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14. ABSTRACT

The goal of the Seasonal Sea Ice Zone Reconnaissance Surveys (SIZRS) is to track and understand the interplay among the ice, atmosphere, and ocean contributing to the recent decline in summer ice extent. The SIZ is the region between maximum winter sea ice extent and minimum summer sea ice extent. Under this grant we coordinated various SIZRS projects making monthly sections of 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 in the summers of 2012- 2014. In addition to SIZRS coordination, this report covers our measurements of ocean temperature, salinity, velocity and mixing across the SIZ. From these measurements and related modeling efforts we have learned that the ocean temperature and salinity distribution across the SIZ shows a dominant response to solar heating and ice melt that moves with the ice edge throughout the melt season, with higher temperature and freshened surface water left south of the ice edge as it retreats.

15. SUBJECT TERMS
Arctic Ocean, Seasonal Sea Ice Zone, Marginal Ice Zone, Beaufort Sea, Chukchi Sea

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LONG-TERM GOALS

This report covers our grant for the coordination of 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 report covers our grant Ocean Profile Measurements During the Seasonal Ice Zone Reconnaissance Surveys (N00014-12-1-236) for measurements of temperature, salinity, velocity and mixing profile 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, assured integration with modeling efforts, maintained the SIZRS website, served as the SIZRS point of contact, and helped 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).

ADA flights prior to this year were conducted twice per month from March through November. On ADA flights, we conduct atmosphere-ice-ocean observations at least once per month. This year, at our

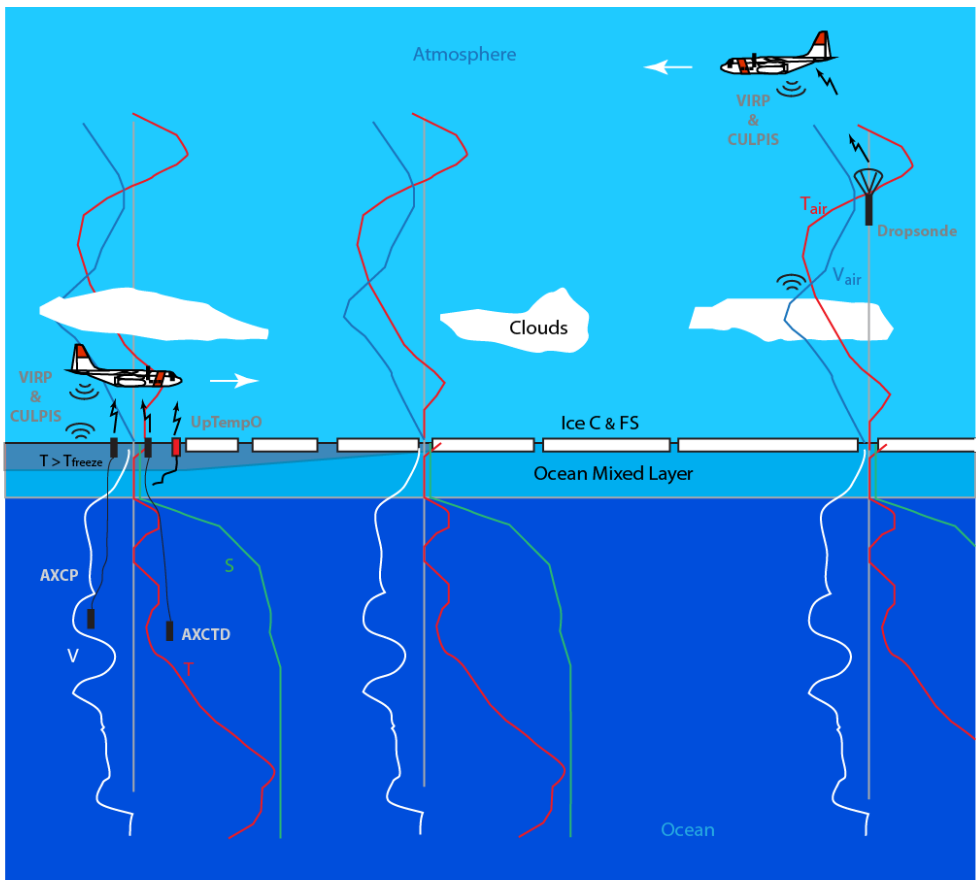

Figure 1. Schematic of the SIZRS core measurements. The column measurements (AXCTD & AXCP at low altitude outbound & dropsonde at high altitude inbound) will be made in five locations (3 shown) with at least one column each in open water, MIZ, and pack ice. The aircraft remote sensing (CULPIS-X) will 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

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 June or when sufficient open water exists (e.g., August, 2014) 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, NSIDC ice extent charts based on a composite of passive microwave products (http://nsidc.org/data/masie/), and daily updated Oceansat-2 (OS2) scatterometer (a clone of QuikSCAT) from Son Ngheim at the Jet Propulsion Laboratory. Starting in 2013, we began a new component of SIZRS (Harry Stern, PI) to collect and analyze Arctic sea ice satellite visible imagery from the USGS Global Fiducials Library (GFL). These are 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. They provide a record of ice conditions across the MIZ and help with preflight planning. We also receive regular images from the site of active AXIB or UpTempO buoys we deploy.

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	**Lindsay**	**Chickadel**	Analysis of visible and IR profiles using CULPIS-X (below) . Remote sensing for analysis and flight planning.
High Resolution Satellite Visible Imagery for SIZRS	**Stern**	**Schweiger**	Collect and analyze GFL visible imagery
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].

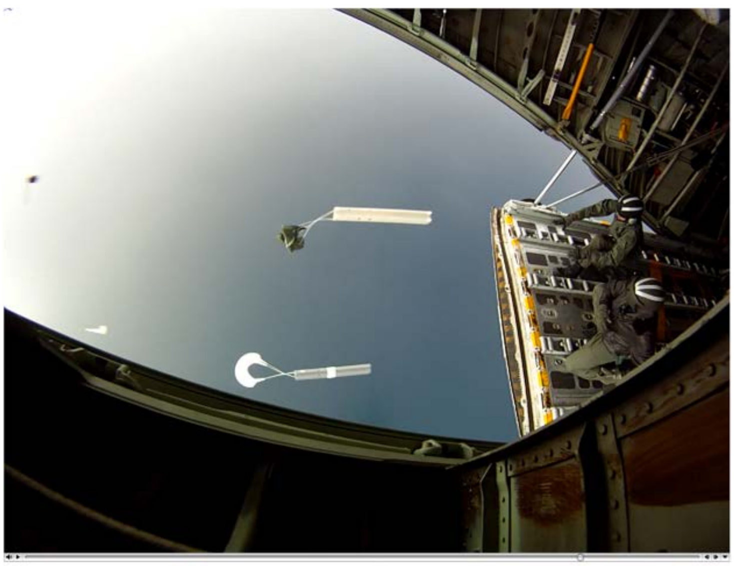

Figure 2. AXCTD (gray) and AXCP (white) being hand-launched simultaneously from rear ramp of USCG C-130H during August 2013 SIZRS flight.

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). 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.

WORK COMPLETED

In 2014 SIZRS completed its third season working with USCG Air Station Kodiak. Subsequent surveys in 2015 have been supported under our follow-on grant Seasonal Ice Zone Reconnaissance Surveys Coordination and Ocean Profiles (N00014-15-1-2295). The coordination effort assembled documentation needed for USCG approval of all the originally proposed UW SIZRS instruments to be used on the ADA flights. The required Safety of Flight Tests (SOFT)* were successfully completed in February 2013, for the AXCTD and AXCP (Morison), dropsondes (Schweiger), and UpTempO buoys (Steele). The AXIB buoy of the IABP (Ignatius Rigor), which we deploy on some of our flights, had received approval prior to SIZRS. The CULPIS-X instrument from Tschudi at the University of Colorado was a complicated and long approval process since before SIZRS began. The process was lengthy for CULPIS-X because it required temporary modification of the aircraft airframe. Given the uncertainty in the CULPIS-X approval process, the Lindsay and Chickadel infrared imagery project purchased a commercial infrared video camera, and we have designed and built a mount that allows us to gather ice-ocean imagery from inside the aircraft when the rear loading ramp is down for the expendable probe and buoy deployments. We put his camera system successfully through its SOFT in February 2014, and we have been deploying it this year

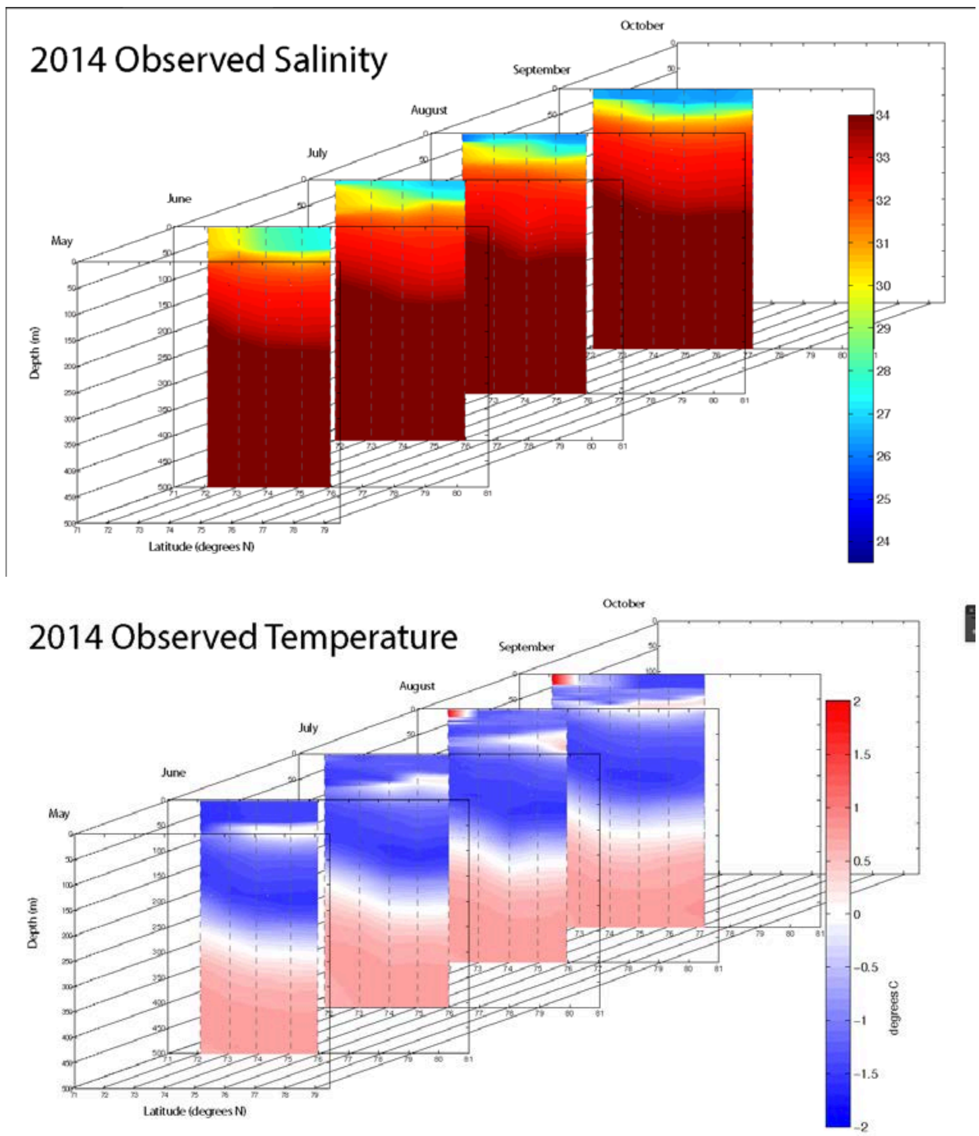

Figure 3. Ocean salinities (a) and temperatures (b) measured once per month by AXCTD during the 2014 SIZRS flights.

Each summer from June through October we conducted monthly missions. June, July, and October missions were mainly 1-day missions beginning and ending in Kodiak with a fuel stop in Fairbanks. These typically sampled every degree from 72° to 76°N along 150°W, except in 2012 when we went as far north as 80°N to reach the ice in that year of record minimum ice extent. As the program developed in 2013 and 2014, the August and September missions came to involve two flights with a stay overnight in Fairbanks between them. One flight would be on 150°W and the other on 140°W.

We coordinated with the ONR MIZ DRI to obtain various images in support of operations and SIZRS research. GFL high-resolution optical images were provided by the SCITOR Corporation and helped guide deployment. SAR imagery, providing detailed information about the evolution of the seasonal ice zone in the SIZRS region were obtained.

RESULTS

The scientific results for most components of SIZRS are described in the grant reports specific to those components. Here we descirbe the science results of our companion Ocean Profiles grant.

Figure 3 shows the monthly evolution of salinity and temperature through 2014 measured by SIZRS AXCTDs along 150°W. The pattern of upper-ocean freshening as the 2014 season progressed is apparent and generally consistent with the pattern in previous years.

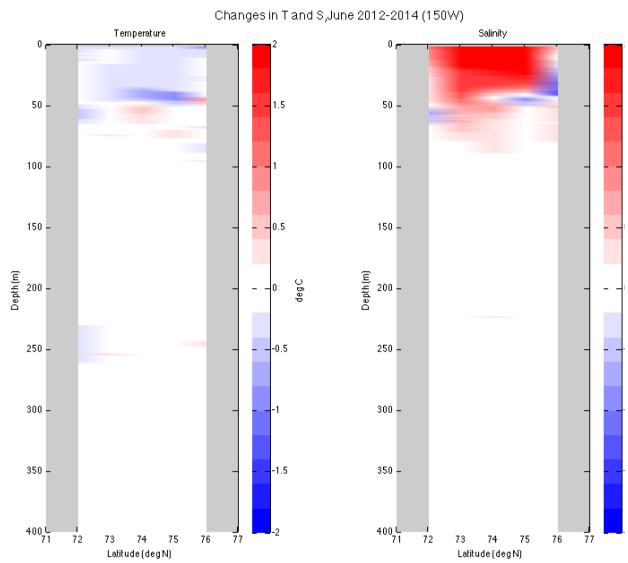

Figure 4. Difference between June 2014 and June 2012 temperature (left) and salinity (right) measured with SIZRS AXCTDs along 150°W.

The appearance of warm near-surface water in the developing open water regions at the south end of the section is also typical. We find that the surface temperature extrema in late-season open water areas (e.g., 72°N) exceed the surface temperatures in similar open water areas south of the ice edge during 2012's season of minimal ice extent. The onset of freezing is apparent in the northernmost latitudes of September's temperature section, where a uniform -2°C layer extends as far south as 75°N. However, while the southern extrema of this year's ocean data show a near-surface layer warmer than that just south of the ice edge in 2012, the overall change from 2012 to 2014 has been an increase in salinity (Fig. 4 right) and a decrease in temperature (Fig, 4 left) at repeat stations.

This increase in salinity and decrease June 2014 relative to June 2012 across all comparable latitudes of the 150°W line result in the water temperature in the upper 50 m being closer to the freezing point than in 2014 (Fig. 5). This at least reduces the initial potential for the ocean to melt the ice cover in 2014. The consequent reduced melting early in the summer delays the onset of sea-ice-albedo feed back in accelerating melt throughout the season and thus reduces the melt-back of the ice edge. The reduction in upper ocean temperatures may also explain our 2014 visual observations of isolated thin layers of ice growth in open leads even in July and August, something we have never seen before.

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.

RELATED PROJECTS

See Table 1 of the report for related Seasonal Ice Zone Reconnaissance Surveys projects.

REFERENCES

McPhee, M. G., A. Proshutinsky, J. Morison, M. Steele, and M. Alkire (2009), Rapid change in freshwater content of the Arctic Ocean, *Geophysical Research Letters*, *36*(L10602, doi:10.1029/2009GL037525.).

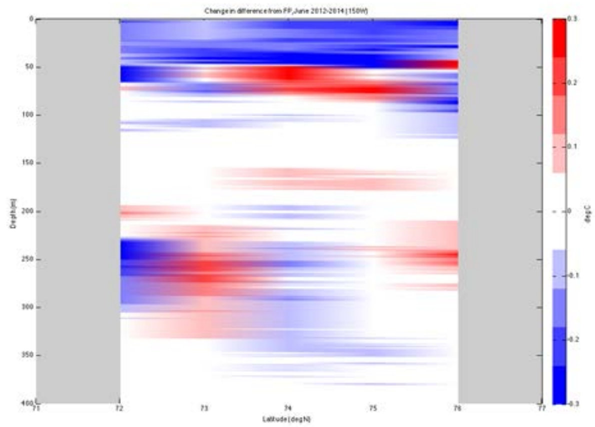

Figure 5. Difference between June 2014 and June 2012 elevation above the freezing point measured with SIZRS AXCTDs along 150°W.

PUBLICATIONS

Paper: S. Dewey, J. Morison, J. Zhang (*submitted*). "An Edge-Referenced Surface Fresh Layer in the Beaufort Sea Seasonal Ice Zone" Journal of Physical Oceanography.

Poster: S. Dewey, J. Morison (2016). “An Edge-Referenced Surface Fresh Layer in the Seasonal Ice Zone”, presented at AGU Ocean Sciences Conference, New Orleans, Louisiana.

Talk: S. Dewey, J. Morison, J. Zhang (2015). “Modeling the Seasonal Ice Zone from the Air: use of repeat aerial hydrographic surveys to constrain a regional ice-ocean model in an area of rapidly evolving ice cover”, presented at American Geophysical Union Fall Meeting, San Francisco, California.

Poster: S. Dewey, J. Morison, et al. (2014). “Aerial Surveys of the Beaufort Sea Seasonal Ice Zone in 2012-2014”, presented at: Forum for Arctic Modeling & Observational Synthesis, Woods Hole, Massachusetts; Graduate Climate Conference, Pack Forest, Washington; American Geophysical Union Fall Meeting, San Francisco, California.

Poster: S. Dewey, J. Morison, et al. (2014). “Aerial Surveys of the Beaufort Sea Seasonal Ice Zone in 2012”, presented at AGU Ocean Sciences Conference, Honolulu, Hawaii.