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

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Many other collaborators and wintering Marine Assistants
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
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/m²)

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
Low ice cover

High ice cover

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
Cooler with less ice at most depths

Warmer near surface in summer and autumn due to reduced stratification

‘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
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
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 averaged light

Low chlorophyll years have more light – less self shading.
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
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

Large stock of micro and macronutrients at depth

Very fresh lenses can become depleted in surface few metres

Nitrate

Bown et al. DOI: 10.1098/rsta.2017.0172

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