Under-ice phytoplankton bloom dynamics controlled by convective mixing in refreezing leads

Kate E. Lowry[1,2], Robert S. Pickart[2], Matthew M. Mills[1], Astrid Pacini[2], Virginia Selz[1], Kate M. Lewis[1],
Hannah Joy-Warren[1], Carolina Nobre[2], Gert L. van Dijken[1], Kevin R. Arrigo[1]

[1]Department of Earth System Science, Stanford University, Stanford, CA; [2]Woods Hole Oceanographic Institution, Woods Hole, MA

Background

Reductions in Arctic sea ice extent and thickness have important implications for marine ecosystems, making it essential to better understand phytoplankton dyamics within the sea ice zone.

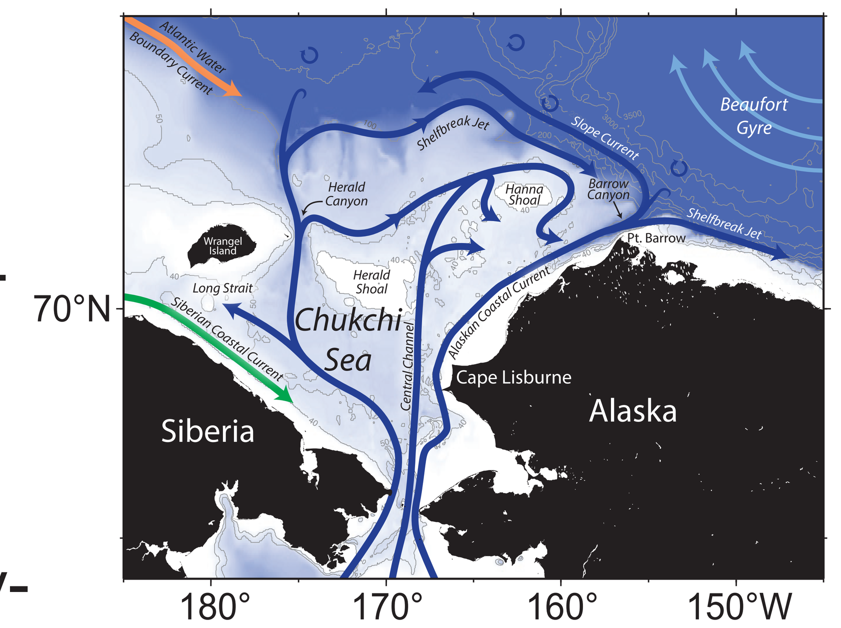

Fig. 1: Chukchi Sea circulation *[Corlett & Pickart, submitted]*.

The NSF **Study of Under-ice Blooms in the Chukchi Ecosystem** (SUBICE) program sampled the ice-covered Chukchi shelf (Fig. 1) in May-June 2014, providing an extensive characterization of spring hydrography, nutrients, and phytoplankton.

Motivation

Light transmission through melt ponds supports phytoplankton growth in ice-covered waters (Fig. 2), as evidenced by the presence of a massive under-ice phytoplankton bloom[1] in the Chukchi Sea.

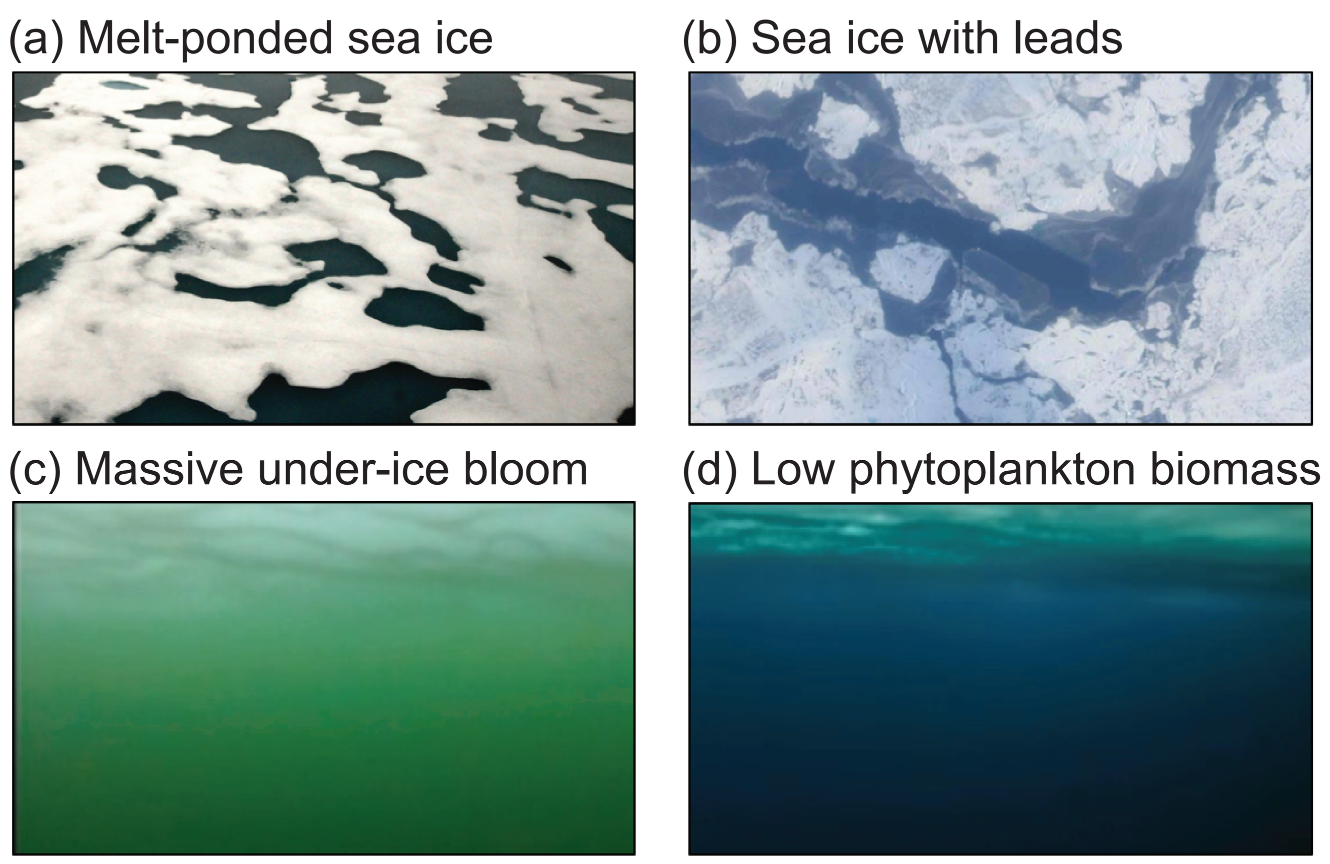

Fig. 2. Photographs of sea ice and under-ice water from NASA ICESCAPE (a, c, d) and NASA ARISE (b).

How important are leads of open water for phytoplankton in the sea ice zone? Leads transmit more incident irradiance to the underlying water column than melt ponds (~97% vs. ~50%).

Field and Satellite Observations

The Chukchi shelf was characterized by snow-covered ice with leads and generally weak stratification (Fig. 3).

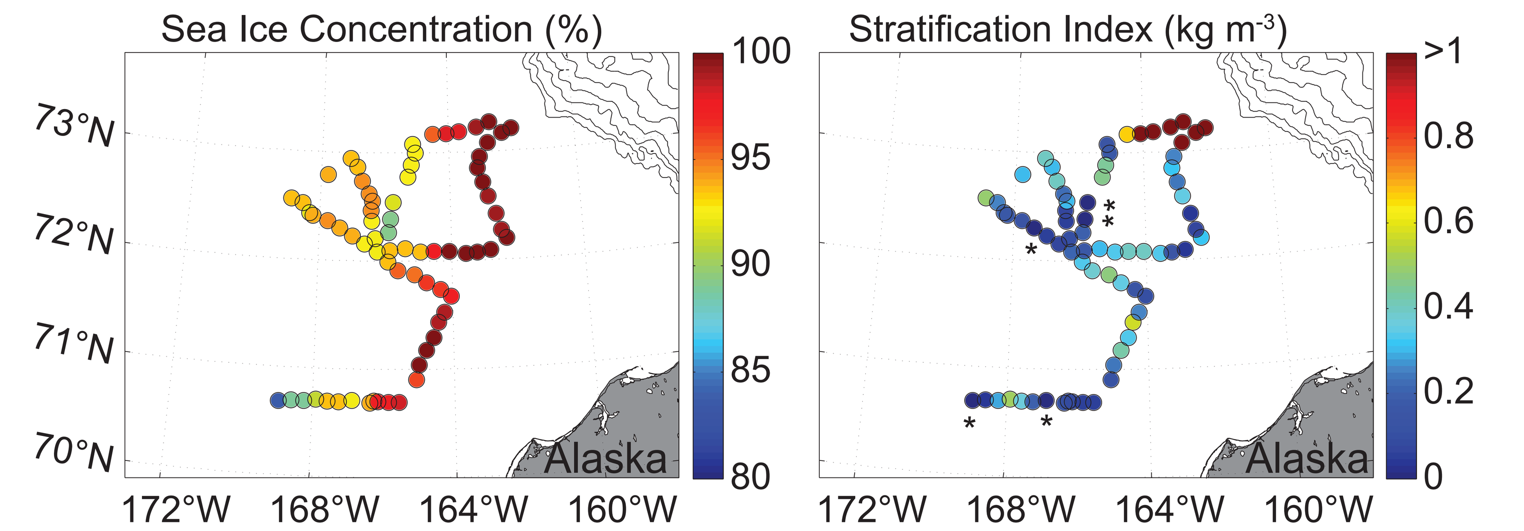

Fig. 3: SSM/I ice cover and stratification index (density jump from upper mixed layer to bottom boundary layer) for subset of stations.

Low phytoplankton biomass was observed in waters beneath sea ice with leads of open water (Fig. 4).

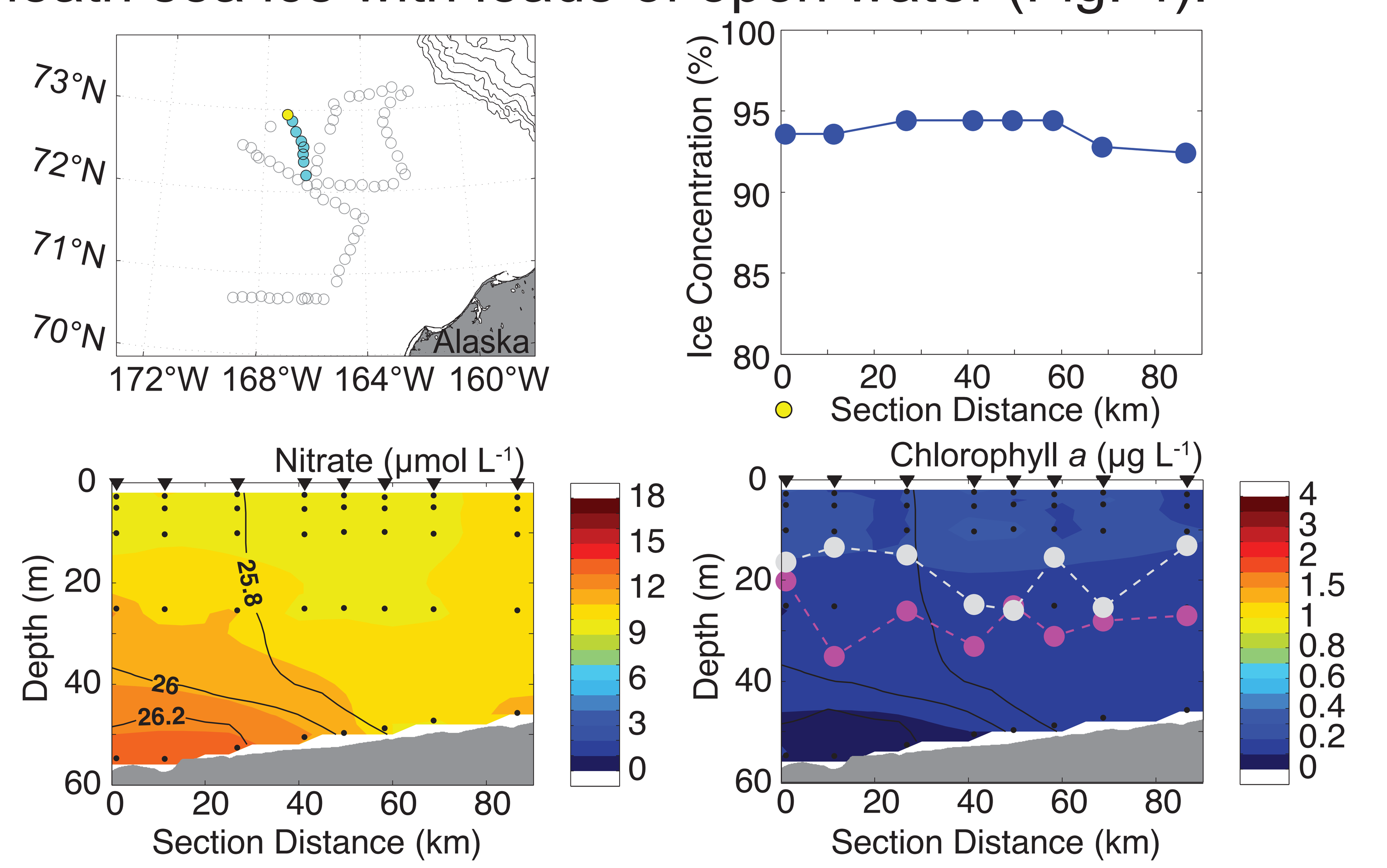

Fig. 4: Chukchi Northwest (24-25 May 2014)

Surprisingly, modest under-ice blooms were present even beneath 100% sea ice cover with snow (Fig. 5).

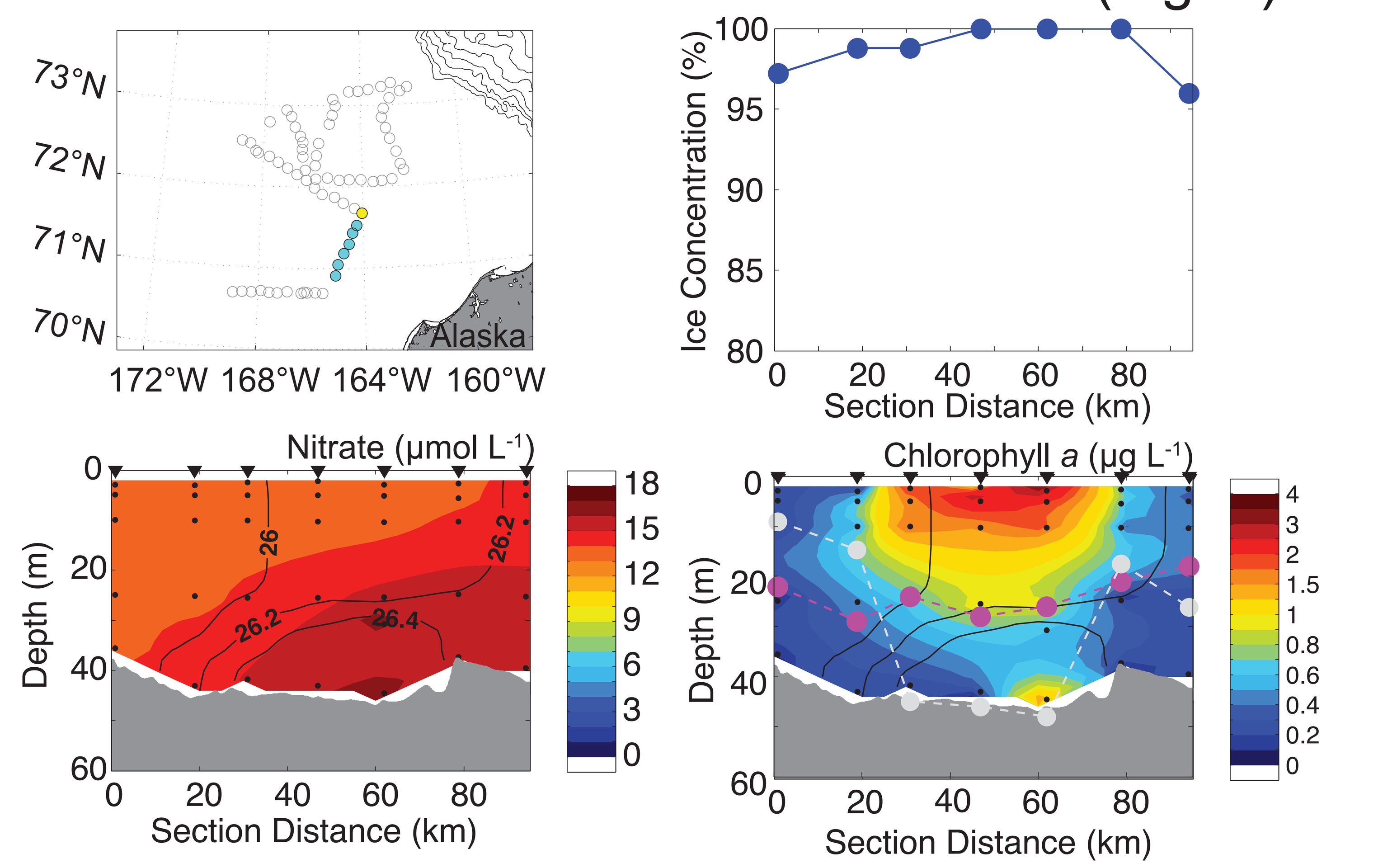

Fig. 5: Chukchi Northwest (24-25 May 2014)

Theoretical Model

Simulations of critical depth (z_{cr}) (Fig. 6) at varied lead fraction suggest that phytoplankton can bloom from background concentrations (0.1 µg L^{-1}) in stratified waters even beneath 100% sea ice cover with snow. As light increases at higher lead fraction, Z_{cr} deepens and exceeds the mean bottom depth of the Chukchi Sea at 67%.

Mixed layer depths shallower than Z_{cr} support bloom formation (Fig. 5), while mixing deeper than Z_{cr} prevents bloom formation (Fig. 4) by reducing the mean light level.

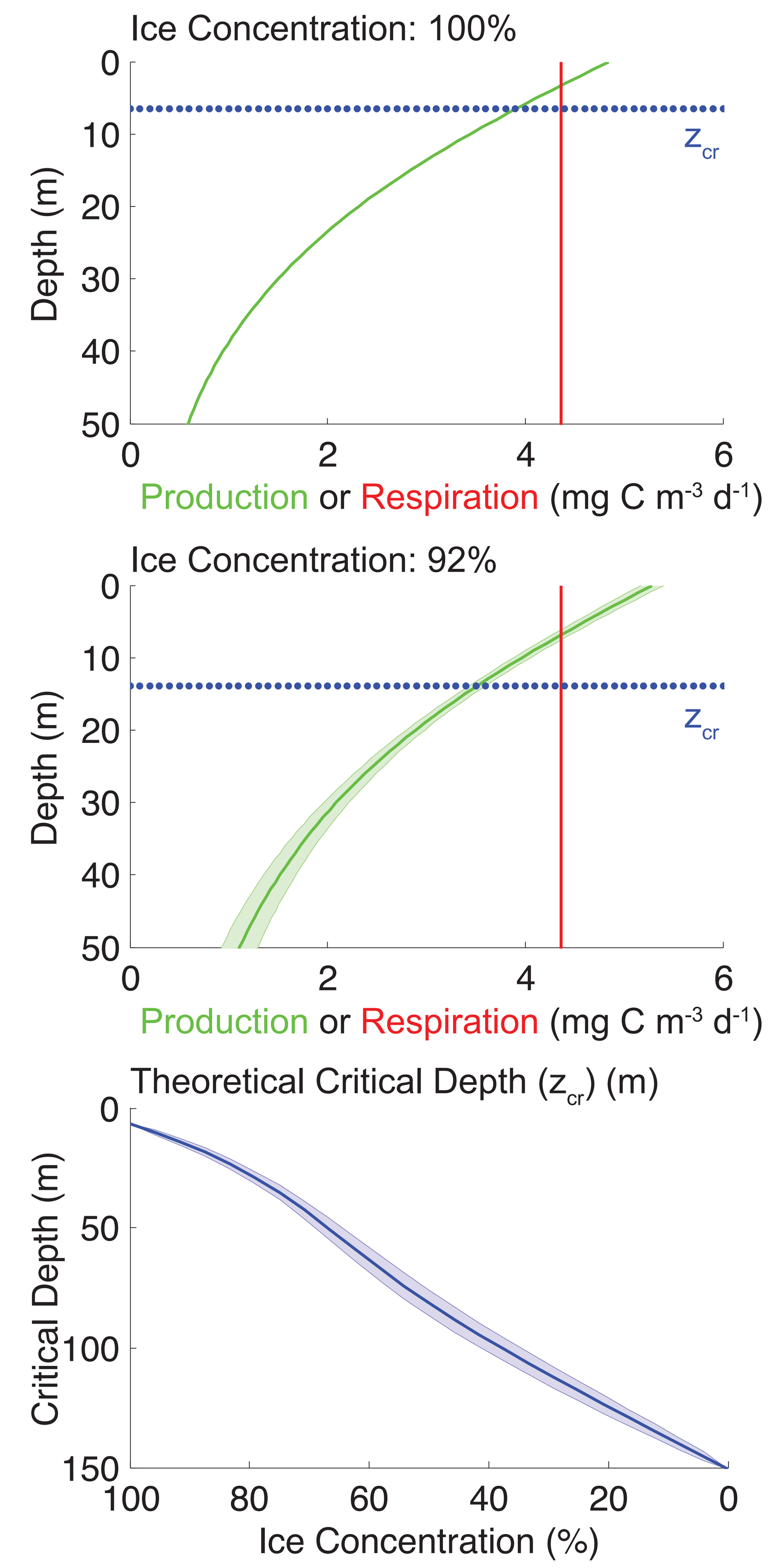

Fig. 6 Theoretical production, respiration, and critical depth (z_{cr}) (where integrated production balances integrated respiration) at varied ice concentration.

Convective Mixing in Refreezing Leads

Leads of open water were correlated ($p<0.05$) with weaker stratification, deeper mixed layers, and reduced phytoplankton biomass relative to 100% ice cover. The likely mechanism[3] is salinity-driven convective mixing in refreezing leads, as proposed by *Pacini et al. [submitted]*. Convective mixing can fully overturn the shallow water column of the Chukchi Sea, preventing bloom formation.

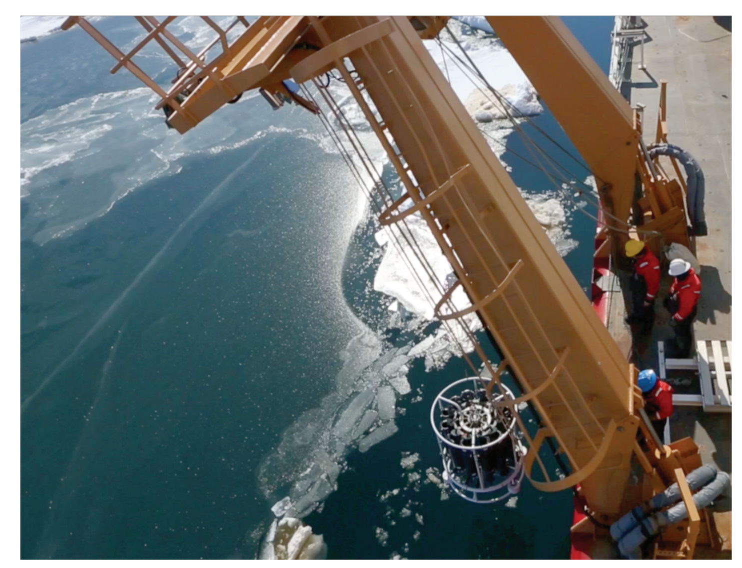

Photo by Amanda Kowalski

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References:
1. Arrigo et al. *Science* 336, 1408 (2012).
2. Sverdrup. *ICES J Mar Sci.* (1953).
3. Pacini et al. *Deep-Sea Res. Part II* (submitted).