CODA Cruise Report, R/V Sikuliaq, Sept-Oct 2020

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Cruise # SKQ2020-13S
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Overview

The R/V Sikuliaq conducted a mooring recovery cruise for the CODA (Coastal Ocean Dynamics in the Arctic) project in autumn 2020. The goal of CODA is to observe the interactions of coastal sea ice with winds and waves along the coast of northern Alaska. More information on CODA is at: http://www.apl.uw.edu/coda .

This report is structured as a sequential narrative of the research cruise, followed a by a synthesis of the observations and directions for future analysis of the data. A detailed central cruise log was maintained for all activities onboard the ship, using the web-based "event logger" hosted by the ship's servers. The event logger automatically embeds the ship's location and event timestamps. This available as a csv file.

The cruise track and mooring locations are shown in Figure 1. There are three CODA focus sites along the coast: Icy Cape (S1), Jones Islands (S2), and Flaxman Island (S3). Additional points on the cruise track are for the deployment of two wave gliders near the Shumigan Islands and deployment/recovery of sea gliders at the Beaufort shelfbreak.

Summary schedule

25 Aug	Science party initial RT-PCR testing for COVID 19
27 Aug	Science party travel to Seward, AK from Seattle, WA
28 Aug to 11 Sep	Science Party self-isolation in Seward, AK
12 Sep	Mobilization, science party move onboard
14-21 Sep	Transit (9 days), wave gliders deployed en route
22-23 Sep	Icy Cape (S1)
24 Sep	Sea gliders (72 N, 152 W)
25-26 Sep	Flaxman Island (S3)
27-28 Sep	Jones Islands (S2)
29 Sep	Harrison Bay
30 Sep	Offshore Ice Edge
1 Oct	Transit around Barrow
2-3 Oct	Icy Cape (S1) revisited
4-12 Oct	Transit (9 days)
13 Oct	Demobilization, science party depart AK

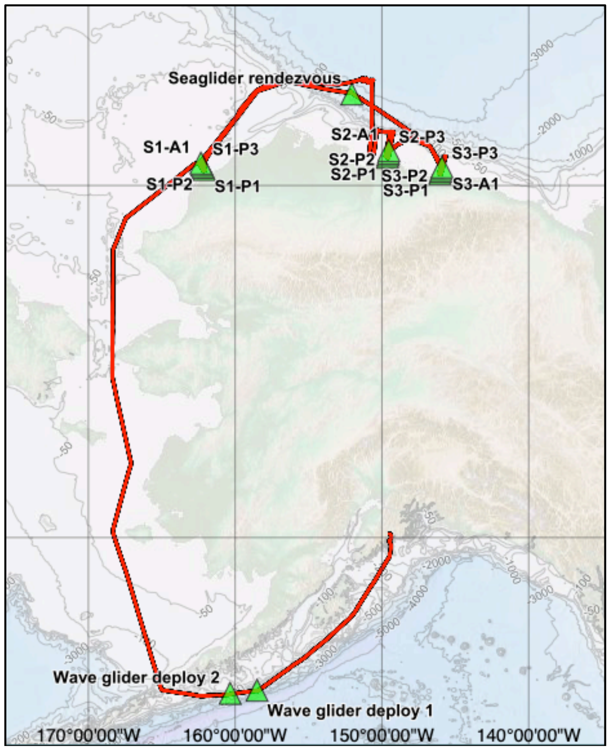

Figure 1. Cruise track (red, Seward to Seward) and mooring sites (green triangles).

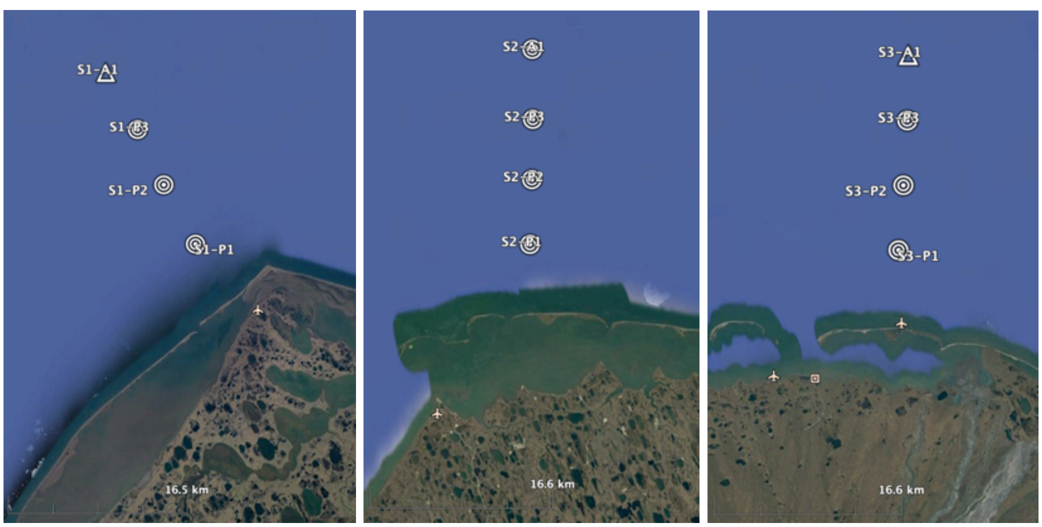

Figure 2. Detailed views of focus sites S1 (Icy Cape), S2 (Jones Islands), and S3 (Flaxman Island). Each site has an array of four moorings. Farthest offshore are A1 moorings with acoustic Doppler profilers. Farther inshore are pressure gages P3, P2, P1.

Outbound transit and wave gliders

Transit from Seward to Icy Cape (S1) took 9 days, including 1 weather day. Two wave gliders were deployed en route, as an ancillary effort for the Aleutian GPSA project (PI: Spahr Webb).

Icy Cape (S1)

We arrived Icy Cape on 22 Sep 2020 and recovered the farthest offshore mooring (S1A1), a seafloor tripod with an Acoustic Doppler Current Profiler (Signature 500). The acoustic profiler operated for the entire deployment, from Nov 2019 to Sep 2020. The heading, pitch, and roll were stable, indicating that the tripod did not move. The instrument interleaved burst and average sampling. The bursts were collected using a vertical beam at 2 Hz for 1024 seconds at the beginning of each hour and used to calculate wave statistics and ice drafts in post-processing. The averages were collected every 10 minutes and used to form ensemble profiles of the currents and the acoustic backscatter echo intensity.
The summary figure below shows that waves are active at the site in the fall, and again in spring and summer. In the winter, the site is covered with sea ice and there are no waves, except for a brief event in January. The water temperature near the seafloor has a related seasonal signal. The flow regime is bimodal, with flow that is either southwest or northeast (i.e., up or down the coast). The phase of the flow is correlated with the water level at the site (given by the average pressures), and this suggest wind-driven upwelling/downwelling modulation of the Bering Strait inflow. The echograms of backscatter amplitude suggest suspended sediment transport is related to phases of this flow, as well as the waves in fall.

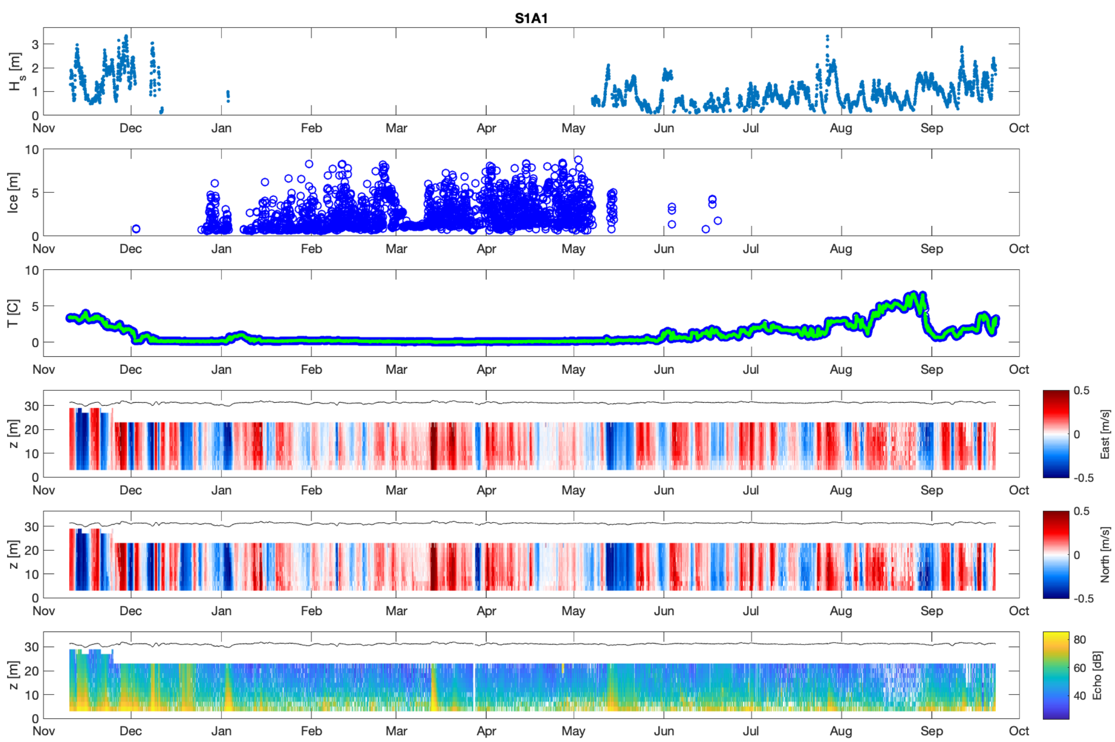

Figure 3. Full time series from Signature 500 data at S1A1 (12 nm offshore in 30 m depth). The first two weeks were a separate deployment during the 2019 cruise.

Later in the day on 22 Sep we recovered the farthest inshore mooring (S1P1), a seafloor pressure gage. After firing the acoustic release, the recovery float took several hours to come to the surface; the cause of the delay is unknown. The continuous seafloor pressure data at 1 Hz are used to calculated wave statistics every 30 minutes in post-processing, which are corrected for depth attenuation to estimate wave statistics at the surface. Comparing the waves at the offshore S1A1 site to the inshore S1P1, there is a clear signal of shorefast ice blocking waves in May and June. Comparing the temperatures between the sites shows a similar signal, in which the cold temperatures at the inshore station persist thru May and June.

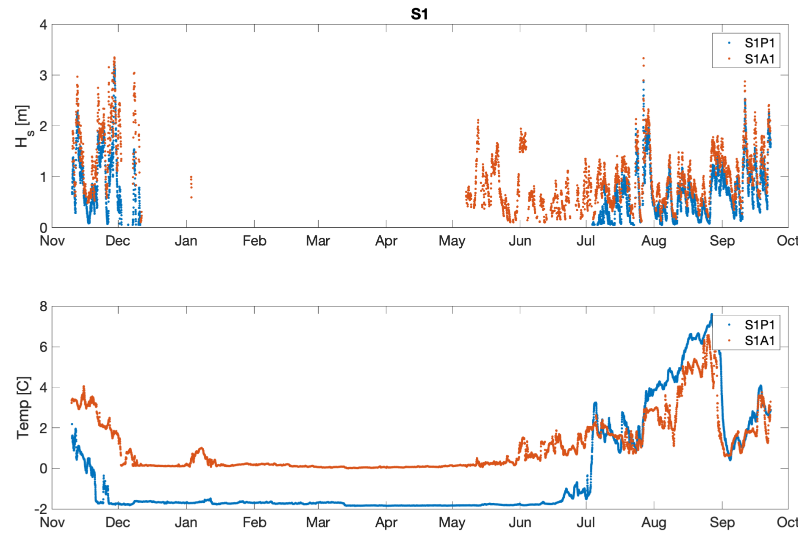

Figure 4. Surface wave heights and bottom water temperatures at S1A1 (offshore) and S1P1 (inshore).

Ice products, provide as special project support by the US National Ice Center, confirm the presence of shorefast ice over S1P1 (inshore) and mostly open water over S1A (offshore) during May and June.

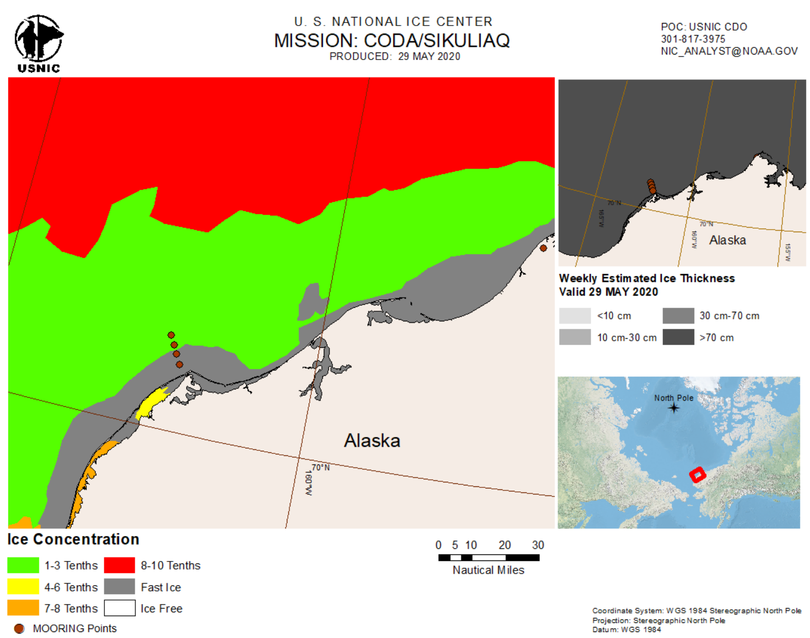

Figure 5. USNIC ice analysis for S1 in late May 2020.

The acoustics releases for the seafloor pressure gages at S1P2 and S1P3 did not communicate. On the second day at S1 (23 Sep), a SCUBA diving search for the pressure gage at S1P3 was not successful. No attempt was made to dive on S1P2, because of extremely low visibility in the water. These middle moorings were not recovered. Luckily, the end-point moorings show the signals of scientific interest quite well.

While at Icy Cape we also conducted multibeam bathymetry surveys, and collected water-column profile measurements, water samples, and seabed grab samples. Water-column profiles were measured using a CTD outfitted with OBS (calibrated turbidity sensor) and LISST (laser in situ scattering transmissometer for particle sizes). A subset of water samples was filtered through GFF (glass) filters for determination of TSS (total suspended solids) and SSC (suspended-sediment concentration). The remaining samples were filtered through nitrocellulose filters for determination of TSS. Results will be used to calibrate the OBS data from turbidity units (NTU) to mass concentration units (mg/L). On 22 and 23 Sep, the water column was salt-stratified with a warm (up to ~5ºC), freshened (~30.5) surface layer with minimal turbidity (Fig. 6). Bottom water (~15 m and deeper) was more saline (~32) and colder (~1ºC) with turbidity up to ~5 NTU. Turbid waters up to ~20 NTU were found within 1–5 km of shore throughout the water column, and up to 20 km within 1-2 m of the bed. Most sediments recovered in grab samples were sorted medium sand, though some coarser sands, gravels, and muds were recovered to the northeast of the cape during the second visit to Icy Cape in October (see later section for figure). Many of the seaward samples (especially near the tripod and P3 sites) included macrobenthos (sand dollars, starfish, bivalves, and other invertebrates).

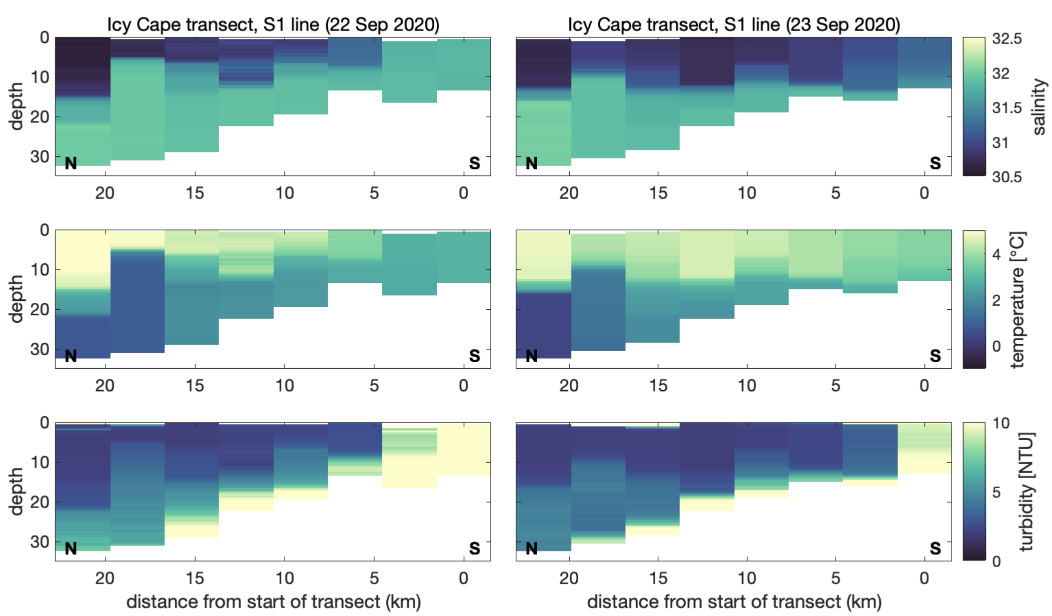

Figure 6. Profiles of salinity, temperature, and turbidity collected along the S1 mooring line on 22 and 23 Sep.

Multibeam data were collected along the S1 mooring line as well as some lines running parallel to the shoal crests established in 2019, in order to assess changes in seabed character. Near the seaward portion of Blossom Shoals, symmetrical ripples were observed in 2019 which had been re-worked and gouged by ice keels by Sep 2020 (Fig. 7).

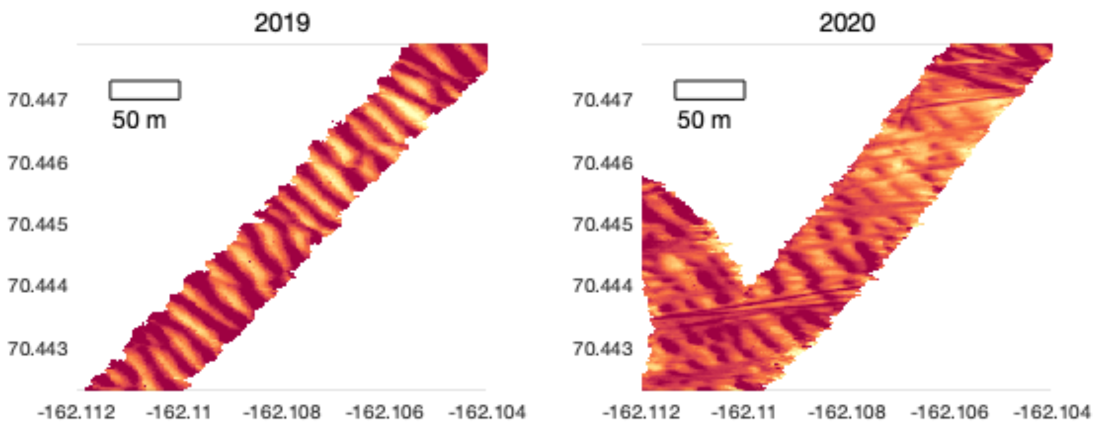

Figure 7. Sand ripples measured near outer Blossom Shoals in 2019 and 2020. (Depth scales are relative for each survey to highlight bedforms). In 2019, nearly symmetrical ripples were observed. In 2020, it appeared the ripples had been reworked by currents and scoured by ice keels.

Additional details about seabed sampling and water-column profiling are given in the later section on 02-03 Oct activities at Icy Cape.

<u>Seaglider recovery and deployments (Beaufort shelfbreak)</u>

After departing Icy Cape, we transited eastward around Point Barrow, maintaining 30 nm and 50 nm distances from the communities of Wainwright and Utqiagvik, respectively. This distance was established to avoid interference with subsistence hunting.

On 24 Sep, one seaglider was recovered (SG196) and two more were deployed (SG233 and SG235) at the Beaufort shelfbreak in the vicinity of 72 N, 152 W. This work was part of the Arctic Mobile Observing System supported by the Office of Naval Research (PIs: Craig Lee and Luc Rainville).

Later that evening, four SVP-B drifters were deployed along the shelfbreak at 152 W, 150 W, 148 W, and 146 W as part of an ongoing program drifter program (PI: Ignatius Rigor).

Flaxman Island (S3)

On 25 Sep, we arrived at offshore of Flaxman Island and recovered the seafloor tripod with Acoustic Doppler Profiler at S3A1. The tripod had the same instrument (Nortek Signature 500) and configuration (burst + average) as the other A1 moorings. It appears that this instrument stopped recording a month early, probably because of an apparent short in the bulkhead connector from the instrument to the battery cannister. The raw data file fails to finish conversion in the vendor software, which likely is related. This is likely to be resolved shoreside; for now, there is a complete record of average values and a partial record of burst results.

The summary figure below shows that the site is covered with sea ice in the winter and then surface waves emerge in June and July. The waves are not very big in the partial record ($H_s < 1$ m), because the open water fetch in June and July is still small. The water temperature near the seafloor has a related seasonal signal. The flow is mostly east-west (i.e., along the coast). The echograms of backscatter amplitude suggest sediment suspension occurs when the waves become active, although there is also an event in December. The ice draft values are typically a few meters, but spike as high as 10 m with the passage of ice keels (and pressure ridges).

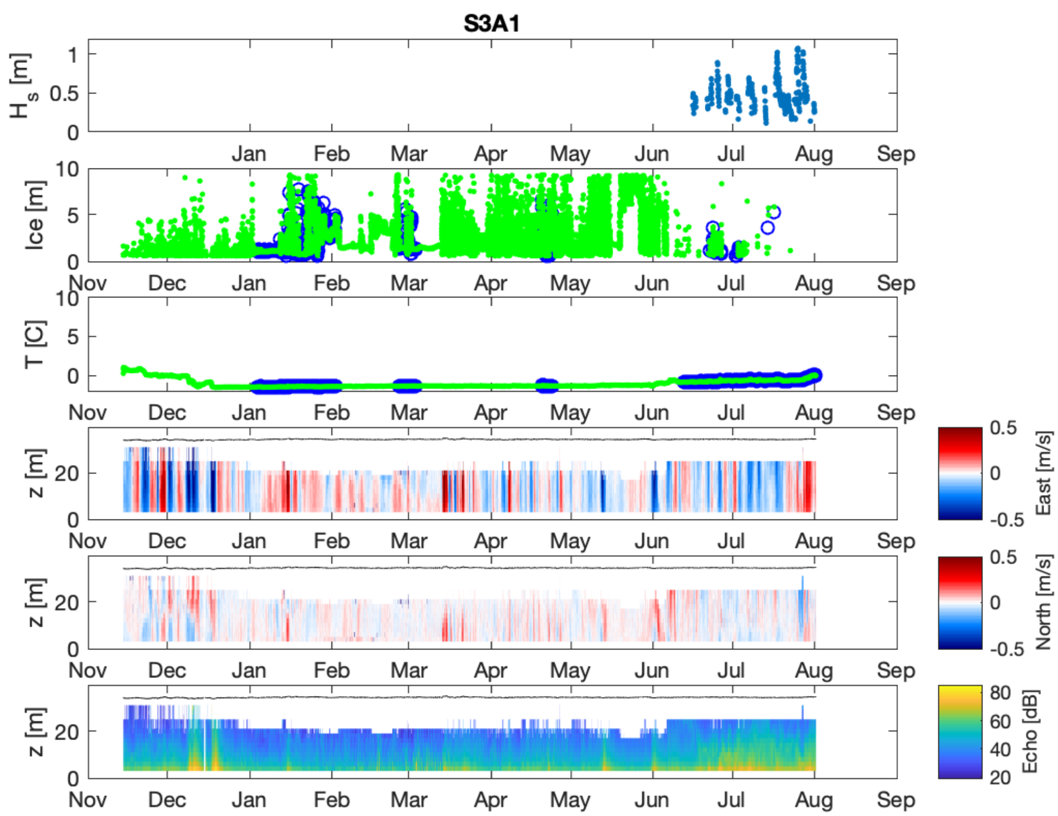

Figure 8. Timeseries from S3A1 (12 nm offshore in 34 m depth). Many burst results (waves and ice [blue points in upper panels]) are missing because of problems with binary files (work in progress). Current profiles have been screened for low Doppler correlations and ice occlusion.

The rest of 25 Sep was spent attempting recoveries of seafloor pressure recorders at S3P3, S3P2, and S3P1. The acoustic release at S3P1 is the only one that communicated, but the battery level was too low to release. A few attempts to drag with the workboat were unsuccessful, but the first attempt dragging with the ship the next morning (26 Sep) recovered the mooring quickly. Attempts to drag for S3P2 and S3P3 were unsuccessful.

The wave results from S3P1 (inshore) are compared with S3A1 (offshore) in the figure below, and again there is a notable lack of waves inshore during the early summer (June-July). Shorefast ice is the presumed cause, and this is evident in the ice analysis from USNIC. There are a few waves events in the winter, which have been verified as real events by examining the spectra. This includes a December event coincident with elevated backscatter at S3A1.

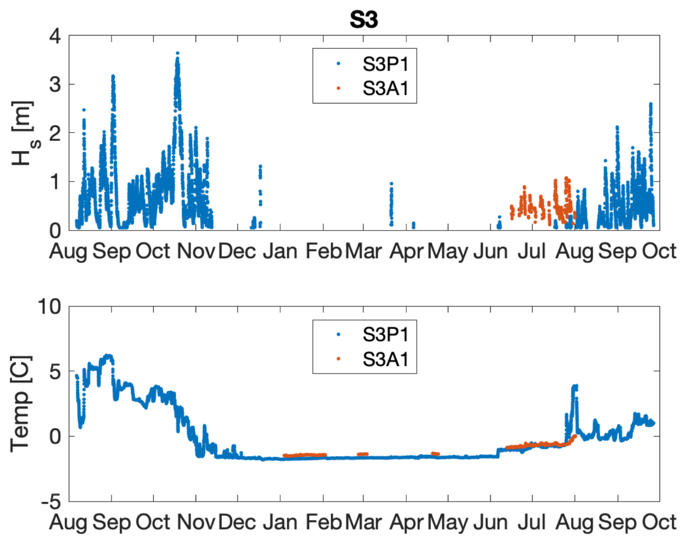

Figure 9. Surface wave heights and bottom water temperatures at S3A1 (offshore) and S3P1 (inshore).

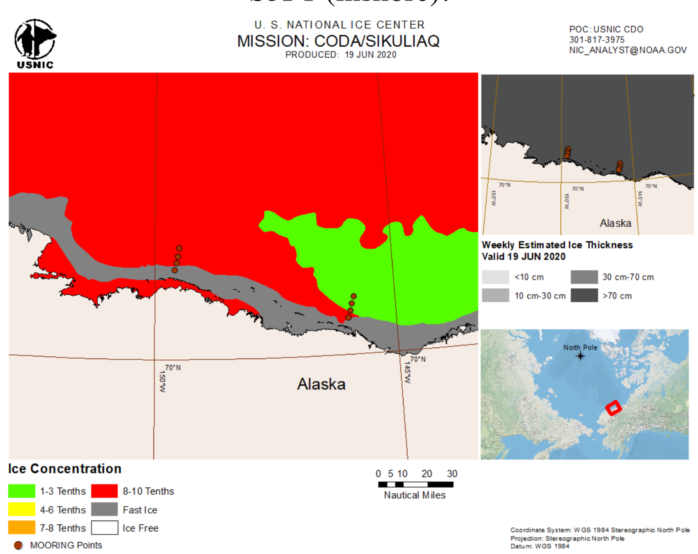

Figure 10. USNIC ice analysis for S3 (and S2) in mid-June 2020.

While at Flaxman Island we also conducted multibeam bathymetry surveys, and collected grab samples and water-column profiles at stations spanning the nearshore zone to outer shelf (Figure 11). On 26 Sep, we used the workboat to sample inshore stations using the mini van veen, LISST, and CTD/Tu. The depth sounder was not working (yet– while at the Flaxman site we worked to construct a data feed from the onboard Furuno depth sounder to a self-contained data logger using a custom serial cable and vessel power). In the cross-shore transects, a slightly fresher surface layer was observed seaward of 25 km. A warm, turbid (up to 20 NTU) surface layer was observed inshore of 15 km. Cold (~0ºC), saline (~32), low-turbidity water was observed below ~20 m depth offshore.

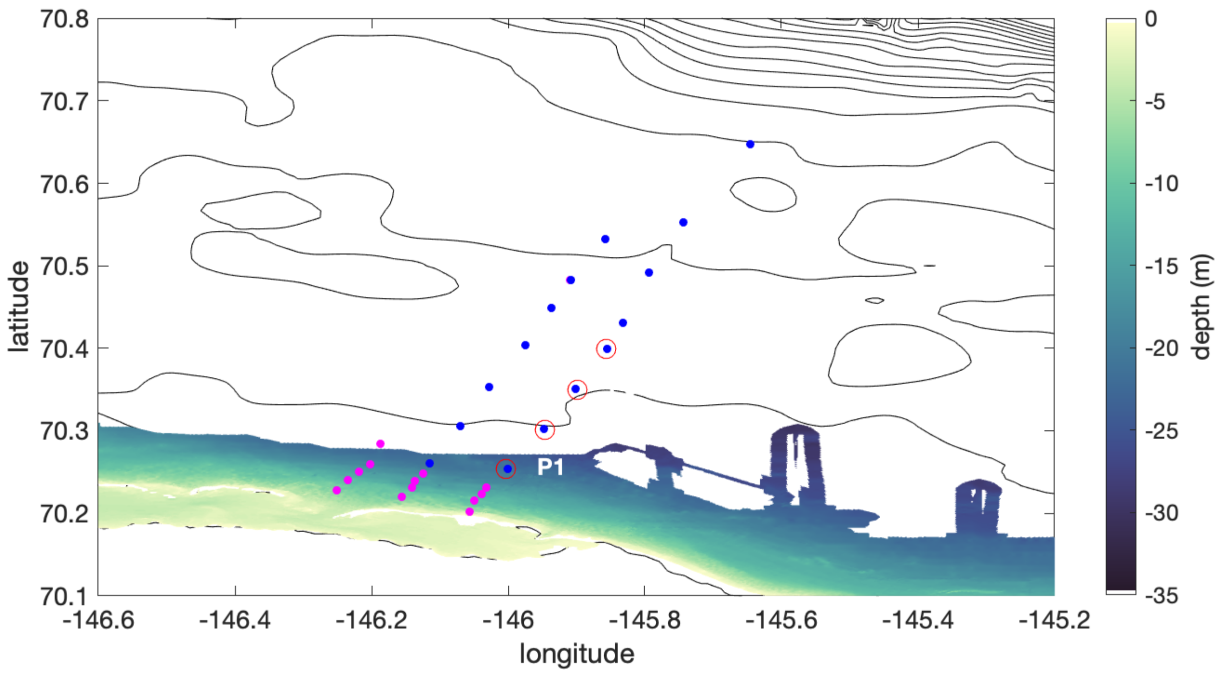

Figure 11. Map of grab sample/water profile sites (blue, SKQ; magenta, workboat) and mooring locations (red circles) superimposed on ca. 1950s NOAA bathymetry gridded by Steve Roberts. Multibeam data were collected in conjunction with SKQ sites, and fathometer data were collected in conjunction with workboat sites.

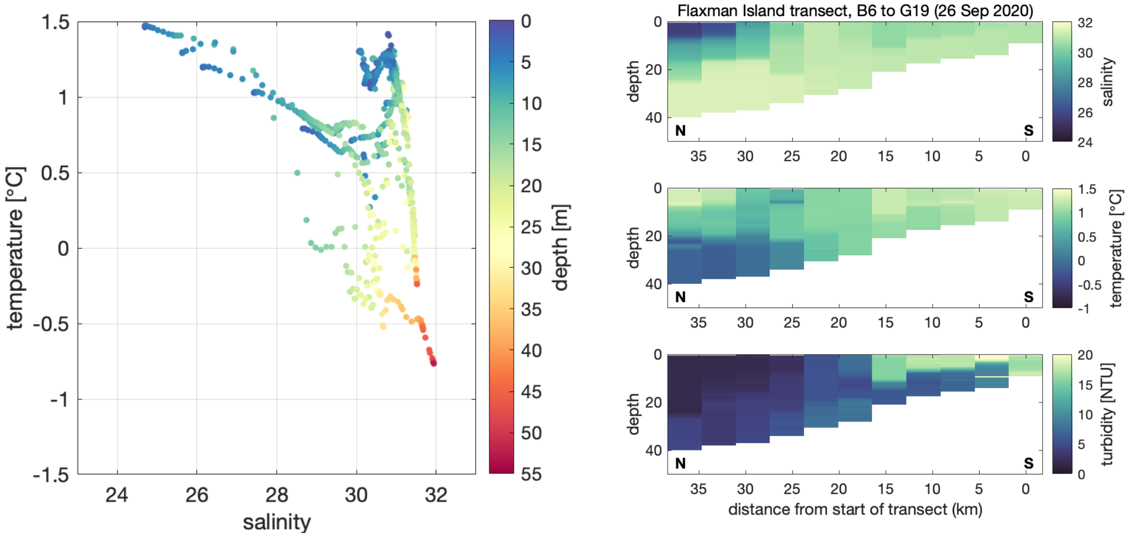

Figure 12. CTD and turbidity data from Flaxman Island transects. (Left) T-S diagram of all stations, highlighting warmer water at the surface and colder water at depth. (Right) Profiles of salinity, temperature, and turbidity from the easternmost transect.

Sediments recovered from Flaxman Island transects were dominantly disturbed mud with a sort of "crumbly" texture. In some cases this mud was highly compact like potter's clay, and in other cases was softer and appeared to include watery, lighter-colored mud. We interpret this to be mid-shelf mud that has been scoured by ice – in the case of the very compact samples, ice scour was likely recent, while the remaining softer samples have likely been re-worked by waves and may have also received new suspension deposition. Near shore, sediments were a complex mixture of fine to coarse sand with intermittent gravel, some evidence of soft, unconsolidated recently deposited mud, and mud clasts indicative of erosion.

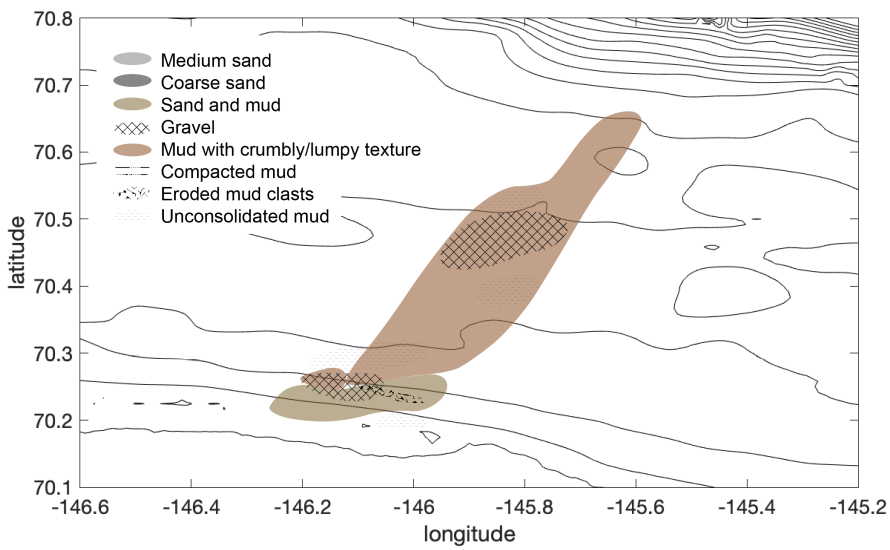

Figure 13. Qualitative summary of sediment types and textures recovered from grab samples near Flaxman Island (S3).

The seabed observed in multibeam data was highly disturbed by keel scours on the order of 1 m deep (Figure 14), though comparison of data from 2019 and 2020 suggested that most of these scours were inactive between the two surveys

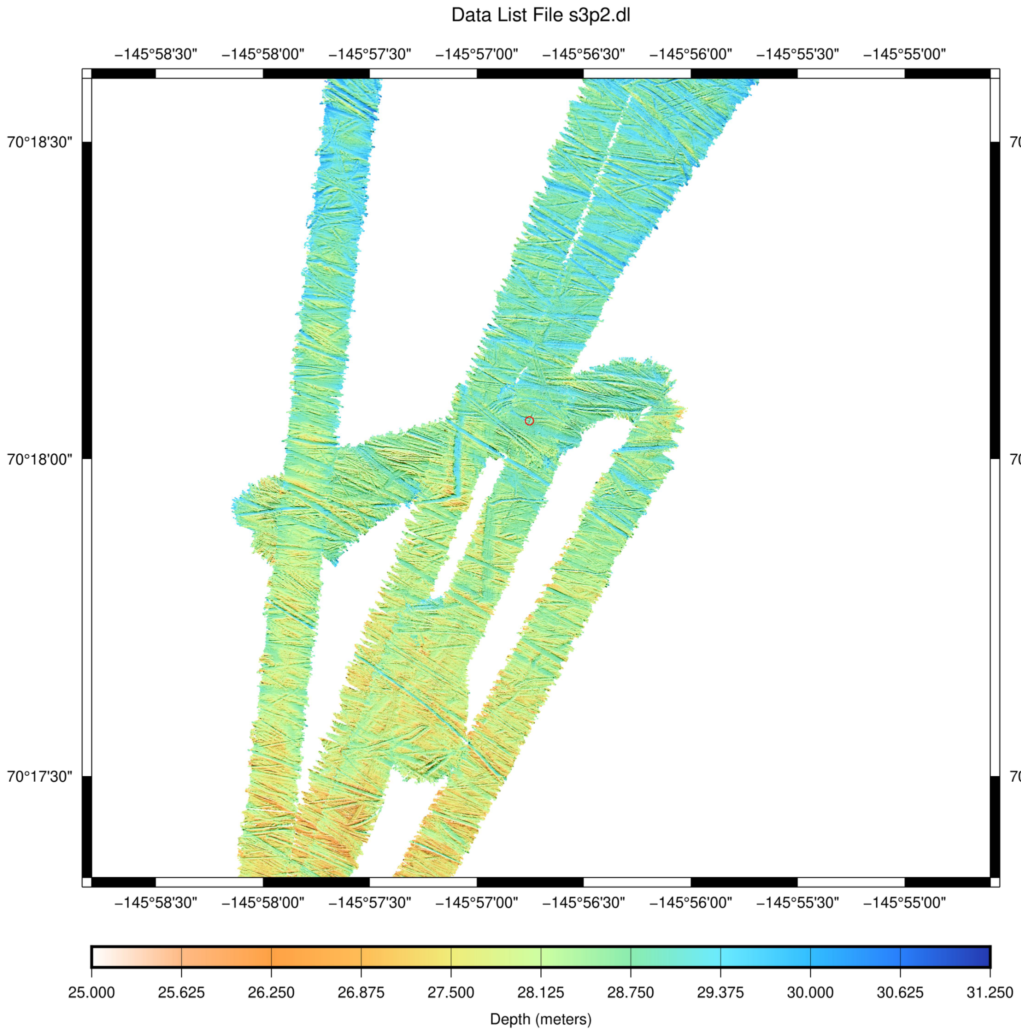

Figure 14. Multibeam image of the seafloor at the S3-P2 mooring site (red circle in center). Large ice keel scours are evident, though little change was observed between 2019 and 2020 images of the same seabed patches.

Jones Islands (S2)

We arrived S2A1 offshore of the Jones Islands on 27 Sep. The acoustic release did not communicate, however a hand-held dive ranger received positions from a Benthos UAT pinger (separate system) on the tripod, and we were able to locate the tripod in a 20-minute SCUBA dive. The underwater visibility was nil, and locating the tripod without the acoustic ranger would have been near impossible. It was a cold dive (~1 C).

The data from S2A1 are shown below, with a familiar pattern of ice drafts in the winter and wave heights in the summer. The sporadic wave results in winter have been verified by examining the spectra; these are real wave events. The ice drafts are clipped around 5 m, which is related to the instrument configuration. The flow is predominantly east-west, as at S3A1, and the echograms suggest elevated suspended sediments beneath the autumn waves.

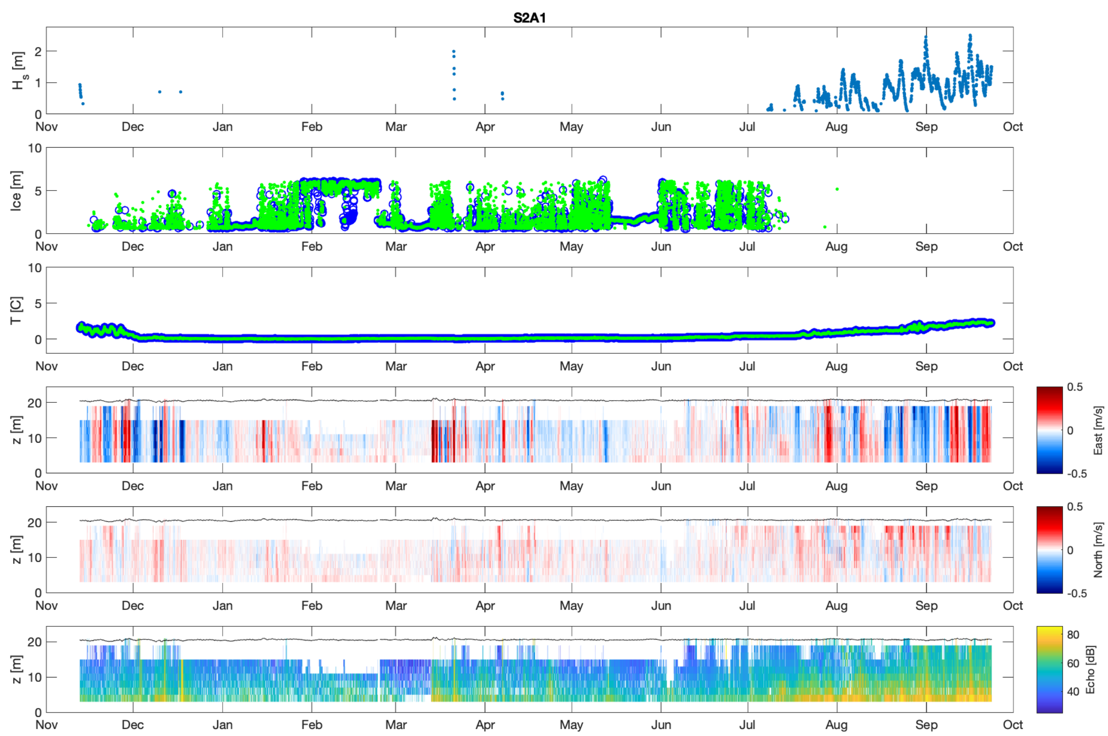

Figure 15. Timeseries from S2A1 (12 nm offshore in 22 m depth).

Later in the day on 27 Sep, our attempts to communicate with the releases at pressure recorders S2P3 and S2P2 were unsuccessful, but the S2P1 communicated and released. It was late in the day, and the float was left at the surface until recovery in the mooring on 28 Sep. The middle moorings were not recovered, despite dragging efforts on 28 Sep. Comparing the data from S2P1 (inshore) and S2A1 (offshore) shows the similar pattern of wave activity offshore preceding wave activity inshore by several weeks during the seasonal ice retreat. The USNIC ice products again make it clear that open water forms first on the shelf and in the basin, followed later by the melting of shorefast ice.

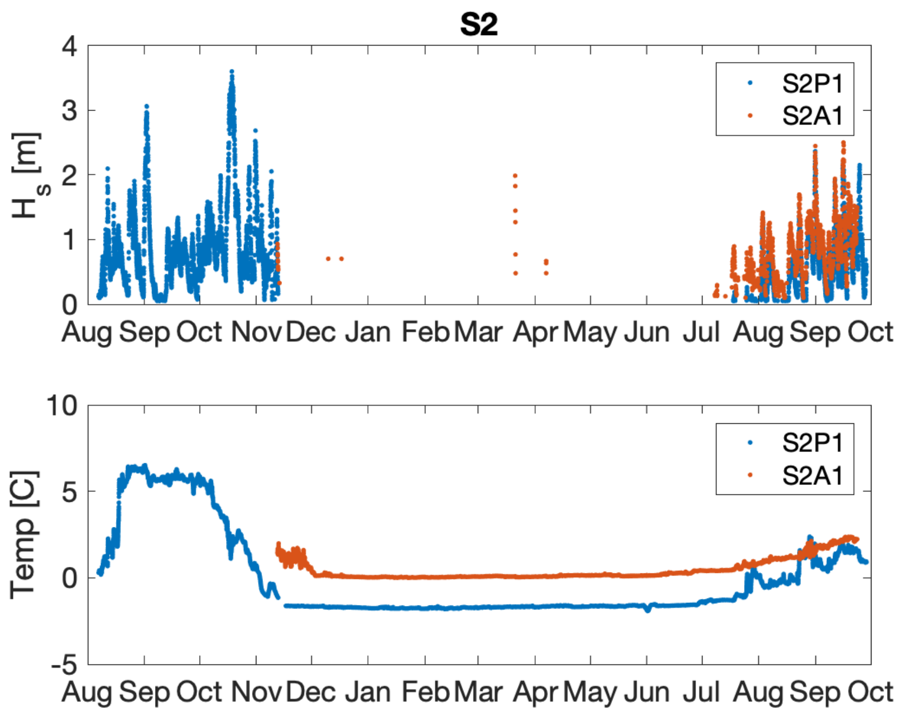

Figure 16. Surface wave heights and bottom water temperatures at S2A1 (offshore) and S2P1 (inshore).

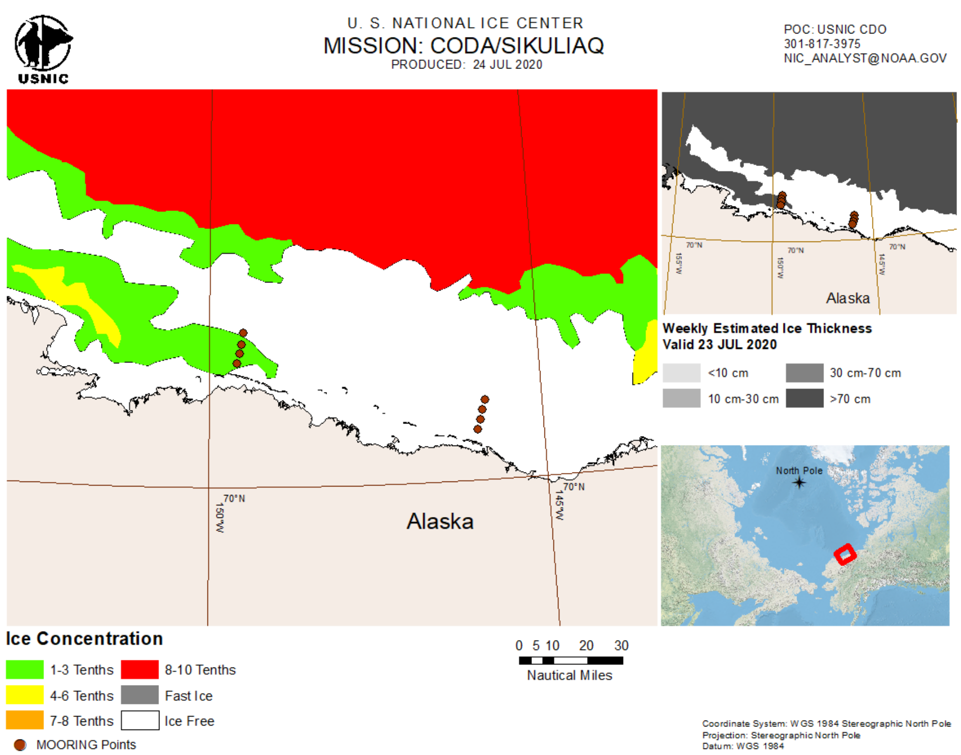

Figure 17. Ice conditions at S2 (and S3) moorings in late July 2020.

While at Jones Islands we also conducted multibeam bathymetry surveys and sampled water-column profiles using a CTD/OBS and LISST. On 28 Sep, we began using the workboat to sample inshore stations. The workboat depth sounder was recorded to map inshore bathymetry. We sampled two survey lines nearshore/offshore, and an additional survey line nearshore farther west near an inlet between barrier islands (Fig. 18). Seabed results are summarized together with Harrison Bay results in the next section. The water column in the Jones Islands transects was stably salt-stratified with salinities of ~32 near the bed and ~27 near the surface. A slightly cold, freshened turbid layer was observed at ~0-7 m water depth inshore of 30 km, and likely represented water flushed from the lagoons based on the depth of the water mass and the turbidity.

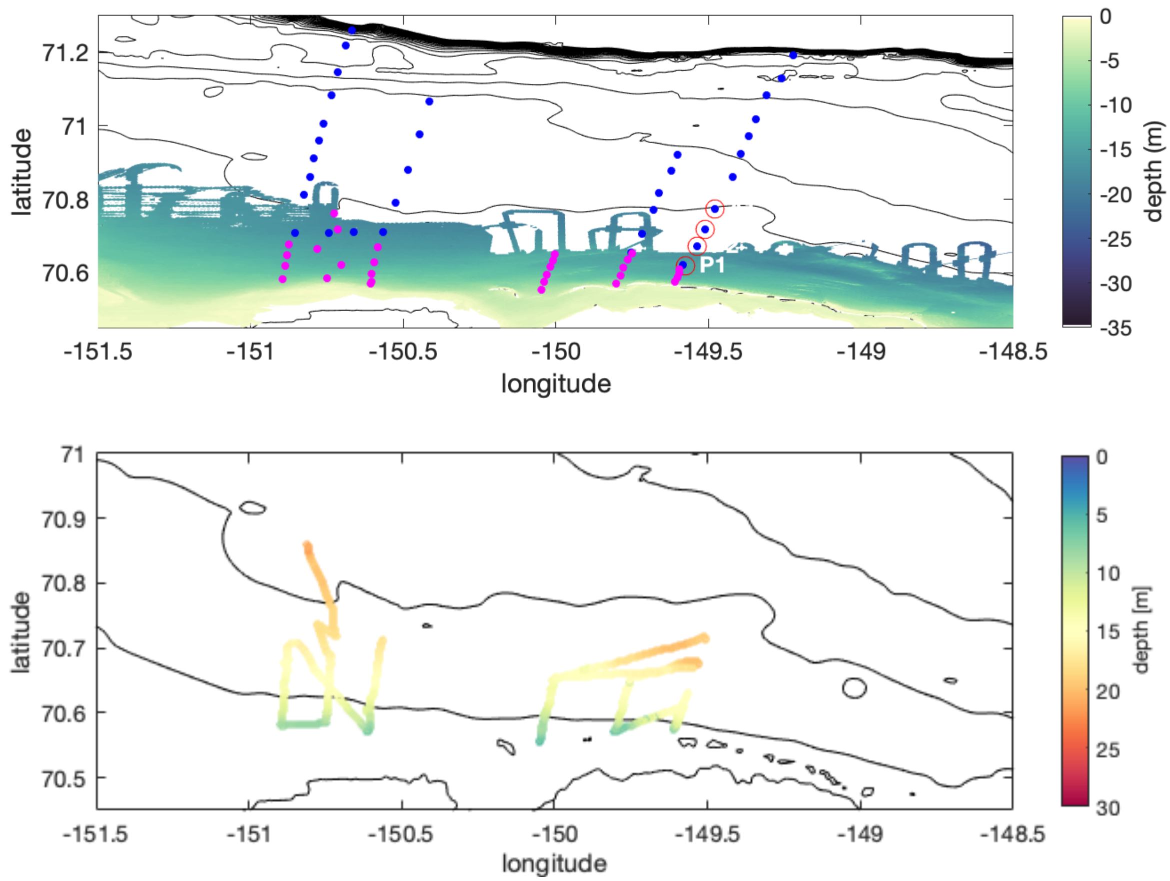

Figure 18. (Top) Map of Jones Island and Harrison Bay sampling sites (blue, SKQ; magenta, workboat) and moorings (red circles). (Bottom) Map of workboat bathymetry survey.

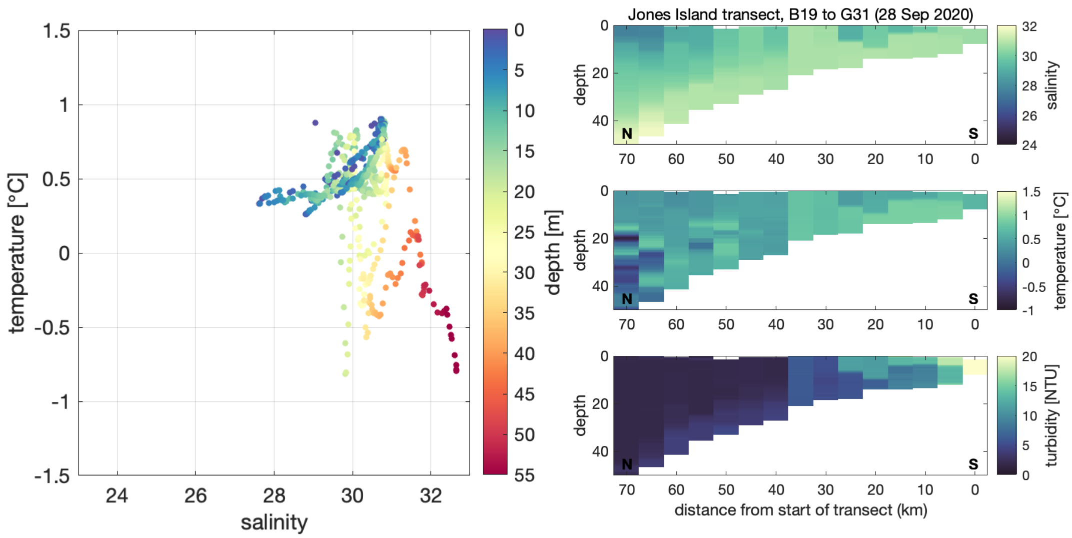

Figure 19. CTD and turbidity data from Jones Island transects. (Left) T-S diagram of all stations, highlighting warmer water at the surface and colder, more saline water at depth. (Right) Profiles of salinity, temperature, and turbidity from the easternmost transect.

Harrison Bay

On 29 Sep, we shifted slightly west of S2 and conducted ship and workboat surveys of Harrison Bay, seaward and slightly westward of the Colville Delta. We collected seabed grab samples and water-column profiles from the ship and workboat along two primary lines, as well as some scattered nearshore stations (Figures 18). Temperatures and salinities were generally similar to those observed near Jones Islands, and a similar near shore (within 20 km) turbid, fresh surface layer was observed.

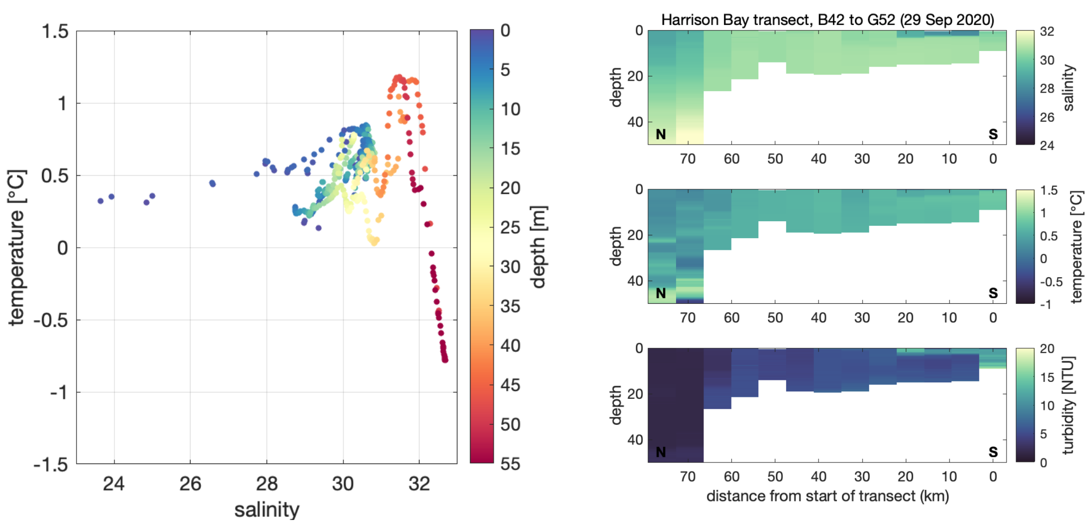

Figure 20. CTD data from Harrison Bay. (Left) Temperature vs. salinity for all Harrison Bay sites, highlighting more saline water at depth. (Right) Cross-shelf profile highlighting a thin (~5 m) freshened turbid surface layer inshore of 20 km.

Sediments recovered from Harrison Bay were largely re-worked muds, with textures ranging from highly compacted to crumbly. Sediments within the 20 m isobath were generally sandy, with some evidence of eroded muds. In the mid-shelf region, a shoal was encountered (depths of ~12-20 m) characterized by sorted medium sands, with evidence of eroded muds on the landward side. Anoxic muds were recovered at two stations: one in shallow water near shore, and one on the seaward side of the mid-shelf shoal. One station was located beyond the shelf break in >100 m of water; sediments were generally mud with a "crumbly" texture, though some soft and light-colored muds were present, possibly indicating recent delivery.

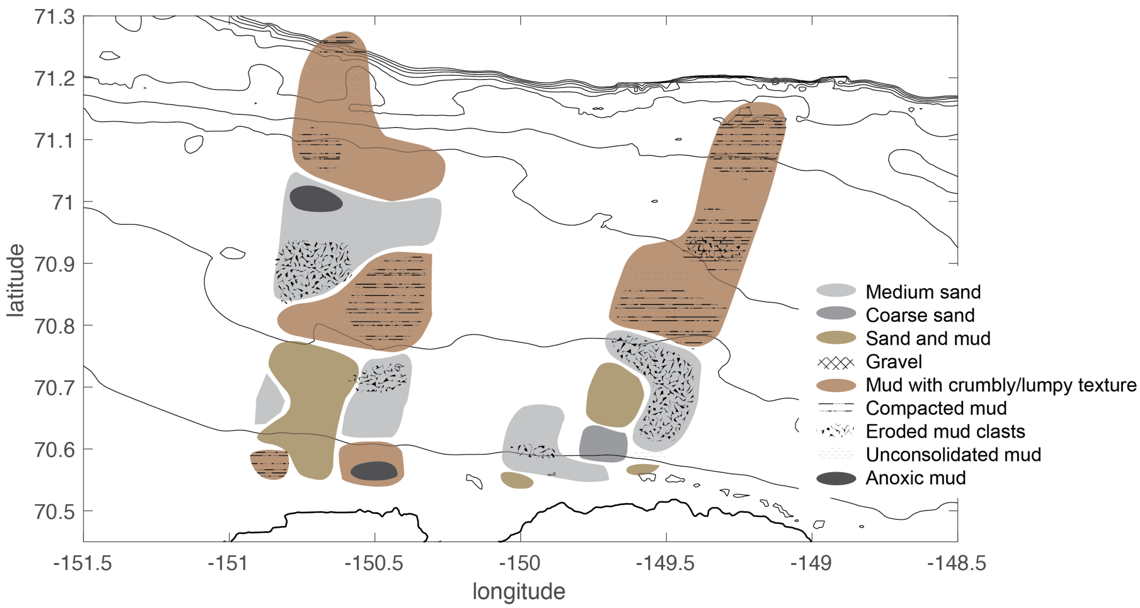

Figure 21. Qualitative summary of sediment types and textures recovered from grab samples near Jones Island and in Harrison Bay.

Offshore remnant ice

On 30 Sep, we paused our return transit around Point Barrow and sampled a marginal ice zone formed by remnant ice that had persisted in the southern Beaufort for the entire summer. Four drifting SWIFT buoys were deployed from open water to ~ 6 km within the ice. The figure below shows a Sentinel-1 satellite radar image of the ice, along with SWIFT positions and shipboard salinity measurements. The surface waters with the remnant ice were cold and fresh, while the surface waters outside of the ice were relatively warmer and higher salinity.

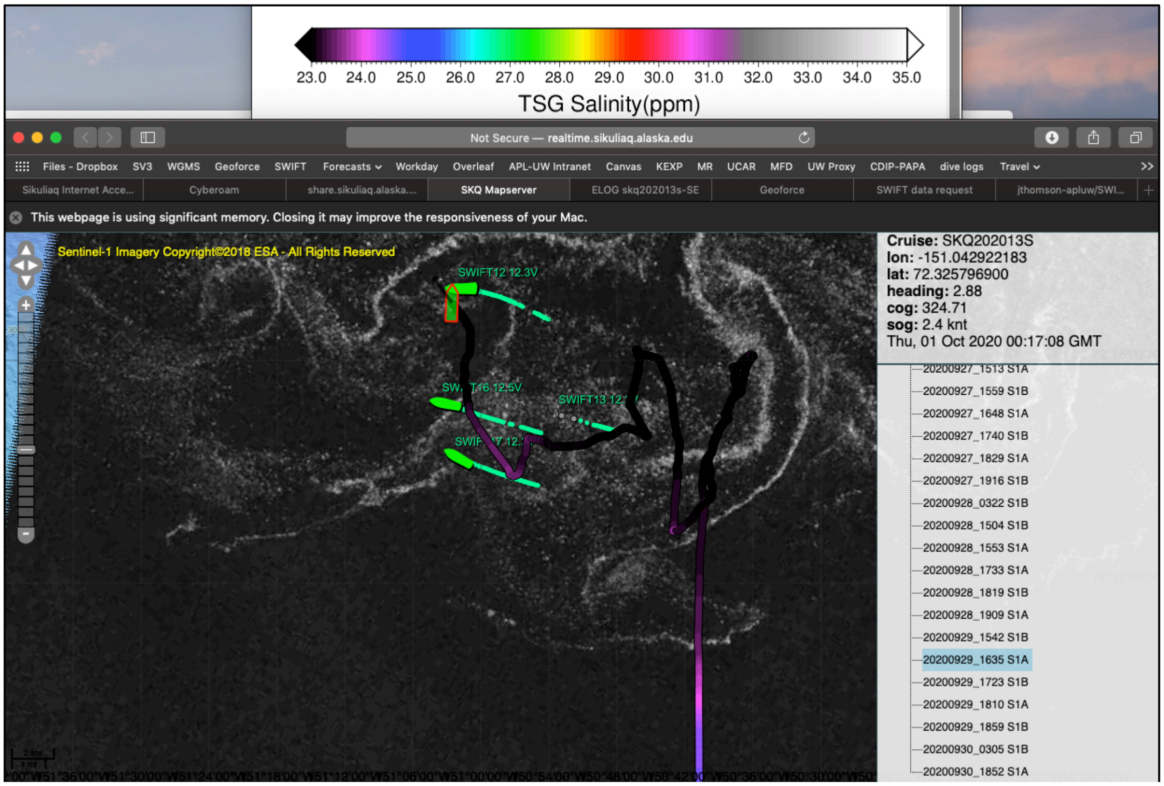

Figure 22. Screen capture from ship's map server. Sentinel-1 satellite radar image of the ice, along with SWIFT positions and shipboard salinity measurements.

CTD casts were collected in a series of four laps through the SWIFT array, and aerial drone videos of the ice were recorded over some of the buoys. Screen captures from the ship's ice radar show the evolution of the ice and the relative position to the ice edge. The CTD profiles show changes in the sub-surface heat content, which are related to the surface signature of cold and fresh water maintained in the marginal ice zone. Outside of the ice and near the edge, at SWIFTs 16 and 17, there is a strong temperature maximum between 10 and 20 m; this is expected from the solar heating accumulated throughout the summer, followed by surface cooling in the early fall. Farther within the ice, at SWIFTs 13 and 12, this signal is muted and shallower; this is because the higher albedo of partial ice cover prevented the accumulation of solar heating during the summer.

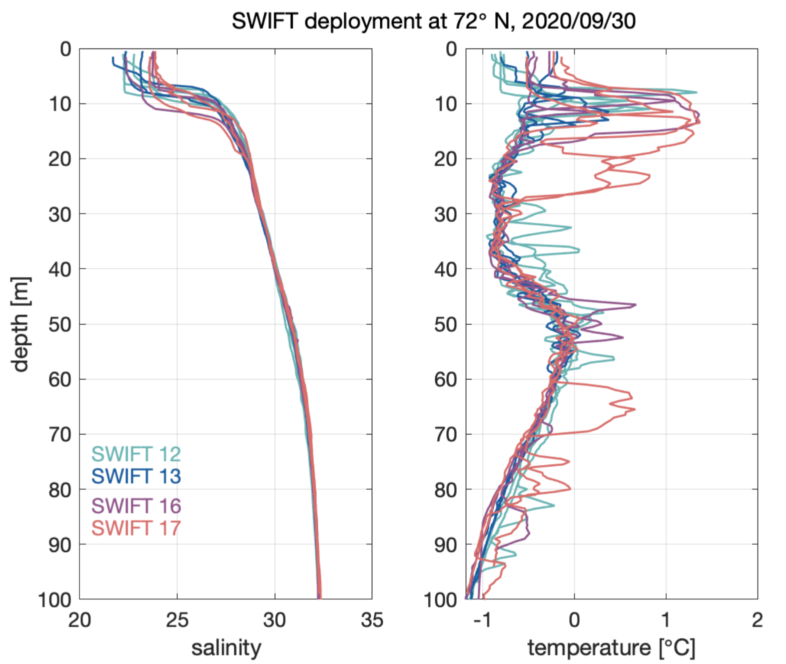

Figure 23. Profiles of salinity and temperature from CTD casts near each SWIFT throughout the one-day deployment.

Time series show that wave heights increased with increasing winds throughout the deployment, especially in open water at SWIFT 17. Initially, only minimal waves were detected far within the ice at SWIFT 12, but there was a noticeable SE swell within the ice by the end of the deployment. This swell was related to the same increasing winds, though there is an important distinction between the regional fetch of open water to the southeast of the remnant ice, relative to the suppression of local wave generation by easterly winds within the ice.

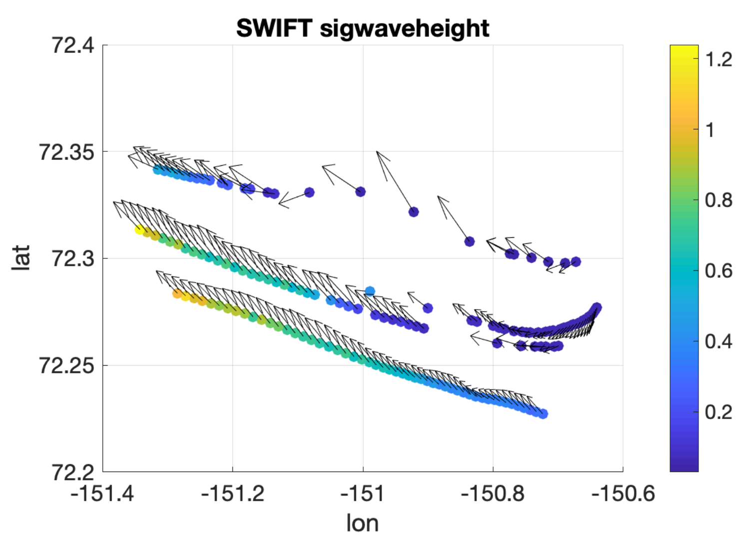

Figure 24. Wave heights recorded during one-day drifted of SWIFT buoys across this marginal ice zone.

Analysis of ocean heat fluxes derived from ship-based measurements reveals loss of heat at the ocean surface through the night (~-80 W/m^2), mainly driven by the negative air temperature. During the day, the incoming shortwave radiation was sufficiently high to reverse the sign of the net surface heat flux for about six hours up to ~150 W/m^2. This is considered representative of the shoulder season in this region and was corroborated by visual observations of frozen melt ponds on the ice floes in the morning, and evidence of melting in the afternoon.

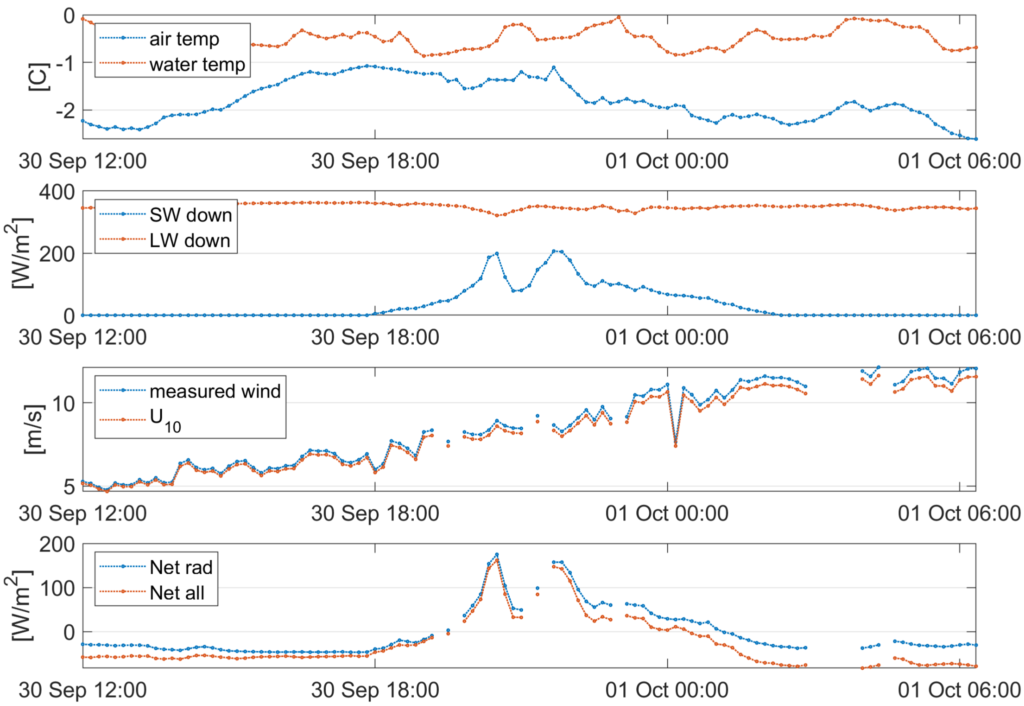

Figure 25. Time series of ship-based observables measured during SWIFT deployments at the ice edge, and associated heat fluxes.

Icy Cape (S1) revisit

On 2 and 3 Oct we revisited Icy Cape as part of our return transit. We sampled at more than 30 shallow stations with the workboat (Figure 26), while dragging for the middle moorings (again not recovered) and conducting additional shelf stations with the ship.

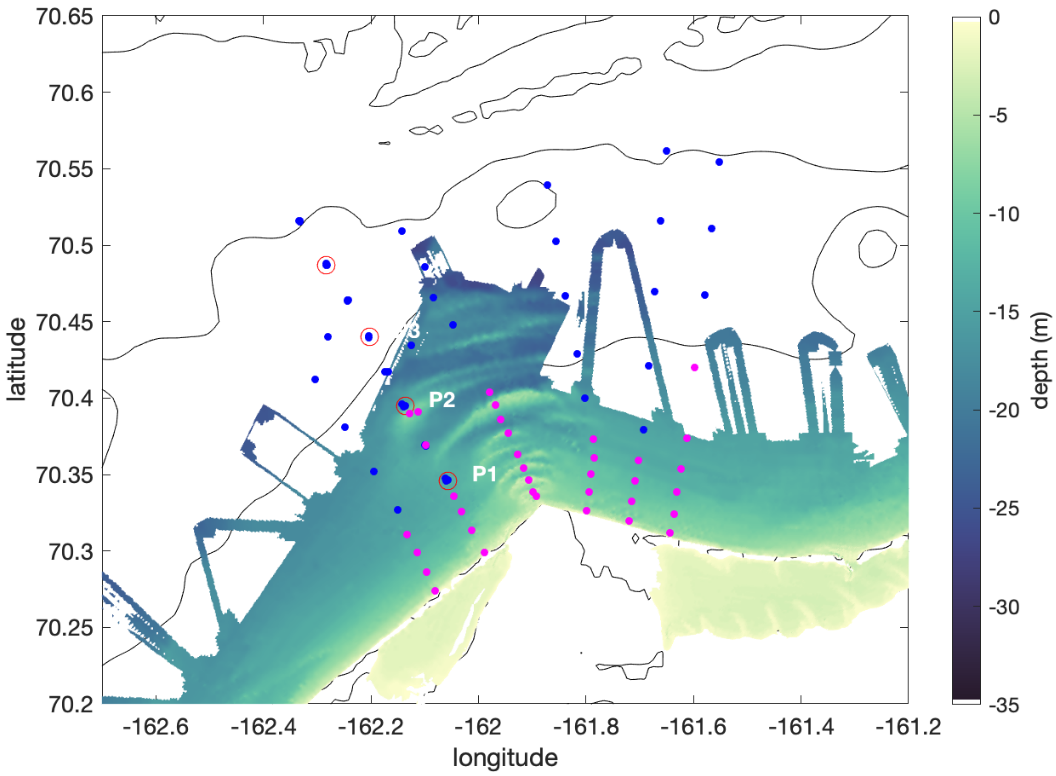

Figure 26. Map of grab sample/water profile sites (blue, SKQ; magenta, workboat) superimposed on ca. 1950s NOAA bathymetry gridded by Steve Roberts. Multibeam data were collected in conjunction with SKQ sites, and fathometer data were collected in conjunction with workboat sites.

The workboat fathometer was used to map the profile of the crests of Blossom Shoals, a cape-associated shoal system formed by convergent sediment transport off Icy Cape. The shoal wavelength is on the order of 1 km, and shoal heights are up to 15 m. These data will be compared to data gridded from older datasets to determine if migration has occurred over the past 50-70 years.

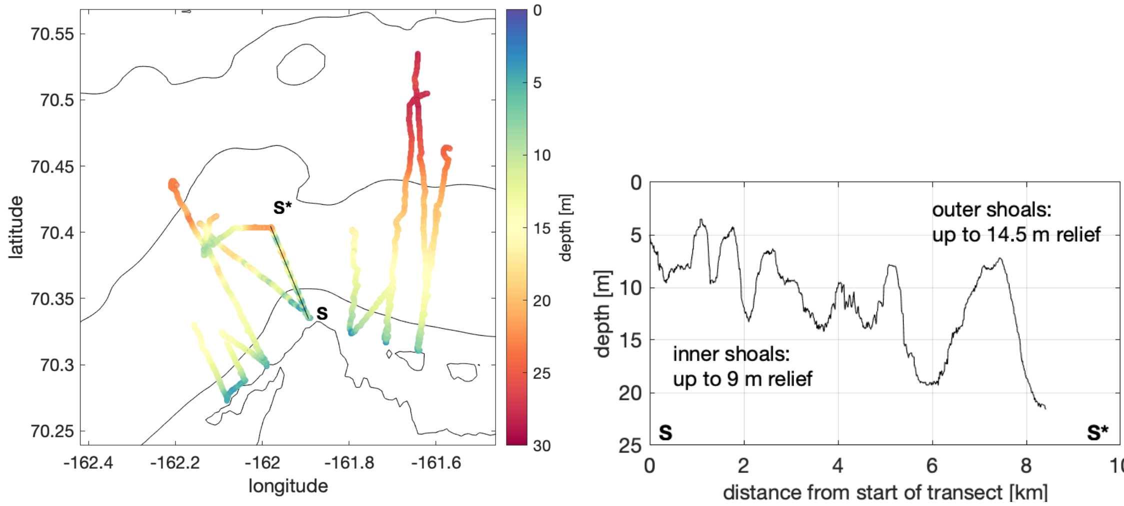

Figure 27. Small-boat bathymetry collected at Icy Cape, 2-3 Oct. (Left) Map view. (Right) Profile view of section S-S*, highlighting shoals of up to 9 m relief near shore and up to 14.5 m relief off shore.

Sediments recovered at Icy Cape were dominantly well-sorted medium sands, with patchy fine sands, coarse sands, gravels, and muds. Coarser sediments and muds most commonly occurred northeast of the cape (Figure 28). Some gravels appeared to be associated with troughs between shoals.

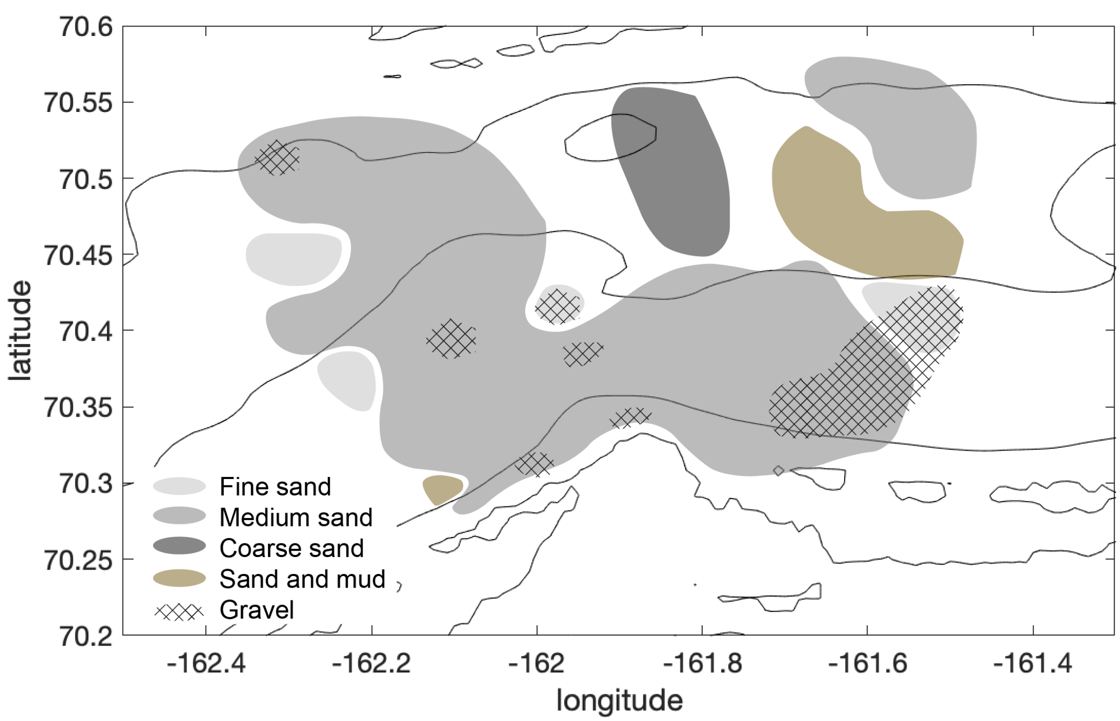

Figure 28. Qualitative summary of sediment types and textures recovered from grab samples near Icy Cape.

In contrast to the first visit in September, water masses at Icy Cape in October were generally more saline and colder (~32-33 and 0.5 to -0.5 ºC; Figure 29). The water column was generally more well-mixed vertically, with a weak gradient toward more saline, warmer, and more turbid water near shore (Figure 30).

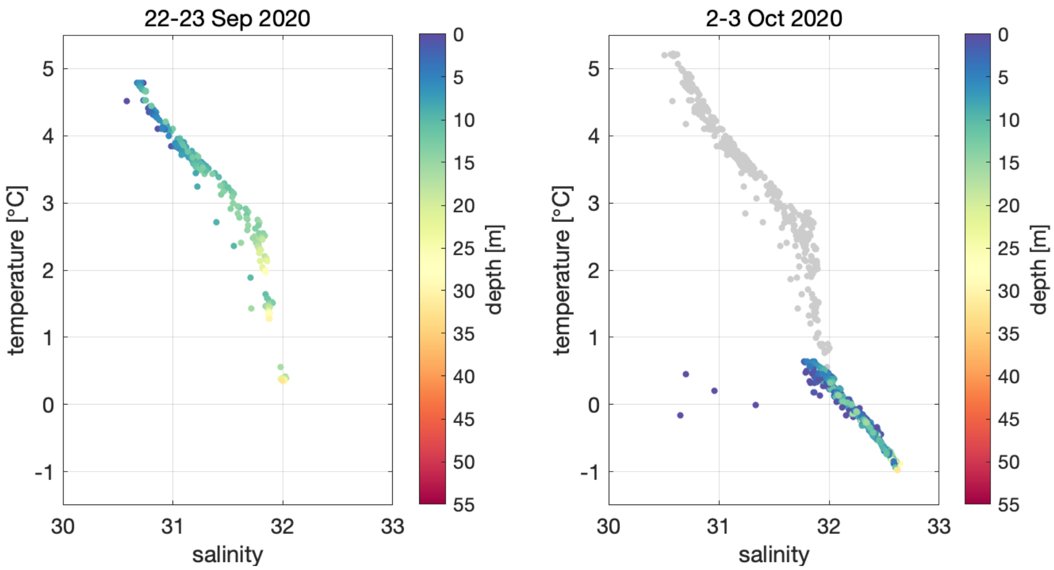

Figure 29. Temperatures and salinities for all stations sampled at Icy Cape. (Left) 22-23 Sep sites, highlighting warm water (~1-5ºC). (Right) 2-3 Oct sites (with 22-23 Sep sites shown in gray), highlighting colder, more saline water than was observed in Sep.

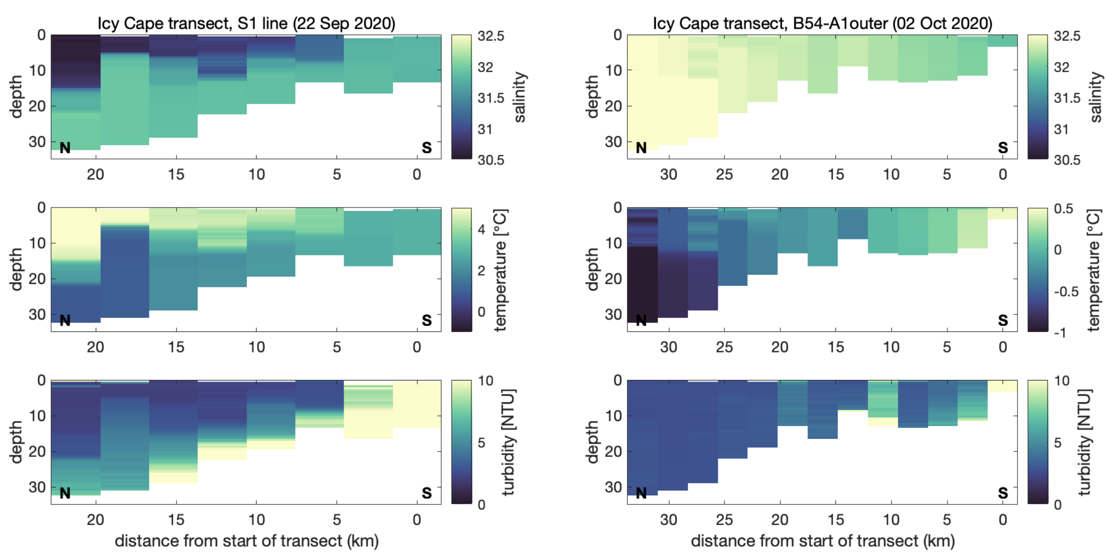

Figure 30. Contrasting profiles of salinity, temperature, and turbidity along the Icy Cape S1 mooring transect for 22 Sep and 02 Oct. In 10 days, the water column transitioned from a stratified state (likely reflecting the intrusion of Bering Strait water at depth coinciding with a relaxation of winds) to a mixed state. Nearshore and near-bed waters were more turbid on 22 Sep, likely as a result of greater wave resuspension.

Underway data

The ship's underway data was collected continuously throughout the cruise. Figures below show a time series of selected underway measurements during the operational portion of the cruise (Icy Cape to Icy Cape).

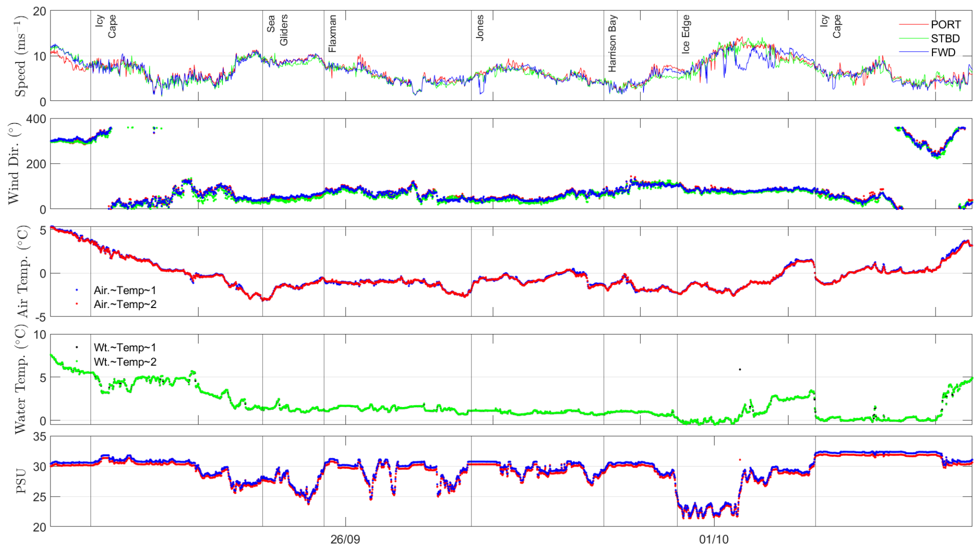

Figure 31. Underway measurements of wind speed, wind direction, air temperature, water temperature, and salinity.

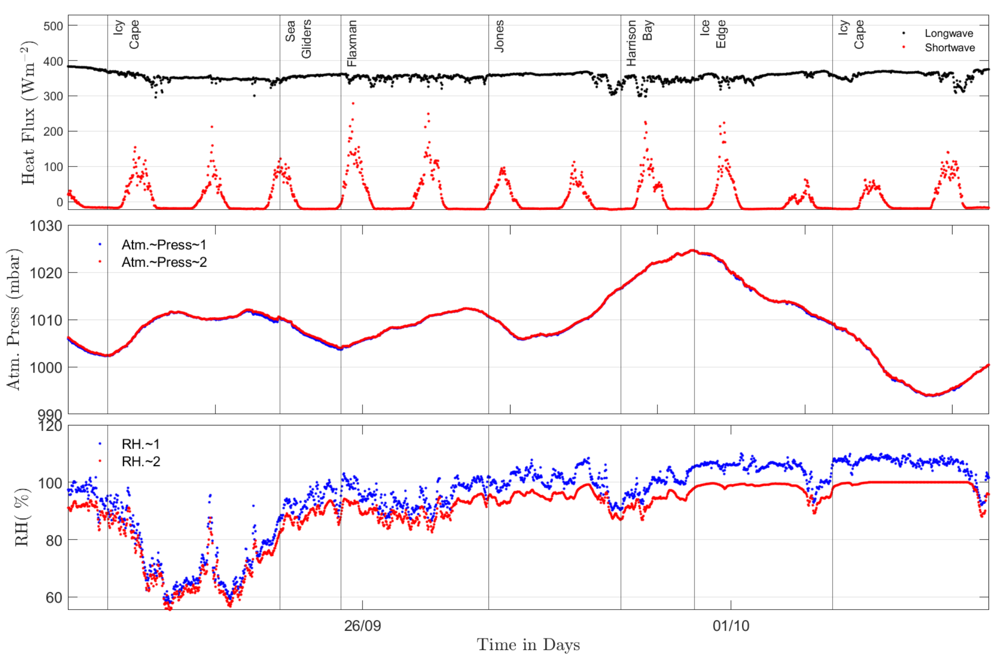

Figure 32. Underway measurements of downwelling longwave and shortwave radiation, barometric pressure, and relative humidity.

Summary of operations
Science operations were largely successful. Of primary note, we were lucky to have successful recoveries of inshore-offshore mooring pairs at each site. This provides observations of the contrasting wave and temperature conditions caused by persistent shorefast ice during the seasonal transitions, which we hypothesize are essential to coastal protection in the Arctic. Although several moorings were not recovered, we did recover the data needed to address the central goals of the CODA project.

Consensus on the moorings is that the middle P2 and P3 moorings were carried off-site by sea ice because they had much taller thermistor chains (up to 10 m) than the A1 and P1 moorings (only 1 m). Essentially, the short seafloor moorings stayed in place, while the taller mornings were drug away. The very short ranges (< 100 m) on acoustic communications in shallow water made it impossible to find moorings if they were moved by ice.

The table below summarizes the science operations, which included many seabed and water column samples-of-opportunity while conducting the mooring operations. This bridges the CODA project with Emily Eidam's coastal sediments project.

Equipment and/or activity	**Total number**
Wave glider deployment	2
Glider deployment	2
Glider recovery	2
Mooring recovery	6
Rescue boat ops for science	3
SCUBA dives	2
Work boat ops	14 (9 for shallow station sampling)
Landing craft ops	2
Shipek grab samples (SKQ)	95 (with replicates at each)*
Van veen grab samples (workboat)	79
CTD profiles (SKQ)	96 (with replicates at each)
CTD profiles (workboat)	79
Multibeam profiles (SKQ)	>480 nm (with sound profiles)
Fathometer profiles (workboat)	>190 nm
Grapnel drags	15
SVP-B drifter buoy deployments	4
XBT profiles	1
SWIFT deployments	4
SWIFT recoveries	4
Ice days	1

*19 subsamples saved for Virginia Tech geotech analysis

One final operational note is the failure of the cooling fan for the ship's bow thruster on 26 Sep (while at S3). The bow thruster was inoperable for the rest of the cruise, and maneuvering for mooring recoveries became more cumbersome.

Summary of science

The mooring pairs from each site show a consistent contrast during seasonal transitions, in which inshore locations have colder water temperatures and smaller waves, relative to offshore locations. The implication is that shorefast ice is a key factor in coastal exposure; it can persist for months after the rest of the region has opened up and wave activity has become significant. Waves hardly seem to penetrate the shorefast ice; wave attenuation rates may be much larger than those determined for pack ice.

Comparisons of our new data with global climate models, such as ERA5, are favorable. However, such models are unable to resolve shorefast ice, and thus generally agree with the offshore A1 measurements more than the inshore P1 measurements.

Science questions to be addressed with the mooring data include:

- What are the attenuation rates of surface waves propagating through shorefast ice?
- Do waves incident from offshore help breakup shorefast ice, or this the process driven solely by temperature (and solar radiation)?
- When, where, and why is sediment in suspension along the Arctic coast?
- What is the significance of the large changes in water level at the coasts (up to 1 m at all sites)? The changes seem muted during the winter; is this related to ice cover and damping of wind-driven circulation? Can water level drops strand the shorefast ice up on the foreshore?
- What is the significance of sporadic wave events in winter/spring (e.g., 4 Jan 2020 at S1 or 10 Dec 2019, 17 Dec 2019, 21 Mar 2020, and 7 Apr 2020 at S2 and S3)?
- How well can the ice capabilities in the regional SWAN wave model (developed in the first phase of the project) represent the effects of shorefast ice?
- Can wave and temperature climatologies built from global models be adapted to include the effects of unresolved shorefast ice?
- Can the wave and temperature climatologies be related to long-term coastal erosion via simple models, such as shoreline equilibrium?

Outreach

Outreach during this research cruise included a collaboration with the STEMSEAS program to include a group of students as virtual participants. The students engaged with the science party throughout the cruise using the Slack platform to chat and share images, along with three live events using Zoom.

Public outreach also occurred at www.iceinmotion.com and on social media via collaboration with the freelance team at OnPoint outreach.

Outreach to local communities along the North Slope of Alaska occurred via collaboration with UIC Science, including a traveling science fair in 2019. A similar trip for 2020 was cancelled because of the COVID pandemic. The 2020 cruise was presented to the AEWC (Alaska Eskimo Whaling Commission) ahead of the cruise, and daily updates to an AWEC email list were used to avoid interference with subsistence hunting.

Acknowledgements

We thank the UAF marine technicians for their expertise and comprehensive help in science operations. We thank the captain and crew of R/V Sikuliaq for their professionalism and commitment to get the science done. We thank the staff at the Seward Marine Center for logistical support during quarantine and all other logistics.

We thank the US National Ice Center for special support products throughout the project, included weekly ice charts over the mooring sites that will be essential to data interpretation in the upcoming analysis phase.

We thank Becca and John Guillote for their incredible outreach efforts.

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We thank our friend and colleague, Nirni Kumar, for the inception of this project and the many contributions that have made this work successful. We miss him dearly.