Sikuliaq debrief Kerry Key SIO 858 822-2975
Cruise dates 7/9/15-7/15/2015 Dutch Harbor-Dutch Harbor AK
Debrief date 11/25/2015 by C. Reimers

Cruise Objectives: Amphibious electromagnetics survey of an offshore volcano. 54 EM sensors placed from island shore to 6 km ocean depth during a previous cruise on Thompson, followed by island field work and then equipment recoveries on this cruise. Work was 24 h/day with two 12 h shifts; 10-15 people per cruise.

Feedback:

1. Size: Ship size was perfect for the science objectives. Length great. They needed a lot of deck space. Staterooms were great, "better quality than most ships". ADA stateroom and head layout seemed "odd". Plenty of lab space and nice labs with attention to detail.
2. Performance: Ship rolls a lot because of flat bottom. Kerry was concerned it may not be well suited for deep towing operations along track lines due to the rolling. He did not know if the U-tube anti-roll system was working. There were some issues with the crew controlling the ship (e.g., taking a long time to get underway, didn't seem to know the ship well yet). They had no in ice ops.
3. OSH Systems: They used the starboard knuckle crane. It worked really well. They did not use the winches.
4. Sonars: The science objectives did not involve the sonar suite. Had to turn off systems when triggering acoustic releases with their own hydrophone system. Crew did operate the EM302 and TOPAS systems.
5. Retractable Centerboard: There was an issue with one of the transducers but Kerry could not remember the details.
6. Acoustically quiet: Didn't notice any noise. "Felt like being in the future", "cool ship to be on."
7. Vans and deck space: Did not have vans but used the large aft deck for stacking EM receivers that are the size of OBSs. They used the fresh water services and appreciated the 2 x 2' bolt pattern to bolt down their frames.
8. DP: was not essential. For recoveries only needed to be within ~1 km of a site, then after pop-up to approach instruments. Thought DP was more critical for deep-towing ops.
9. Labs: Used wet lab to rinse equipment and main lab to disassemble equipment and download data. Noted there was plenty of space. Kerry liked the glove and boot drying rack.
10. Pilothouse: Used observation areas when one instrument was lost. Noted good visibility and plenty of room for up to 6 look outs.
11. Internet and bandwidth: laptops were locked off network to prevent cloud services etc hogging the bandwidth. There were ships terminals for doing email and other communications and this was fine for this cruise. They had no telepresence activities.
12. Other comments: Most important to Kerry was the good crane and plenty of deck space. He thought the galley staff were exceptional, food great and galley design good. Kerry and a student were picked up from shore using the rescue boat and this went smoothly. They also had a helicopter drop of equipment to the deck. Liked the sauna on board and remote controls for crane. Glad to see the techs were routinely collecting multibeam data for databases.

"Quality was incrementally improved on existing technologies. Just better than older ships."

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R/V *Sikuliaq* Debrief Questions – UNOLS Fleet Improvement Committee 2015

Dear Chief Scientist:

The UNOLS Fleet Improvement Committee requests that you provide feedback on your recent cruise on the *R/V Sikuliaq*. The purpose of these questions is to help determine how key underlined design and outfitting features of the vessel have either benefited or hindered your cruise objectives. The FIC will use your feedback to inform design recommendations for future Ice Capable and Global Class Research Vessels. A member of FIC will contact you by phone shortly after your cruise to get your responses. You may also submit written responses to me if you prefer.

Sincerely,

Clare Reimers
FIC, Chair
Email: creimers@coas.oregonstate.edu

Responses from Jen MacKinnon, taken by phone by Miles Sundermeyer, 11/25/15

1. Size: The *R/V Sikuliaq* has a LOA of 261 ft, a beam at midship of 48 ft, and has berths for 26 scientists and technicians. Science labs occupy 2250 sq ft and the deck working area is 4360 sq ft. **Has the overall size of the vessel either enabled or hindered you in meeting the science objectives of your cruise? Is there sufficient lab space of the appropriate type? Are there sufficient berths available to accommodate an optimal science party? Were the living arrangements satisfactory? Please explain using specific examples that relate to your science objectives.**

- Size was fine. More used to global, so felt a little smaller, but fine for 20 scientists. Can envision problem for larger groups.
- Lab space + Living arrangements were great
- Mostly positive on all counts

2. Performance: The endurance of the *R/V Sikuliaq* is ~45 days with an expected range of 9,000 nm at 11 knots. The vessel has a design maximum speed in calm open water of 14 kt and is designed to operate in 3 ft of ice at 2 kts. **Have any of these performance capabilities of the vessel either enabled or hindered you in meeting the science objectives of your cruise? If the ship operated in ice during your cruise, how was the performance? Please explain using specific examples.**

Ship has great performance overall. They are very cautious through ice, presumably because they are still calibrating how well it can do? When needed to get from Point A to B, had to consider through or around ice? In working this out, seemed it often came down to taking twice as long to go around vs. through. Have never sailed on ice breaker, so not comparing this to them. The above said, for summer work, the ship was great.

3. Over-the-Side Handling Systems: The *R/V Sikuliaq* has been outfitted with a system that allows "hands free" launch and recovery of CTD and other systems within a Baltic Room on the starboard side using an overboarding boom with docking head and motion controlled winch systems. It also has:

- An articulating Stern A-Frame
- Port and Starboard Knuckle, Extension Boom Cranes
- Two Mo-Comp Hydro Winches (.322 EM Cable)
- Traction Winch with two tension member drums (.680 EM Cable and 9/16 3X19 Wire Rope)

Did these systems have a positive impact on your work and if so how? Are there any negative impacts associated with these systems?

- Very much liked the articulating A-frame – longer reach than most A-frames have
- Booms were great
- CTD worked great – awesome compared to Revelle, dramatically better. Docking head system worked great; worked well to have CTD in Baltic room. Did not use in significant seas on this trip, so cannot comment on that.
- Overall, ship was fantastic

4. Hull Mounted Sonar Suite: The ships sonar flat is outfitted with:

- Kongsberg Ksync - Sonar Synchronizing system
- Kongsberg EM302 .5X1 - Multibeam
- Kongsberg EM710 .5X1 - Multibeam
- Kongsberg TOPAS PS-18 - Parametric Sub Bottom Profiler
- Kongsberg EK60 (18, 38, 70, 120, and 200 kHz) - Split Beam Sonar
- Knudsen 3260 12 kHz - Chirp PDR
- Benthos UDB-9000 - Acoustic Modem
- Teledyne RDI OS 75 kHz - Acoustic Doppler Current Profiler (UHDAS)
- Teledyne RDI OS 150 kHz - Acoustic Doppler Current Profiler (UHDAS)
- LSE 297 50 kHz - Bridge Navigation Sonar
- LSE 297 200 kHz- Bridge Navigation Sonar
- HAP 5050 Array - Self Noise Monitoring Array
- Doppler Speed Log

Which of these systems were essential to science objectives during your cruise? What is the quality of the data collected?

- 150 KHz ADCP - was broken
- 75 KHz ADCP - data were bad, not clear why, lots of drop outs, funny amplitude to it that images ship velocity. Past experience shows that every time there is a new ship, its ADCP has to be "dialed in", including considerations such as adding insulation in the well, minimizing hull reverberation modes of ship, etc. A similar

issue occurred on Palmer, something was causing reverberations in the ADCP well so that foam needed to be added to the well. Science party's understanding is that issues have existed with these ADCPs for over a year, but since previous science parties did not require the ADCPs, the issues were not addressed. For this cruise, the ADCP was important. Complaints were made during the cruise, and the Chief Scientist later received follow-up email from Steve Hartz indicating that the ADCP issues will be addressed during a scheduled dry dock in January. Since this was a physical oceanography cruise, the situation was frustrating.

- No comment on other instruments – didn't use

5. Retractable Centerboard with mounted acoustic transducers: The *R/V Sikuliaq* is fitted with a retractable centerboard that can be lowered to 8 feet below the keel and on which there is an EK 60 array and a spare 12' acoustic well for ship and science use. Transducers are changeable alongside. **Has this arrangement had any significant positive or negative impacts on your work?**

Put in own 300 KHz ADCP in centerboard, worked great, happy with it. Moving the ship about in space and time, the science party figured out that there were issues simply due to there being few scatterers in the water column – in the daytime they migrate down to 600 m, so the ADCPs simply do not do well. This notwithstanding, there were still the additional issues w/ 75 KHz that went beyond this.

6. Acoustically Quiet: The *R/V Sikuliaq* was designed, engineered and built to meet ICES 209 noise limits above 200 Hz at 8.0 knots. Radiated airborne noise within the ship is also designed to be at low levels. **Have you noticed any difference compared to other vessels, and has this had any positive or negative impacts on your work?**

Pleasant, very noticeable, but were not doing any science that it affected.

7. Vans and deck space: The van set up of the *R/V Sikuliaq* for any particular cruise is "modular" in that there is a choice between more deck space or more enclosed lab, berthing or storage space. The design of the *R/V Sikuliaq* incorporates the ability to fit three 20 ft ISO Containers vans on the aft deck for berthing, lab space or other uses and a 10 ft van forward on the 02 Deck. These vans are mounted to dedicated deck fittings, and provided with services such as power, water, comms, drains etc. **If you have used the vans, how well did they accommodate your space requirements? Did this modularity have a positive or negative impact on your cruise planning and work at sea?**

Space on deck was fine for this cruise – brought 1 container onboard.

8. Dynamic Positioning: The *R/V Sikuliaq* was designed and outfitted with dynamic positioning (DP) capabilities. This is accomplished by using twin rotatable Z-Drives, a trainable bow thruster and a commercially available computer controlled precision navigation system. All of these components add cost, maintenance requirements and

complexity to the operation of the vessel. **How important was the DP system to your work? How well did this system operate during your cruise?**

DP was essential to operations, appreciated it. Overall ship handling / driving was very good/accurate

9. Lab Arrangement: The *R/V Sikuliaq* labs were pre-outfitted with lab benches and science services (air, electricity, water, seawater, etc). **Did you find the existing arrangement easy to modify and was the quantity of service outlets for air and water adequate, too many or too few?**

All was good.

10. Pilothouse Arrangement: The *R/V Sikuliaq* has some areas for observers to sit and stand in the Pilothouse, as well as on top of the pilothouse. **Did you find those areas adequate for science observations?**

Pilothouse was great – spent lots of time in pilot house, some looking for walruses, some for fronts. Very welcoming, lots of room.

11. Internet access and bandwidth**: Did you plan telepresence activities and were facilities satisfactory? Did you have high speed internet or special bandwidth requirements for science? Was the internet connectivity adequate for other broader impact, science or normal communication activities?**

No telepresence, just normal high seas net, which worked fine / as expected

12. Other Features: **Can you describe other design, outfitting or operational features of the *R/V Sikuliaq* that had significant positive or negative impacts on your work at sea? Should these features be requirements of other new UNOLS Research Vessels? Were there any important design features missing which would benefit a wide variety of projects?**

- Sauna was great, nice quality of life / extra touch
- Overall, ship is well laid out – lots of small things that never thought about until saw them on Sikuliaq. Example is the remote control crane operation. Normally crane operator is up in crane pilot house – hard to communicate / see for hand signals from deck. Here remote control allows crane operator to be next to scientist on deck – this worked great on many fronts.
- All physical facilities were fantastic.
- Best crew ever sailed with – responsive, excellent. New excitement about them with new ship. Seems to be a self selecting group as part of a new ship and new philosophy. Everyone is there because they want to be – creates a new culture, responsive, helpful, flexible. Example: facilities – on other ships, used to attitude

of "don't touch in machine shop". Here they let science use machine shop, borrow tools, offer to help or let science do themselves.

- This cruise put out 1 mooring. On recent cruise off Tasmania on Revelle, put out 15 moorings. While Sikuliaq was fine on this particular process study cruise, envision other cruises that could only be done on a global ship. It would limit science to not have access to globals.

Post Cruise Assessment Report Information

PCAR ID: 102285

Date Created: 11/19/2015 9:23:00 AM **Date Modified:** 11/20/2015 2:50:00 AM

Cruise Information

Ship: Sikuliaq **Area of Operations:** AR07

Cruise Dates: 10/1/2015 - 11/10/2015 **Chief Scientist:** James M. Thomson, UW_APL

Cruise Number: SKQ201512S

PIs and Funding Agencies:

PI: James M. Thomson, UW_APL **Funding Agency:** NAVY/ONR

Type of Work: Sea State DRI **Grant #:**

Ship Personnel

Master: Mike Hoshlyk **Marine Technician:** Ethan Roth, Bern McKiernan, Steve Roberts

Completer's Information:

Person's Name: Dr. James M Thomson **Position on this cruise:** PI/Chief Scientist

Institution: University of Washington - Applied Physics Lab

Assessment:

1. To what extent were the planned science objectives of this cruise met?

rating: 91-100%

comment:

The cruise objective was to observe advancing sea ice during autumn in the Arctic and to understand the effects of sea state (i.e., wind and waves) on the ice advance. This required a combination of shipboard measurements, buoy deployments, and mooring deployments. The ship preformed well and the objectives were met, however the lack of a functional workboat limited our ability to place buoys accurately.

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2. Rate how well the science party contributed to achieving the scientific objectives of this cruise (pre-cruise planning, communication, adequate personnel, equipment, attention to safety, organization, etc.).

rating: Excellent

comment:

The science party was generally well-prepared and preformed well. Some of the buoys should have undergone more testing prior to the cruise, but adaptations during the cruise were sufficient to meet the science objectives. Attention to safety was excellent; there were no injuries or incidences during the 42 day cruise.

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3. Rate how well ship operator pre-cruise activities (planning, coordination, and logistics) and shore support contributed to achieving the scientific objectives of this cruise.

rating: Excellent

comment:

Support from UAF, in particular Steve Hartz, for pre-cruise planning was excellent. Steve participated in several planning meetings in-person, and he answered questions constantly during the lead-up to the cruise. The onboard science support contributed to pre-installation activities, which made our mobilization much more efficient. The port captain, Doug Baird, provided clear and prompt logistics information.

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4. Rate how well the ship operator supplied scientific equipment and marine technicians supported this cruise (appropriate equipment, equipment operational and ready for cruise, calibrations, documentation, technicians trained and familiar with equipment).

rating: Excellent

comment:

The marine technician support was world-class. Ethan Roth and Bern McKiernan are incredibly dedicated to their jobs and to this ship. Steve Roberts provided a mission-critical service for real-time mapping of ice and forecast products. The combination of these three individuals meant that science productivity could stay high for every minute of our 42 day cruise. They were always at the ready to contribute their expertise, and the ship's comprehensive suite of equipment, to our science. I can only wish every future UNOLs cruise I do will have even half of this level of support.

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5. Rate how well the scheduling of this cruise supported achieving the scientific objectives of this cruise (appropriate ship, year, season & dates, communications regarding schedules, online systems and scheduling process).

rating: Excellent

ship requested: Sikuliaq

comment:

The scheduling process worked well, however the late-change of final port (Alameda, CA, instead of Seattle, WA) caused problems in the logistics of our return shipment.

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6. Rate the level of safety in shipboard and science operations (safety briefing and instructions, procedures & equipment).

rating: Excellent

comment:

Procedures were clear, concise, and effective. Safety gear (PPE) was always out and available.

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7. Rate how well the officers and crew and the manner in which the research vessel was operated contributed to achieving the scientific objectives of this cruise (communications, ship handling, deck procedures, attitude towards the science objectives, training, adequate number of crew, shipboard routine, etc.).

rating: Excellent

comment:

A ship is made of people, not of steel. In that sense, the Sikuliaq is off to a great start. The camaraderie and capability of this crew are superb. They always made our science the priority, and they were always willing to make adjustments to get things done for us. At times, however, it felt like they were working with their hands tied behind their backs, because the ship itself still has several deficiencies (see next entry).

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8. Rate how well the research vessel and its installed equipment contributed to achieving the scientific objectives of this cruise (material condition, readiness, living conditions and habitability, condition of lab spaces, design, layout, deck equipment, winches, cranes, frames, propulsion, power, etc.).

rating: Fair

comment:

The Sikuliaq holds much promise to become the flagship of the UNOLS fleet, however several substantial problems must be addressed: 1) The bridge controls are inadequate. This appears to be largely a software issue, although more physical problems of adjusting power requirements are also apparent. (We lost power completely on one occasion.) Problems with the thrusters and the steerage occurred almost daily. The most notable event was the loss of steerage on Oct 11th: we were suddenly beam-to in 5 m waves with several people on deck. The decks were awash and we were lucky to not loose anyone overboard. 2) The anchors do not secure properly underway. As a result, the anchors bang loudly on the hull continuously when underway in any waves greater than 3 m. This is more than just an embarrassing deficit of skill in naval architecture; it is a safety issue. If the crew and science party cannot sleep, they cannot serve their watches well. 3) The workboat and davit were not in working order; we were depending on them for tending buoys and conducting CTD casts in leads. We were able to complete these operations from the Sikuliaq instead, but it was not ideal because the large ship was very disruptive to the ice and wave signals we were trying to measure. 4) The visibility from the bridge wings is very limited, which made it difficult to recovery buoys. 5) The port holes accumulate large amounts of ice during cold conditions, which eventually melts and makes a wet mess of the science staterooms, lab areas, etc. This will eventually cause mold in the science staterooms and damage to the electronics in the labs. 6) The anti-roll tanks were not tuned properly, and, I think, made the vessel roll response worse… i.e., amplifying the roll, rather than damping it.

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9. Number of science days lost:

due to weather: 2.00

due to ship equipment:

due to ship science equipment:

due to user science equipment:

comment:

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R/V *Sikuliaq* Debrief Questions – UNOLS Fleet Improvement Committee 2015

Dear Chief Scientist:

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Sincerely,

Clare Reimers
FIC, Chair
Email: creimers@coas.oregonstate.edu

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1. Size: The *R/V Sikuliaq* has a LOA of 261 ft, a beam at midship of 48 ft, and has berths for 26 scientists and technicians. Science labs occupy 2250 sq ft and the deck working area is 4360 sq ft. **Has the overall size of the vessel either enabled or hindered you in meeting the science objectives of your cruise? Is there sufficient lab space of the appropriate type? Are there sufficient berths available to accommodate an optimal science party? Were the living arrangements satisfactory? Please explain using specific examples that relate to your science objectives.**

The size of the vessel and lab space were sufficient for our program. We filled every berth onboard and used every station in the labs. The berths and lab space is well matched for a "maximum capacity" cruise such as ours. The only things we did not use were the fume hoods in each lab, although these seemed sufficient. The living arrangements were fine, however the mattresses do not fit the bunks and slide side to side when the ship rolls (which it does a lot). Also, the ports (windows) condense severely in cold conditions, and this leaves large puddles of water in each room.

2. Performance: The endurance of the *R/V Sikuliaq* is ~45 days with an expected range of 9,000 nm at 11 knots. The vessel has a design maximum speed in calm open water of 14 kt and is designed to operate in 3 ft of ice at 2 kts. **Have any of these performance capabilities of the vessel either enabled or hindered you in meeting the science objectives of your cruise? If the ship operated in ice during your cruise, how was the performance? Please explain using specific examples.**

The in-ice performance was essential to our cruise, and it was excellent. We moved through new ice at up to 8 knts and only encountered a few ridges that stopped the vessel.

Fuel appears to be the limiting aspect of the endurance; our planning during the later portion of our 42 cruise was tightly constrained by fuel usage.

3. Over-the-Side Handling Systems: The *R/V Sikuliaq* has been outfitted with a system that allows "hands free" launch and recovery of CTD and other systems within a Baltic Room on the starboard side using an overboarding boom with docking head and motion controlled winch systems. It also has:

- An articulating Stern A-Frame
- Port and Starboard Knuckle, Extension Boom Cranes
- Two Mo-Comp Hydro Winches (.322 EM Cable)
- Traction Winch with two tension member drums (.680 EM Cable and 9/16 3X19 Wire Rope)

Did these systems have a positive impact on your work and if so how? Are there any negative impacts associated with these systems?

The overboarding systems were used extensively during our cruise, in particular the cranes. Everything worked well. The CTD system is particularly slick. One minor criticism is that the cranes do not secure well underway (the head block rests on the deck and is thus in a regular salt bath).

One overboarding system did not work at all: the davit for the work boat. This negatively impacted our science, but constraining use to make measurements and conduct recoveries from the ship. The ship contaminates near-surface measurements and is inefficient for recovering small buoys.

4. Hull Mounted Sonar Suite: The ships sonar flat is outfitted with:

- Kongsberg Ksync - Sonar Synchronizing system
- Kongsberg EM302 .5X1 - Multibeam
- Kongsberg EM710 .5X1 - Multibeam
- Kongsberg TOPAS PS-18 - Parametric Sub Bottom Profiler
- Kongsberg EK60 (18, 38, 70, 120, and 200 kHz) - Split Beam Sonar
- Knudsen 3260 12 kHz - Chirp PDR
- Benthos UDB-9000 - Acoustic Modem
- Teledyne RDI OS 75 kHz - Acoustic Doppler Current Profiler (UHDAS)
- Teledyne RDI OS 150 kHz - Acoustic Doppler Current Profiler (UHDAS)
- LSE 297 50 kHz - Bridge Navigation Sonar
- LSE 297 200 kHz- Bridge Navigation Sonar
- HAP 5050 Array - Self Noise Monitoring Array
- Doppler Speed Log

Which of these systems were essential to science objectives during your cruise? What is the quality of the data collected?

The 150 kHZ ADCP was not available during our cruise, and this negatively impacted our science. The other systems worked well. We used the UDB-9000 to successfully release a mooring, and we used the multibeams to survey the location of that mooring.

The 75 kHZ ADCP had poor data quality, but that is expected in the very clear Arctic waters.

5. Retractable Centerboard with mounted acoustic transducers: The *R/V Sikuliaq* is fitted with a retractable centerboard that can be lowered to 8 feet below the keel and on which there is an EK 60 array and a spare 12' acoustic well for ship and science use. Transducers are changeable alongside. **Has this arrangement had any significant positive or negative impacts on your work?**

We did not use the centerboard, and I understand that, at present, it cannot be fully deployed.

6. Acoustically Quiet: The *R/V Sikuliaq* was designed, engineered and built to meet ICES 209 noise limits above 200 Hz at 8.0 knots. Radiated airborne noise within the ship is also designed to be at low levels. **Have you noticed any difference compared to other vessels, and has this had any positive or negative impacts on your work?**

It is indeed a quiet ship. This has a positive impact on everyone aboard, and it probably improved our acoustic communications to an AUV.

7. Vans and deck space: The van set up of the *R/V Sikuliaq* for any particular cruise is "modular" in that there is a choice between more deck space or more enclosed lab, berthing or storage space. The design of the *R/V Sikuliaq* incorporates the ability to fit three 20 ft ISO Containers vans on the aft deck for berthing, lab space or other uses and a 10 ft van forward on the 02 Deck. These vans are mounted to dedicated deck fittings, and provided with services such as power, water, comms, drains etc. **If you have used the vans, how well did they accommodate your space requirements? Did this modularity have a positive or negative impact on your cruise planning and work at sea?**

We carried two 20 ft vans on this cruise, using the assigned locations. This worked well. The 10 ft location up forward is not available, as it is used for a van full of survival gear.

8. Dynamic Positioning: The *R/V Sikuliaq* was designed and outfitted with dynamic positioning (DP) capabilities. This is accomplished by using twin rotatable Z-Drives, a trainable bow thruster and a commercially available computer controlled precision navigation system. All of these components add cost, maintenance requirements and complexity to the operation of the vessel. **How important was the DP system to your work? How well did this system operate during your cruise?**

The DP system was terrible. As I understand it from the bridge officers, this is primarily a software issue. The bridge software appears to have numerous bugs. I have never heard so many alarms on a bridge, at such regular intervals, on any ship. Loss of steerage was a regular occurrence. I am familiar with the benefits of DP, having used it on the T. G. Thompson and other AGORs, and the present implementation on Sikuliaq offers almost none of these benefits.

9. Lab Arrangement: The *R/V Sikuliaq* labs were pre-outfitted with lab benches and science services (air, electricity, water, seawater, etc). **Did you find the existing arrangement easy to modify and was the quantity of service outlets for air and water adequate, too many or too few?**
The science services were excellent and generally well laid out.

10. Pilothouse Arrangement: The *R/V Sikuliaq* has some areas for observers to sit and stand in the Pilothouse, as well as on top of the pilothouse. **Did you find those areas adequate for science observations?**

There was ample room for science observations from the bridge. This was essential to our cruise, as we made hourly ice logs for the entire trip. However, the bridge wings do not offer any visibility astern. This is mostly a problem for ship operations, not science observations, but it is a big problem.

11. Internet access and bandwidth**: Did you plan telepresence activities and were facilities satisfactory? Did you have high speed internet or special bandwidth requirements for science? Was the internet connectivity adequate for other broader impact, science or normal communication activities?**

We did not have any telepresence activities, other than a simple blog. The internet connection was essential to our science, because we used real-time satellite data. The connection adequate for this purpose, and, in fact, the connection was much better than expected.

12. Other Features: **Can you describe other design, outfitting or operational features of the *R/V Sikuliaq* that had significant positive or negative impacts on your work at sea? Should these features be requirements of other new UNOLS Research Vessels? Were there any important design features missing which would benefit a wide variety of projects?**

In general, we had a very successful cruise and used the Sikuliaq to its fullest capabilities. The software issues and general bridge control systems are clearly the biggest negative (and make me long for the simple mechanical controls of an old ship like the New Horizon). The positives are many, and the science support is generally excellent.

The modern networking, in particular at the foremast and around the bridge, was a real advantage relative to older ships. The computer lab and overall integration of high-quality shipboard sensors is excellent.

The seawater system is inadequate—it leaks and the flow rate is low.

The anchor, which does not secure underway, is an embarrassment to UNOLS.

ONR Sea State DRI Cruise Report

R/V Sikuliaq, Fall 2015 (SKQ201512S)

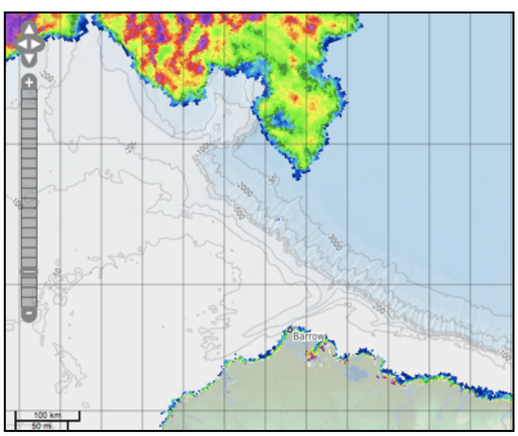
Revision date: 11 November 2015 (final)

Chief scientist: Jim Thomson

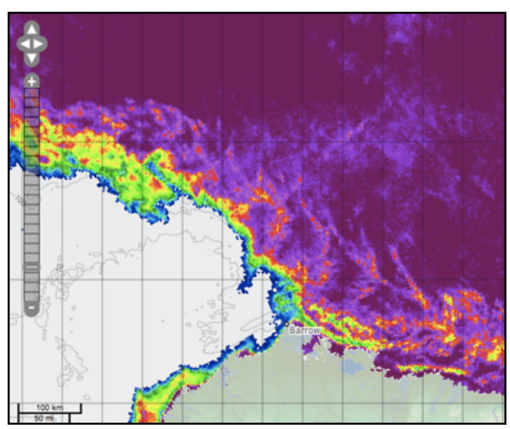
Overview

The primary observational component of the Sea State Department Research Initiative (DRI) was a research cruise to the western Arctic Ocean in the fall of 2015 (1 Oct to 10 Nov). The goal was to observe the fall ice advance and the interactions with winds and waves. The cruise plan was driven by the detailed objectives laid out in the science plan (published in 2013 as APL technical report #1306). That document and more information are available at the project web page: http://www.apl.uw.edu/project/project.php?id=arctic_sea_state . This cruise report is a summary and narrative of the measurements and activities completed during the research cruise, as well as preliminary findings.

Our measurements suggest that waves play an important role in the fall freeze-up of the Beaufort and Chukchi Seas, especially near the ice edge facing the prevailing easterly winds. Pancake ice formation was common, and, in one particular event, extended for almost 100 nm. Our measurements suggest that ocean heat also is important, and that mixing can delay or temporarily reverse the formation of first-year ice. Eventually, strong heat loss to the atmosphere becomes the dominant process, especially during off-ice wind events, and large expanses of the ocean freeze rapidly. As intended, we observed a significant advance in ice cover, and we sampled several wave/wind events.



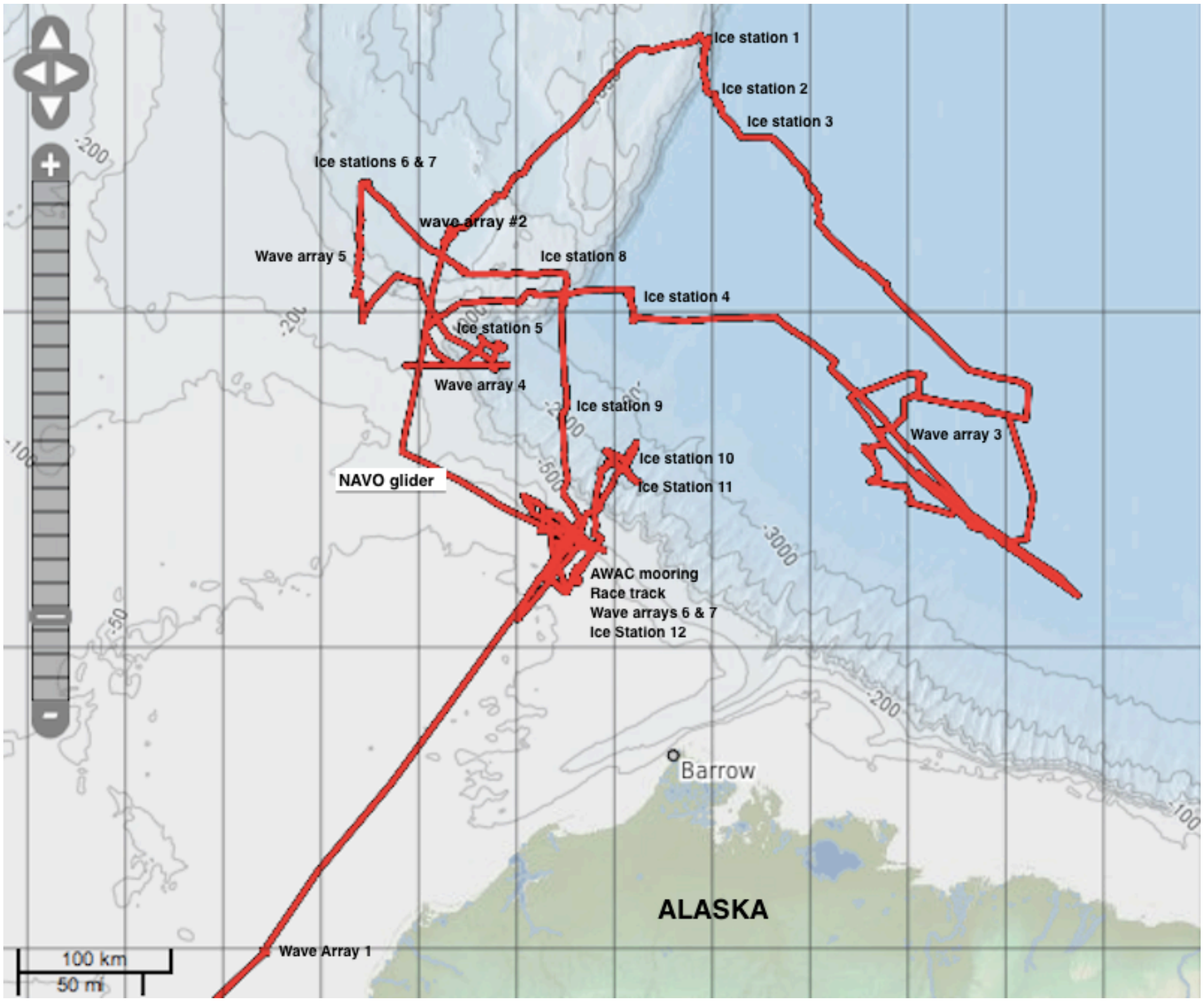
AMSR2 ice conc. on 1 Oct 2015



AMSR2 ice conc. on 1 Nov 2015

SUMMARY: Cruise track

An overview of the cruise track is shown below. The summaries and narrative text that follow include more detailed views of each leg along the track. The track plan was constantly updated throughout the trip according to weather/wave forecasts and ice conditions.



Cruise track and stations

SUMMARY: Cruise log

A detailed event log, available as a csv file, was maintained for all activities onboard the ship, including the time (UTC) and position of each activity. An overview of the daily activities is below. Summaries of the activities and a chronological narrative follow.

28 Sep	Staging (Nome), install cameras, LiDAR and flux system
29-Sep	Mobilize (Nome), crane on vans and heavy gear
30-Sep	Mobilize (Nome), depart at 21:00 ADT
1-Oct	Transit
2-Oct	Wave array #1 (open water inter-calibration), transit
3-Oct	Deploy AWAC mooring, UAS tests, NAVO glider recovery
4-Oct	Wave array #2 (ice edge w/ flux stations), ROV testing
5-Oct	SIMS survey north thru nilas ice sheets
6-Oct	Ice station #1 ("Ben"), with NASA UAVSAR overflights
7-Oct	Ice station #1 completed
8-Oct	Ice stations #2 ("potato") & 3 ("cake")
9-Oct	SIMS survey southeast ice edge
10-Oct	Wave array #3 (combined array for pancake ice at southeast ice)
11-Oct	Wave array #3 (combined array for pancake ice at southeast ice)
12-Oct	Wave array #3 (combined array for pancake ice at southeast ice)
13-Oct	Wave array #3 (combined array for pancake ice at southeast ice)
14-Oct	SIMS survey westward into ice
15-Oct	Ice station #4 ("mixed nuts"), NRL flight #1 along E-W transect
16-Oct	Wave array #4, NRL flight #2 completing E-W transect
17-Oct	Wave array #4 & Ice station #5 (Peter's floe)
18-Oct	Wave array #5 & flux line for off-ice winds
19-Oct	Ice station #6 ("Ethan")
20-Oct	Ice station #7, evening SIMS survey eastward
21-Oct	Ice station #8, NRL flight #3 (E-W transect + station)
22-Oct	Ice station #9 ("goldilocks"), evening SIMS survey southward
23-Oct	Wave array #6 (line near AWAC mooring), NRL flight #4
24-Oct	Wave array #6 (line near AWAC mooring), NRL flight #5
25-Oct	Recover AWAC mooring, begin six flux stations and uCTD along a "race track" survey
26-Oct	Race track survey at advancing ice edge, ROV & LiDAR ice survey at point #6
27-Oct	Race track survey at advancing ice edge, ROV & LiDAR ice survey at point #6
28-Oct	Ice station #10 (w/ fluxes)
29-Oct	Ice station #11 (w/fluxes)
30-Oct	Ice station #12 (w/fluxes) at race track point #1
31-Oct	Wave array #7, partial race track survey
1-Nov	Wave array #7, partial race track survey
2-Nov	Race track survey at advancing ice edge, ROV & LiDAR ice survey
3-Nov	Race track survey at advancing ice edge,
4-Nov	Transit with underway CTD until 71 N
5-Nov	Transit
6-Nov	Transit
7-Nov	Transit
8-Nov	Transit
9-Nov	Transit, arrive Dutch Harbor at 15:00
10-Nov	Demobilize (Dutch Harbor)
11-Nov	Demobilize (Dutch Harbor)

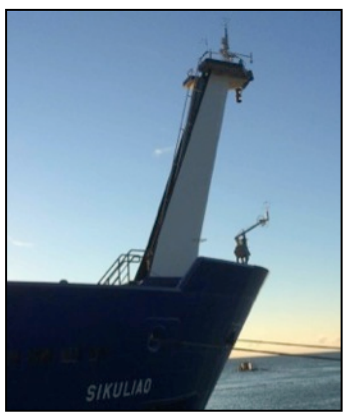
SUMMARY: Underway measurements

Numerous measurements were made continuously throughout the research cruise:

- 32 days (559 hours) of visual ice observations (ASSIST & ASPeCt protocols)
- 228423 ice camera images
- 467 physical ice samples
- 1520 nm of SIMS (Sea Ice Measurement System) transects
- 4292 casts of the underway CTD (underway Conductivity, Temperature, Depth)
- 35 days of wave and ice measurements from the ship's Rutter radar (2,325,000 images)
- 169 weather balloon (radiosonde) launches
- 487 hours of covariance flux measurements from two meteorological masts
- 95 high-quality 1-hour turbulent flux stations (table available as .csv and matlab files)
- continuous radiative energy fluxes, surface temperatures, and ceilometer (cloud height)
- continuous scanning LiDAR measurements of waves and ice forward of the bow
- 10 hours of underway (mobile) LiDAR scans of sea ice topography off port beam
- 18 hours of stereo video (3D wave mapping) acquisition

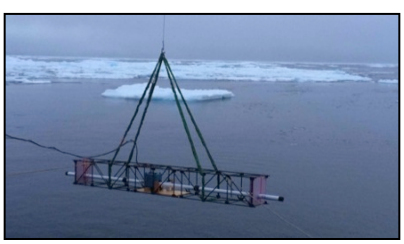
The ship had additional underway measurements, including: GeoCam images (every 20 s), thermosalinograph (TSG), multibeam bathymetry, and standard meteorological parameters. A separate document comparing the ship meteorological data to the flux data is available. These measurements provide context for all activities, as well as datasets for synthesis of the overall air-ocean-ice system in autumn.

Underway CTD winch



Flux measurements at the bow

Weather balloons

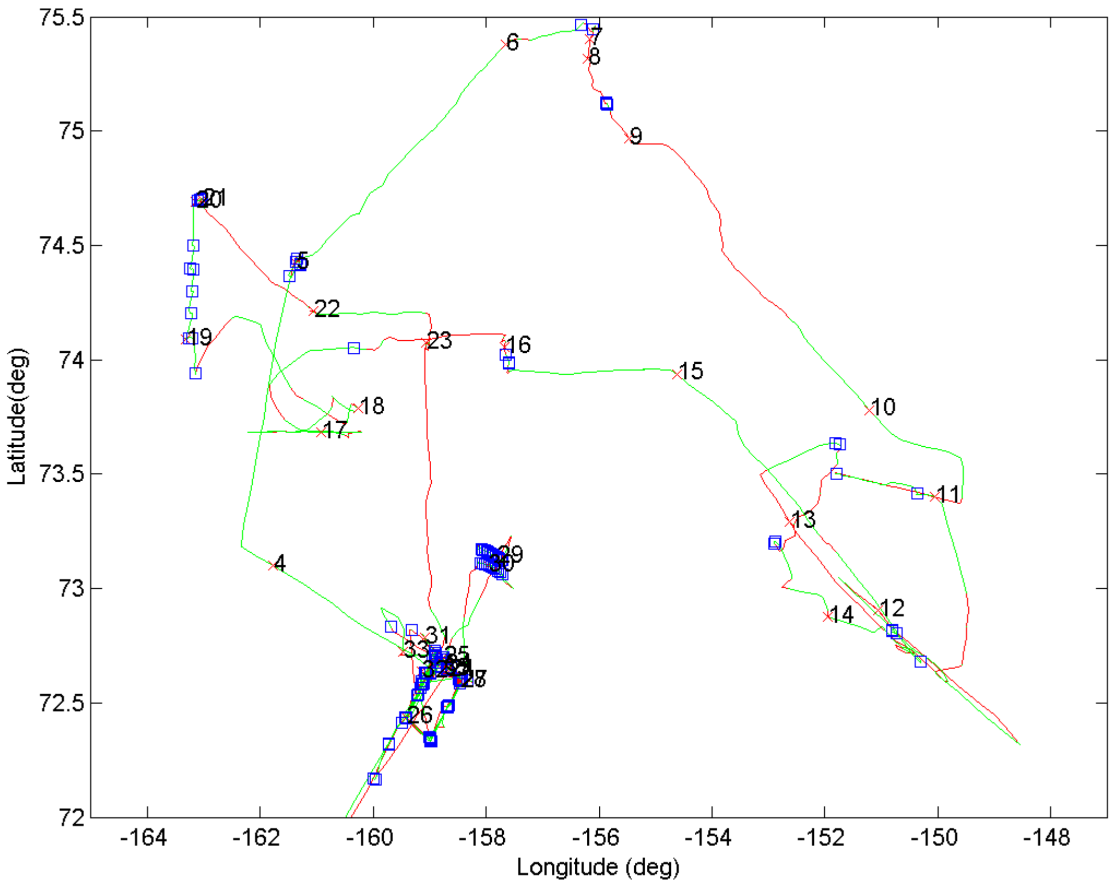


SIMS (Sea Ice Measurement System) suspended from port crane

Rutter radar antenna (center)

SUMMARY: turbulent flux and bulk meteorological measurements

Ultrasonic anemometers (10 Hz) were installed at two heights on the ship's bow: at the top of the bow tower 16.5 m above the waterline and on a small davit mounted to the ship's nose below the tower at 10m above the surface. Instrumentation for fast (10 Hz) measurements of ship motion and water vapor were placed at the top of the tower. Fast pressure sensors were located at both levels. In addition, sensors for 1-min mean temperature / relative humidity, pressure, longwave radiation, shortwave radiation and sea surface temperature were installed to duplicate similar measurements from the ship's underway data system. Surface temperature measurements included a towed thermistor ('sea snake') and two infrared pyrometers (Heitronics KT-15). We are preparing a separate data quality report comparing various bulk meteorological measurements and plan to release an edited data set for these parameters shortly after the cruise is completed. Scanning and fixed-point laser rangefinders were installed at the top of the tower for continuous underway wave height measurements.



The Sea State track showing 60-min flux stations (blue squares) and times of ship-relative wind direction < 60 degrees (i.e., acceptable conditions for turbulent flux measurements) (green). Numbers show the October date at 00 UTC.

SUMMARY: SIMS (Sea Ice Measurement System) underway sampling

Indirect sampling of sea ice thickness through electromagnetic induction sounding (EMI) and ranging techniques was accomplished with the SIMS rig suspended on the aft port crane during most underway transits from Oct 5 – 23. Only in high wind conditions and in open water transits were SIMS operations curtailed. Data were collected at a 1 Hz sampling rate. At a nominal ship speed of 4 knots, this temporal sampling rate corresponds to a spatial sampling interval of 2 m. The SIM system was also instrumented with a FLIR thermal imaging camera that acquired a thermal record of sea ice and sea water temperature at a 1 Hz sampling rate. Preliminary assessment of the thermal record indicates that very thin ice, below the sensitivity threshold of the EM method, may be empirically quantified by its temperature signal.

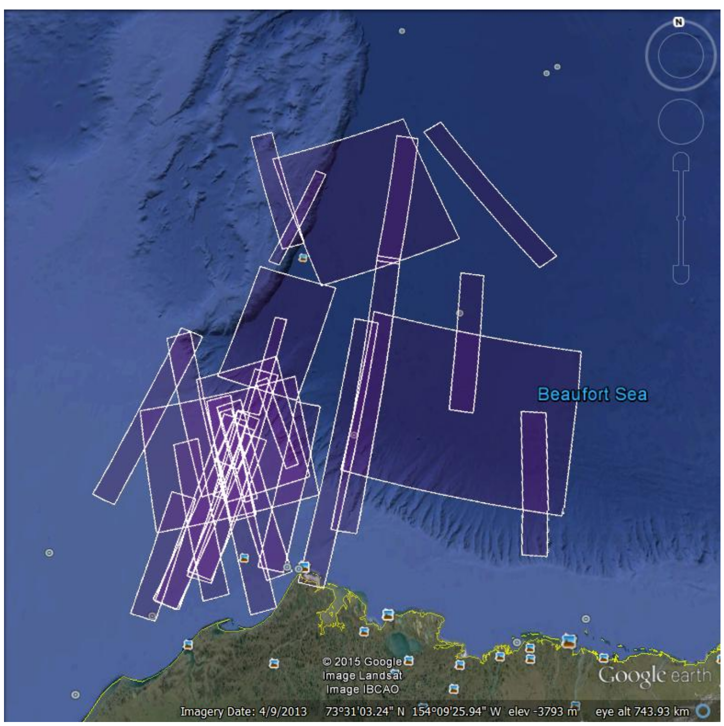
SUMMARY: CTD (conductivity, temperature, depth) profiles

Three instrument packages were used to acquire vertical ocean profiles, the first in stationary mode (the ship's CTD rosette package equipped with a SeaBird 911 and deployed via the starboard Baltic Room), and second in underway mode (an OceanSciences uCTD system deployed off the ship's stern), and the third during ice stations (a YSI CastAway through holes in the ice). The ship's CTD was used primarily in locations where water samples for oxygen isotope analysis were desired. Otherwise the uCTD was used, particularly during transiting in a non-interfere mode in a single-cast hourly fashion or in continuous "tow-yo" mode in areas where strong spatial gradients were suspected. The uCTD is a light-weight sampling system that efficiently acquires high precision ocean measurements to resolve both spatial and temporal scales. The uCTD system was also used in the ice, with the only requirement that the ship move slowly enough to create an open channel for casting (3-6 kts, depending on ice conditions). The quickly deployed and versatile uCTD system allowed us to resolve the temperature and salinity structure of the upper ocean throughout our sampling area, while also allowing us to resolve the intense gradients near the ice edge.

SUMMARY: Satellite remote sensing

Satellite images were provided by the US National Ice Center, DLR in Germany, the Bedford Institute of Oceanography, the Department of Fisheries and Oceans Canada, CSTARS at the University of Miami, and CNR (Consilio Nazionale per la Ricerca) in Italy. Over 400 images were collected and made available in near-realtime for operational use onboard the ship. The operational use was greatly enhanced by a map server running locally onboard the ship. Screen shots from the map server are included in this report.

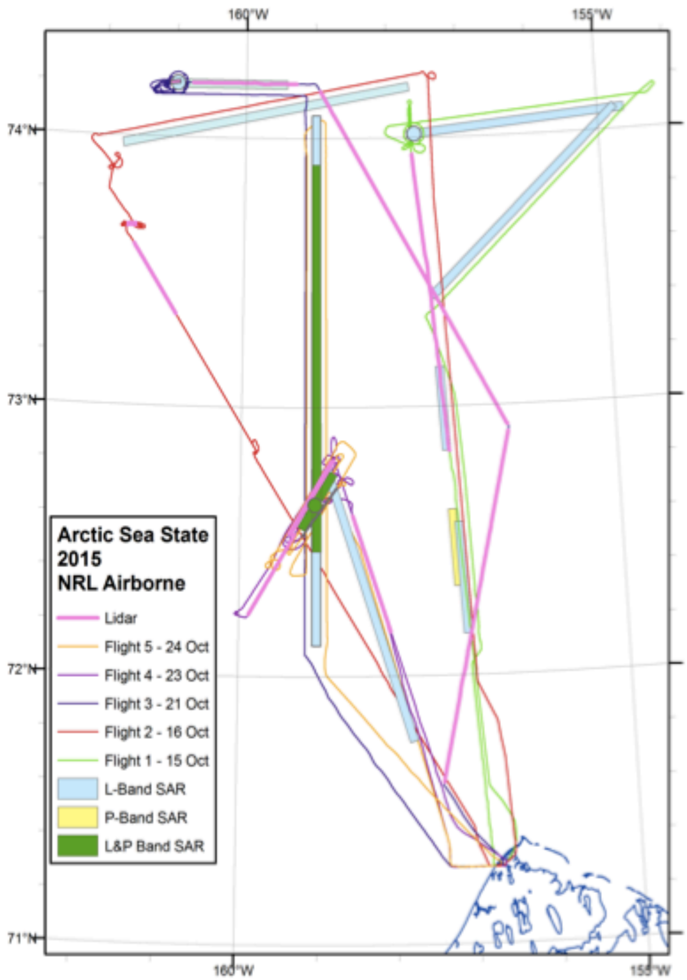
On a daily basis, the satellite remote sensing opportunities were evaluated looking ahead 2-3 days based on the rolling Plan of the Day (POD) and estimates of the position of upcoming stations. If Radarsat-2 planned acquisitions provided by the National Ice Center and the Department of Fisheries and Oceans Canada did not match the cruise plans, a separate request was developed and submitted to NIC who in turn would submit such requests to MDA. On a shorter lag period of 24-36 hours, plans were also developed between U. Victoria and the ship for TerraSAR-X acquisitions. Often these plans were coordinated with CSTARS at the University of Miami for either TerraSAR-X and/or CosmoSkyMed. Acquired and processed data were retrieved by the ship from land-based FTP sites or via email as attachments. Additionally, SAR acquisitions of opportunity were obtained from the Sentinel-1 and ALOS-2 SAR missions. All available processed imagery was displayed on the MapServer to be used for navigation, and assessment and possible revision of station plans. The ftp site at the University of Victoria is the primary location of acquired remote sensing imagery.



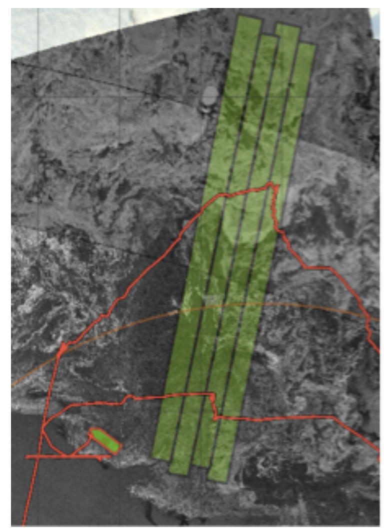
TerraSAR-X satellite orders

SUMMARY: Airborne Remote Sensing

In addition to the satellite acquisitions, airborne LiDAR, SAR, and visible images were collected by NRL operating a Twin Otter aircraft (five missions on 15, 16, 21, 23, 24 Oct) and UAVSAR data were collected by NASA operating a Gulfstream aircraft (one mission on 6 Oct).



NRL aerial surveys

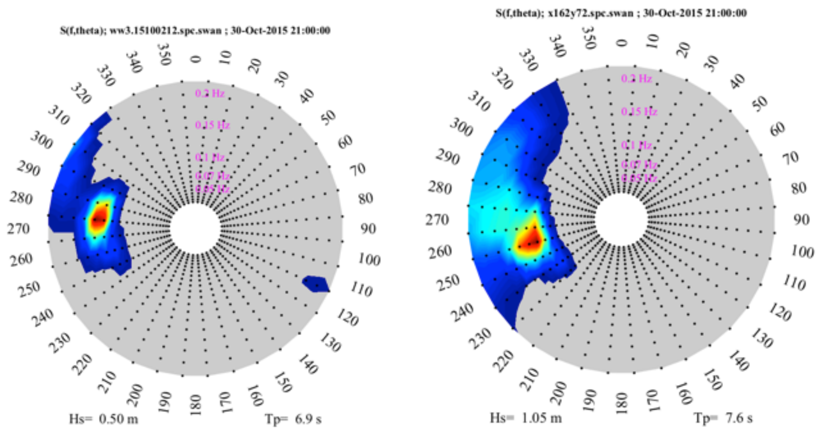


NASA UAVSAR flight lines

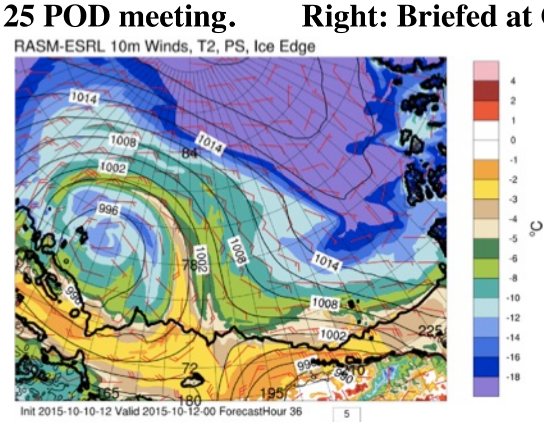
SUMMARY: Wave and Weather Forecasting

Daily wave and weather forecasts were used to adjust plans throughout the cruise and balance priorities. Wave forecasts were especially useful during design of the wave experiments. The forecasts were briefed at the Plan of the Day (POD) meetings held each evening on the ship. The wave forecasts were based on wave model simulations from three sources. The first was a nested modeling system run from the ship, a development version of the open-source community model, WAVEWATCH III(R). The second wave modeling system used was provided by ECMWF, using the WAM model. The third wave modeling system was another WAVEWATCH III implementation run by personnel at NRL-Stennis, using a system that was established for support of the USCCG Healy cruises in the summer of 2015. Weather forecasts were provided by NOAA, using both the standard GFS system and an experimental RASM forecast with higher resolution. ECMWF forecasts were also used, in particular the EPSGRAM output for specific locations. The weather forecasts were essential for identifying periods of active ice formation and for ensuring a balance of data collection during on-ice, off-ice, and along-ice winds.

Several months prior to the cruise, automated systems were created to deliver the outputs from the second and third modeling systems, and the ice and wind inputs necessary to run to the ship-based modeling system, to the ftp site administered by the University of Victoria. This proved to be a highly reliable method for aggregation and transfer of data.



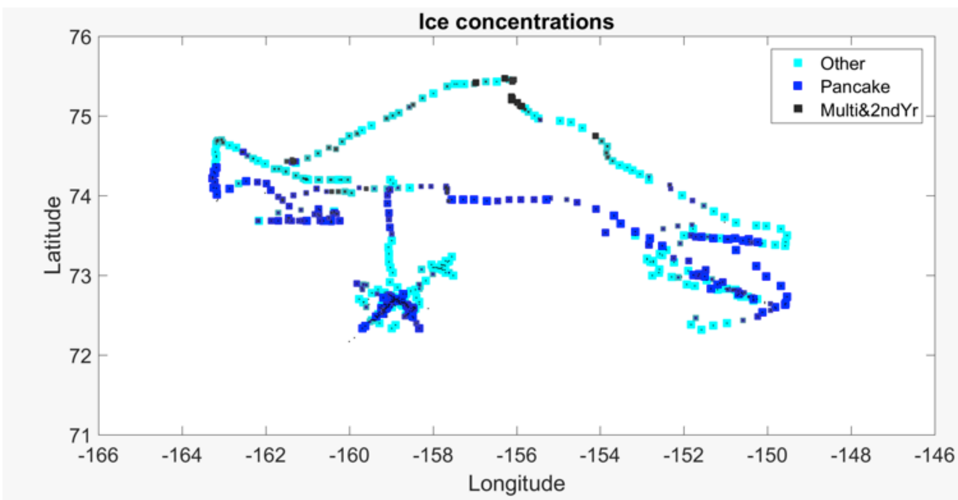
Two forecasts of directional wave spectrum used in planning Wave Array #7.
Left: Briefed at Oct 25 POD meeting. Right: Briefed at Oct 30 POD meeting.



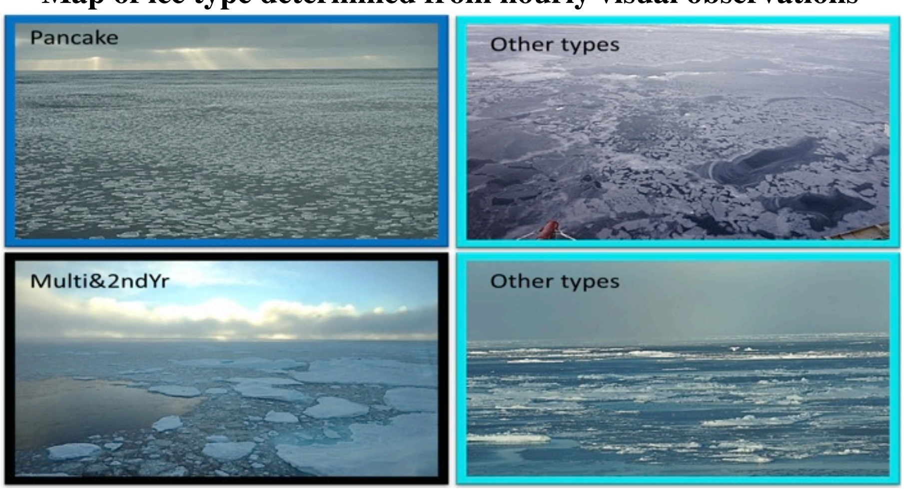
Surface winds and isobars from NOAA RASM forecast during Wave Experiment #3.

SUMMARY: Visual Ice Observations

Visual ice observations were made every hour from the bridge while underway and logged using the ASSIST protocols. These logs are available as daily csv files, as well as a summary of the entire record. The small scale of the pancakes, ice cakes and brash (meters to submeters) are well below the resolution of satellite radar images. Occasional ground truth from sampling is noted in the record whenever possible. The summary of ice observations along the track shown below therefore offers a new view of the ice edge region only available from near surface observations. The figure shows the observations divided into Pancake ice, Multiyear ice and Other (consisting mostly of Nilas and broken young ice forms into brash and small cakes). A previously unreported finding for this region from this cruise is the widespread occurrence of newly forming pancake ice as shown in the figure throughout the ice edge region observed on the cruise track. These observations will be closely compared with the remote sensing products (satellite and airborne radars and LiDAR) obtained simultaneously over the study area to identify distinct signatures associated with the surface observed ice types. Pancake ice formation, because of its close association with waves, will present a significant challenge to predictive models of the ice edge advance and eventual configuration of the seasonal ice pack. However, pancake ice is characteristic of the "new normal" Arctic ice pack.



Map of ice type determined from hourly visual observations



Examples of visual ice observations

SUMMARY: Physical Ice Sampling

Direct sampling of the ice was carried on throughout the voyage whenever the ship stopped or slowed, and was carried out 24 hours a day. At each stop two samples were taken. Frazil ice was sampled by a frazilometer, a tube closed at one end by fine mesh, which was lowered below the surface and pulled up through the frazil layer so that the volume of frazil collected could be converted into a volume per unit area of sea surface (equivalent to a thickness). Sea water was allowed to drain out of the frazilometer then the sample collected in a plastic bottle. Pancake ice samples were collected by an over-the-side landing net. During the early days of the cruise when the ice consisted of small pancakes embedded in frazil, this brought in representative whole pancakes, but later the cakes sampled were the smaller cakes or fragments of ice broken up by the ship's reamer. In every case efforts were made to obtain samples that were as representative as possible of the visually observed dominant thickness nearby, and sometimes more than one sample was taken with the results collected in different bottles according to thickness.

The samples were analyzed for salinity using a conductivity meter, and most of them were packaged up in small sample bottles for later analysis of O18/16 ratios, which will mainly indicate the fractional meteoric (snow) origin of the ice. It was always found to be the case that when pancake and frazil were collected at the same site, the pancake ice had the lower salinity. This was because the pancakes were growing out of the frazil by the frazil freezing-on, and the cake would start draining salt through newly forming brine drainage channels once the pancake structure was established. Typical salinities were 10-12 PSU for frazil and 7-10 PSU for pancakes. As the autumn progressed the pancake ice grew thicker and became more like a continuous ice cover, with many pancakes rafted and cemented together in groups ("cemented pancakes") and then cemented together further to yield vast ice sheets. New ice was now adding itself at the bottom by the congelation process so that frazil was no longer evident. The later samples therefore tended to be solid pancakes or fragments of pancake. The salinity in the solid pancakes was found to be inversely correlated with thickness, again indicating that in the older thicker pancakes the brine drainage process had been going on for longer. The thickest ice cakes had salinities of 5-6 PSU and thicknesses of 20-25 cm.

In addition to under-way sampling, physical ice samples were taken from the following sources:

a) Systematic cross-sectioning of a small number of the pancakes that were recovered whole, to study salt distribution through the pancake;
b) Ice samples from 10 cm sections of ice cores done during ice stations;
c) Ice samples from refrozen melt pools, again during ice stations, to test whether the pools had thawed through to the ocean before refreezing;
d) Ice samples from frost flowers. These are delicate crystals which sometimes form on new dark nilas and look like small white flowers strewn over the surface. They grow by a wicking process from the mushy nilas beneath, and they are highly saline, giving frost flower-covered ice a bright return on SAR imagery. Two of the samples taken had salinities of 89 and 92 PSU, about three times that of the Arctic Ocean surface water.
e) Ice samples from riming of ship structures (rails, antennas)

A total of 467 ice samples were taken and analyzed, comprising 70 frazil, 154 under-way pancake, 24 cross-sectional pancakes, 136 ice core samples, 64 melt pool samples, 11 riming and 6 frost flowers. Representative samples of all ice types recovered were kept in the freezer and the crystal structure examined using thick sections and crossed polaroids.

SUMMARY: Atmospheric Profile Measurements

A variety of atmospheric profile measurements were performed throughout the cruise. Every 6 hours (nominally at 0530, 1130, 1730 and 2330 UTC) weather balloons with attached radiosondes were launched. The frequency was increased to every two or three hours during certain periods (usually when crossing the ice edge). These measured pressure (height), temperature, humidity and wind vector. There were two types of balloon measurements: 1. Complete troposphere and 2. "Up/downs". The former were standard radiosonde observations where the balloon ascended to between 13000 and 16000 meters elevation (well into the stratosphere) before popping. Data were collected during the ascent and sometimes while the sonde descended but usually not all the way back to the surface. For the "up/downs" a leak was induced in the balloon which caused it to rise to about 4000 meters and then descend back down, data were collected throughout the up and down portions of the flight. The up/downs allowed two profiles to be obtained and allowed quantification of small scale horizontal variations. Typical distances between launch and touch down were 3-15 km.

InstantEye UAS with radiosonde attached below

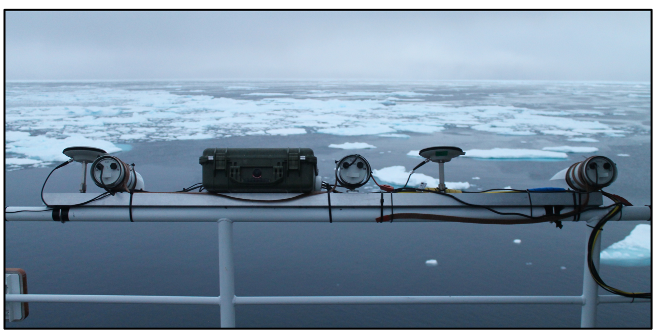
During several of the ice stations, a radiosonde was attached to an "Instant Eye" miniature quad-rotor UAS to perform low-level measurements of pressure (height), temperature and humidity. By flying upwind and downwind of leads and open water or thin ice regions it was possible to quantify the heat and moisture fluxes coming out of these regions. These also allowed detailed studies of the atmospheric surface layer structure and horizontal and vertical variations that were not possible with the balloon measurements. At ice station #10 similar measurements were performed using a fixed wing UAS.

Fixed wind UAS with radiosonde on top.

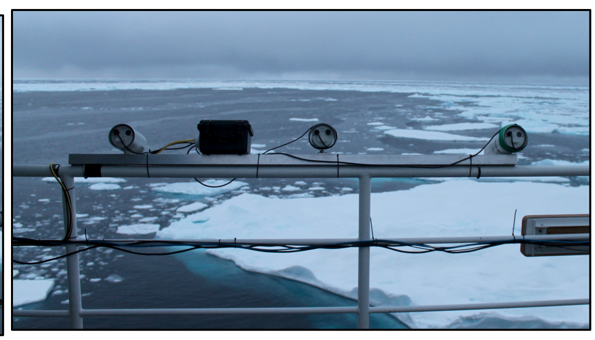
SUMMARY: Stereo Video

A stereo camera setup on both the port and starboard side were used throughout the cruise to measure waves and ice. Each setup consists of three small Point Grey "flea" cameras, installed at 18˚ below horizontal on the rail. The two outer cameras have approximately the same field of view, and are used to find the stereo solution. The center camera has a wider field of view, giving the context for the stereo measurement and a view of the horizon for motion correction in post processing. Both setups were calibrated during mobilization in Nome. The port side setup also consists of a Novatel IMU, which can be run concurrently with either camera setup to allow correction for the ship's motion in post processing. The IMU was also used to give a solution for mobile LiDAR scans.

The primary objective of the stereo camera setup is to measure surface waves via 3D mapping. In particular, we are interested in the motion of ice at a wavy ocean surface, and were able to capture a number of such cases with an in situ wave measurement from a SWIFT wave buoy close by. Such wave measurements are best made while holding station, but the stereo cameras were also used to measure waves and while underway at relatively low speeds. At some ice stations, the stereo cameras captured the surface of the floe, with the intent of calibrating the setup as an alternative method for mapping the surface roughness. As the stereo camera setup is daylight limited, amount of recording was limited later in the cruise.



Port Side Stereo Cameras and IMU



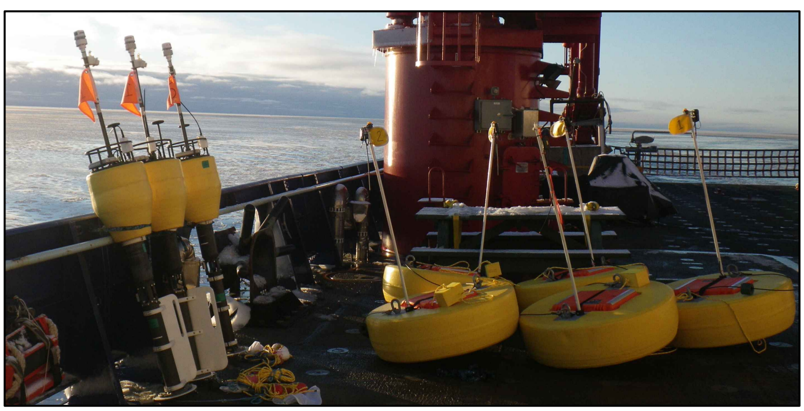
Starboard Side Stereo Camera Setup

SUMMARY: Wave buoy deployments

Four types of wave measurement buoys were used during the cruise: SWIFT (Surface Wave Instrument Floats with Tracking, made by APL-UW), WaveBuoys (made by Polar Scientific, Ltd), Wave-Ice buoys (made by NIWA), and a Waverider G4 (made by Datawell). The buoys were deployed in a variety of arrays during wave events. Deployments lasted 1-3 days temporally and spanned up to 100 km spatially. The buoys were recovered between each wave event, so that raw data could be offloaded and ice could be removed from the antennas. The buoys were tracked using a combination of Iridium beacons (global coverage) and Garmin Astro collars (local coverage, approximately 3 nm range).

The buoys measured waves using a combination of Inertial Motion Units (IMUs) and Global Positioning System (GPS) receivers sampling at 25 Hz or greater. The combined approach was important to obtain valid heading estimates (and thus wave direction) at high latitudes. After inter-calibrating the buoys, true heave (vertical displacement in the earth reference frame) was established as the consistent variable for calculation of the scalar wave energy spectra and bulk wave parameters (i.e., significant wave height, dominant wave period). Wave directions are quantified using the standard spectral moments (a1, b1, a2, b2), from which full directional spectra can be estimated using a variety of methods. The spectra and bulk parameters are calculated at regular intervals, with hourly ensembles preferred as the final data product.

The SWIFTs provided addition measurements, including: ocean surface turbulent dissipation rates (0-1 m depth), ocean shear (1-20 m depth), ocean surface salinity and temperature (0.5 m depth), ocean surface drift (2 m depth drogue), time lapse surface images (every 4 s), surface winds (1 m height), atmospheric pressure and temperature (1 m height).

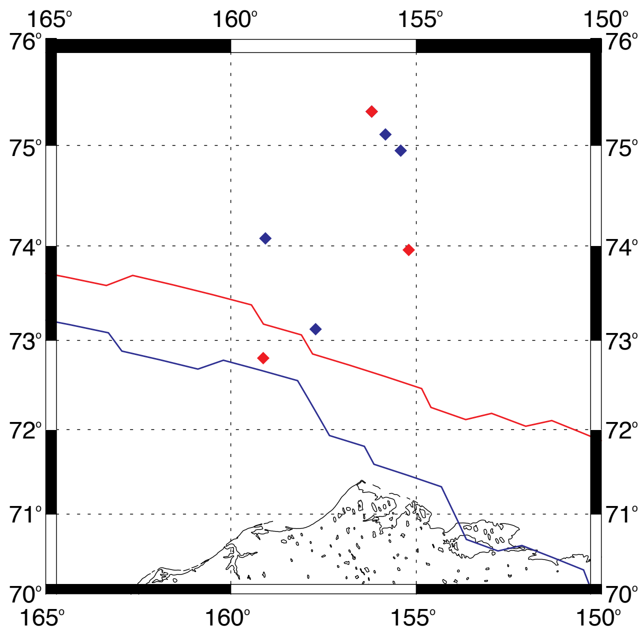


SWIFTs and WaveBuoys

NIWA buoy

SUMMARY: Ice buoy deployments

Expendable ice mass balance buoys (IMBs) were originally intended to be deployed in a small (~20 km) deformation array of five buoys. This included three IMBs from the Scottish Association for Marine Science (SAMS), one seasonal IMB (SIMB) from CRREL, and one experimental IMB with webcam built by Bruncin for WHOI. In addition, an ocean heat buoy built by WHOI was co-sited with an IMB. Additional expendable buoy deployments included an AXIB met buoy and two SVP buoy provided by UW-APL. The deformation array deployment was adjusted to best accommodate the capturing of wave events at the ice edge, and deployment location was determined by ice conditions, with the buoys roughly forming a larger deformation array with placement expected to capture varying conditions across the study area.



Map of buoy deployment locations. Blue dots indicate IMBs, red dots indicate drifting met buoys. The red line is the SSMIS ice edge on Oct 8 (day of first buoy deployment), and the blue line is the ice edge on Nov 1(after last buoy deployment).

Details of each deployment, with initial deployment location are described below:

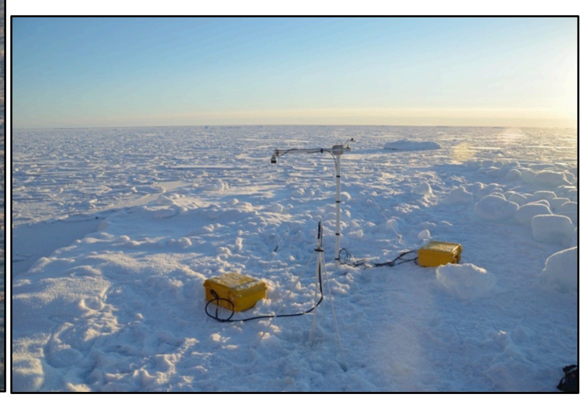
IMB 1. **(Deployed 10/08/15; 75.3236 N, 156.2008 W)** This was an experimental Bruncin IMB with a high-resolution temperature chain and web cam. Was deployed on ice station 1 in a large refrozen melt pond with an ice thickness of 50 cm with trace snow (largely removed at deployment site). The buoy worked on deck, but failed to transmit properly after deployment. A short-range Lidar scan was also obtained of the area.

IMB 2 (Deployed 10/08/15; 75.1058 N, 155.8311 W) SAMS IMB (WHOI02-2) deployed on ice station #2 on small level area surrounded by hummocks. Ice was 227 cm thick. A short-range Lidar scan was also obtained of the area. The IMB reported GPS every 15 minutes, temperature every 6 hours, and heating cycle every 12 hours.


IMB #1 (left) Photo: T. Maki. IMB #2 (right) Photo: J. Thomson

IMB 3 (Deployed 10/09/15; 74.9500 N, 155.4191 W) a CRREL Seasonal ice mass balance buoy was deployed on a rafted pancake (~60 cm thick, with trace snow cover) amongst a field of unconsolidated pancakes about 20-30 cm thick at ice station #3.

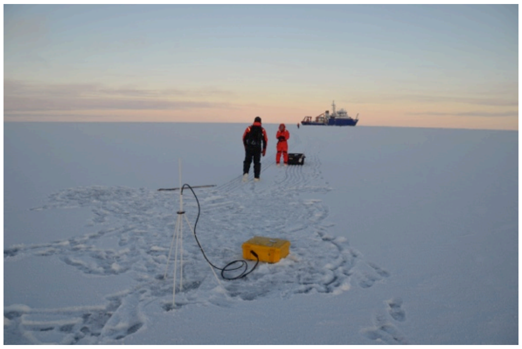
IMB 4 (Deployed 10/22/15; 74.0766 N, 159.067 W) A SAMS IMB (WHOI02-1) was deployed at ice station #9 on a small piece of remnant MY ice, in a field of consolidated pancakes (~30 cm thick). The ice thickness was 272 cm, with a snow depth of 6 cm. The IMB reported GPS every 15 minutes, temperature every 6 hours, and heating cycle every 12 hours. Adjacent to the IMB, and WHOI built ocean heat buoy (OHB) was deployed. This consisted of an 85m long chain of 14 thermistors at selected depths, and a pressure sensor to determine wire angle. A SBE 37SI CTD was deployed at 3 m depth, and a Campbell Scientific sonic snow depth sensor and Apogee SP110 pyranometer were mounted on the surface. These data are reported every 6 hours.

IMB #3 (left) Photo: T. Maksym. IMB #4 and OHB (right). Photo T. Maksym

IMB 5 (Deployed 10/28/15; 73.1216 N, 157.714 W) A SAMS IMB (WHOI 03) was deployed at ice station #10 in a vast field of consolidated pancake ice (25 cm thick) with ~2 cm snow cover. The SD card reader on this IMB failed, so it reported only in the default configuration (GPS every 2 hours, temperature every 6 hours, and heating every 12 hours). Temperature chain was lost on 11/01, during the ice retreat event, suggesting that the ice was ridged.

AXIB (Deployed 10/08/15; 75.3236 N, 156.2008 W) (Provided by I. Rigor APL-UW) Drifting met buoy, with surface temperature, humidity, pressure, and SST. Deployed on hummock adjacent to IMB 1 on ice station #1.



IMB #5 (left) Photo: T. Maksym. AXIB buoy (right). Photo: T. Maki

SVP buoy #1. (Deployed 10/15/15; 73.9579 N, 155.2040 W) AN SVP buoy was deployed on a pancake about 5 m in diameter, in a field of newly consolidating pancakes en route to ice station #4.

SVP buoy #2 (Deployed 10/31/15; 72.8049 N, 159.1264 W) An SVP buoy with drogue provided by I. Rigor (UW-APL) was deployed on a large finger raft (total thickness 124 cm – likely 4 rafts of 30 cm ice).

SVP buoy #1 (left). Photo: J. Thomson. SVP buoy #2 (right) Photo T. Maksym.

SUMMARY: Under Ice Vehicle Operations

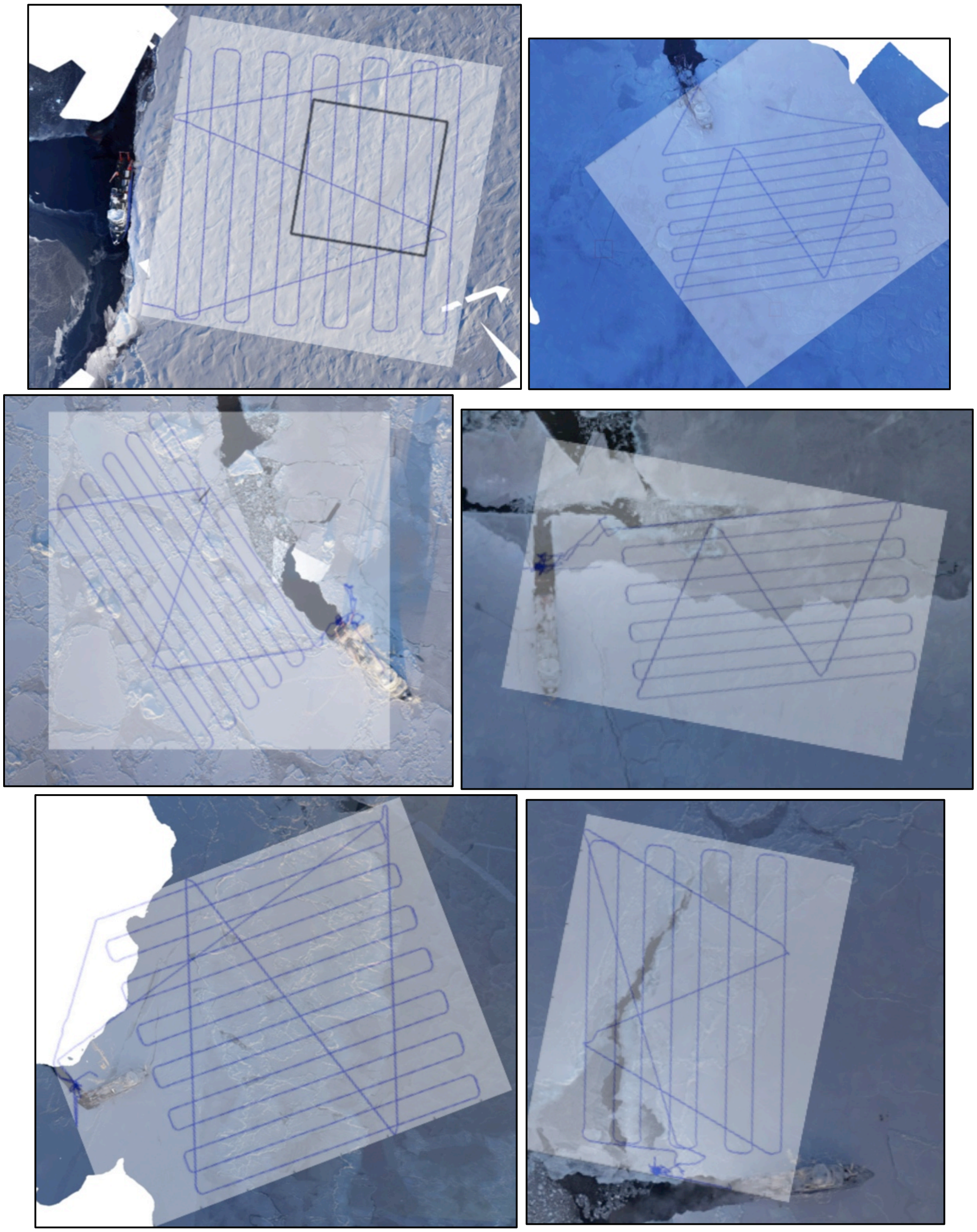
An autonomous underwater vehicle (AUV) and remotely operated vehicle (ROV) from WHOI were used to survey under the ice at many of the ice stations. The AUV was the SeaBED-class *Jaguar*, a hover-capable vehicle (enabling deployment and recovery through small area of open water) equipped with a Imagenex DeltaT multibeam sonar for under ice topographic mapping, an RDI workhorse ADCP (for DVL bottom tracking), and a SeaBird CTD. The AUV served as the primary under ice survey vehicle. As the new, thin ice in the vicinity of the advancing ice edge was not a practical target for long under ice transects, AUV surveys consisted of gridded surveys under selected floes with morphological features (rafting, ridging, hummocks) representative of the dynamical processes driving sea ice thickness in the autumn ice regime. Vehicle navigation was aided using 2-3 long baseline transponders deployed from the ice up to 400 m from the ship at each station.

At stations where it was impractical to deploy the AUV (e.g., for short stations, thin ice, or rapidly changing conditions) A Seatronics Predator ROV equipped with a Norbit broadband multibeam sonar, SeaBird SBE49 Fastcat CTD, and a Nortek Signature 1000 ADCP (in bottom tracking mode) was used on short transects (~100 m) from the ice to obtain imagery and thickness distribution of the ice underside under newly consolidated pancake ice and large finger rafts/ridging features.

The AUV performed extremely well in diverse ice condition. Rotation of the ice field was modest during all missions, easing navigation. Missions 5 and 6 were performed near the shelf break, where significant current was present (ice speeds between 0.6 and 1.0 kt). Little relative current speed was observed during mission 5, but it was evident during mission 6. Nevertheless, the missions were not adversely affected. Good navigation was significantly aided by the ability to deploy navigation beacons on the ice even when the ice was quite thin. Most critically, the AUV was able to navigate to small areas of open water (as small as 15 by 15 m) reliably for all missions.

<u>AUV deployments</u>

1. Oct 7. Ice station #1. 200 by 200 m grid under hummocks and refrozen melt ponds on multiyear floe. Coincident with on ice lidar and snow depth surveys. AUV depth of 20 m.
2. Oct 19. Ice station #6. 300 by 200 grid in rubbly and ridged area consisting of small multiyear blocks in thin ice, with ridges and rafts composed of thin ice blocks. Coincident with on ice lidar survey. AUV depth of 20 m
3. Oct 20. Ice station #7. 250 by 150 m grid in new ice ridges and rafts at the edge of a newly refrozen lead. AUV depth of 18 m.
4. Oct 21. Ice station #8. 180 by 100 m grid under floes of various sizes (newly refrozen) composed of brash, pancakes, and a few multiyear fragments. AUV depth of 10 m.
5. Oct 28. Ice station #10. 300 by 200 m grid, long direction under new rafting/ridging features in a lead, amongst thin consolidated sheets of pancakes (25 cm) and nilas. AUV depth of 15 m.
6. Oct 29. Ice station #11. 200 by 100 m grid under new ridges and large finger rafts formed from new sheet ice ~ 30 cm thick. AUV depth of 15 m.

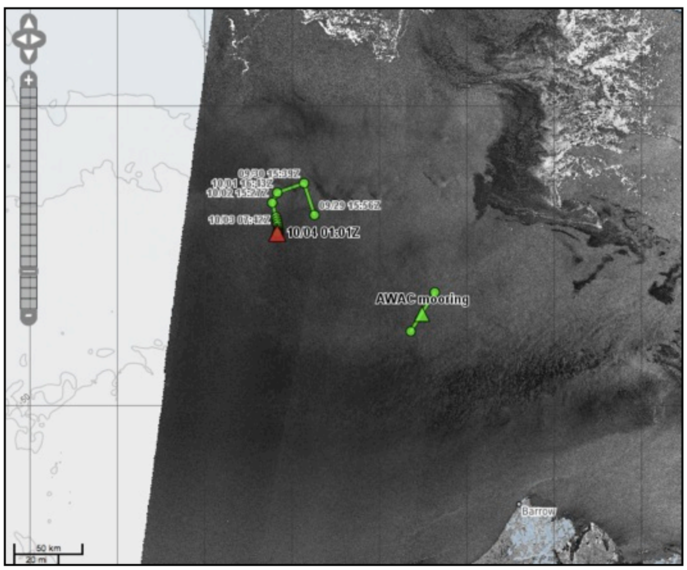


Approximate AUV mission grids overlaid on UAS photomosaics for each station. Order of missions is from left to right and top to bottom.

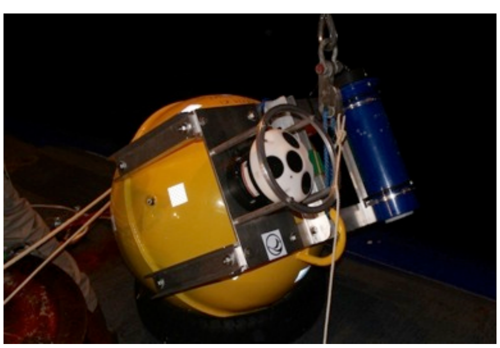
NARRATIVE: Outbound Transit, Wave Array #1, and AWAC Mooring (1-3 Oct 2015)

R/V Sikuliaq departed Nome, AK on the evening of 30 Sept 2015 and headed north towards the Chukchi and Beaufort Seas. We paused during transit on the afternoon of 2 October to briefly deploy wave measurement buoys for inter-calibration (wave array #1). Wave conditions were approximately 1.2 m waves at 5 s from the east-northeast. The results indicate that the buoys agree well when using true heave to calculate the frequency spectra of scalar wave energy. A Datawell Waverider was used for independent verification. The Rutter radar measurements agree with the buoys in terms of peak wave period, peak wave direction, and directional distribution of wave energy. A calibration of significant wave height from the radar is still pending. Buoys and radar indicate the presence of a secondary swell wave system from the south.

A sub-surface mooring with a Nortek Acoustic Wave and Current (AWAC) sensor was deployed on 3 Oct 2015 in open water at 72°38.220'N, 159° 00.674’ W in 100 m water depth. A CTD cast was acquired near the mooring site and water was taken for oxygen isotope analysis. A few test casts of the uCTD were also obtained. Later in the afternoon, a NAVO glider deployed earlier in the season was recovered in open water.



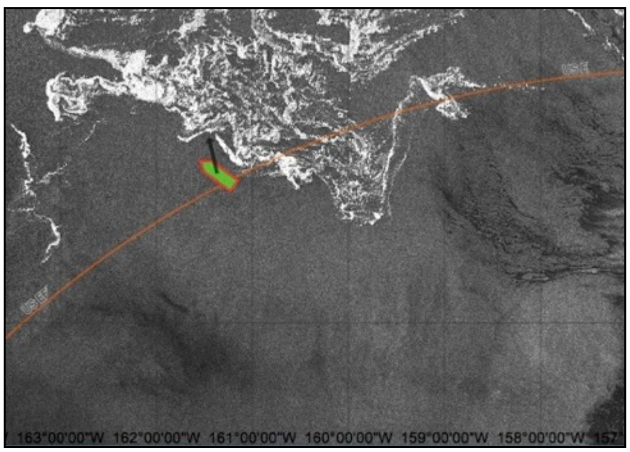
Mooring and glider locations shown over SAR image from the same day



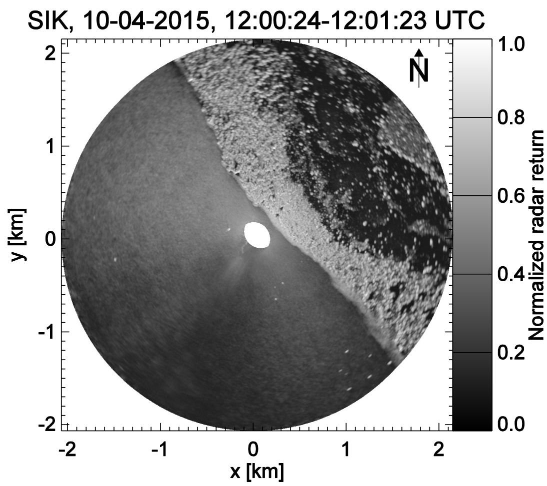
AWAC mooring **NAVO glider**

NARRATIVE: Wave Array #2 (4 Oct 2015)

We arrived at the ice edge for the first time early in the morning on 4 Oct 2015, where we had entered the deeper waters (> 1000 m) of the Northwind Ridge area. The edge was clearly visible in the Rutter radar. We deployed wave array #2, consisting of three SWIFT buoys crossing from open water into partial ice cover beyond a band of old ice, plus one wave buoy in the ice bands. We held the ship head-to-wind for several flux stations from the meteorological mast. We also conducted a tow-yo of the uCTD perpendicular to the ice edge, as well as hourly uCTD's while transiting and one ship's CTD cast for water collection for oxygen isotope analysis. Winds were obliquely off-ice from the northwest to north and generated 0.5 m waves at 3 s from the same direction. A second wave train at 4 s from the west was also detected, but was small. Waves were detected inside the ice band at 10 cm wave height and 7 s period from the southwest. The Rutter radar was acquiring during this and all subsequent stations. The resulting imagery can be used to document relative ice drift. Ballasting and operational readiness tests were conducted for the Woods Hole Oceanographic Institution SeaBED-class autonomous underwater vehicle (AUV) *Jaguar* as well as the Predator remotely-operated vehicle (ROV) system.



Ice edge and ship position on SAR image



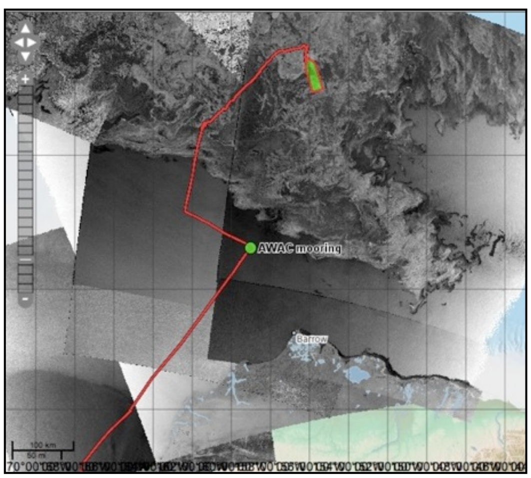
Ice edge on Rutter radar

***JAGUAR* AUV deployment**
(Guy Williams photo)

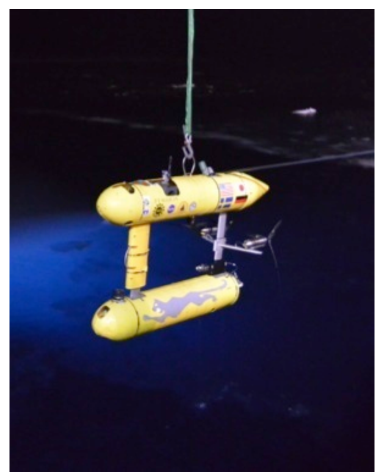
SWIFT in ice band

NARRATIVE: SIMS survey and Ice Station #1 (5-7 Oct 2015)

We transited northward, conducting hourly uCTD's, while passing through nilas ice sheets surrounding small thick older floes on 5 Oct, then found a large multi-year floe for Ice Station #1 ("Ben's floe", which had been tracked and targeted using the remote sensing imagery) early in the morning on 6 Oct 2015. We spent 6 and 7 Oct 2015 conducting a large ice station on this floe, including: an AUV multibeam grid survey under the ice with twelve 200 m legs separated by approx. 18 m, UAS surveys and meteorological measurements, LiDAR scans, EMI thickness surveys, drilled ice thickness lines, Magnaprobe snow-depth surveys, and CTD casts (one with the ship's CTD with water collected for oxygen isotope analysis and hourly with the uCTD). The floe was next to a wide lead, in which two SWIFTs were deployed that immediately froze in place. There was evidence of several refrozen former melt ponds in the big floe. Four locations were core sampled for ice properties and water in the core holes. The floe was at least 100 nm from any ice edge, and there was no sign of wave activity as this station. The NASA airborne UAVSAR sensor collected SAR imagery over this floe and the surrounding area while we were on station. One IMB and one AXIB were deployed at this station. Air temperatures were cold (~ -10 to -8° C), skies were often clear, and winds were weak and from the north-northeast. The orientation of the lead and ship did not allow on-bow wind component for flux measurements.



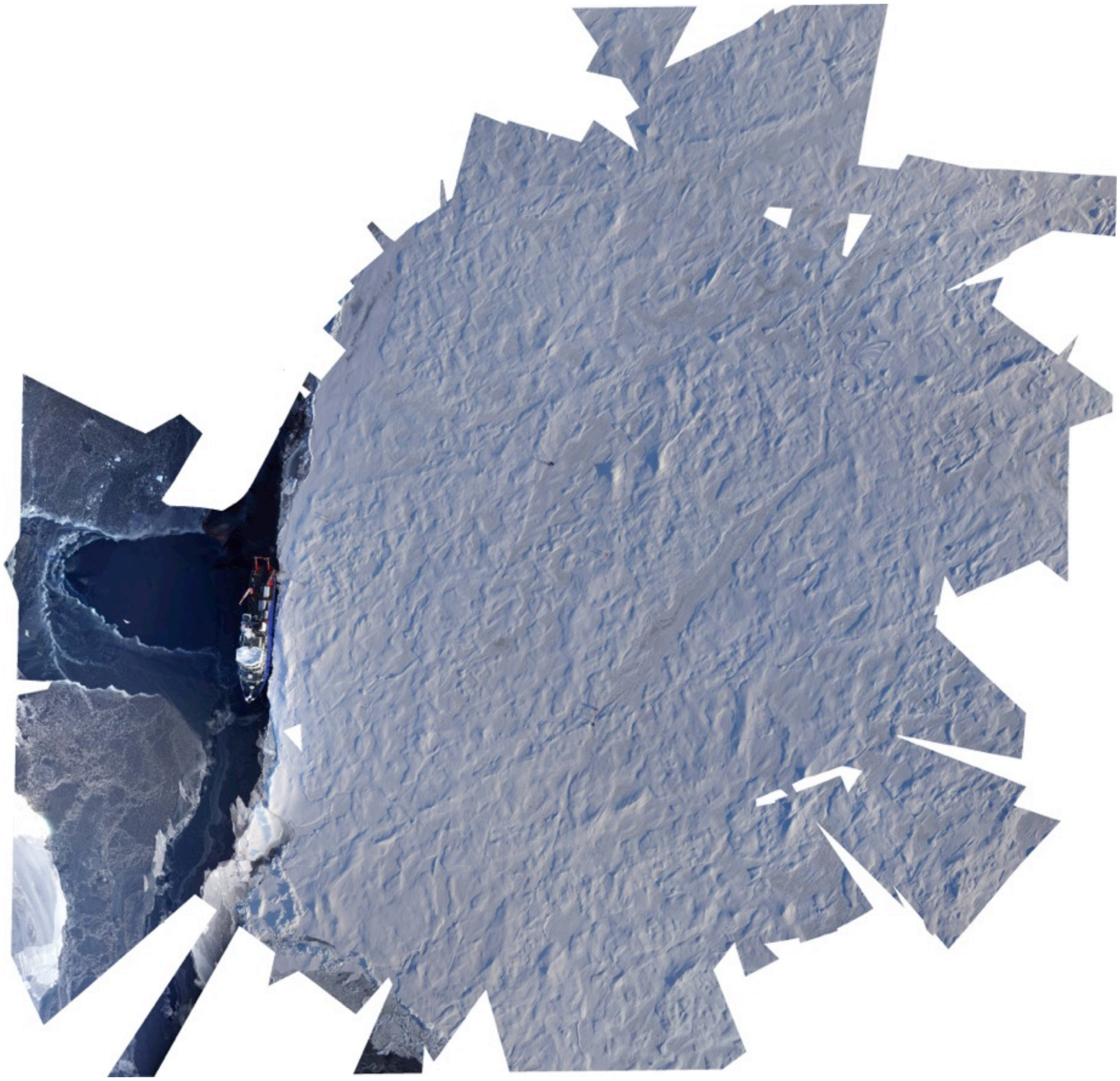
Sikuliaq postion and SAR image



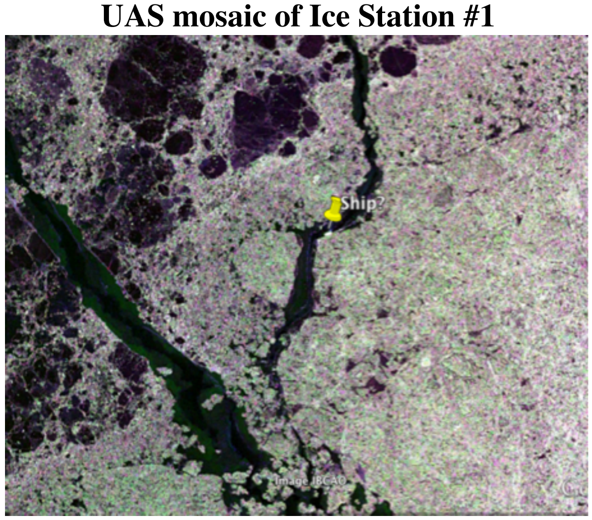
***JAGUAR* AUV recovery after approx. 4.5 hr survey under ice station #1 (Toshihiro Maki photo)**

Ship from LBL & CTD hole

AXIB and IMB



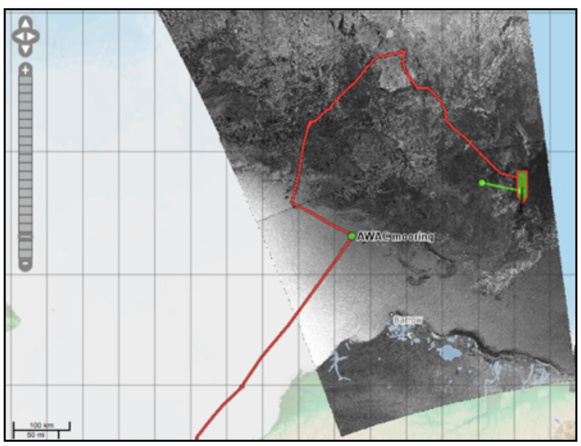
UAS mosaic of Ice Station #1



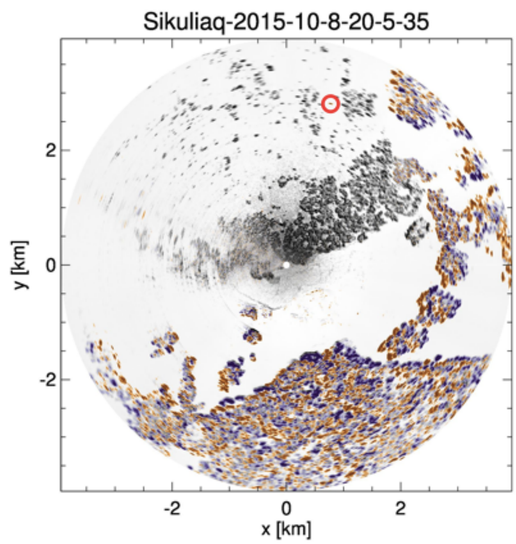
UAVSAR enlargement showing Sikuliaq at
Ice Station #1. Colors provided by different polarizations.

NARRATIVE: Ice Stations #2 and #3, SIMS survey (8-9 Oct 2015)

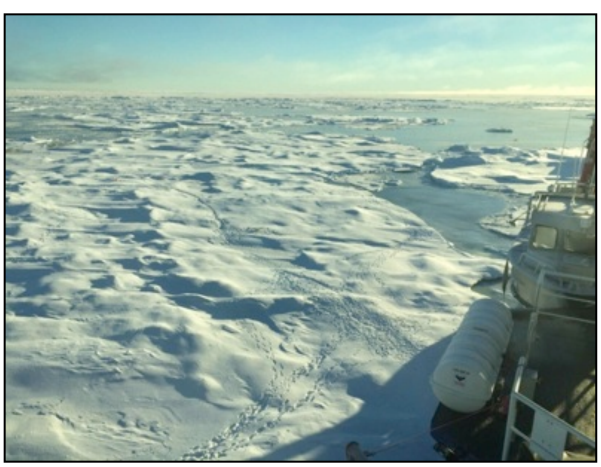
Ice Station #2 was conducted on 8 Oct at a small (200 m major diameter) multi-year floe (named "potato" after its shape) approximately 10 nm southeast of the first station. This was in an area with large leads. UAS photogrammetric surveys and UAS meteorological measurements, LiDAR scans, EMI thickness surveys, snow-depth surveys, flux measurements across a large expanse of nilas, and uCTD casts were conducted. An IMB was placed on the floe and a core (272cm) taken adjacent to it. Ice Station #3 followed later that afternoon; this was simply the deployment of an SIMB with a 27cm core on a large pancake (3-5m) about 10 nm southwest of the second ice station. This location is when we first began to see pancake ice (as we approached the ice edge on the Beaufort Sea side). SIMS survey data was collected along the track, as well as hourly uCTD casts. As we continued the transit to the southeast on 9 Oct, sheets of nilas ice were most common, but areas of pancake ice were also observed, suggesting wave activity had reached this portion of the domain.



SIMS survey track and SAR on 8 Oct 2015

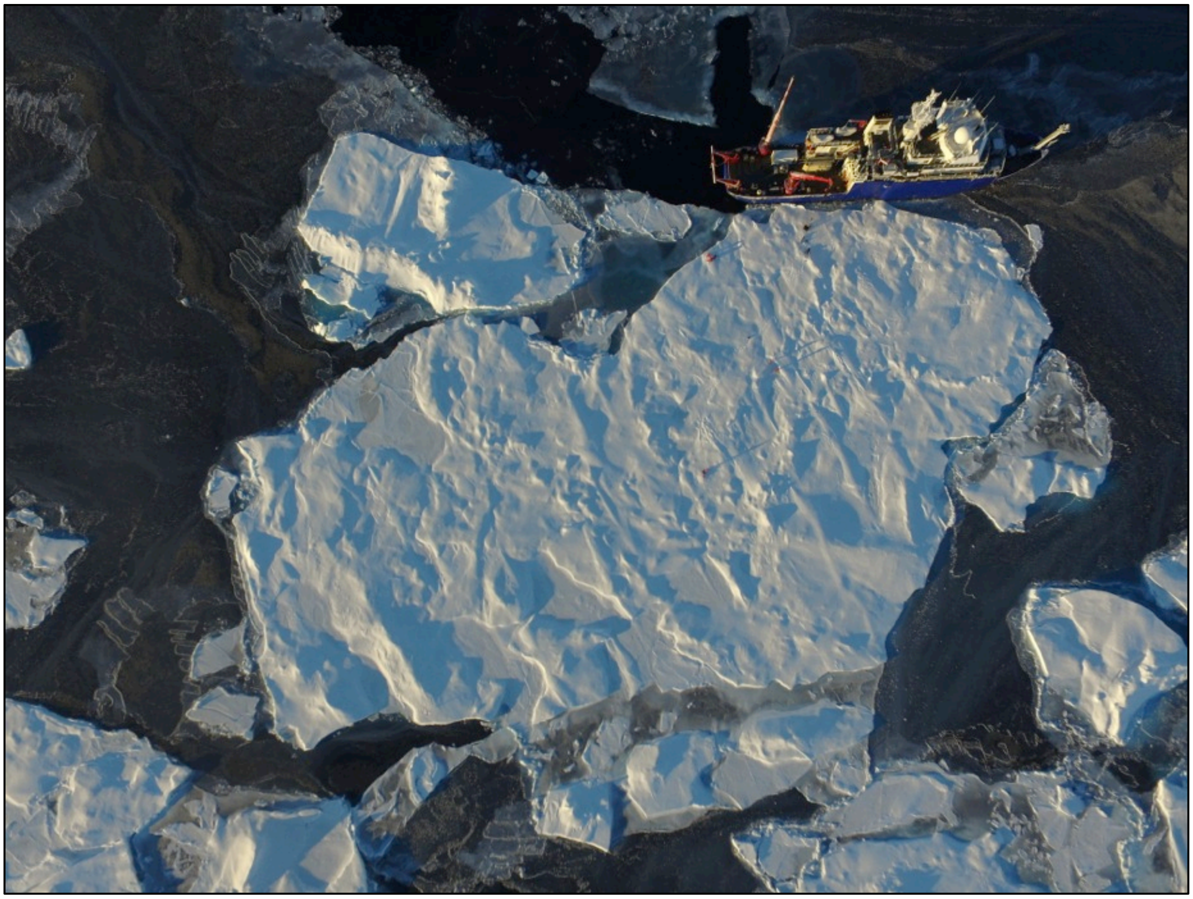


Rutter radar of Ice Station #2: colored areas illustrate relative ice drift and a polar bear is at red circle



Ice station #2

Ice Station #3



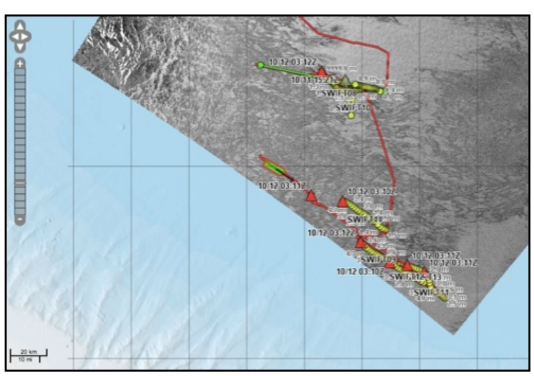
UAS mosaic of Ice Station #2

Fluxes obtained across nilas at Ice Station #2

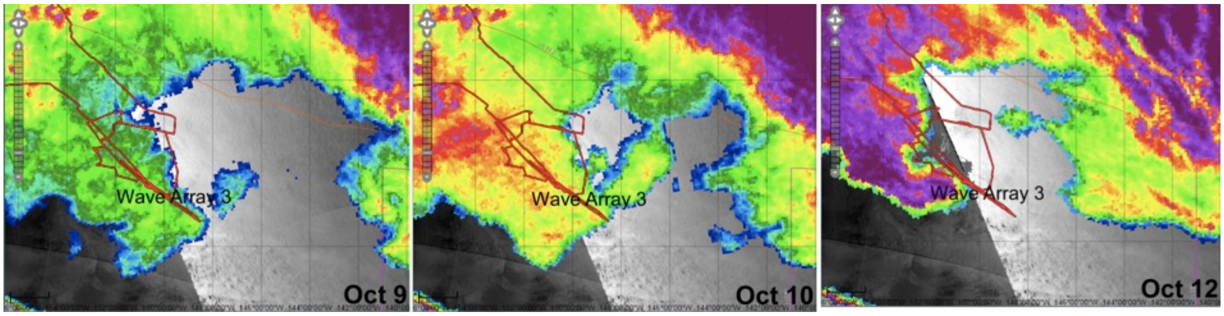
NARRATIVE: Wave Array #3 (10-13 Oct 2015)

Upon reaching the ice edge on the Beaufort side on 10 Oct, we began deploying SWIFTs, wave buoys, and one NIWA buoy to drift in an array aligned with the forecasted wave directions. We also conducted several uCTD tow-yos perpendicular and parallel to the ice edge. Pancake ice was forming rapidly and waves were approximately 1 m from the southeast. A few hours into the deployment, we received new RadarSat2 image and AMSR2 product, and we realized that the fetch for these waves was rapidly decreasing as an embayment of ice filled in. We decided to recover most of the buoys and shift the array to the south, where the full fetch of the Beaufort Sea would be available for this E-SE wind event and where waves were forecast to reach 4 m significant wave height. We left two SWIFTs and one NIWA buoy in place on the original line, to measure any waves propagating that far into the ice.

The second line of buoys spanned 60 nm, from open water to deep within a field of rapidly growing pancakes. This event was part of prevailing easterly winds, with E-SE winds of up to 16 m/s. Throughout the event, uCTD transects, both tow-yos and hourly, were completed across the buoy line, and stereo video of pancake motion in large waves was recorded as daylight allowed. Early in the storm, waves up 3 m were propagating all the way through the array (i.e., very little attenuation). The expectation was for the pancake ice to eventually freeze in place as the storm progressed. However, the pancakes largely disappeared overnight from 11 Oct to 12 Oct in the immediate vicinity of the buoy array, while the waves reached a maximum 5 m in the middle of the array. Further to the west, the ice concentration increased from this event. The working hypothesis is that near-surface heat flux convergence melted the existing pancake ice cover because of the observed decrease in the magnitude of the heat loss to the atmosphere and an increase in upward mixing of ocean heat stored in the “near surface temperature maximum” observed with the uCTD casts. The former was likely caused by warm air advection while the observed waves were likely instrumental for the latter. The waves may not have penetrated into the ice farther to the west, so heat loss to the atmosphere dominated and instead enhanced the ice concentration there during this wind event. The buoys were recovered on 13 Oct, in alternating bands of open water and pancake ice over a span of 100 nm. Heavy icing on the buoys caused many buoys to miss Iridium reports of position. The NIWA buoy, which was the farthest from the open water, recorded waves reaching 3.3 m during the peak of the storm, and was recovered in compacted pancake ice with little evidence of melting. The two SWIFTs left behind along the initial line were not recovered. We also acquired a ship’s CTD cast and collected water for oxygen isotope analysis before departing the area.



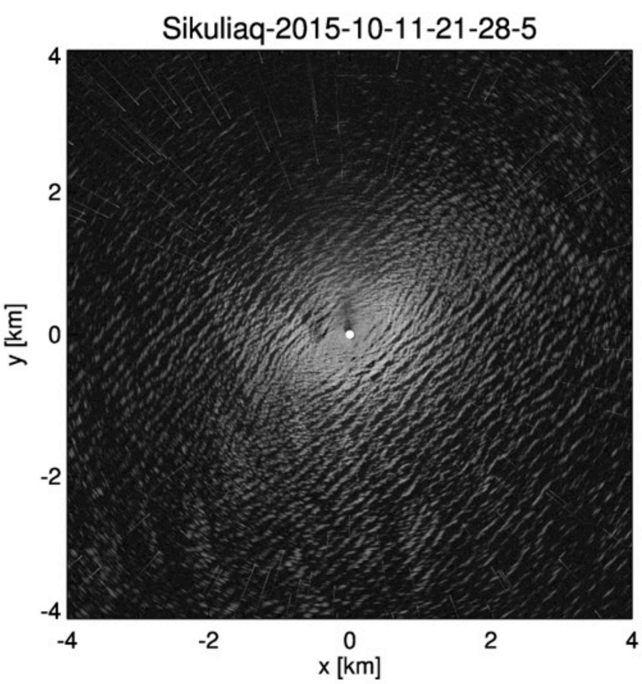
Buoy positions and SAR image for 12 Oct



Progression of AMRS2 ice concentration (color scale) during Wave Array 3


WaveBuoy 02: an example of the heavy icing during the deployment

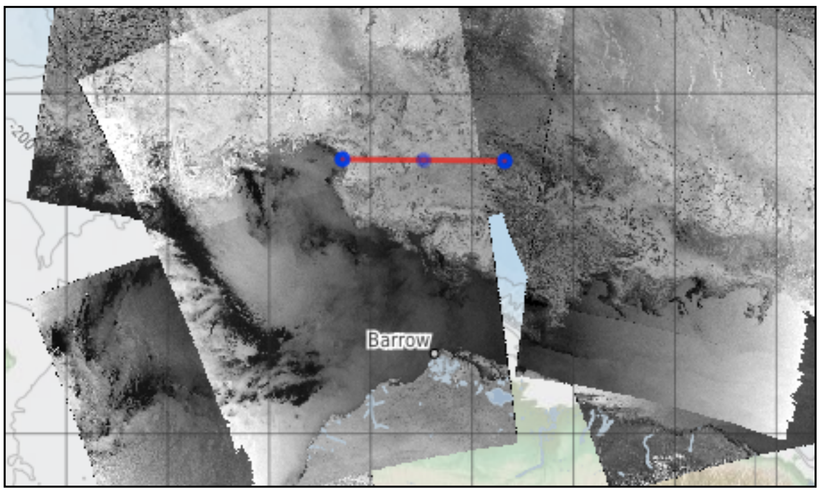

Big waves amongst the pancakes



Rutter radar raw image of wave signal within the pancake ice

NARRATIVE: SIMS Ice Survey and Ice Station #4 (14-15 Oct 2015)

A westward ice thickness survey using the shipboard SIMS (Sea Ice Measurement System) was conducted along 74° N from the buoy sites on the Beaufort side to an ice station in the middle of the pack ice, while also conducting hourly uCTD casts. An SVP was deployed en route. Once far (> 100 nm) within the ice, there were no more pancakes or evidence of wave activity. Ice station #4 was an ROV and LiDAR survey of a region filled with bits of old floes and ridges ("mixed nuts"), surrounded by new ice. A quad rotor UAS sampled low level atmospheric profiles of temperature and humidity over ice and open water regions. After the short station, the westward transect continued, with hourly uCTD casts, over to the Chukchi side. NRL airborne remote sensing flight #1 was conducted simultaneously, collecting L-band SAR along the same line. Useful underway flux measurements were obtained along parts of this track, as were a few flux stations.



SIMS survey line overlaid on SAR images for 14-15 Oct 2015

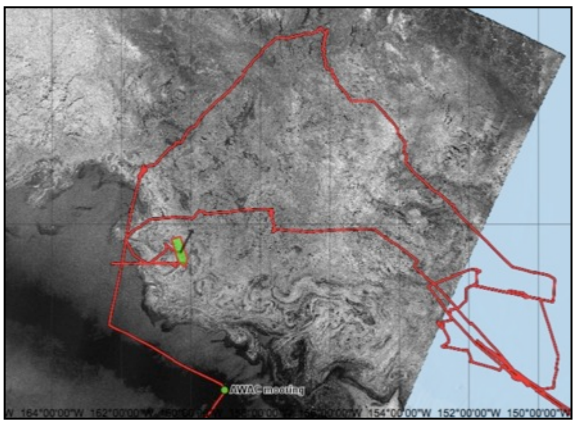
SVP deployed on a large pancake

Ice Station #4 ("mixed nuts")

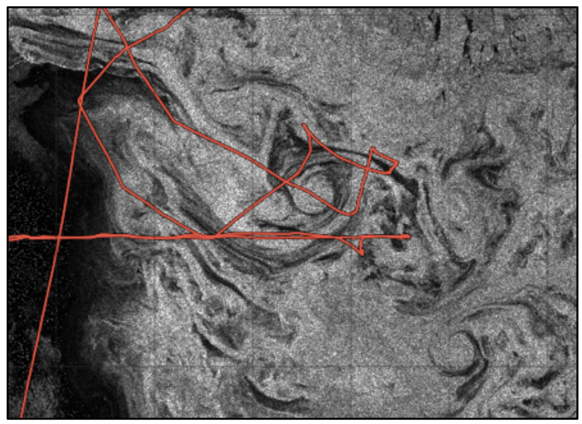
NARRATIVE: Wave Array #4 and Ice Station #5 (16-17 Oct 2015)

Upon reaching the ice edge on the Chukchi side, we found a diffuse ice edge with small pancakes. The incident waves were 0.3 m at 6 s from the southwest, and we deployed a line of buoys perpendicular to the ice edge and conducted two uCTD tow-yos. The ice was advancing rapidly, and the buoy farthest out was in grease ice. NRL airborne remote sensing flight #2 was conducted, finishing the L-band SAR line from the day before and collecting LiDAR over the small pancakes near the ship. On the 17th, small eddies were apparent in the region, detected by loose pancake ice being traced by underlying eddy current patterns. Hourly uCTD casts were also obtained through one or more of the eddies.

While deploying the line of buoys, we encountered a medium sized piece of multi-year ice that was heaving gently amongst the pancakes. We deployed wave buoys on and around this on 16 Oct, and surveyed the floe as Ice Station #5 ("Peter's floe") the following day. We conducted an ROV mission, thickness drilling, coring of refrozen melt ponds and a hummock, and LiDAR scans. In the meantime, some of the buoys became frozen in when the waves decreased, while others drifted northwest towards more open water.



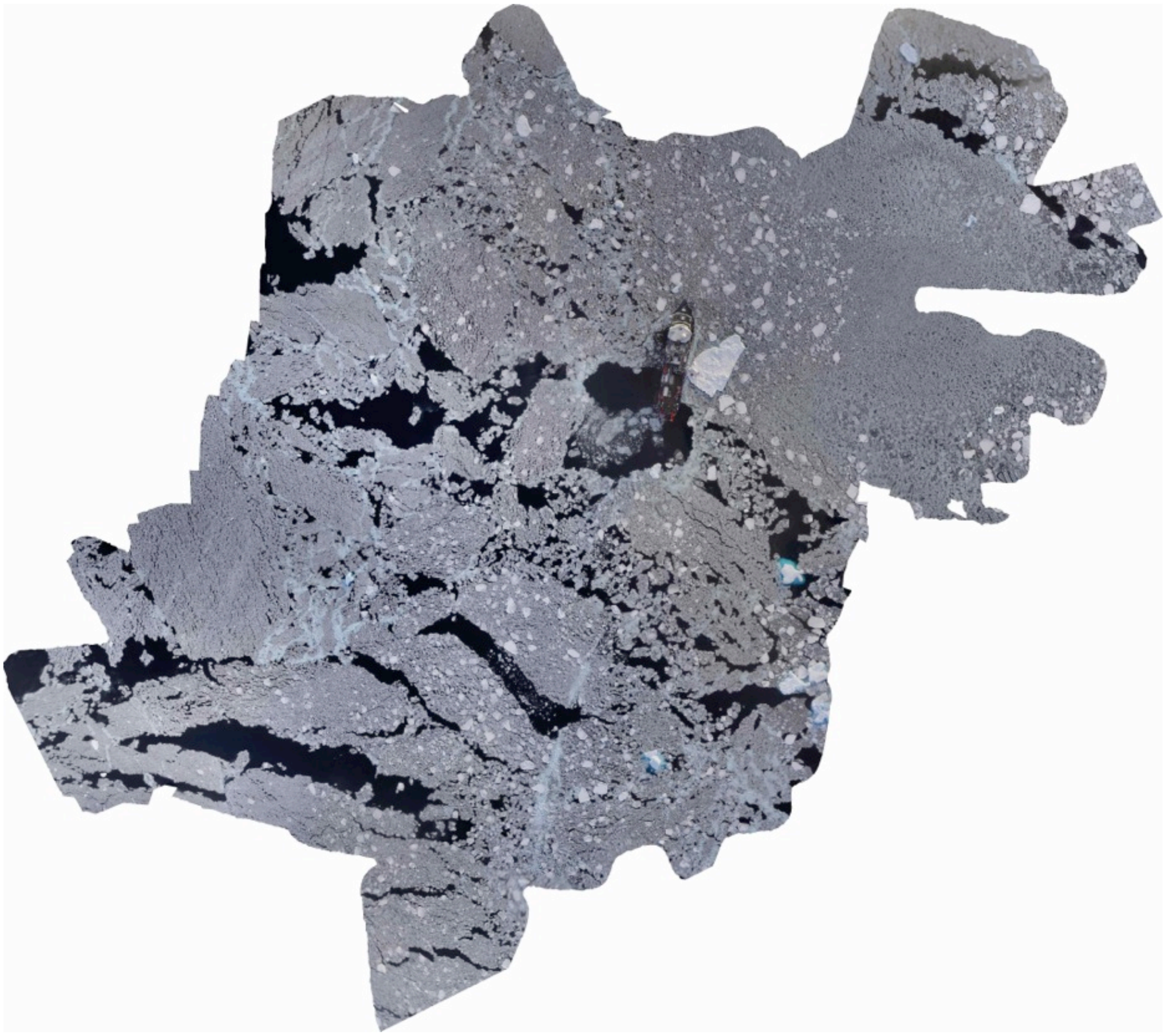
SAR image for 16 Oct



SAR image for 17 Oct

Pancake Ice at wave array 4

Ice Station #5 ("Peter's floe")

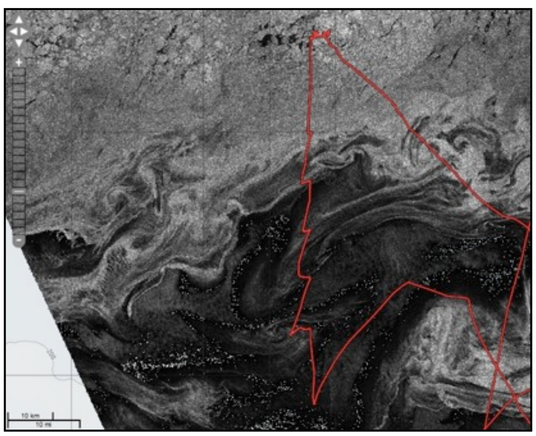


UAS mosaic of Ice Station #5

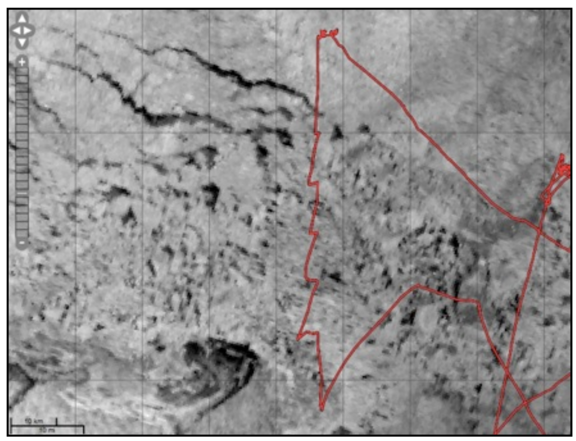
NARRATIVE: Northward flux line and Wave Array #5 (18 Oct 2015)

After recovering the buoys from the third pancake line early in the morning on 18 Oct, we stopped northwards on hourly flux stations (ship head-to-wind) through an embayment of open water that was experiencing off-ice winds and rapid cooling. Between each flux station we conducted uCTD tow-yos to acquire near-continuous upper ocean observations along the flux line. Stereo video of ice at the ocean surface was recorded at two of the flux stations. Underway fluxes were also obtained. At the second flux station, a narrow sharply-defined band of pancakes was encountered, which under the action of very short waves were causing reflection and scattering at the band edges. To investigate this effect, one SWIFT and two wave buoys were deployed to each side of, and inside, the band (wave array #5). There were very small (<10 cm) local wind waves from the northwest and a hint of the remnant swell at 6 s from the southwest. The array was in place for just over two hours, then recovered.

A distinct ice-edge cold front was encountered near the southern end of the flux line. Winds were off-ice from the north at 7-10 m s^{-1}, with low-level, cold-air outflow from the ice interior causing significant heat loss to the atmosphere. This entire embayment was later observed, via satellite, to freeze up within a day of our measurements.



Flux line and SAR image on 18 Oct



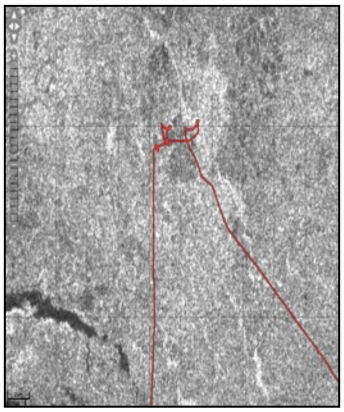
Flux line and SAR image on 19 Oct

Pancake ice on 18 Oct

NARRATIVE: Ice Stations #6 and #7 (19-20 Oct 2015)

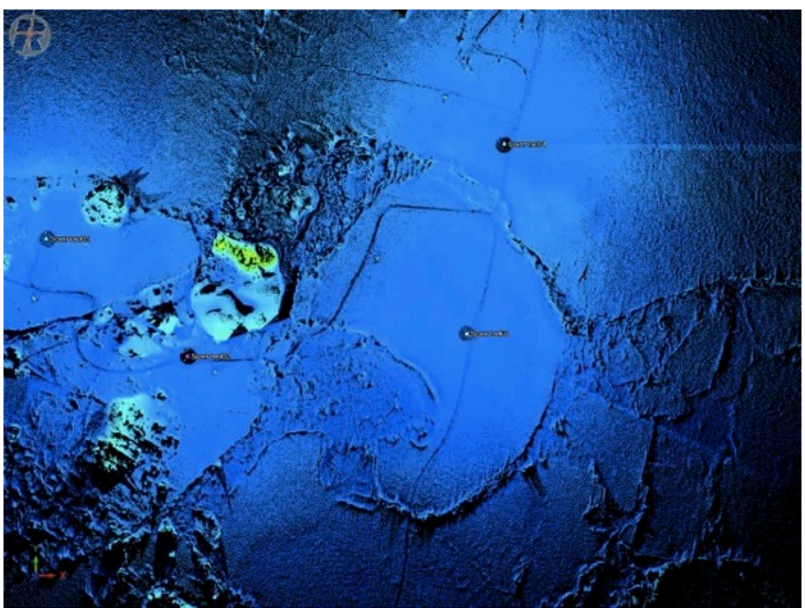
Ice Station #6 ("Barney rubble") was conducted on 19 Oct in a rubble field of ice between a few large expanses of very flat young ice sheets. Although the satellite images suggested that ice would be substantial in the north-central part of the Chukchi, it proved to be slushy and marginal for on-ice work. An AUV multibeam grid survey under the ice with twelve 300 m legs separated by approx. 18 m. A LiDAR survey was also conducted and CTD casts were taken. The ice was sufficiently flat and smooth to suggest no wave activity.

Ice Station #7 ("Seal Bear"; after a Polar bear stalking a seal hole nearby) was conducted nearby on 20 Oct, at a rubble field next to a large lead. An AUV multibeam grid survey under the ice was conducted, with ten 250 m legs separated by approx. 17 m. UAS, and LiDAR surveys also were conducted, along with coring and CTD casts. A quad rotor-UAV performed atmospheric profiles up and downwind of an open water region behind the ship to quantify "lead" heat fluxes. A few flux stations were obtained in weak northeasterly winds.

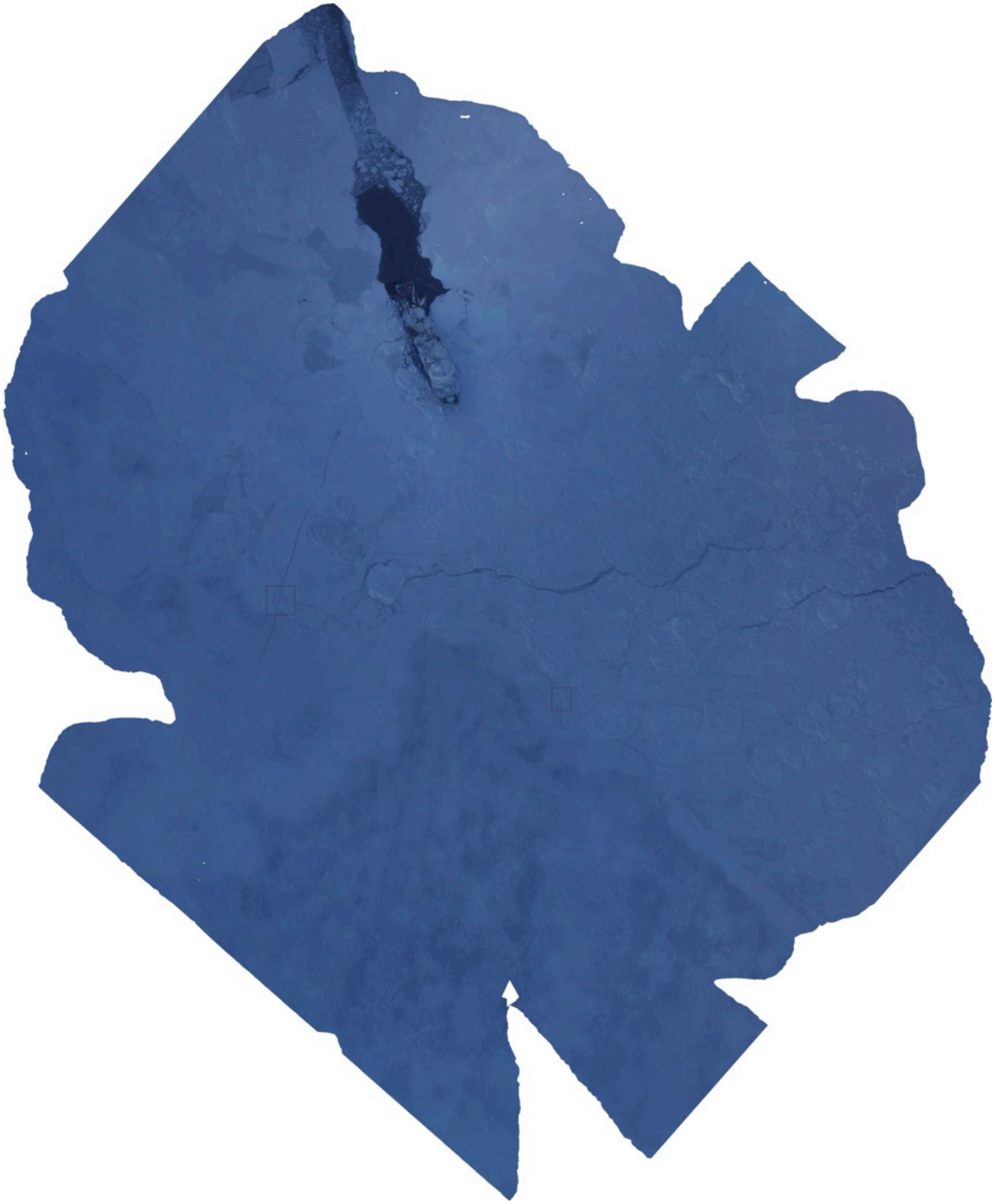


Ship track and SAR

AUV launch at Ice Station #6



LiDAR topographic map of Ice Station #6



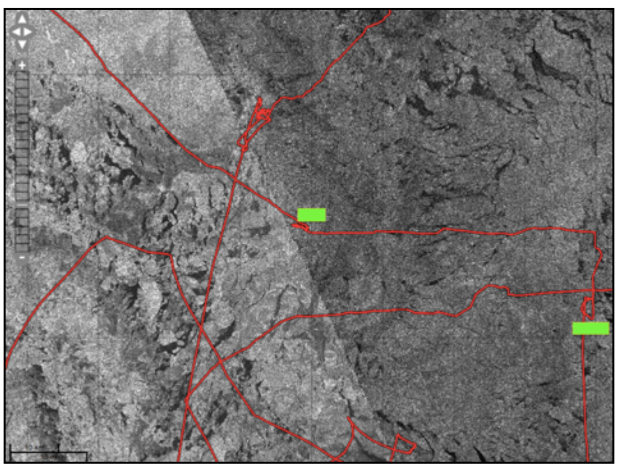
UAS mosaic of Ice Station #6

UAS mosaic of Ice Station #7

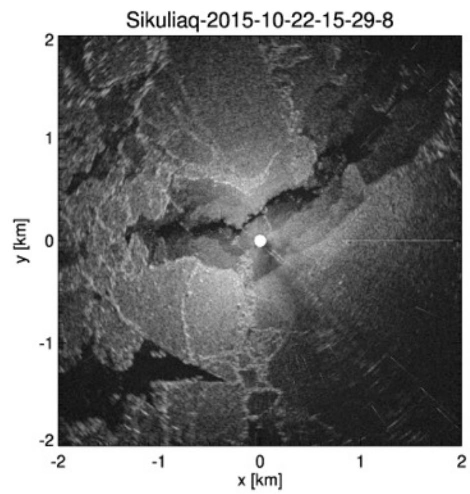
<u>NARRATIVE: Ice Stations #8 and #9 (21-22 Oct 2015)</u>

Ice Station #8 was conducted on 21 Oct after transiting eastward back into the middle of the pack. This station used a medium floe for the AUV baseline, and focused on a field of new rafting ice. An AUV multibeam grid survey was conducted under the ice with eleven 180 m legs separated by approx. 10 m. UAS and LiDAR surveys, as well as UAS atmospheric profiles, also were conducted, along with coring and CTD casts. NRL airborne remote sensing flight #3 was conducted, repeating the L-band SAR survey along 74° N, collecting LiDAR over the station, and finally an L-band SAR southward along 159° W. The Rutter radar provided high-resolution sea ice images here, and over the full duration of the cruise. The images were used heavily, both for navigation and identifying areas of interest for ice stations.

Ice Station #9 ("goldilocks" not too thick, not too thin) was conducted on 22 Oct after transiting southwards from the previous station. This station used a small second-year floe to deploy an Ocean Heat Buoy. The southward transit coming into and leaving from this station ran along 159° W, mimicking the NRL flight #3 survey.



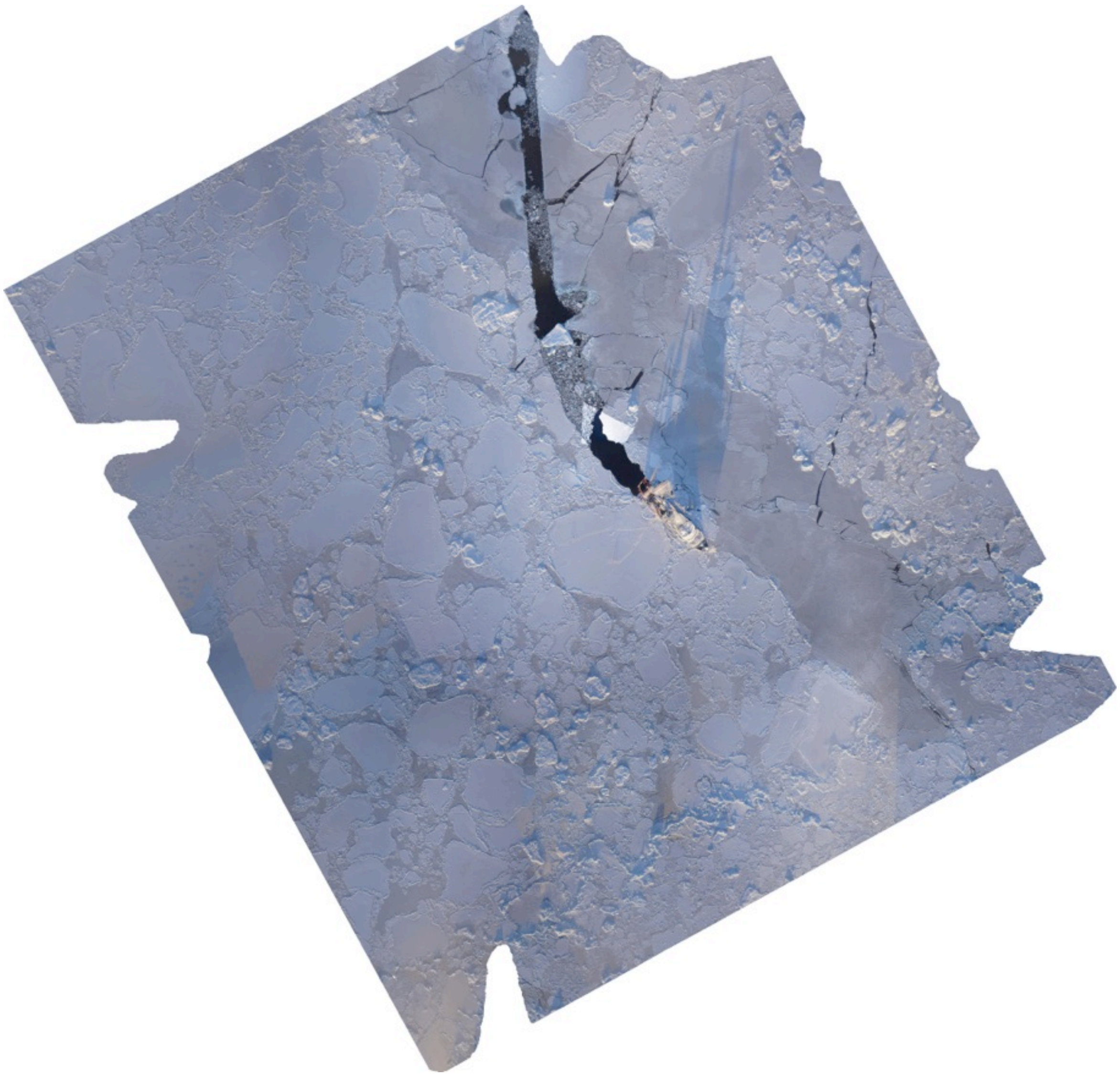
Ship track and SAR image



Rutter radar image at Ice Station 9

Ice Station #8

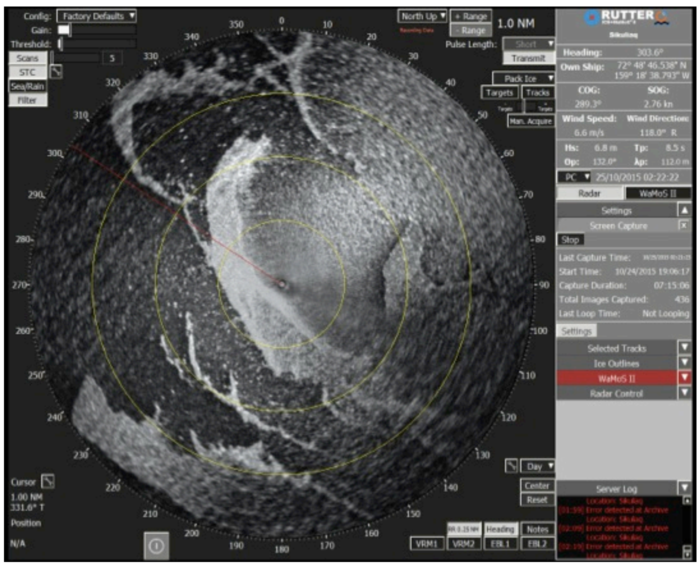
Ice Station #9



UAS mosaic of Ice Station #8

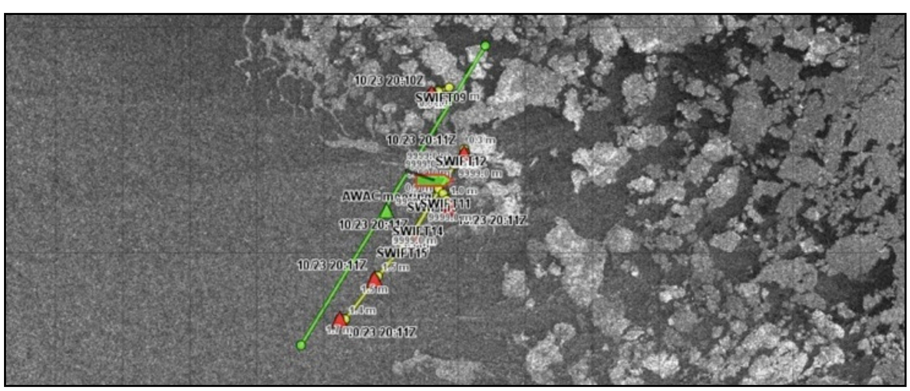
<u>**NARRATIVE: Wave Array #6 (23-24 Oct 2015)**</u>

During the southward transit, we conducted hourly uCTD casts and then arrived at the southern ice edge, near the AWAC mooring site, on the morning of 23 Oct. We deployed wave array #6 as a line of buoys extending from 20 km penetration out to open water. Near-continuous uCTD observations were acquired via tow-yos during transits between buoy deployments, as well as a ship's CTD cast and water collection for oxygen isotope analysis. Bands of pancakes were forming. Waves were 0.5 m at 7 s from the southeast and 0.5 m at 4 s from the east-southeast. Drift patterns suggested strong eddies at the shelf-break, and the buoys were alternately drifting in and out of bands of ice. The Rutter radar produced wave results throughout. It was also used to monitor the relative position between buoys and ice. Buoys were recovered on 24 Oct.



A typical band of pancake ice during this deployment, observed on the Rutter radar

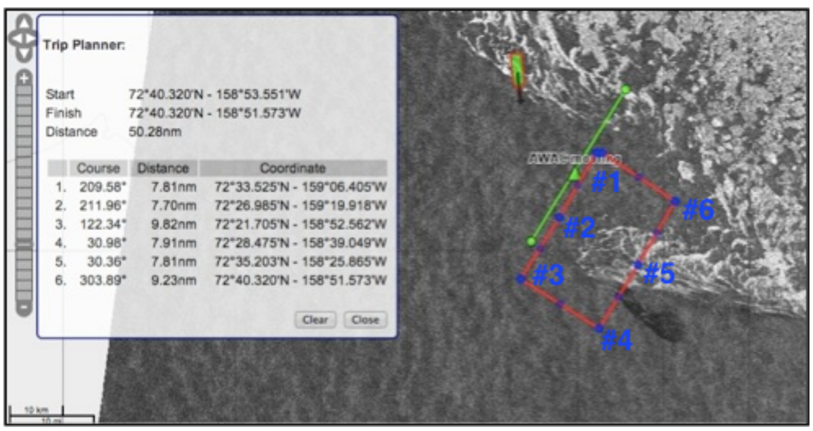
NRL airborne remote sensing flight #4 was conducted on 23 Oct, with LiDAR and SAR lines crossing the ice edge. NRL airborne remote sensing flight #5 was conducted on 25 Oct, with select repeated lines at the ice edge, and a repeated SAR line up 159° W. Several flux stations were obtained in 9-12 m s^{-1} winds blowing obliquely off ice from the ESE.



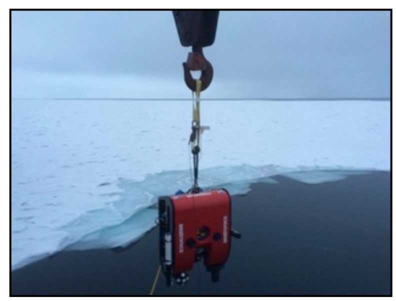
Ship and buoy positions over SAR image for 23 Oct

NARRATIVE: Flux "Race Track" and AWAC mooring recovery (25-27 Oct 2015)

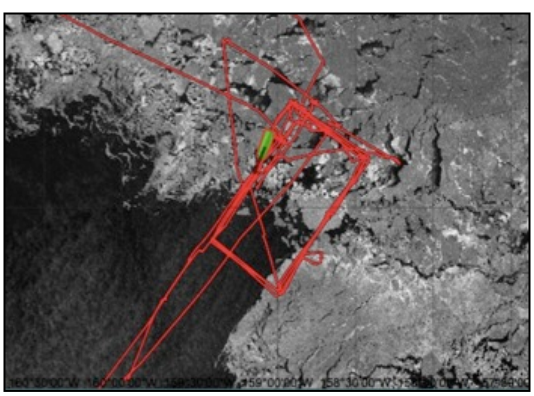
The AWAC mooring was recovered on the morning of 25 Oct, and then a race track pattern was established to measure the fluxes and ocean structure of the advancing ice edge during a forecasted cooling event with weak off-ice winds from NW through NE. The race track had six stations, each separated by 8 nm, running in a counter-clockwise sequence. The western leg of the race track included the AWAC location. The flux stations were held for 1 hour each and the uCTD tow-yos were nearly continuous during the transits between stations. A ship's CTD was also acquired at the southern station (point #4) with water collected for oxygen isotope analysis. Stereo video was recorded at flux stations when daylight and wave conditions allowed. Two SWIFTs were redeployed in open water and eventually froze in place as pancakes formed around them and joined together (see buoy video timelapse). Ice advanced rapidly across the race track, which changed from mostly open water to mostly ice cover in 48 hours. Some of this change was clearly due to advection of existing ice, but many areas experienced new freezing during this time. ROV and LiDAR surveys of the ice were conducted on 26 and 27 Oct at point #6 in the race track. While doing the race track, we left our marks on a large floe "cookie" 10 km across, as later captured by the TSX image on Oct. 29



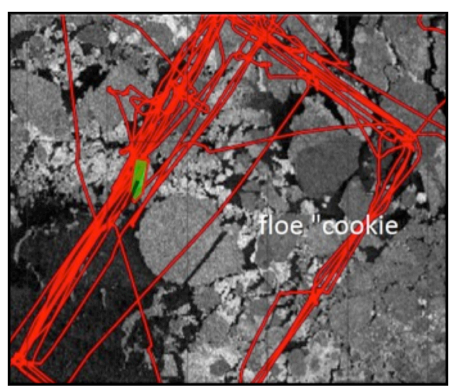
Race track, AWAC, and SAR image on 25 Oct



ROV on 26 Oct



SAR image on 27 Oct



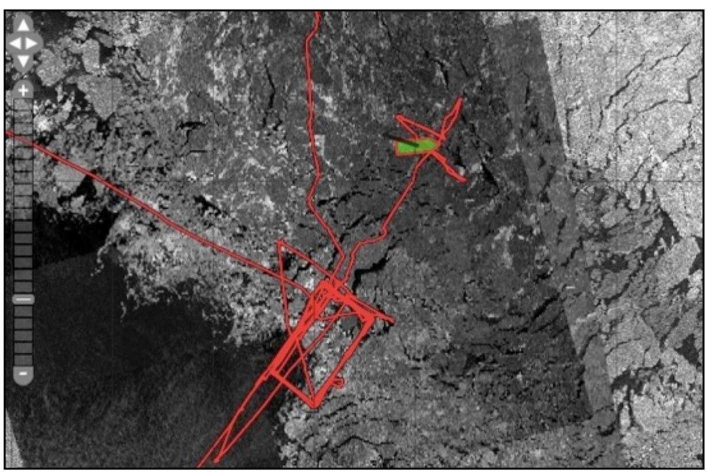
SAR image on 29 Oct

NARRATIVE: Ice Stations #10, 11, and 12 (28-30 Oct 2015)

We transited back into the ice pack approximately 40 nm overnight while conducting hourly uCTD casts, and then selected a broken up ridge for Ice Station #10 on the morning of 28 Oct. An AUV multibeam grid survey under the ice with fourteen 300 m legs separated by approx. 15 m was conducted, along with uCTD casts, a UAS survey, and drilling/coring. Atmospheric profiles were obtained with both fixed wind and quad rotor UAS. The ship was exactly head-to-wind to maximize the quality of the flux measurements from the met mast in weak (4-5 m s^{-1}) easterly winds. A LiDAR survey was conducted from the ship after the station was complete, by circling around the AUV survey domain.

We shifted approximately 10 nm overnight and selected another broken ridge for Ice Station #11 on the morning of 29 Oct. An AUV multibeam grid survey under the ice with eight 200 m legs separated by approx. 15 m was conducted, along with CTD casts, a UAS survey, and thickness drilling. The ship was exactly head-to-wind to maximize the quality of the flux measurements from the met mast. The coldest air of the cruise (~ -21° C) was encountered at this station. A LiDAR survey was conducted from the ship after the station was complete, by circling around the AUV survey domain.

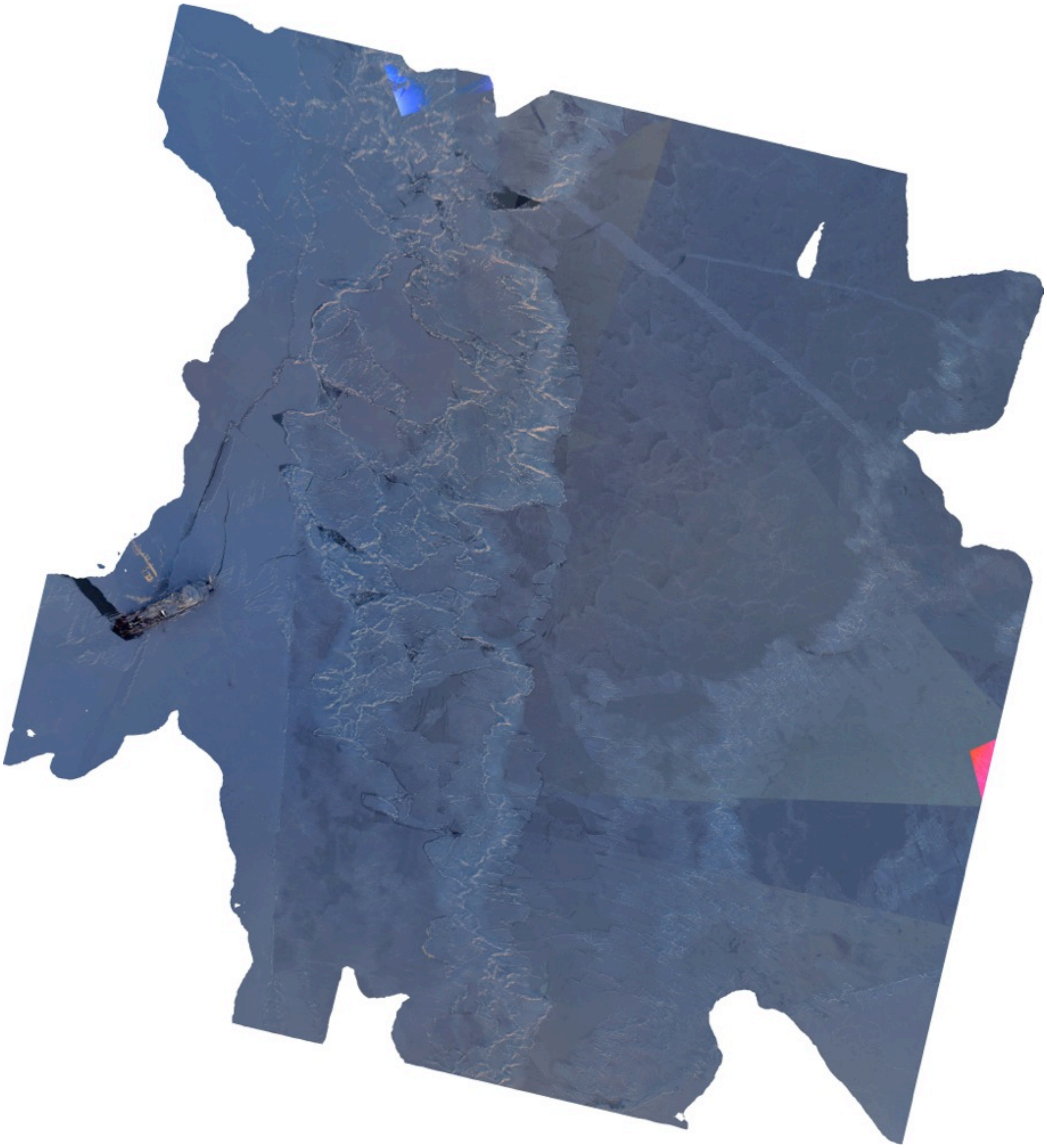
Overnight we transited back to point #6 of the race track (NE corner), then ran the line up to point #1 (NW corner) while tow-yo casting the uCTD. Upon reaching point #1 in the morning on 30 Oct, we set up for Ice Station #12 on a finger-rafted floe. We conducted a total of four ROV surveys, with repositioning and a LiDAR scan between the first and second surveys. Finally, an SVP buoy was deployed.



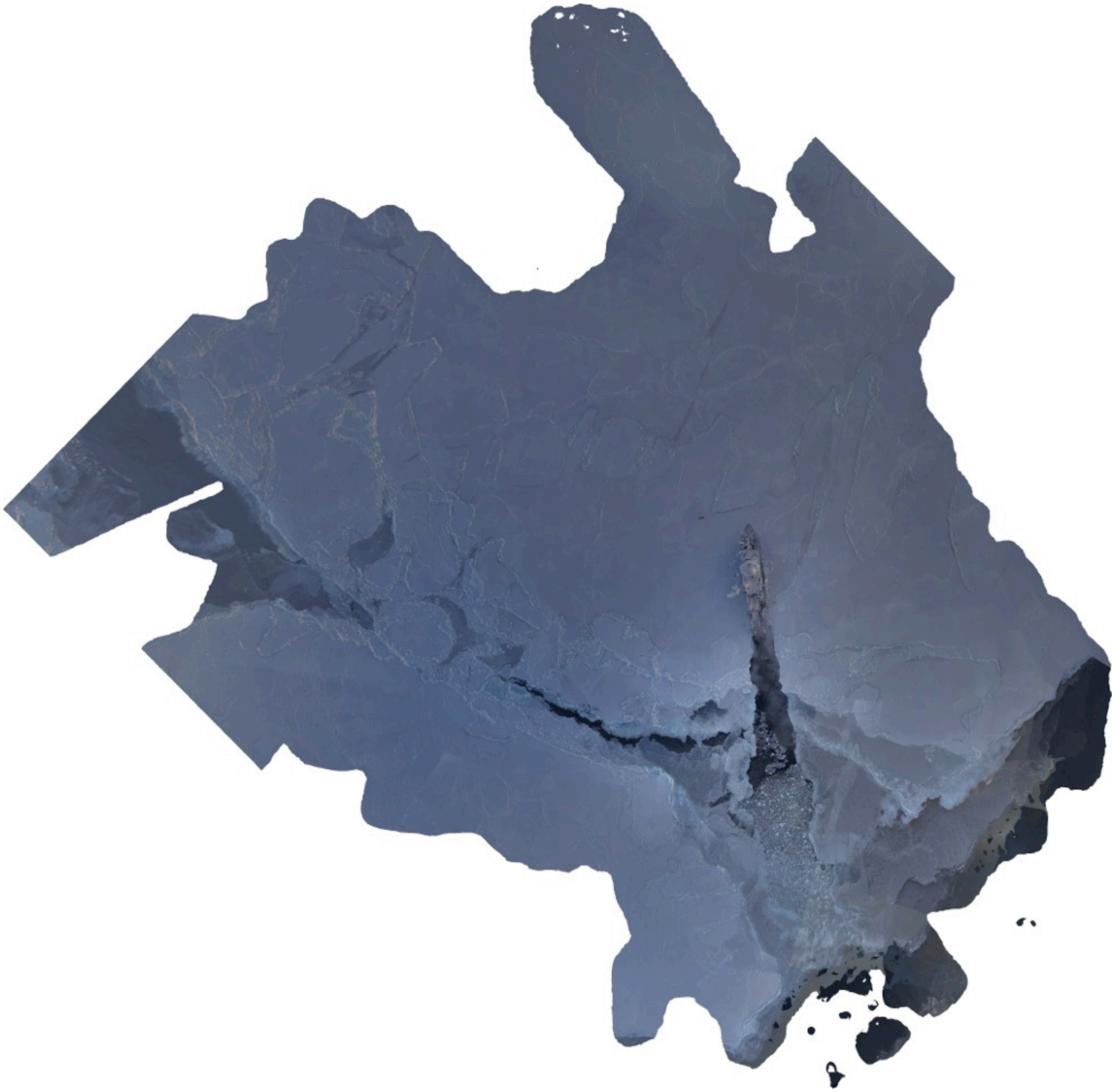
Ship track and SAR image

Ridge at Ice Station 11

Finger rafts at Ice Station 12



UAS mosaic of Ice Station #10

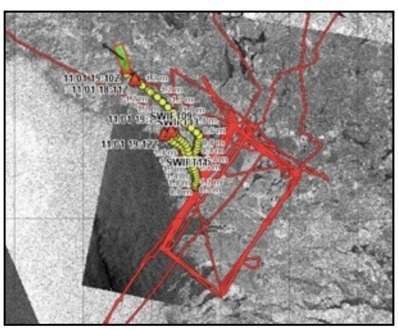


UAS mosaic of Ice Station #11

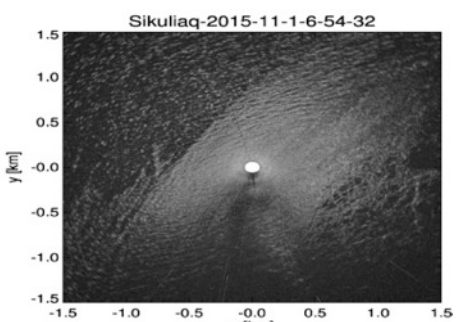
<u>NARRATIVE: Wave Array #7 (31 Oct – 1 Nov 2015)</u>

We ran the western side of the race track with flux stations (#1, #2, #3) and uCTD during the night, arriving at the end of the line in the morning. This line had been mostly sheet ice during the previous race track laps just a few days prior, but was now broken by waves into small cakes and brash ice. Presumably, this was caused by the western swell arriving at the ice edge (0.6 m at 7 s from W and another system from SW). We intended to deploy buoys to measure these waves at the edge around point #3, based on recent SAR images, but the ice retreated almost 10 miles overnight and we deployed at the new ice edge in the vicinity of point #2 instead. We deployed a tight array of 5 wave buoys, 4 SWIFTs, and 1 NIWA buoy for the morning inside the pancakes, at an internal boundary which marked a transition from pancakes to larger cemented floe-sized ice elements of 20 m and more in diameter. Then, we ran a stereo camera and flux station nearby, while yo-yo-ing the ship's CTD for ~1.5 hr. The tight array was designed to measure scattering, reflection and spectral broadening at a transition to large cakes whose diameters were a substantial fraction of a wavelength, with the hypothesis of scattering as the dominant mechanism of local wave-ice interaction. In the afternoon, we moved two SWIFT buoys out to open water for a larger-scale attenuation measurement. In the evening, we moved one wave buoy further inside the ice. We then resumed the flux stations and upper leg (#1-2-3) of the racetrack. The Rutter radar was collecting data throughout the experiment. It detected waves in a variety of conditions ranging from new sheet ice, pancake ice, and brash ice, to open water.

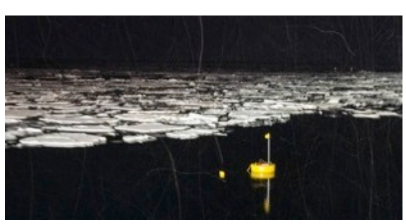
The ice retreated farther during the early morning of 1 Nov, to about halfway between race track points #1 and #2. Active breaking of sheets was observed while transecting out #1-2-3 and back on #3-2-1. The westerly swell died and the southwesterly swell built to 1.7 m at 4.5 s (from the buoys on the edge). In the morning, we left point #1 to recover buoys that had drifted to the northwest. A few of the buoys were recovered from open water, the rest were in loose-cake ice. Moderate SSE winds transitioned into weak and variable as a shallow low-pressure system moved over the array, bringing substantial warm-air advection.



Positions and SAR on 31 Oct



Ice edge from Rutter radar

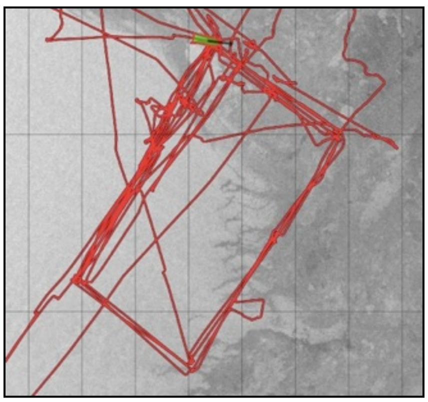


WaveBuoy in cake and brash ice

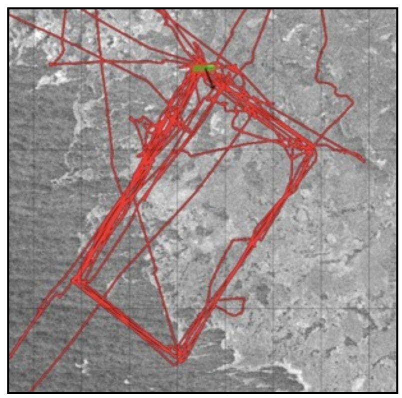
NIWA buoy

NARRATIVE: Race track with flux stations (2-3 Nov 2015)

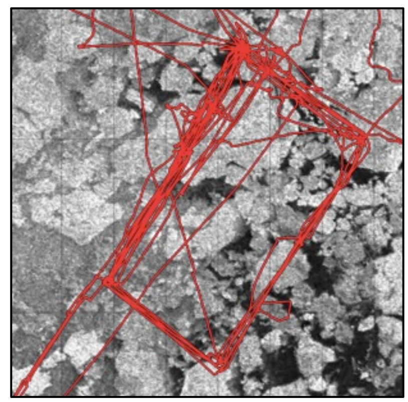
After buoy recoveries on Nov 2, we began a full race track (#1-6) in a clockwise direction, conducting hourly flux stations and doing near-continuous uCTD tow-yos between stations. We added short SWIFT deployments during each of the first three flux stations (#6, 5, 4 for 1 hour each). Strong winds from the east (15 m/s) advected cold air over the racetrack and produced a steep wind sea in patches of open water. On 3 Nov, the ice was drifting fast (0.6 m/s) to the west and substantial first-year ice was moving through the region. In the evening, during the last TSX satellite acquisition, large floes and large leads were both common, with up to 1 m breaking seas in the open areas.



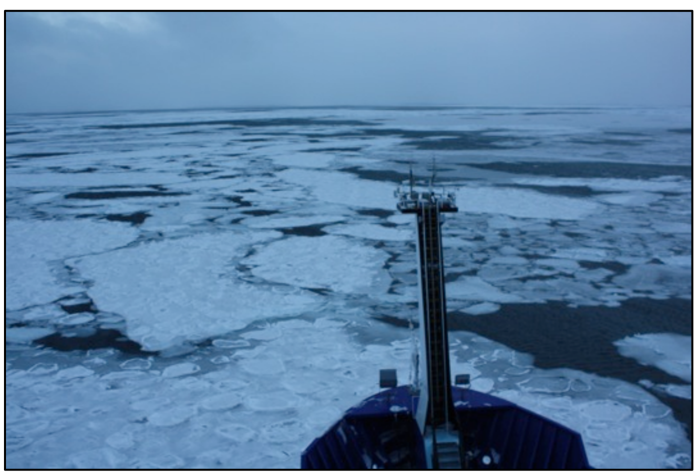
SAR on 2 Nov



SAR on 3 Nov



SAR on 5 Nov



Mixed ice conditions at Racetrack Point 2 flux station on 2 Nov

NARRATIVE: Transit and wrap up

We began our transit south to Dutch Harbor in the evening on 3 Nov. We continued to conduct flux stations until 50 km from the ice edge, and we continued uCTD casting until approximately 71° N (late afternoon on 4 Nov).

The Sea State DRI team is funded by the Office of Naval Research for two more years to analyze and synthesize the data collected during this effort. Results will be presented in a special issue of an academic journal and at academic conferences. A preliminary list of paper topics was drafted by the team onboard the ship. Results will be used to improve forecasts of ice and waves in the Arctic region.

Sea State DRI Science Team for R/V Sikuliaq 2015 (left to right):

Ethan Roth (ship's tech), Mike Hoshlyk (Captain), Martin Doble, Bjorn Lund, Byron Blomquist, Erick Rogers, Jeff Anderson, Ola Persson, Maddie Smith, Jim Thomson, Alex de Klerk, Peter Guest, Toshi Maki, Alison Kohout, Robin Clancy, Peter Wadhams, Guy Williams, Hayley Shen, Ted Maksym, Sharon Stammerjohn, Steve Ackley, Ben Holt, Blake Weissling, Bern McKiernan (ship's tech).

Not Pictured: Bob Ziegenhals, Steve Roberts (ship's tech).

Acknowledgements

Ship's Crew: Mike Hoshlyk (Captain), Bob Anderson, John Hamill, Elliot Salyer, John French, Rob Worrad, Chris Gabaldo, Arthur Gould, Marian Tudoran, Terry Anderson, Randy Flannigan, Richard Null, Kevin Reinhardt, Patrick Bedard, Michael Henderson, Jonathan Pierce, Marcel Beaudin, Matt Tocchini, Susan Swartz, Ann Parcels Kurek, Ethan Roth, Bern McKiernan, and Steve Roberts, Doug Baird, and Steve Hartz.

Shore team (satellite remote sensing and forecasting): Johannes Gemmrich (chair), Adam Inch, Hui Shen, Will Perrie, Susan Lehner, Rudolf Ressel, Egbert Schwartz, Birgit Schaettler, Staci Langston, Hans Graber, Flavio Parmiggiani, Tripp Collins, David Hebert, Jim Dykes, Pam Posey, Rick Allard, Jean Bidlot, Amy Solomon, Janet Intrieri, Thomas Holden, Micki Ream and the analysts at the National Ice Center.

NRL aircraft team: John Brozena, Joan Gardner, David Ball, Richard Webb, Robert Liang

ONR program managers: Dr. Martin Jeffries and Dr. Scott Harper