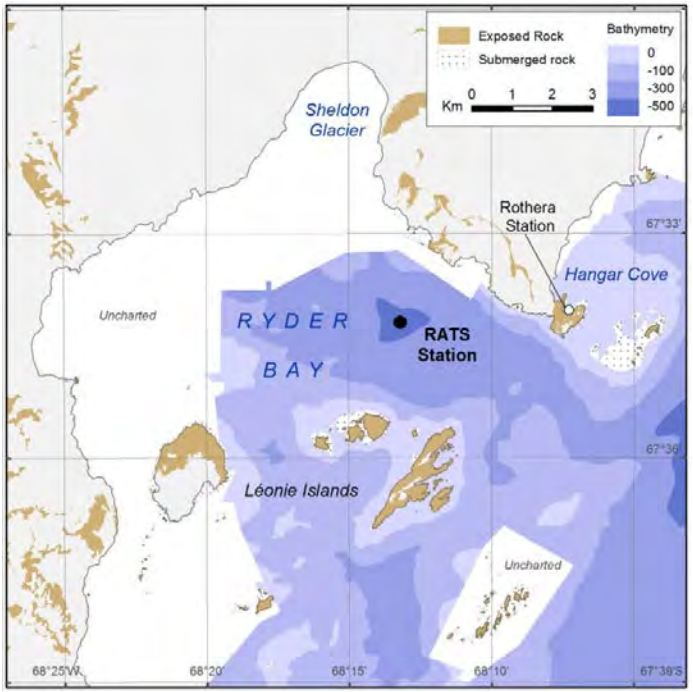
Sampling site 4km from British Antarctic Survey's Rothera base.

Just inside Antarctic Circle. No sun for about three weeks in mid winter.

Year round sampling

Access by small boat, or sledge

Wintering scientists spend one or two years on base collecting data and assisting dive projects



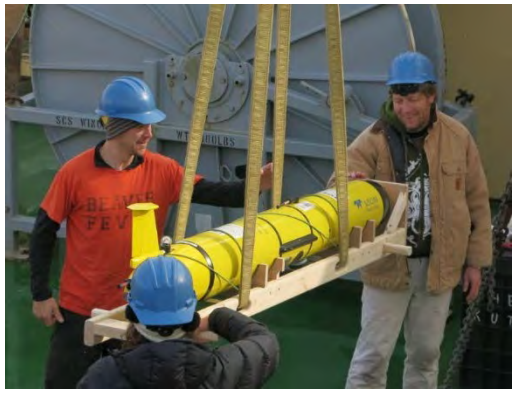
Rothera Time Series (RaTS)

Year-round oceanographic sampling, since 1997/8

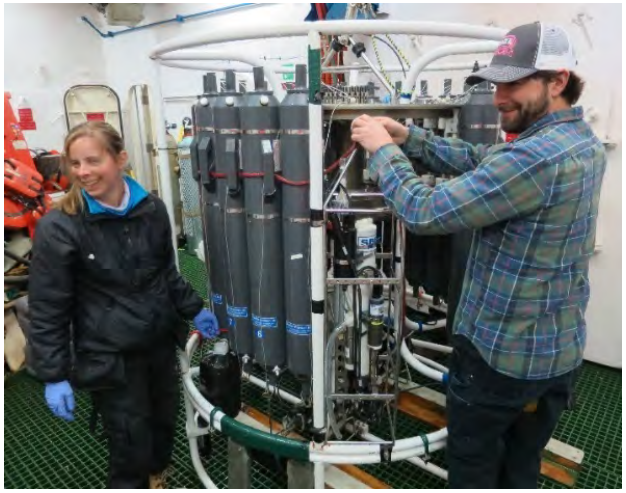
Temperature, Salinity, chlorophyll, light, turbidity profiles

Water samples for chlorophyll, HPLC nutrients, O18 and salinity calibration

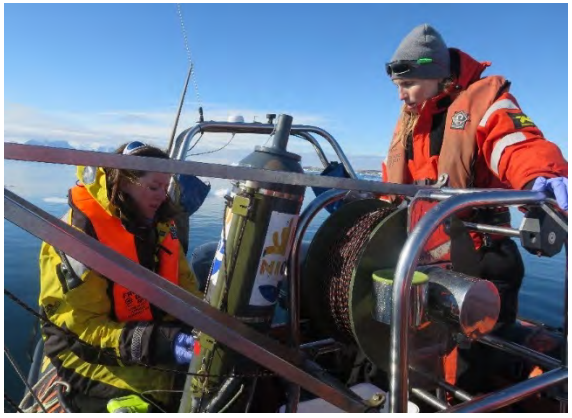
Many UK and Dutch collaborators have sampled for shorter periods for other projects – Carbon, iron, DMS, viruses, phytoplankton/light dynamics etc.

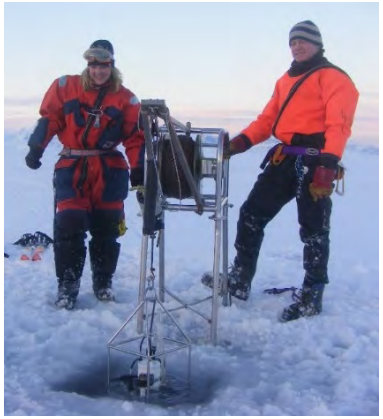


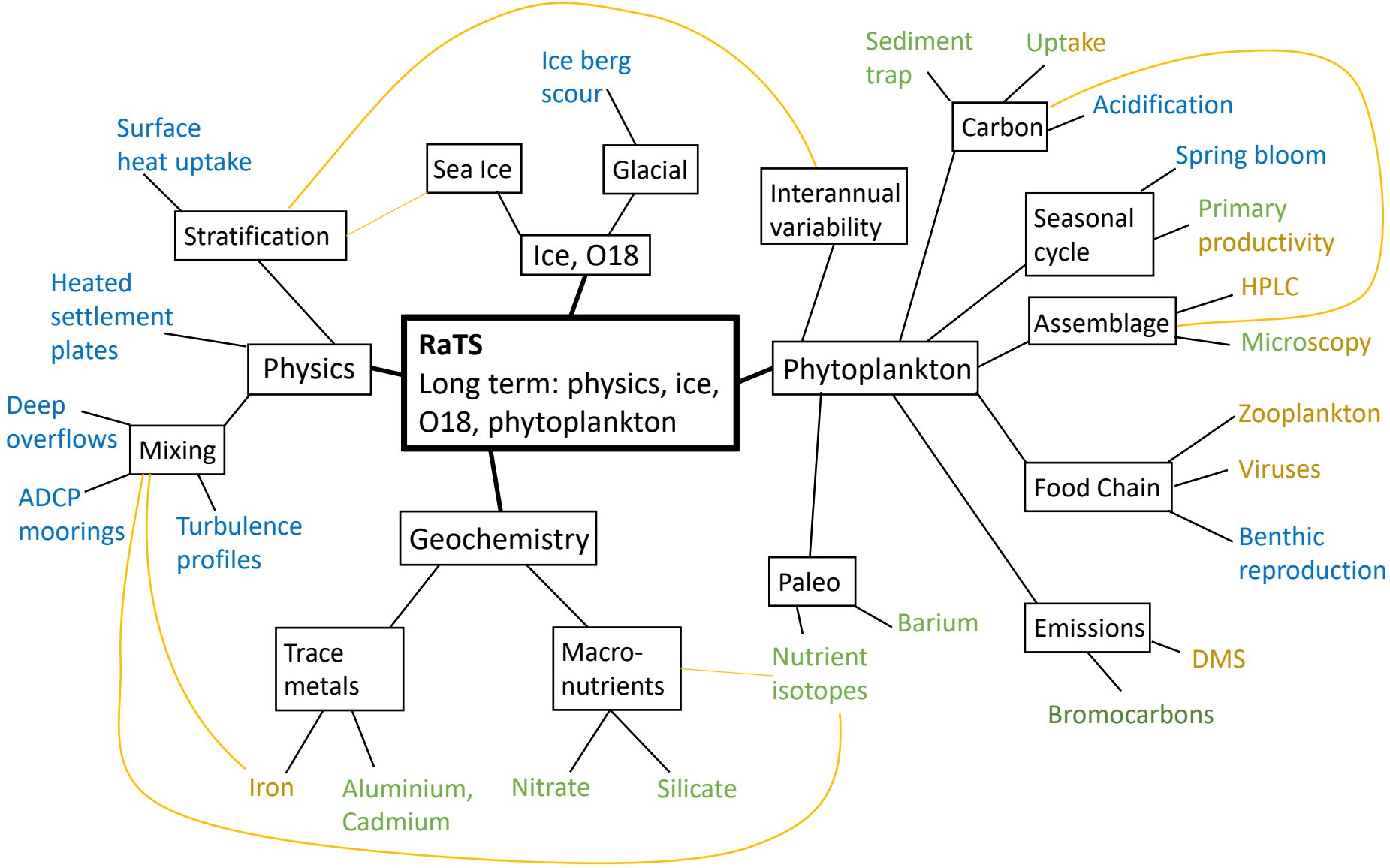
Sampling now augmented by ocean gliders to increase sampling area and assess how water gets to Ryder Bay



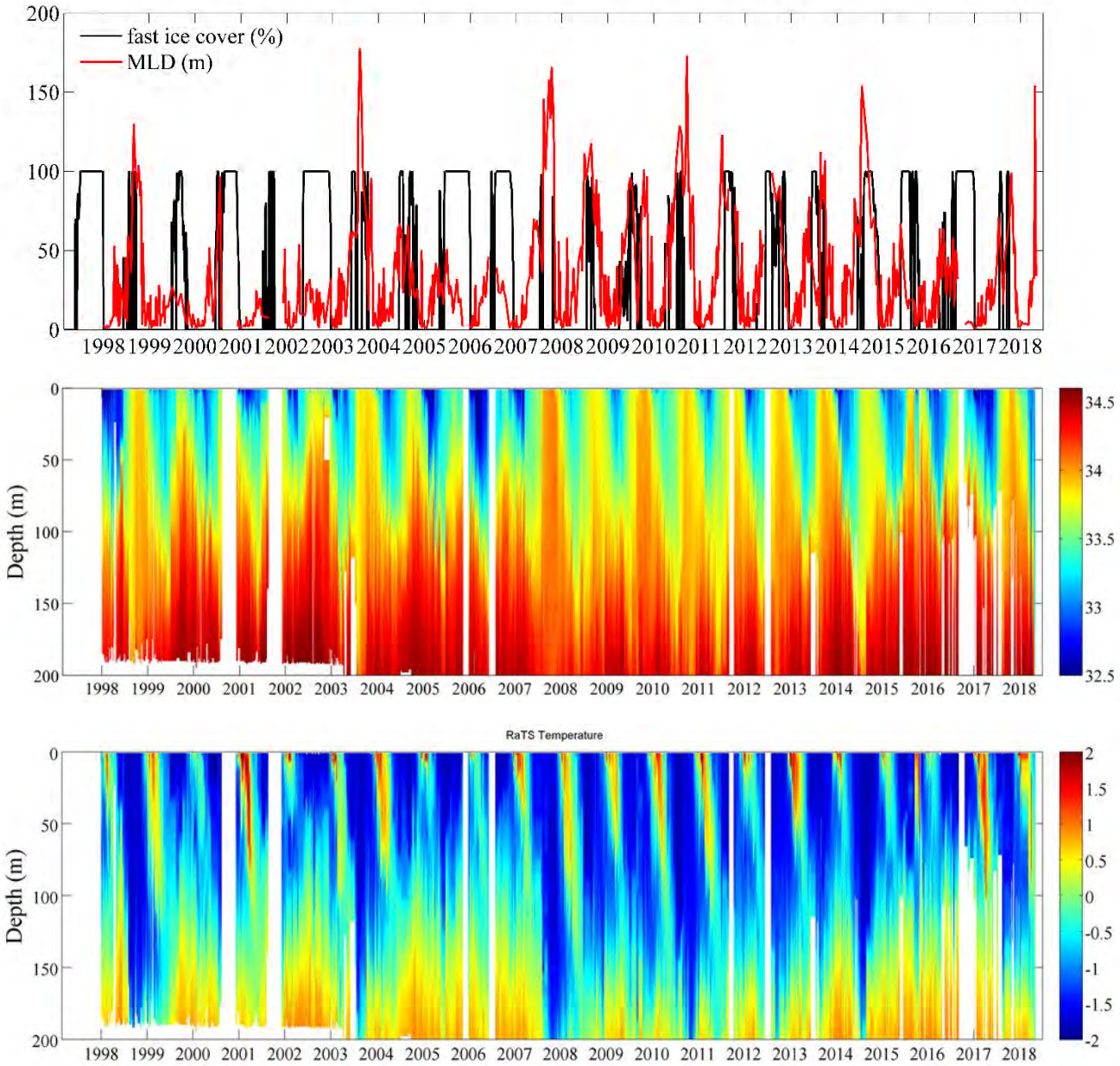
Calibration cast, mounting our CTD on R/V Gould's CTD






RaTS
Long term: physics, ice, O18, phytoplankton
Physics
Stratification
Surface heat uptake
Heated settlement plates
Mixing
Deep overflows
ADCP moorings
Turbulence profiles
Ice, O18
Sea Ice
Glacial
Ice berg scour
Geochemistry
Trace metals
Iron
Aluminium, Cadmium
Macro-nutrients
Nitrate
Silicate
Phytoplankton
Interannual variability
Carbon
Sediment trap
Uptake
Acidification
Seasonal cycle
Spring bloom
Primary productivity
Assemblage
HPLC
Microscopy
Food Chain
Zooplankton
Viruses
Benthic reproduction
Emissions
DMS
Bromocarbons
Paleo
Barium
Nutrient isotopes

Rothera Time Series (RaTS)

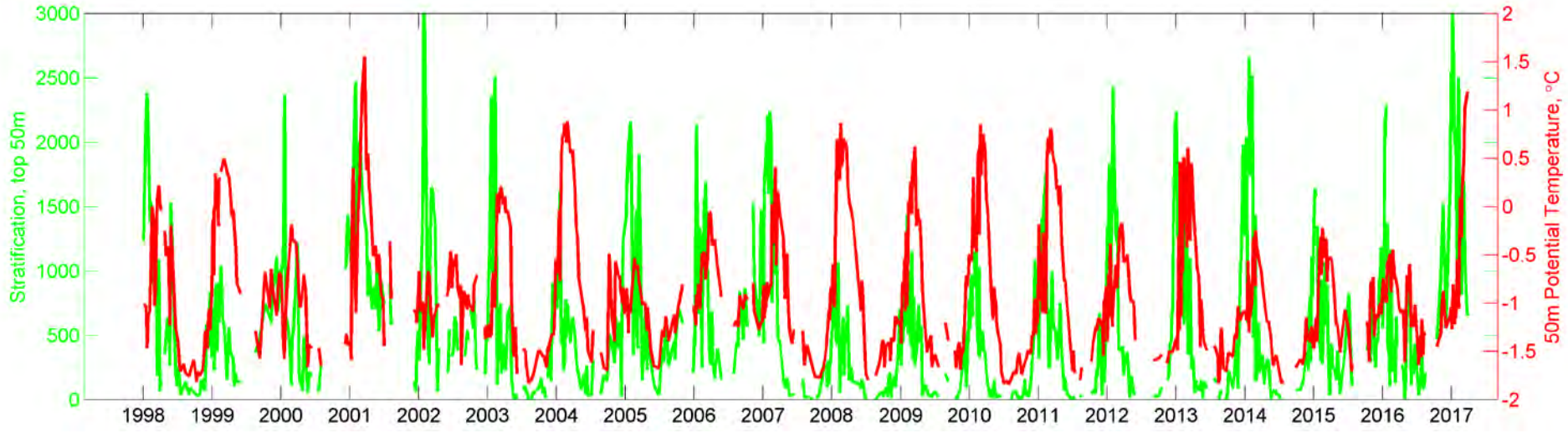


Variable winter ice

More winter mixing when less ice cover

Heat lost from Circumpolar Deep Water (CDW) during deep mixing.

Loss of stratification persists into following summer, leading to increased heat uptake



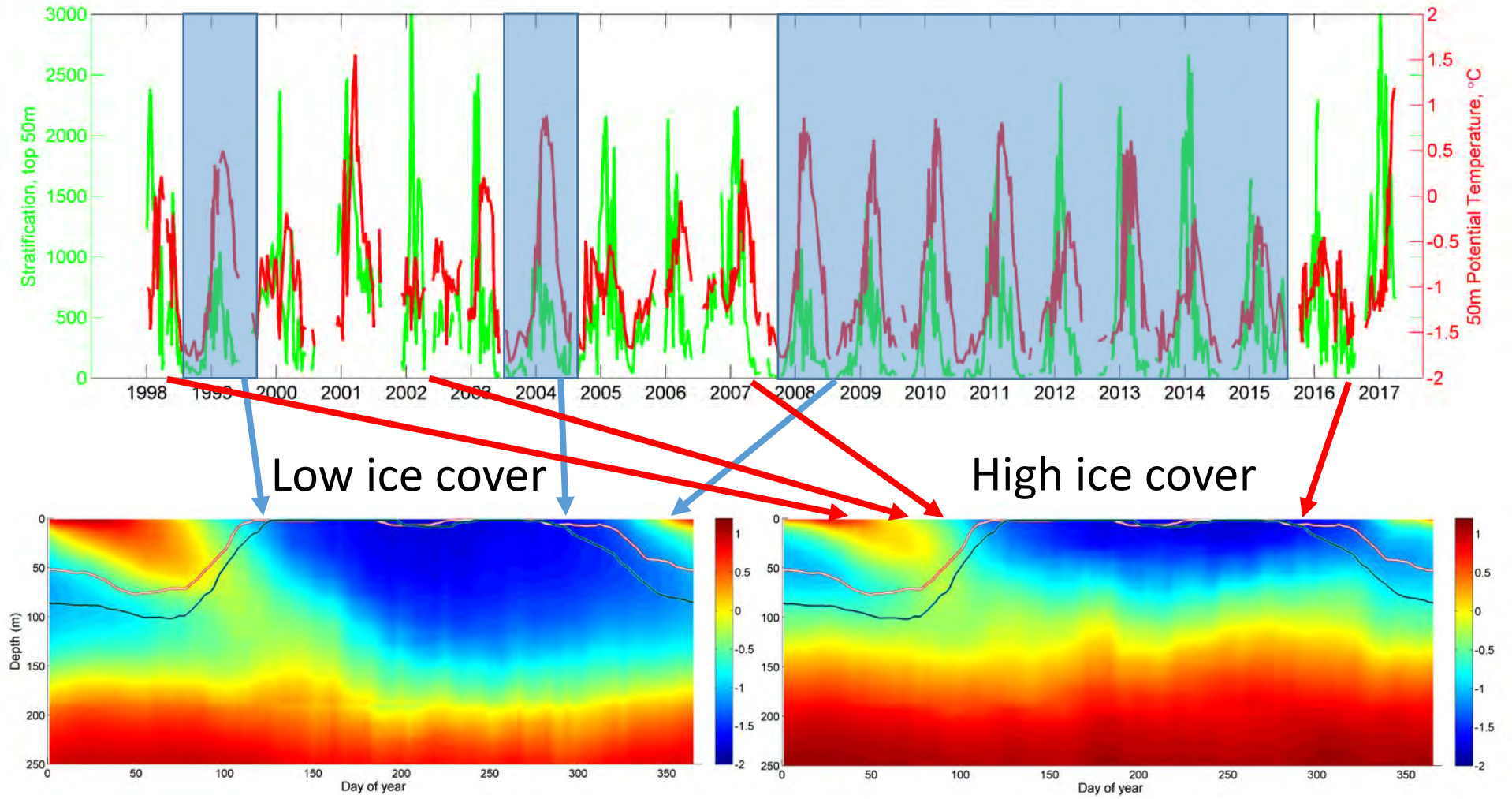
Stratification quantified as the amount of potential energy needed to homogenize a depth range (units: J/m^2)

Ice melt leads to shallow mixed layer depths in all summers

Deep winter mixing means low ice seasons start from lower base and freshwater more easily distributed to depth

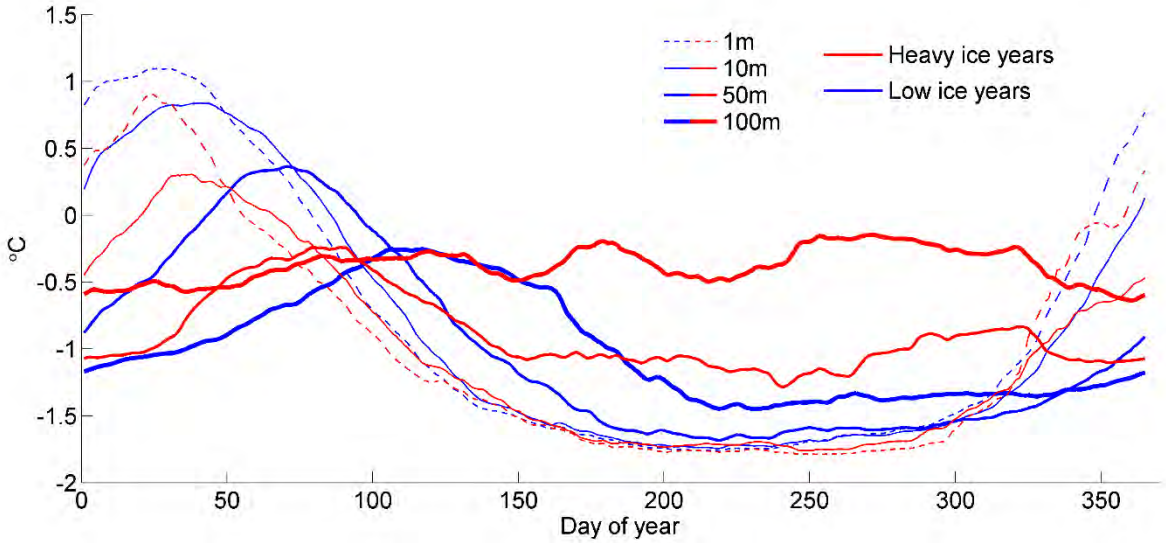
Repeating pattern of reduced summer stratification and enhanced temperatures at 50m

Split time series into ‘High ice’ and ‘Low ice’ years



Greater variability in temperature in top 200m

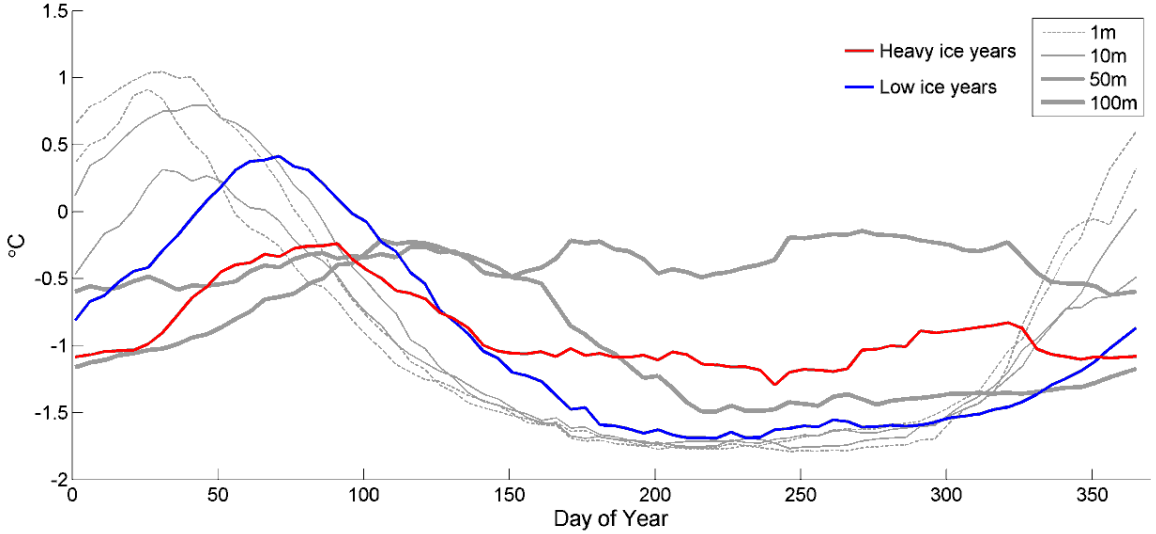
Water column protected by ice in winter and stratification in summer



Near surface

Always near freezing in winter

Strong warming in summer



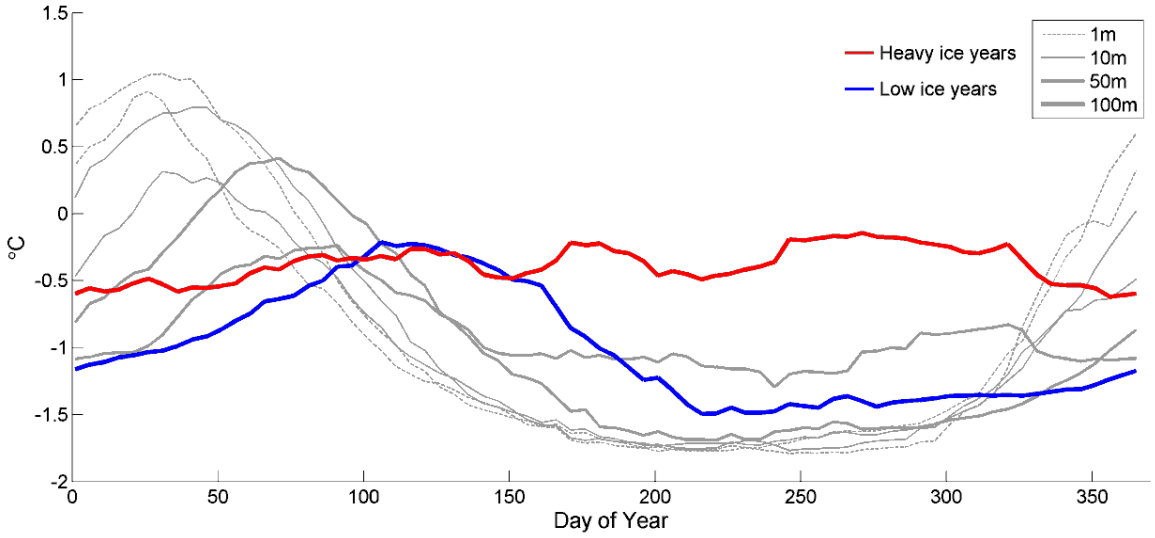
50m

Seasonality stretched both ways

Winter heat loss more than regained through summer mixing







100m

Mixing causes seasonality

Lost heat regained through increased downward mixing in summer and from warm water below (decadal process)

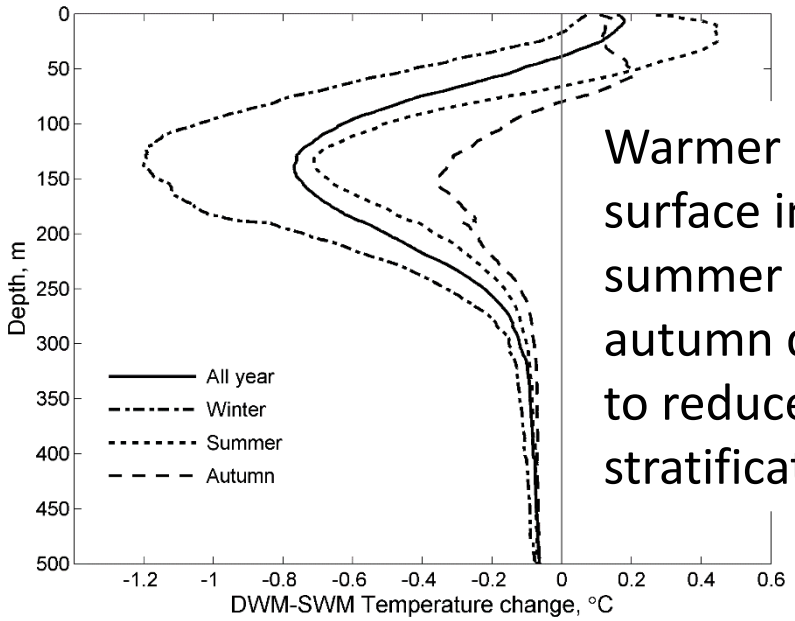
From 100m downwards, low ice exerts a cooling effect overall, together with increased variability

Potential impacts for benthic creatures





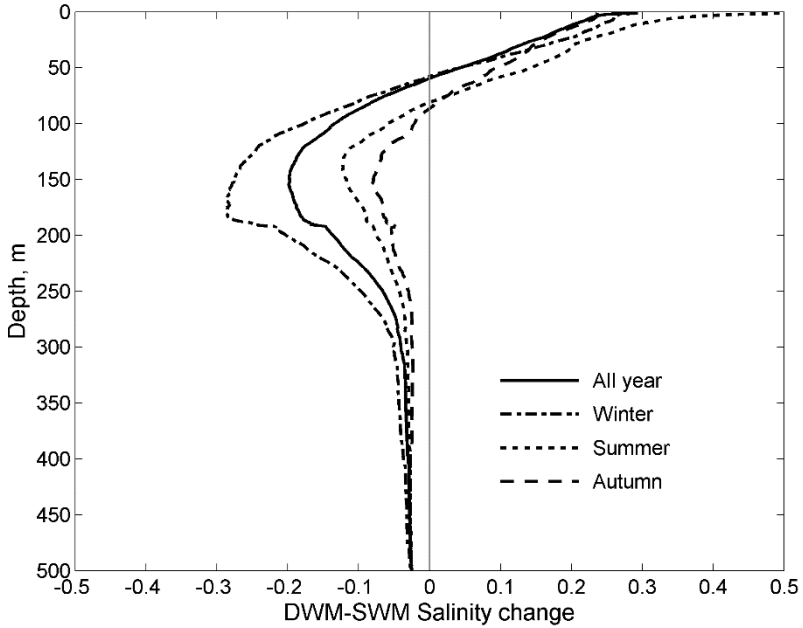
Temperature



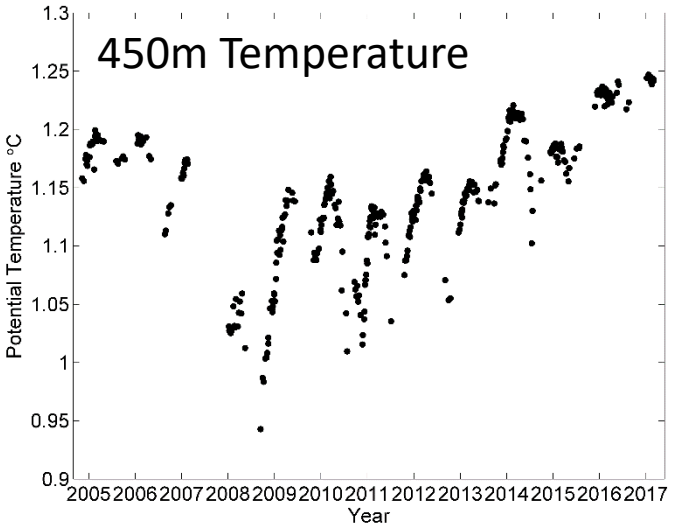
Warmer near surface in summer and autumn due to reduced stratification

Cooler with less ice at most depths

Salinity



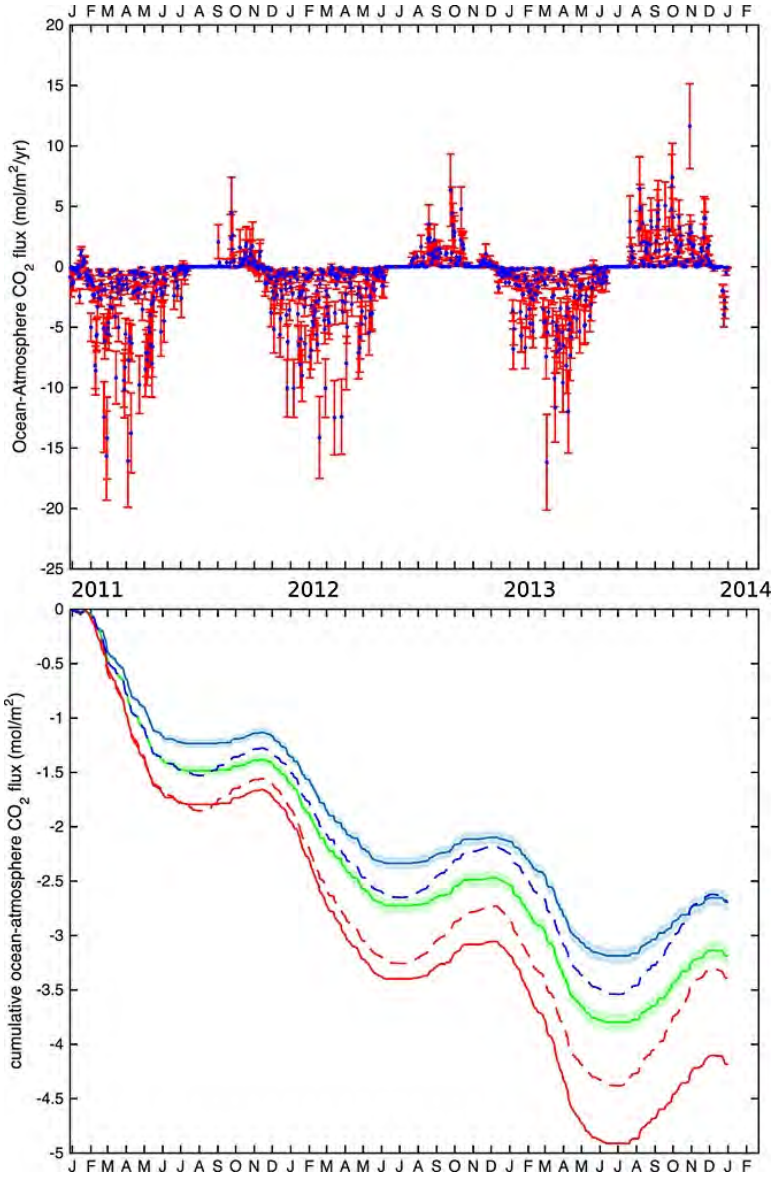
'See-saw' change in salinity, due to deep wind-driven mixing

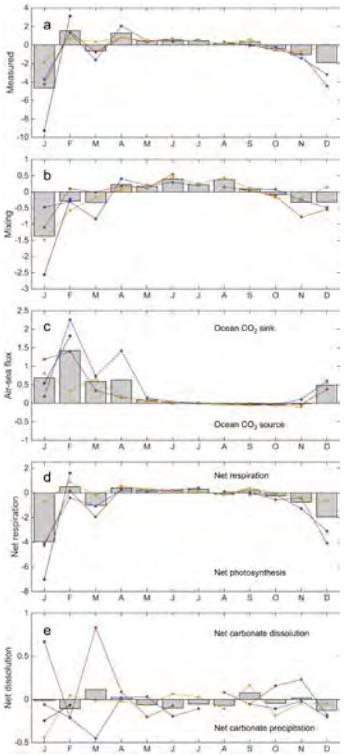


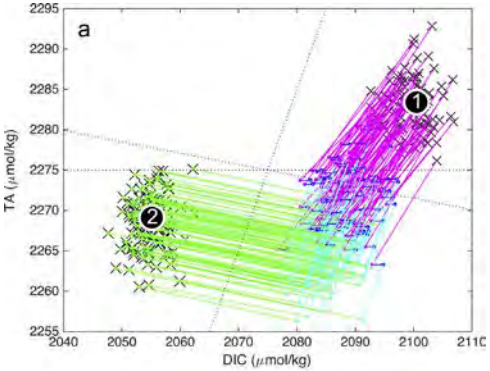
Overflows at the sill (350m) propagates the cooling to depth

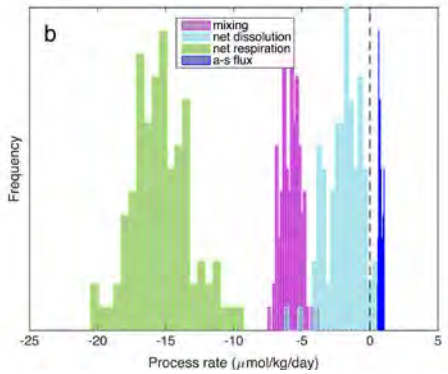
Decadal increase as ice increases

Carbon fluxes









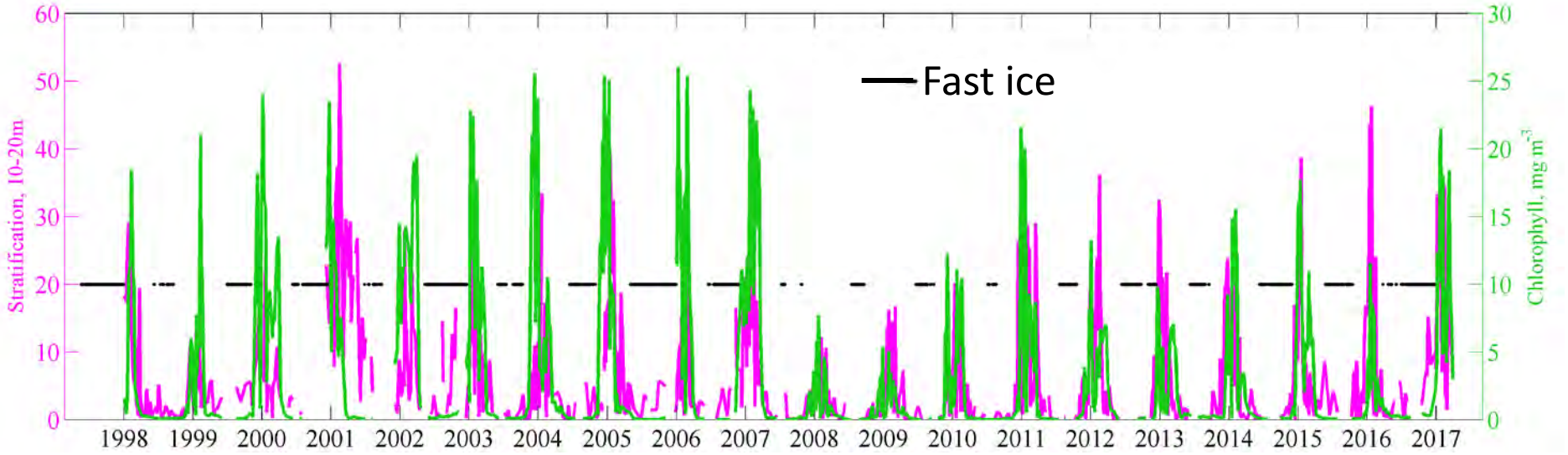
Biological drawdown greater than winter outgassing

Deepest mixing events not measured, but short timescale limits outgassing

Can decompose timeseries into mixing, flux, photosynthesis/respiration and dissolution

Legge et al. doi.org/10.1002/2015GL063796 and doi.org/10.1016/j.dsr2.2016.11.006

Biological effects of extra mixing



Temperature changes show that mixing extends deeper in low stratification years (as pre-conditioned)

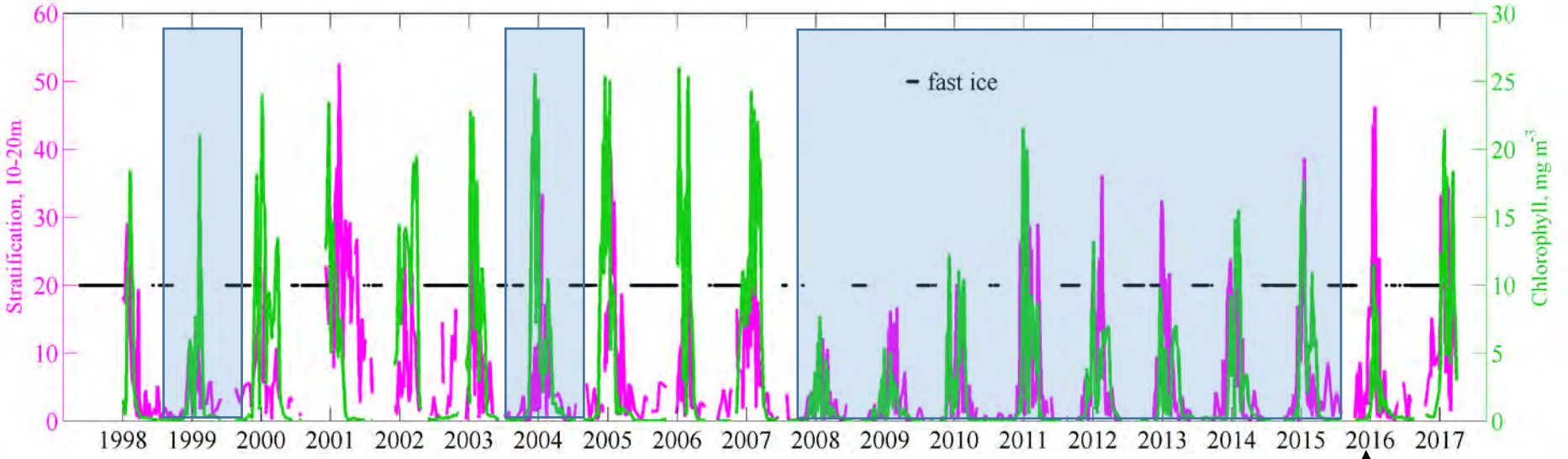
Reduces phytoplankton bloom by an order of magnitude

Low sea ice

↘ Low summer stratification

↘ Preconditioned to more vertical mixing

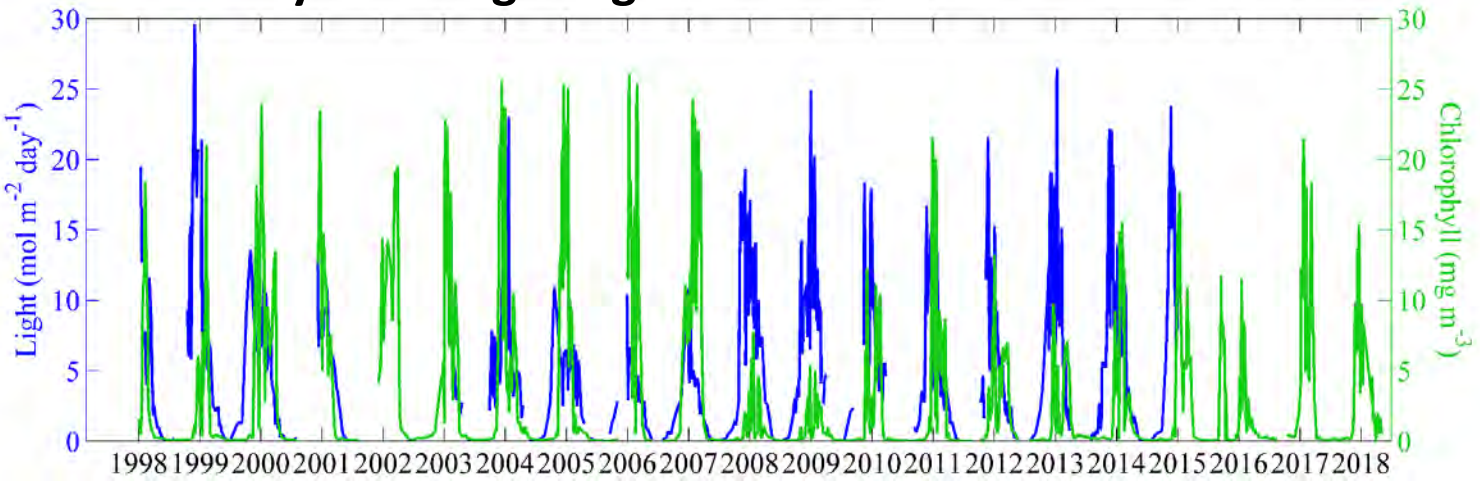
↘ Weaker blooms (probably)



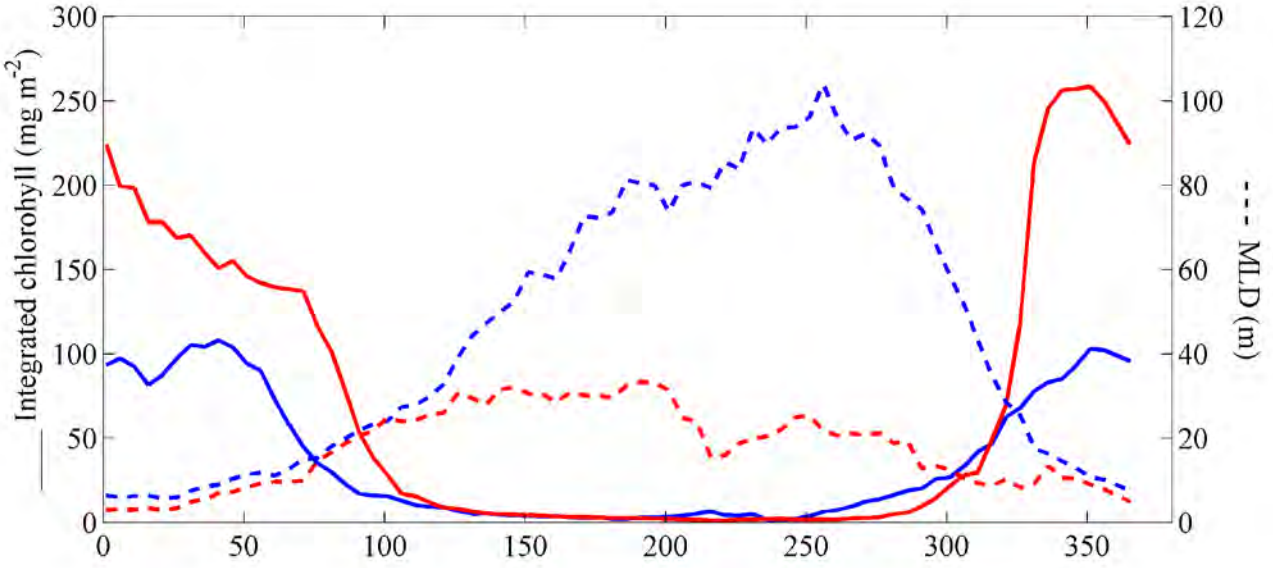
Low ice year largely have low chlorophyll concentrations

Stratified but little chlorophyll – many other effects can also occur despite preconditioning

Mixed layer averaged light



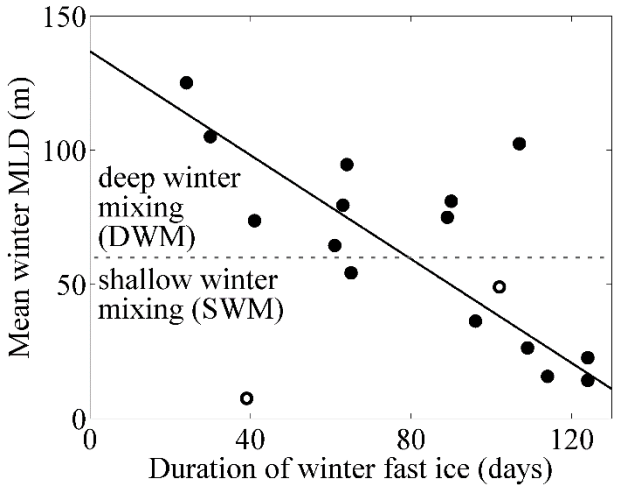
Low chlorophyll years have more light – less self shading.

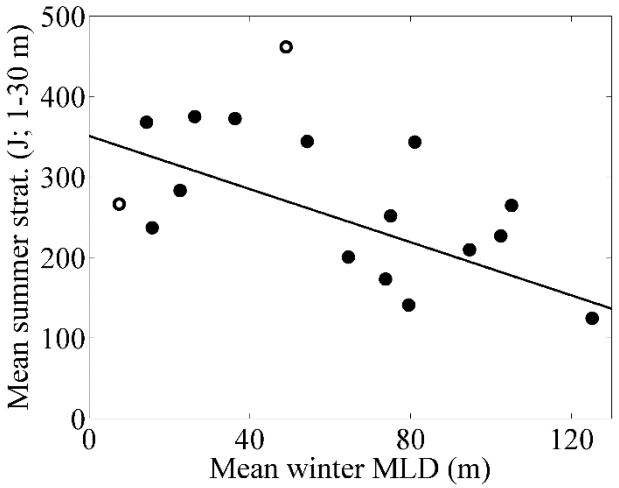


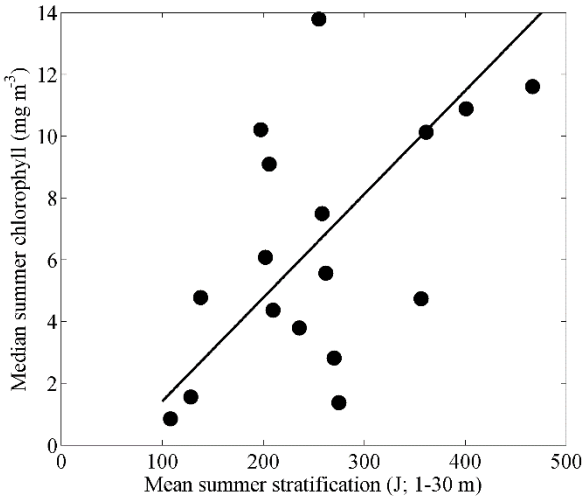
Early spring depth integrated chlorophyll is higher, then much lower

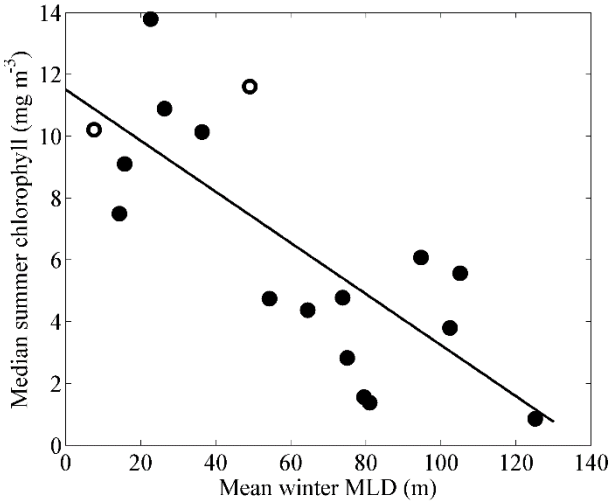
Level or falling chlorophyll hides large changes in species composition through the bloom

Mixed layer integrated chlorophyll









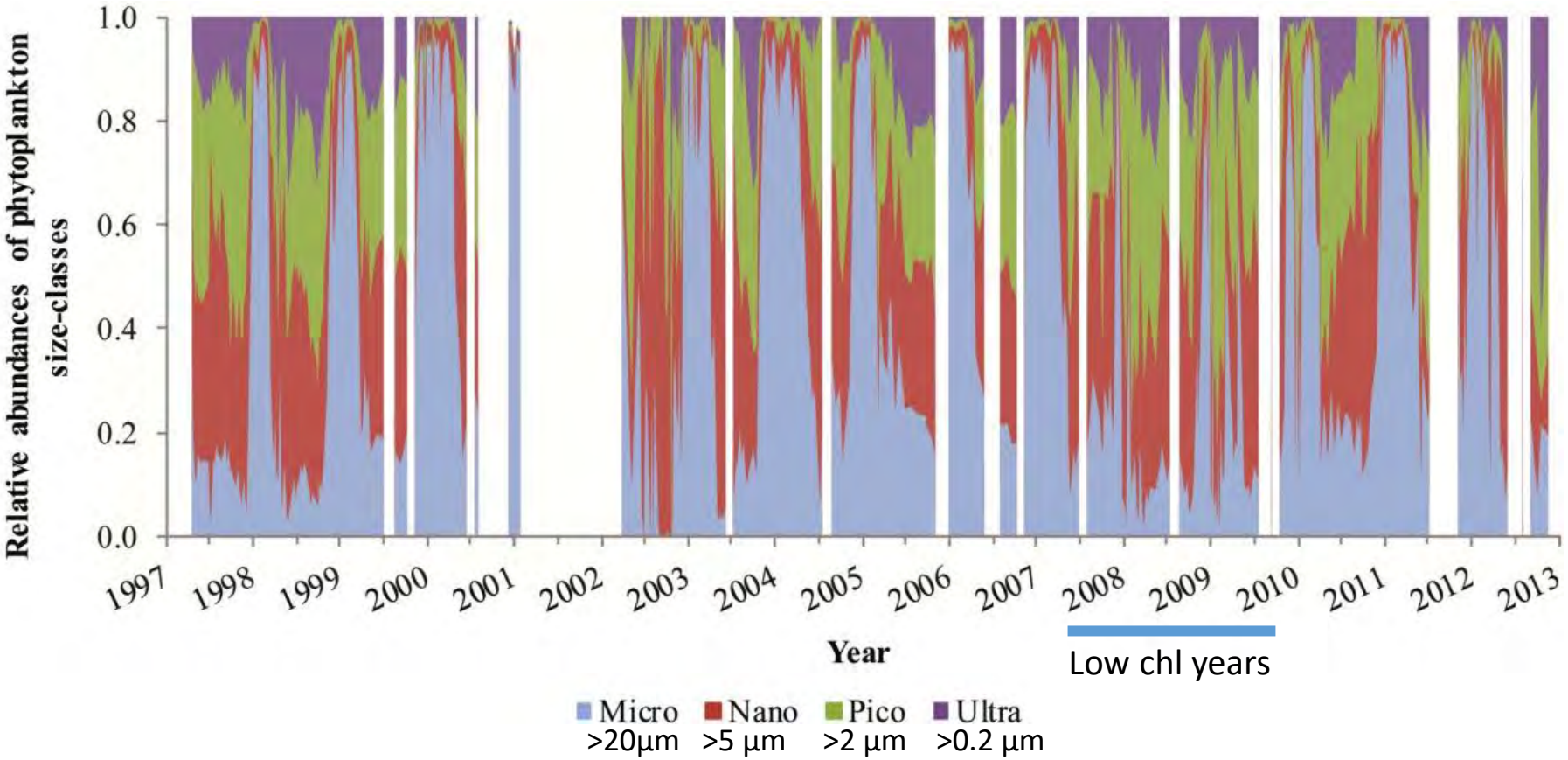
Stratification provides a ‘memory’ in the system

Variability driven by winter changes (sea ice all melted by summer)

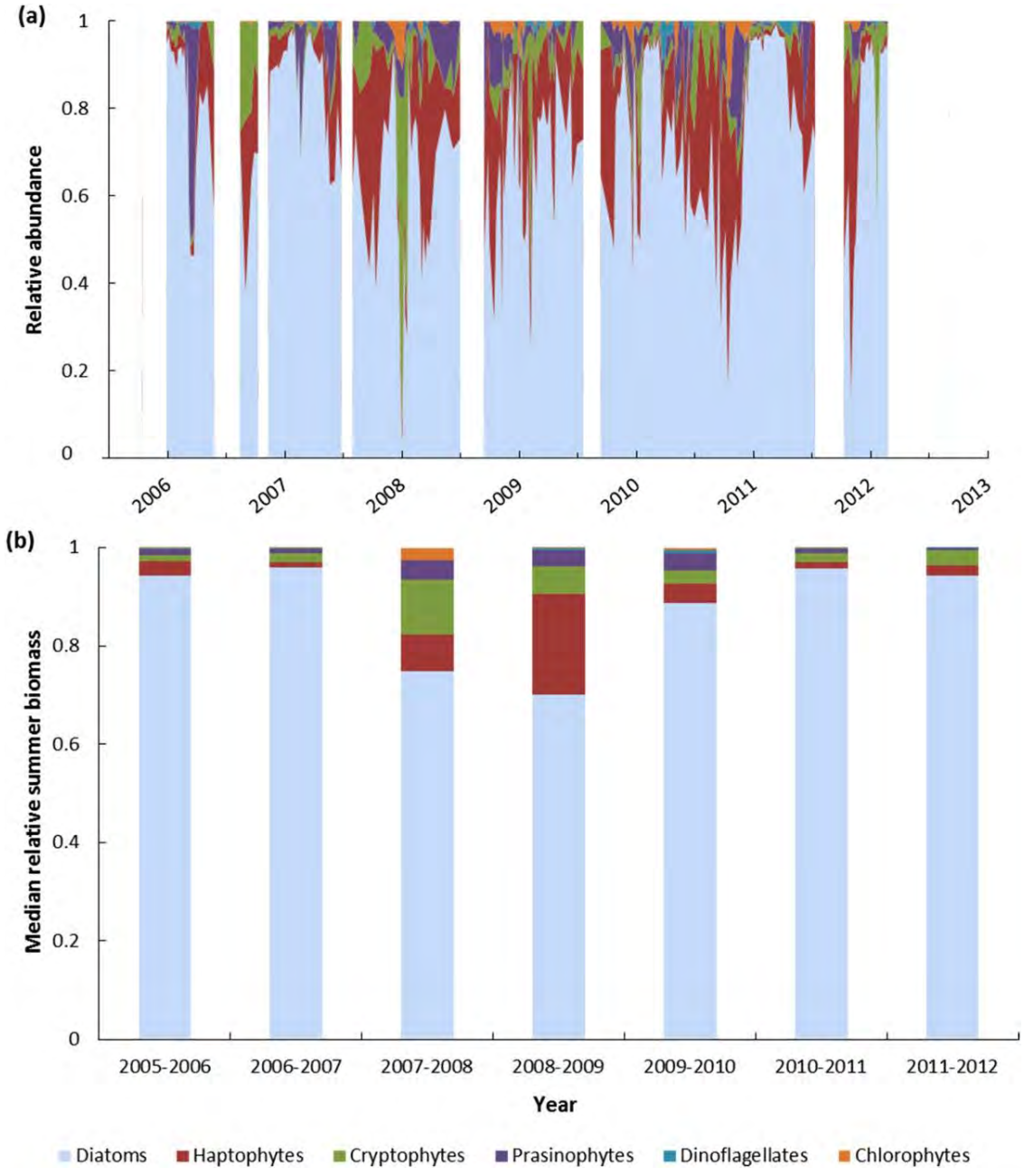
Biological feedbacks on seasonal basis.

Not driven by absolute light availability

Rozema et al. doi.org/10.1002/lno.10391



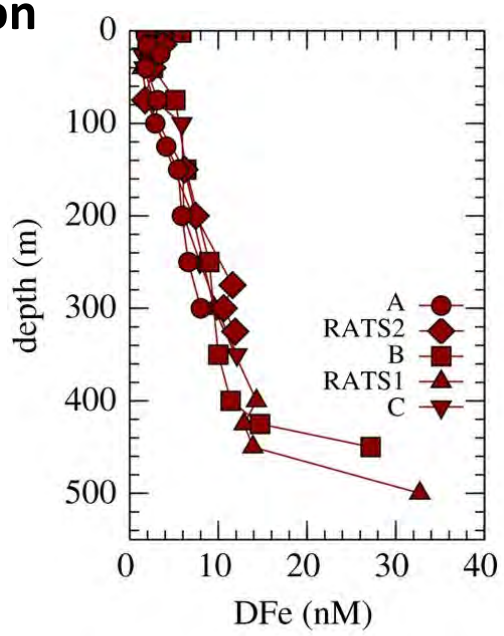
Low stratification, low chlorophyll years show shift to low cell sizes, more similar to winter

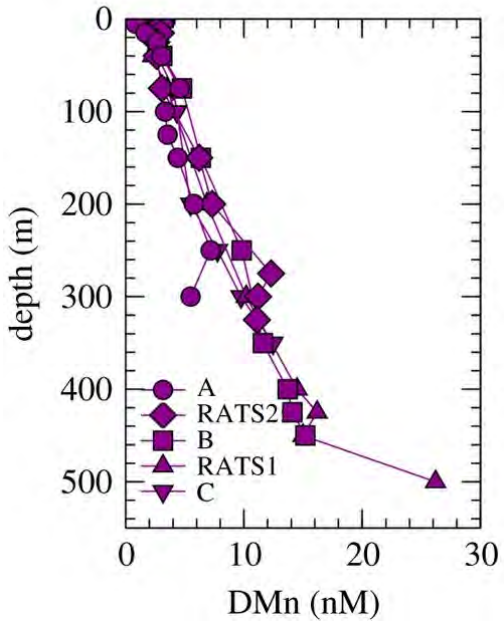


HPLC analysis

As well as smaller cells, shift to Haptophytes and Cryptophytes in low chlorophyll summers

Iron



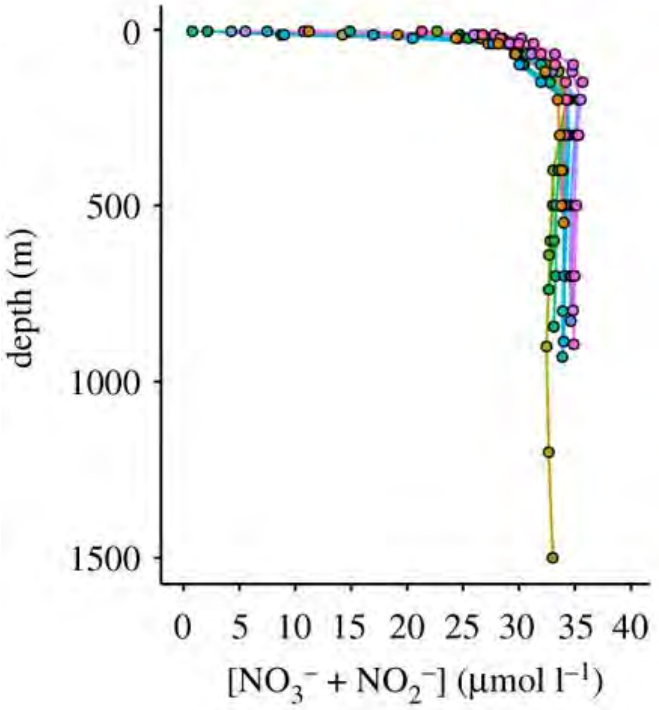


Bown et al. DOI: 10.1098/rsta.2017.0172

Large stock of micro and macronutrients at depth

Very fresh lenses can become depleted in surface few metres

Nitrate



Henley et al. DOI: 10.1098/rsta.2017.0168

Summary

Ice ↓

Winter mixing ↑

Heat and carbon loss ↑

Iceberg scour ↑

Winter stratification ↓

Summer stratification ↓

Mixing ↑

Heat uptake ↑

Phytoplankton ↓

Biological carbon export ↑

Benthic food source ↓

Heat content ↑

Ice ↓

Despite winter heat loss, positive feedback effect due to summer heat uptake exceeding winter loss

Sensitive to local details:

- Winter air temperatures
- Meltwater input and solar radiation
- Wind stress
- Initial stratification
- Initial nutrient distributions