Seasonal Ice Zone Reconnaissance Surveys Coordination and Ocean Profiles

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LONG-TERM GOALS

[This grant is for the coordination of and participation in the Seasonal Ice Zone Reconnaissance Surveys (SIZRS) program of repeated ocean, ice, and atmospheric measurements across the Beaufort-Chukchi sea seasonal sea ice zone (SIZ) utilizing US Coast Guard Arctic Domain Awareness (ADA) flights of opportunity. 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 that has occurred in recent years. The SIZ is the region between maximum winter sea ice extent and minimum summer sea ice extent. As such, it contains the full range of positions of the marginal ice zone (MIZ) where sea ice interacts with open water. In addition to SIZRS coordination, this grant covers our profile measurements of temperature, salinity, velocity and mixing across the SIZ, with the long-term goal of understanding the role of the ocean in controlling the evolution of the SIZ.

OBJECTIVES

The overarching objectives for SIZRS are to determine seasonal variations in air-ice-ocean characteristics across the SIZ extending over several years and for a variety of SIZ conditions, investigate and test hypotheses about the physical processes that occur within the SIZ that require data from all components of SIZRS, and improve predictive models of the SIZ through model validation and through the determination of observing system requirements.

For the ocean profiles component of SIZRS, our objective is to determine variations in ocean characteristics across the SIZ extending over several years and for a wide variety of SIZ conditions.

APPROACH

This grant coordinates the various SIZRS observations on the ADA flights, assures integration with modeling efforts, serves as the SIZRS point of contact with the Coast Guard, and helps gain the necessary Coast Guard approvals for the SIZRS instruments.

The U.S. Coast Guard Arctic Domain Awareness (ADA) flights offer the way to make regular measurements over long ranges in the Beaufort and Chukchi seas at no cost for the platform. SIZRS includes a set of core measurements needed to, make complete atmosphere-ice-ocean column measurements across the SIZ, make a section of ice conditions across the SIZ, and deploy drifting buoys to give time series of surface conditions. These operations and the relation of SIZRS to the Coast Guard mission are described by Hyles (2014). Our measurements are illustrated in Figure 1. Specifically, the core elements (Table 1) are aircraft expendable CTD (AXCTD) vertical profiles of ocean temperature and salinity plus aircraft expendable current profiler (AXCP) ocean velocity shear (Morison), UpTempO buoy measurements of sea surface temperature (SST), sea level atmospheric pressure (SLP), and velocity (Steele), and dropsonde measurements of atmospheric properties (Schweiger et al.) in-flight, and inflight laser profiling for ice thickness using the CU Laser Profiler Instrument-extended (CULPIS-X) (Tschudi, University of Colorado collaborating with Lindsay and Chickadel, UW). In addition, atmospheric modeling and ice-ocean modeling components (Schweiger et al.) will tie the SIZRS observations together. Other collaborating projects (Table 2) have come forward to participate in or collaborate with SIZRS, including buoy deployments for the International Arctic Buoy Program (Rigor, UW).

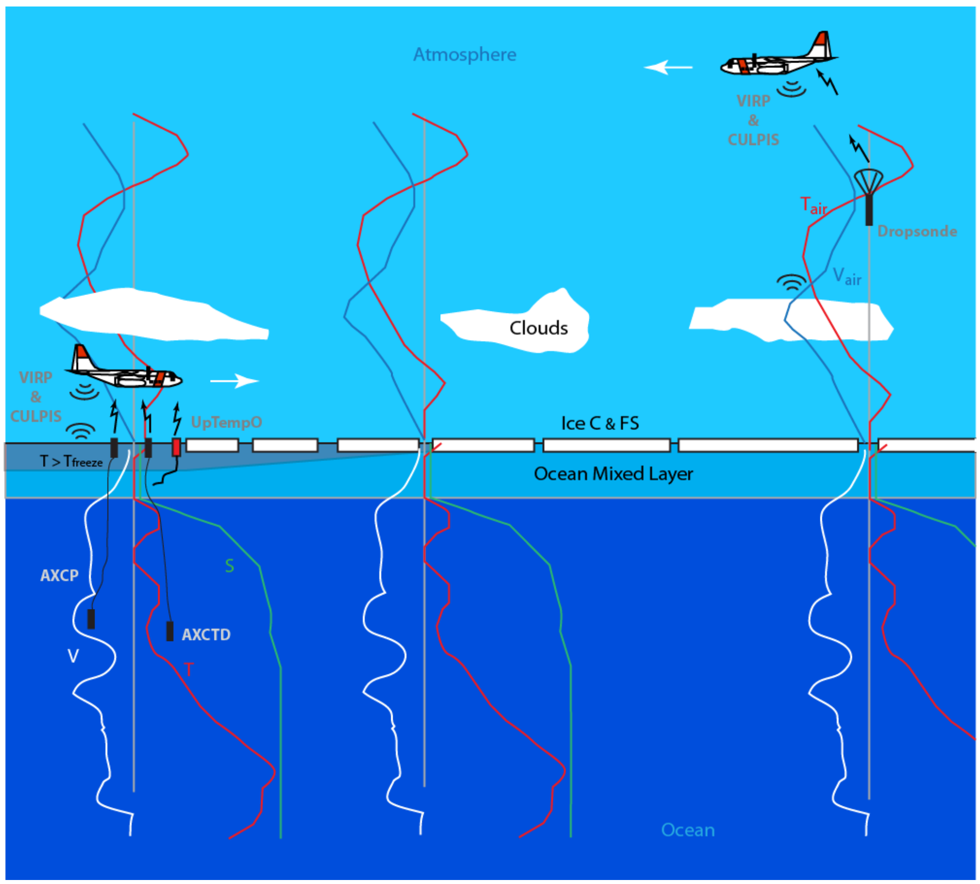


Figure 1. Schematic of the SIZRS core measurements. The column measurements (AXCTD & AXCP at low altitude outbound & dropsonde at high altitude inbound) will be made in five locations (3 shown) with at least one column each in open water, MIZ, and pack ice. The aircraft remote sensing (CULPIS-X) will give sea ice concentration, floe size, and thickness and surface temperature profiles across the SIZ. Buoy deployments (core UpTempO and other IABP buoys) will provide time series at several locations across the SIZ. Missions will be flown monthly during the April-Oct time frame for three years

ADA flights prior to 2014 were conducted twice per month from March through November. On ADA flights, we conduct atmosphere-ice-ocean observations at least once per month. Since 2014, at our request, instead of two one day missions per month, the Coast Guard substituted single multi-day missions operated out of Fairbanks in July, August, and September. With forward staging like this, we have been able to conduct flights farther into the Arctic Ocean and on two lines of longitude (150°W and 140 °W) on consecutive days. These include lines of about 5 stations across the SIZ with profile measurements through the complete air-ice-ocean column (Fig. 1). UpTempO and IABP buoy deployments are made in July or when sufficient open water exists and the buoy sites revisited with column measurements several times per season.

Flight paths are based on science priorities and on remote sensing estimates of ice conditions at the time of the flights. In general we focus on repeat sections on the 150°W and 140°W in order to provide interannual comparability. Remote sensing resources include MODIS visible and IR imagery, and NSIDC ice extent charts based on a composite of passive microwave products (http://nsidc.org/data/masie/). In 2013 and 2014, a new component of SIZRS (Harry Stern, PI) collected and analyzed Arctic sea ice satellite visible imagery from the USGS Global Fiducials Library (GFL). These were provided a few days prior to flights for every degree of latitude from the Alaska coast up the 150°W longitude line into the ice up to about 80°N.

Table 1: Core Projects of the SIZ Reconnaissance Survey Flights

Project	PI	Co-PIs	Observations/Activity
Ocean Profile Measurements During the SIZRS	**Morison**		Ocean expendable probes AXCTD & AXCP for T, S, V, internal waves/mixing
Clouds and the Evolution of the SIZ in Beaufort and Chukchi Seas	**Schweiger**	**Lindsay, Zhang, Maslanik, Lawrence**	Atmospheric profiles (dropsondes, micro-aircraft), cloud top/base heights
UpTempO buoys for understanding and prediction….	**Steele**		UpTempO buoy drops for SLP, SST, SSS, & surface velocity
Visible and Thermal Images of the SIZ from the Coast Guard Arctic Domain Awareness Flights	**Chickadel**	**Lindsay (retired 2015)**	Analysis of visible and IR profiles using CULPIS-X (below) . Remote sensing for analysis and flight planning.
Ice thickness and character using CULPIS-X	**Tschudi**	**Maslanik**	CULPIS-X Laser profiler for ice thickness, reflectance, skin temperature, visible imagery
AXCTD= Air Expendable CTD, AXCP= Air Expendable Current Profiler, SLP= Sea Level atmospheric Pressure, SST= Seas Surface Temperature, A/C= aircraft, SIC=Sea Ice Concentration			

We have used the AXCTDs successfully in prior surveys, primarily from smaller aircraft, and developed the method for dropping the Sippican-TSK AXCTD from C-130 aircraft during one test mission with the Alaska Air National Guard Search and Rescue Squadron in Anchorage, Alaska and with three Coast Guard ADA flights, one on September 30, 2009, one on May 25, 2010 (Fig. 6), and one during a buoy deployment flight Oct. 26, 2010. In addition to the Sippican-TSK (Tsurumi-Seiki)

AXCTD expendable probes, the equipment includes a TSK AXCTD TS-RX100W Receiver (Ch.14), a T.S.K. AXCTD TS-MK150N Converter, a Marantz PMD-660 Solid State Sound Recorder, and a Macintosh laptop computer.

During an AXCTD deployment, once the aircraft nears the nominal station location, we search for an open lead at least 100 m wide and free of newly formed ice. The aircraft flies down the lead at an altitude of 60-120 m, and the AXCTD is deployed by hand from the side "paratrooper" door or the open rear ramp. It parachutes to the lead surface, a float inflates on contact with water, and after a short delay, the CTD probe drops from the float unit. Data is transmitted from the probe to the buoy via an ~1500-m copper wire spooled from the probe and the float. While the aircraft circles at 100 to 300 m, the data is transmitted from the float to the aircraft as 172 MHz FM radio signal (channel 14). The data transmission is received by the T.S.K. TS-RX100W through one of the standard aircraft VHF antennas. The raw reception is converted to engineering units by the TSK Converter and recorded on the laptop computer. A backup recording of the raw received signal is made with the solid-state sound recorder. Based on comparison among AXCTD drops and surface CTD stations we find AXCTD are accurate to 0.02 psu and 0.02°C [*McPhee et al.,* 2009].

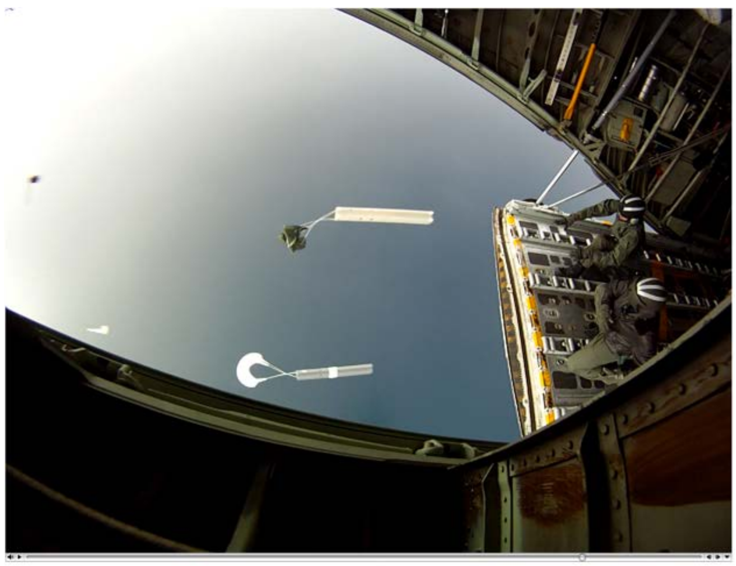
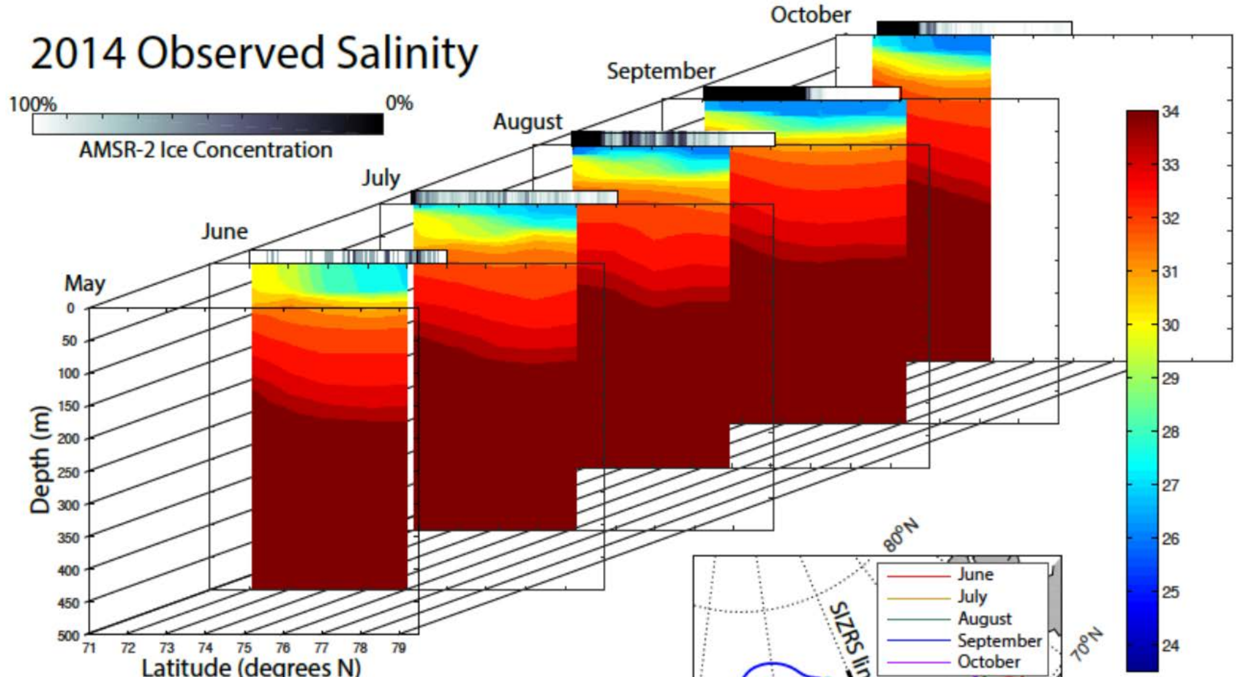


Figure 2. AXCTD (gray) and AXCP (white) being hand-launched simultaneously from rear ramp of USCG C-130H during August 2013 SIZRS flight.

We have been using expendable current profilers (XCP) as part of the NPEO and Switchyard surveys and analyzing their data as part of our NSF Arctic Ocean Mixing Grant (http://psc.apl.washington.edu/northpole/Mixing.html). We have been using the AXCP in SIZRS since 2013. The AXCP use a surface float and dropped probe similar to the AXCTD arrangement described above. The AXCP radio uplink receiver and recording equipment are the same as the equipment used in our lightweight NPEO equipment, which includes an ICOM IC-R20 receiver set to 172 MHz wide-band FM and a Marantz PMD-660 Solid State Sound Recorder. In the SIZRS application, we use the same manual deployment through the paratrooper door for the AXCP that we use for the AXCTD. At each station, the two types of probe are dropped simultaneously (Fig. 2). We use the same aircraft VHF antenna through a splitter to feed both receivers, and we use AXCP transmitting at 170.5 MHZ

(Channel 12) to allow simultaneous radio reception and recording of AXCTD and AXCP. The raw AXCP transmission recorded on the Marantz recorder is played back through a sound card to a laptop computer with XCP processing software developed here at the UW Applied Physics Laboratory by John Dunlap for the inventor of the XCP, Tom Sanford. Dunlap has developed a special Arctic version of the software, which is better suited than the standard Sippican deck units to the high geomagnetic latitude and commonly weak velocity shear of the Arctic Ocean. The raw audio-frequency content of the AXCP transmission is recorded on the solid state recorder as a backup.



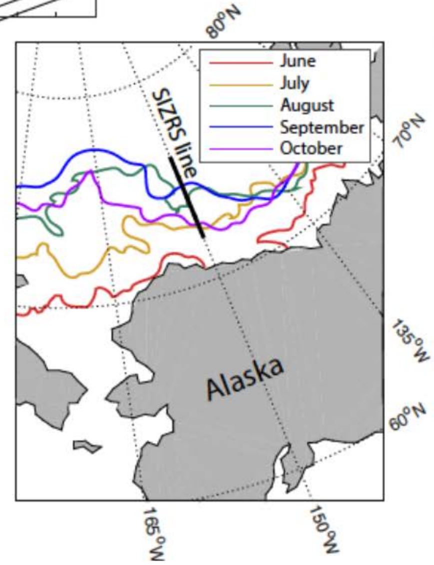


Figure 2. Sections of salinity to 500m are shown with over plotted AMSR-2 ice cover on the date of deployment (above). The SIZRS 150°W line is also shown in its regional context, against lines representing the 15% AMSR-2 ice edge average for the week of each deployment in 2014 (right).

WORK COMPLETED

In February 2015 our PI and one of our staff visited Coast Guard Air Station Kodiak to work with the Coast Guard flight crews on improving UpTempO buoy deployment procedures. For this we had a mockup of the buoy package built and sent to Kodiak so that we all could practice drop procedures. The PI to took the opportunity to brief the Station leadership on the SIZRS program and present an early request for 2015 mission times.

Progress was made on approvals for several instruments. Most notably, the CULPIS-X received ACCB approval for flight and was scheduled for our October flight. Unfortunately, that flight had to be canceled at the last minute for reasons of aircraft availability, but a test flight of CULPIS-X over local Alaska waters is being planned for November. The "Glidersonde" atmospheric profiler (Lawrence) and the GPS repeater (Schweiger) received approvals for Safety of Flight Tests. These were completed successfully and we anticipate flight testing them in November.

During the 2015 SIZRS field season, we flew aboard USCG Kodiak-based C130 aircraft for six days. Each of these missions began and ended in Kodiak. Two one-day missions were conducted on July 14 and July 23. August 11-12 and September 9-10 were two-day missions for which we spent one night in Fairbanks. Additionally, we flew an NSF-supported mission to the North Pole on August 25-26 that staged to Barrow on the first day and flew round-trip to the Pole on August 26.

On July 14 we deployed one AXIB in the Chukchi Sea, and recorded an ocean section with AXCTDs and AXCPs, and an atmosphere section using Dropsondes along 150°West from 72° to 76°North. On July 23 we flew a similar line along 140°West that included UpTempO buoy deployments at 72° and 73°North.

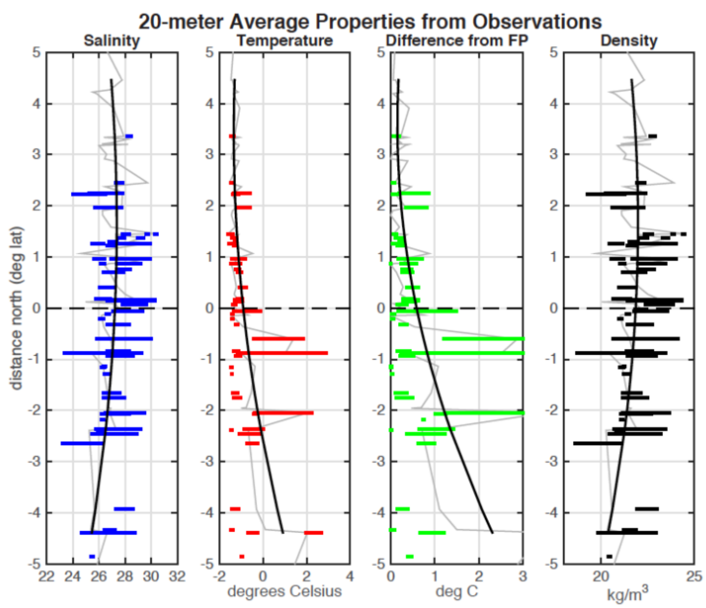


Figure 3. All 20-meter average ocean properties (gray) from all deployments are plotted relative to the ice edge. Thick black lines show a quadratic fit to the data, and colored bars display the full range of values at each distance. Average salinity values decrease both to the north and south of the ice edge, while temperature increases above the freezing point south of the ice edge. Variance in temperature is substantially greater to the south of the ice edge, as insolation heats open water, whereas salinity variance remains relatively consistent throughout the section.

On August 11 we repeated the 140°West ocean and atmosphere lines including another two UptempO buoys, stayed overnight in Fairbanks, and the following day completed sections along 150°North that reached 77°North, before returning to Kodiak.

On September 9 we deployed one UpTempO buoy in the Chukchi Sea, and recorded ocean and atmospheric sections along 150°West from 72° to 76°North including an AXIB deployment at 74°North. Then on September 10, we flew from Fairbanks to record ocean and atmospheric sections along 150°West, 72°-77°North, returning to Kodiak.

As in previous years, the Coast Guard crews showed a remarkable degree skill in finding and hitting small, ice-free leads in frequent conditions of fog and precipitation.

The Coast Guard was able to provide us with aircraft and crew time despite what seems to be a steadily increasing demand for C130 missions in the Alaskan summer season. One-day missions originally scheduled for June 9 and October 6 had to be cancelled due to other urgent requirements or mechanical issues, but overall the Coast Guard has made an extraordinary effort to meet our science requirements.

RESULTS

In addition to data collection, 2015 featured new analysis and insight into the 2012-14 SIZRS dataset. Examination of 20-meter average salinities through each melt season along the 150°W line reveals the formation of a fresh surface layer near the ice edge (Fig. 2).

For the purpose of determining if there is a typical ice edge-linked pattern, this observation lead us to register all SIZRS observations in the top 20m relative to the satellite-observed ice edge position at the time of data collection (Fig. 3). While temperature varies only with distance south of the ice edge, the 20-meter salinities appear to have an edge signal with a large basin-scale signal superimposed (Fig. 4). Areas of maximum freshening are found south of the ice edge and at the center of the Beaufort Gyre (~74.5°N on 150°W). The basin-scale signal is the freshening at the center of the Gyre and is expected to have both climatological mean and seasonal variation [*Proshutinsky et al.*, 2009].

In order to remove the basin-scale signal without eliminating the ice-edge signal, we look at several proxies for background gyre strength in the Beaufort Sea. The first is the monthly Arctic Oscillation (AO) index; second, the meridional tilt of two different isopycnal surfaces across the Canada Basin; and third, the measured bottom pressure at two discrete locations beneath the survey line. We find that these proxies correlate with the meridional salinity gradient at each SIZRS station. Interestingly, for the AO lagged by two months, the correlation with northward salinity gradient is negative south of 74°N and positive north of 74°N, consistent with a positive correlation between the AO and doming of the Beaufort Gyre. The position of the AO low-pressure center along the Russian side of the Arctic Ocean makes a positive phase of the cyclonic AO effective at converging water into the center of the anticyclonic Beaufort Gyre. A regression of either of the proxies onto the salinity gradient yields salinity residuals that in every case correlate significantly with distance from the ice edge (Fig. 5). This is the SIZ ice edge signal.

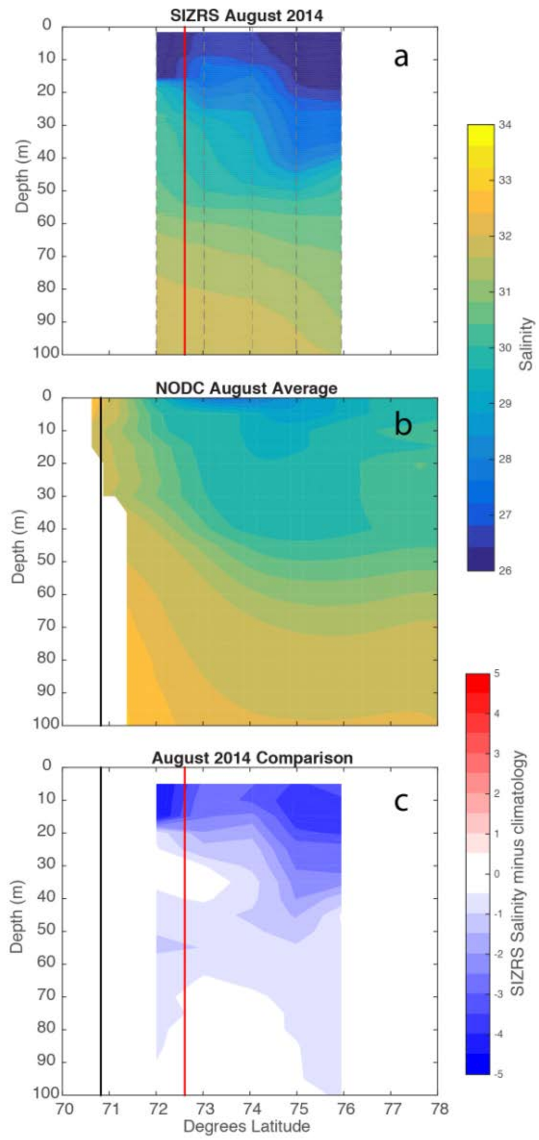


Figure 4. Comparison of SIZRS data to regional monthly climatology along 150°W. Observed ice edge (15% threshold, AMSR-2 passive microwave product) is over plotted in red; climatological ice edge (15% threshold, from NSIDC's monthly sea ice concentration climatology from passive microwave data, available at http://nsidc.org/data/smmr_ssmi_ancillary/monthly_means.html) is over plotted in black. SIZRS drop locations are shown with dashed gray lines in panel a. The National Ocean Data Center climatology (panel b) uses World Ocean Atlas data through the end of 2011. Panel c shows the difference in salinity, in psu, when the climatology is subtracted from the SIZRS data. Areas of maximum freshening are found south of the 2014 ice edge and at the center of the Beaufort Gyre (~75°N on 150°W).

Having shown that the fresh layer near the ice edge is independent of the large-scale gyre signal, we use a 1-D model of Price, Weller, & Pinkel (PWP) [*Price et al.*, 1986] adapted for ice-covered seas to explain the formation of this fresh edge layer. The model simulates mixing processes in the top 100 meters of the ocean. Surface forcing fluxes are taken from the Marginal Ice Zone Modeling and Assimilation System (MIZMAS). Since it is able to replicate salinity profiles and changes in freshwater content in the upper 20m, our PWP output supports local formation of the fresh layer by ice melt. This may have implications for the fate of freshwater in the Beaufort Gyre as the SIZ changes.

IMPACT/APPLICATIONS

The SIZRS effort is a pioneering program in the use of aircraft expendable ocean and atmosphere sensor probes in tracking changes in the sea-ice environment of the Arctic. It will lead to greater availability of synoptic snapshots of environmental properties over extended ranges.

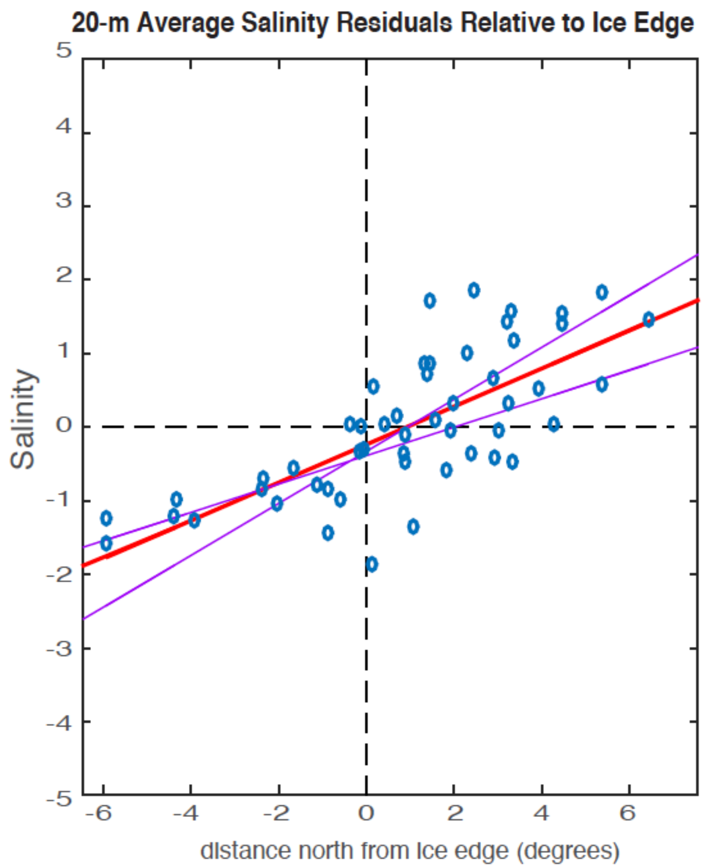


Figure 5. Salinity residuals from AO detrending plotted with ice edge. When the gyre signal is removed, residual values correlate significantly with distance from the ice edge. The blue circles show residuals from all SIZRS months in 2012-14; the red line is a linear fit to the data, and the purple lines are extrema for such a fit, generated in a 1000-iteration bootstrap Monte Carlo simulation.

RELATED PROJECTS

See Table 1

REFERENCES

Price, J. F., R. A. Weller, and R. Pinkel (1986), Diurnal cycling: Observations and models of the upper ocean response to diurnal heating, cooling, and wind mixing, *Journal of Geophysical Research: Oceans*, *91*(C7), 8411-8427.

Proshutinsky, A., R. Krishfield, M. L. Timmermans, J. Toole, E. Carmack, F. McLaughlin, W. J. Williams, S. Zimmermann, M. Itoh, and K. Shimada (2009), Beaufort Gyre freshwater reservoir: State and variability from observations, *Journal of Geophysical Research-Oceans*, *114*.

PUBLICATIONS

S. Dewey, J. Morison, R. Andersen, and J. Zhang (2014), "Aerial Surveys of the Beaufort Sea Seasonal Ice Zone in 2012-2014", poster presentation C11A-0344 at 2014 Fall AGU Meeting, San Francisco, California.