

## **Seasonal Ice Zone Reconnaissance Surveys Coordination and Ocean Profiles**

James Morison

Polar Science Center, APL-UW

1013 NE 40<sup>th</sup> St.

Seattle, WA 98105

phone: (206) 543 1394 fax: (206) 616 3142 email: [jhm2@uw.edu](mailto:jhm2@uw.edu)

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### **LONG-TERM GOALS**

This grant with extensions has been for the coordination of and participation in the Seasonal Ice Zone Reconnaissance Surveys (SIZRS) program through FY 2020. SIZRS is a multi-investigator<sup>1</sup> program of repeated ocean, ice, and atmospheric measurements. These measurements make use of U.S. Coast Guard flights across the Beaufort-Chukchi Sea seasonal sea ice zone (SIZ), the region between maximum winter ice extent and minimum summer ice extent. The long-term goal of SIZRS is to track and understand the interplay among the ice, atmosphere, and ocean, contributing to the rapid decline in summer ice extent.

### **Methodology**

The fundamental SIZRS approach is to make monthly flights, June to October, with US Coast Guard Air Station Kodiak C-130s across the Beaufort Sea Seasonal Ice Zone (SIZ), e.g., along 150°W from 72°N to the maximum of 76°N or beyond the ice edge. We make oceanography stations every degree of latitude by dropping Aircraft Expendable CTDs (AXCTD) and Aircraft Expendable Current Profilers (AXCP) typically while traveling northbound (PI: J. Morison). On the return leg, we drop atmospheric dropsondes from 3000 meters altitude to measure atmospheric temperature, humidity, and winds (PI: A. Schweiger). We also drop UpTempO drifting buoys that report time series of ocean temperature profiles (PI: M. Steele) and various meteorology and ice-tracking buoys of the International Arctic Buoy Program (IABP, PI: I. Rigor).

In addition to overall coordination of SIZRS, this grant covered profile measurements of ocean temperature, salinity, velocity, and mixing across the SIZ that are a core components of the SIZRS field campaigns. Our objective is to determine variations in ocean characteristics across the SIZ and how these relate to small- to mesoscale ice and ocean processes; to the larger-

scale ocean processes of the Beaufort Sea; and ultimately to the variations in Arctic Ocean and atmospheric circulation.

### **Accomplishments**

Over a total of 43 flights through 2019, more than 260 Aircraft eXpendable CTD (AXCTD) and Current Profiler (AXCP) profiles have been recorded, with an estimated 95% instrument success rate. SIZRS has also deployed a number of meteorological buoys for the International Arctic Buoy Program (IABP). The 2012-2019 SIZRS data show a Beaufort Sea that warmed and freshened at the surface. Individual sections have shown freshening and warming associated with a receding ice edge, as well as a layer of Pacific inflow (50-80 m) similarly warming and freshening. The month-to-month variations are consistent in their connection to ice edge retreat [Dewey *et al.*, 2017]. As the ice edge retreats, it leaves a layer of freshened open water that is warmed by solar heating. The pattern at any one location is consistent with simulations using a Price-Weller-Pinkel 1-D mixing model [Dewey *et al.*, 2017] and became stronger likely due to recent increases in ice melt-back. These variations have been set within a changing Beaufort Gyre circulation. Model and observational evidence have indicated that over the last 15 years, the intensity of the Beaufort Gyre increased and stabilized [Zhang *et al.*, 2016]. We have found by including the ocean surface velocity derived from CryoSat-2 altimetry in the ice-ocean stress calculation, that under anticyclonic wind stress, the Beaufort Gyre spins up until ocean velocity exceeds ice velocity retarded by internal ice stress. This negative feedback is responsible for stabilizing the gyre spin up. The time scale of gyre energy dissipation due to this process is on the order of days to 1 or 2 months versus the 6-year scale of dissipation by eddy generation [Manucharyan and Spall, 2016].

Our SIZRS graduate student, Sarah Dewey, received her Ph.D., in August 2019. Also, in 2017, 2018, and 2019, working with LCDR Dr. Shawn Gallaher (USNA), we have had US Naval Academy midshipmen as summer interns, taken them on SIZRS deployments, and sourced their senior projects [Alleyne *et al.*, 2018; Cecchini *et al.*, 2018; Sweeney *et al.*, 2020].

### **Recent Developments**

Two of our recent publications, Morison *et al.* [2021] and Guthrie and Morison [2021], motivate new foci our work. In trying to understand the connection between variations in the SIZ and interannual variability of Arctic Ocean circulation as a whole, we have analyzed dynamic heights (DH) from Russian hydrography, 1950 to 1989, and SCICEX 1993 hydrography and dynamic ocean topography (DOT) from satellite altimetry, 2004 to 2019. Our work [Morison *et al.*, 2021] reveals that the dominant mode of variability in Arctic Ocean circulation, exemplified by the first EOF of sea surface height (Figure 1), is not the strength of the Beaufort Gyre, but a low in sea surface height with cyclonic circulation on the Russian side of the Arctic Ocean. When this mode of variation is in the positive (cyclonic) phase is superimposed on the mean surface height pattern, characterized by the Beaufort Gyre, the result is a cyclonic mode circulation pattern expressed as an intensified but contracted Beaufort Gyre opposite a large trough with cyclonic circulation on the Eurasian side of Arctic Ocean. In Morison *et al.* [2021], we show that under the influence of an increased Arctic Oscillation (AO) index since 1989, the cyclonic mode has become more dominant, with associated losses of sea ice and freshwater and a weakening of the cold halocline layer that insulates sea ice from Atlantic Water heat. The critical upshot of this finding is the recognition that the dominant mode of variability is almost completely unobserved by present *in situ* measurements. Understanding the observed order 1-year latency between the AO forcing and circulation response promises to provide an

improvement in predictive capability.

The result of our internal wave modeling effort under ONR grant N000141612379

[Guthrie and Morison, 2021]

addresses a key issue for SODA, namely whether the historically low Arctic Ocean internal wave energies and background mixing would increase as sea ice diminishes and thus change the stratification. Our SIZRS AXCP data from ice-free conditions show no increase relative to ice-covered conditions. Clearly something besides ice cover keeps Arctic Ocean internal wave energy low. Our modeling result is that the low values of  $\beta$  (the variation of Coriolis parameter with latitude) characteristic of the Arctic, limit the amount of near inertial wave energy that propagates into the halocline and thus keeps internal wave energy and background mixing low even when no ice is present. This raises the question, if background mixing is low, what controls stratification? We think the answer is shelf-basin interaction.

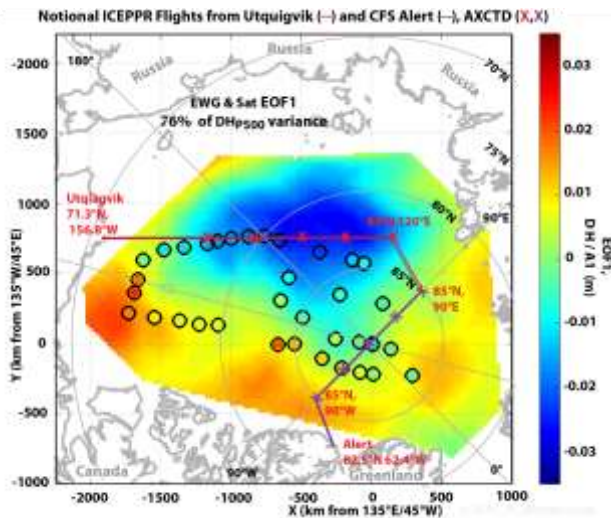


Figure 1. The proposed SIZRS/ICE-PPR Utqiagvik-Makarov-Utqiagvik and Thule-North Pole-Thule missions overlaid on the principle EOF of  $DH_{500}$  and satellite DOT, 1950-89 and 2004-2019. Also shown are the anomalies of dynamic height at the 1993 SCICEX *Pargo* stations,  $DH_{Pa}$ , relative to the mean of combined EWG  $DH_{500}$  and satellite DOT. A fit of the EOF1 to  $DH_{Pa}$ , explains 76% of the variance of the *Pargo* anomalies.

## Future Work

The monthly SIZRS sections will continue to provide spatial and temporal coverage of atmospheric and oceanic conditions across Beaufort Sea SIZ, and as it has been ongoing since 2012, we are nearing the point where we will be able to examine decadal-scale changes in the manner of seasonal ice retreat. Consequently we have proposed and been funded to continue monthly USCG C130 flights (typically June-October) along the 150°W dropping AXCTDs and AXCPs every degree of latitude starting at 72°N and continuing to the greater of 76°N or the Marginal Ice Zone around the ice edge.

The PIs will begin to look at the interannual variability in the seasonal evolution of the SIZ. Initially this may take the form of compositing years with the greatest and least sea ice retreat to see if there are any commonalities in the edge-referenced ocean structure. Ultimately we want to compare such composites with hemispheric indices such as the AO and Arctic Dipole (second EOF of Northern Hemisphere atmospheric pressure). It is noteworthy in this respect that latency in the response of the ice extent [Rigor *et al.*, 2002] and ocean circulation [Morison *et al.*, 2021] to the AO promise to provide predictive capabilities for these characteristics.

We will collaborate with SIZRS PI Steele to explore the fate of the oceanic heat from summer solar radiation A synthesis of AXCTD and UpTempO data and the SIZRS 1-D Price-Weller-Pinkel model [Dewey *et al.*, 2017] will be used to analyze this phenomenon and explore

changes month-to-month and differences relative to the earlier years of SIZRS studied by Dewey *et al.* [2017]. We will also collaborate with SIZRS PIs Liu, Schweiger and Steele to explore the role of early-season ocean heat content as a possible predictor of late-season sea ice extent.

We have recently received an internal APL IR&D award to adapt an inertial motion sensor, infrared camera, and radiometer to a Riegl lidar acquired under NASA funding. We propose to gain Coast Guard ACCB approval to mount LATIS inside the SIZRS C130s and operate it through an open paratrooper door, avoiding the great technical and approval difficulties of a previous flare tube mounted lidar. LATIS will allow us to measure the surface properties of sea ice and ocean during deployment of our AXCTD, AXCP, and buoys, providing the surface measurements we've always needed commensurate with our atmospheric and ocean sections.

Finally, to understand the dominant mode of Arctic Ocean circulation change, its connection to climate indices, and role in changing the SIZ, we will a) continue to lead organization of the upcoming CLIVAR workshop on the Arctic Ocean Circulation [[Morison, 2020](#)], b) continue to serve on the SCICEX Science Steering Committee and recover hydrographic data from SCICEX and past ONR projects, and c) collaborate with Ignatius Rigor of the IABP to apply the SIZRS approach using Coast Guard C-130J aircraft and expendable probes and buoys to make ocean sections into the center of action of the cyclonic mode on the Russian side of the Arctic Ocean (Fig. 1).

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