Marginal Ice Zone: Biogeochemical Sampling with Gliders

Mary Jane Perry
School of Marine Sciences
University of Maine
Ira C. Darling Marine Center
193 Clark's Cove Road
Walpole, ME 04573-3307
phone: (207) 592-0317 fax: (207) 563-3119 email: perrymj@maine.edu

Ivona Cetinic
School of Marine Sciences
University of Maine
Ira C. Darling Marine Center
193 Clark's Cove Road
Walpole, ME 04573-3307
and
NASA Goddard Space Flight Center/USRA
Ocean Ecology Laboratory, Code 616
Greenbelt, MD 20771, USA
phone: (626) 200-9374 fax: (207) 563-3119 email: icetinic@gmail.com

Award Number: N000141310840
http://www.apl.washington.edu/project/project.php?id=miz

LONG-TERM GOALS

The long-term goal is to understand how phytoplankton, the primary producers of the ocean and base of marine food webs, are responding to changing conditions in the Arctic Ocean. The high-level project goals are to use underwater profiling gliders to determine the distribution of phytoplankton, particulate organic carbon, and rates of production of organic carbon in the Arctic under the ice and in the marginal ice zone. The project specific goals are to develop biogeochemical and optical proxies for glider optics; to use the proxies to project biogeochemical and optical measurements from ship-board measurements to the larger spatial scales sampled by the gliders in open water, in the marginal ice zone, and under the ice; to use glider optical measurements to compute fields of rates of photosynthetic carbon fixation; and to build collaborations with Arctic scientists at KOPRI.

OBJECTIVES

The scientific objectives are to:

1. Calibrate the biogeochemical sensors on the MIZ Seagliders deployed during the ONR Marginal Ice Zone DRI with shipboard measurements taken on the Korean icebreaker IBRV

Araon and glider deployment vessels RV Ukpik and Norseman to develop optical proxies for phytoplankton concentration and particulate organic carbon.

2. Characterize the development and spatial extent of blooms of phytoplankton under full ice cover, in the MIZ, and in open ice-free water through analysis of calibrated glider data and other shipboard data. Gliders were operated by University of Washington Applied Physics Lab collaborators Dr. Craig Lee and Dr. Luc Rainville.
3. Determine how upper ocean vertical structure and turbulent mixing rates affect development of blooms in the MIZ and open ice-free water, and the role of entrainment of nutrient rich waters into the euphotic zone in supporting these blooms.
4. Apply a light and chlorophyll primary productivity model to estimate and compare phytoplankton productivity under full ice cover, in the MIZ, and in open ice-free water.

APPROACH

In late summer 2014 during the Marginal Ice Zone (MIZ) Experiment, an international project sponsored by ONR, four Seagliders transited open water, through the marginal ice zone, and under ice-covered regions in the Beaufort Sea, penetrating more than 100 km into the ice pack. They were deployed by Drs. Lee and Rainvilles's team in late July on the *R/V Ukpik* out of Prudhoe Bay and were retrieved in early October by the *R/V Norseman*. The gliders navigated either by GPS in open water or, when under the ice, by acoustics from sound sources embedded in the MIZ autonomous observing array (Fig. 1). The glider sensor suite included temperature, temperature microstructure, salinity, oxygen, chlorophyll fluorescence, optical backscatter, and multi-spectral downwelling irradiance. Cruises on the *IBRV Araon* operating in the open Beaufort Sea and on the *R/V Ukpik* and *Norseman* operating in continental shelf waters off Alaska's north slope allowed us to construct proxy libraries for converting chlorophyll fluorescence to chlorophyll concentration and optical backscatter to particulate organic carbon concentration. The downwelling irradiance measurements, coupled with chlorophyll concentration, are being used to calculate rates of primary productivity. This work is a collaboration among Dr. Craig Lee and Dr. Luc Rainville of the University of Washington and Korean scientists Dr. Eun Jin Yang and Dr. Sung-Ho Kang from KOPRI.

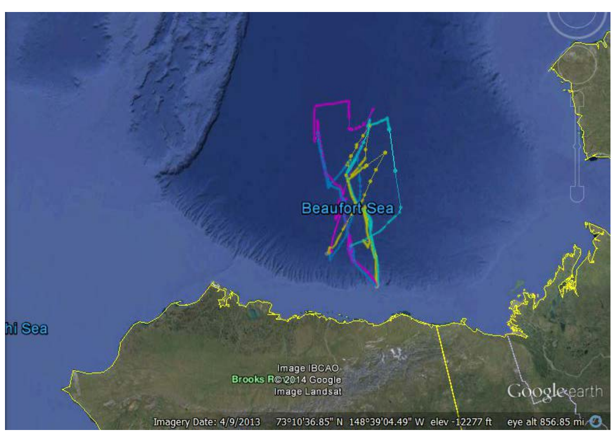

Figure 1. Track of the four Seagliders from late July to early October 2014, projected on a Google Earth map.

Calibration of glider biogeochemical sensors and development of optical proxies
Glider and ship sensors were calibrated simultaneous in a batch calibration at the factory both before and at the end of the 2014 field season. The glider sensors were also vicariously calibrated during the deployment and retrieval cruises by taking deliberate simultaneous CTD profiles with the ship's CTD and the glider. Because the cruise track of the *IBRV Araon* did not intersect the gliders (Fig. 2), no direct glider-ship calibrations were possible from the *Araon*.

Proxy libraries were constructed by correlating a biogeochemical measurement to an optical measurement. On all three cruises, water samples were collected for chlorophyll and particulate organic carbon analysis on the CTD upcast and were mapped to upcast optical measurements. Sensor data from the ship's CTD downcast were interpolated in density coordinate space to align with the glider profile. The optical proxy relationships were then applied to the glider optics to compute field of chlorophyll concentrations and particulate organic carbon. Over 250 chlorophyll samples and over 200 particulate organic carbon samples were collected on the *IBRV Araon.*

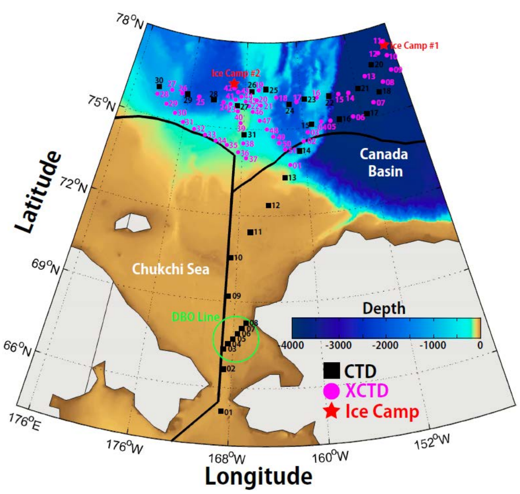

Figure 2. Track of IBRV Araon during August 2014 cruise. Only stations off the shelf (St. 15 and higher) were used to develop optical proxies.

Figure 3 shows the relationship for all *IBRV Araon* stations between chlorophyll fluorescence and optical backscatter. Chlorophyll fluorescence is a proxy for chlorophyll concentration and optical backscatter is a proxy for particles. When samples with suspended sediment particles are excluded from the analysis, optical backscatter can be used as a proxy for particulate organic carbon. The insert shows data only for non-shelf stations (Station 15 and higher).

Data with low chlorophyll fluorescence and high backscatter were associated with suspended sediment. This pattern was used to flag backscatter that could not be converted to particulate organic carbon with the optical proxy (Fig. 4).

Figure 5 shows the optical proxy for chlorophyll concentration. The power law fit for chlorophyll concentration from chlorophyll fluorescence incorporates the effects of fluorescence quenching and nutrient limitation on phytoplankton in the upper 30 m and low light photo-adaptation on phytoplankton from the subsurface chlorophyll maximum layers. The relationship between particulate organic carbon and optical backscatter was noisy, in part due to the low concentration of organic carbon in these waters. The POC/backscattering regression was similar to that found by Stramski et al. (1999) for Antarctic waters.

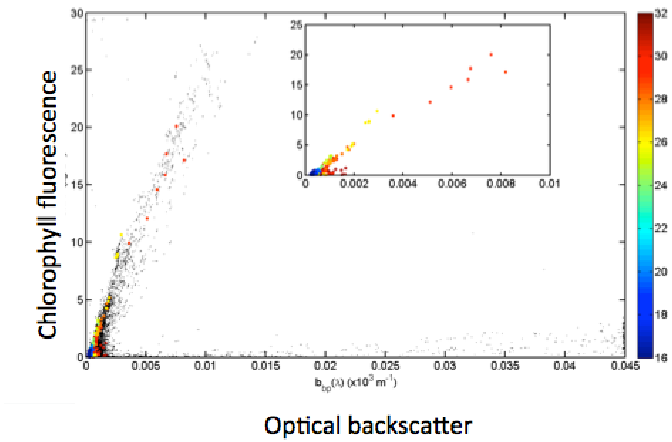

Figure 3. Chlorophyll fluorescence vs. optical backscatter.

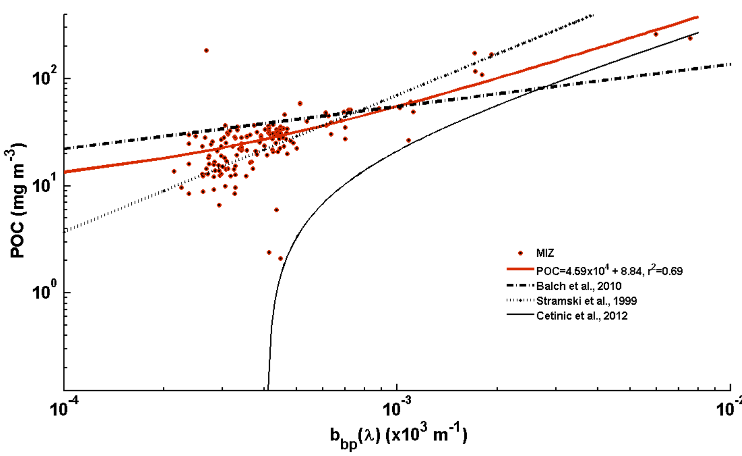

Figure 4. Particulate organic carbon vs. optical backscatter.

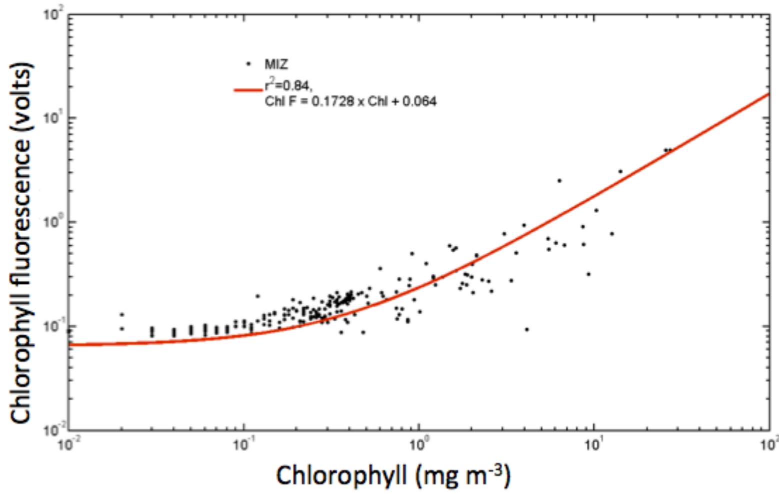

Figure 5. Chlorophyll concentration (mg m^{-3}) vs. chlorophyll fluorescence (volts).

Characterization of phytoplankton distribution and primary productivity under the ice, in the MIZ and open water

The Seaglider lines are being used to characterize the distribution of phytoplankton and particulate organic under full ice cover, in the MIZ, and in open ice-free water. Glider measurements of spectral irradiance and chlorophyll concentration are being used to calculate rates of primary productivity, based on published photosynthesis vs. irradiance functions. Irradiance under the ice primarily depends on ice thickness and presence of melt ponds and leads, and hence will be expected to vary spatially; this is expected to change as melting progresses. In the Chukchi Sea continental shelf, Arrigo et al. (2012) observed the presence of large phytoplankton blooms under the ice, which they attributed to higher light transmission through the relatively thinner (0.5 – 1.8 m) one-year ice. However, their measurements under the ice were sufficiently sparse to prevent them from assessing spatial patchiness. There appears to be a fall bloom that developed in open water at the end of September. Turbulent dissipation rates will be examined to determine if this were associated with mixing of nutrients into the euphotic zone.

WORK COMPLETED

Biogeochemical samples were collected on three cruises during 2014: a ten day cruise in late July/early August on the *R/V Ukpik*, a small vessel out of Prudhoe Bay; a twenty-six day cruise in August on the *IBRV Araon* from Nome to Barrow, Alaska; and a ten-day glider retrieval cruise in late September-early October. Chlorophyll, particulate organic carbon, and particulate absorption coefficient samples were collected. Chemical and optical analysis of samples were completed in the past year and optical proxies for chlorophyll concentration and particulate organic carbon concentration were constructed. Current efforts are begin directed toward computing fields of primary productivity using glider irradiance and chlorophyll. Preliminary results will be presented at the Ocean Sciences meeting in February 2016 in New Orleans; an abstract has been submitted.

Two first-authored poster were presented last year. One was presented at the international Ocean Optics XXII conference in Portland, Maine, in October 2014 (*Phytoplankton Distribution Measured by Gliders during the Marginal Ice Zone Experiment***),** and the other at AGU in San Francisco, California, in December 2014 (*Distribution of Phytoplankton and Particulate Organic Carbon in the Beaufort Sea during the 2014 Marginal Ice Zone Experiment*).

Two co-authored talks were presented at the Arctic Science Summit Week in Toyama, Japan, in April 2015 (*Direct Observations of Ocean Variability Across the Arctic Marginal Ice Zone from Autonomous Gliders* by Dr. Rainville and *Autonomous Investigations of Marginal Ice Zone Processes – Changing Feedbacks and Observational Challenges* by Dr. Lee).

RESULTS

Chemical analyses have been completed and optical proxies for chlorophyll and particulate organic carbon constructed (Figs. 4 and 5). In open water at the end of September, a phytoplankton bloom appeared to develop, possibly due to mixing of nutrients into surface waters. Figure 6 shows data from one glider between 13 September and 1 October for temperature (ºC), salinity (g/kg), chlorophyll (µg/L), particulate organic carbon (POC, mg/m^3) plotted as distance from the ice edge. Figure 7 shows the glider track for that period, supper imposed on a RadarSat image. The red dot is location of glider on date image was collected (26 September 2014). A key characteristic of phytoplankton and particulate organic carbon distribution under the ice is the deep subsurface maximum layer. Analyses are beginning to examine the spatial and temporal variability in phytoplankton and particulate organic carbon, using data from the four gliders.

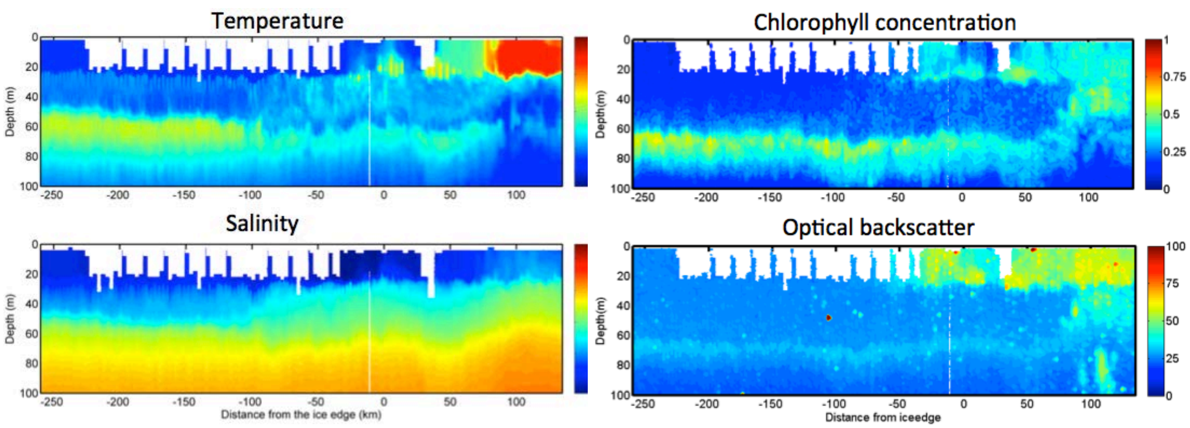

Figure 6. Temperature (upper left), salinity (lower left), chlorophyll concentration (upper right), and optical backscatter (lower right) from a glider track 13 September through 1 October 2014.

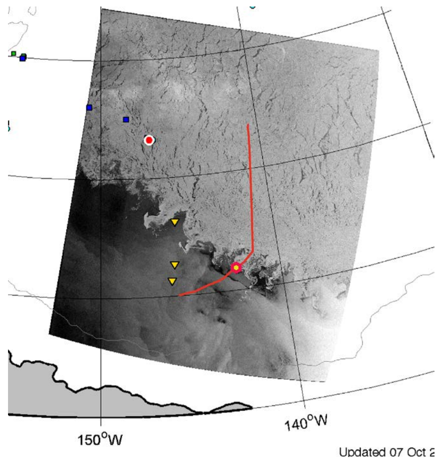

Figure 7. RadarSat image for glider track for Fig. 6.

IMPACT/APPLICATIONS

The results of this project will provide improved knowledge of the distribution, magnitude and productivity of phytoplankton under the ice, in the MIZ, and in open water through collection of data with well calibrated and validated autonomous sensors. A new collaboration with Korean scientists at KOPRI was forged with the potential for future collaborative Arctic studies.

RELATED PROJECTS

This project is a component of the Marginal Ice Zone DRI (MIZ) and is most closely aligned with the project entitled *Evolution of the Marginal Ice Zone: Adaptive Sampling with Autonomous Gliders*, PIs C. Lee, L. Rainville, and J. Gobat. http://www.apl.washington.edu/project/project.php?id=miz. This work will also rely on collaboration with with Korean scientists at KOPRI and with other DRI team members collecting irradiance measurements and measuring entrainment of deeper (nutrient rich) water into the euphotic zone.

REFERENCES

Arrigo, K. R., and thirty others, 2012. Massive phytoplankton blooms under Arctic sea ice. Science 336: 1408. doi: 10.1126/science.1215065.

HONORS/AWARDS/PRIZES

Mary Jane Perry
University of Maine
Rachel Carson Lecture, Fall AGU 2015
Sponsored by the American Geophysical Union