IceTrackers: Low-Cost Tracking of Sea Ice in Remote Environments

Principal Investigators: Jeremy Kasper[1], Andrew Mahoney[2]

Co-Authors: J.Arsenau[3], P.Winsor[4], A. Sybrandy[5], E. Dobbins[4], B. Irving[4]

[1]Institue of Northern Engineering, University of Alaska Fairbanks
[2]International Arctic Research Center, University of Alaska Fairbanks
[3]Museum of the North, University of Alaska Fairbanks
[4]College of Fisheries and Ocean Sciences, University of Alaska Pacific Gyre, LLC
[5]Pacific Gyre, Inc.

Final Report
OCS Study BOEM 2017-076
September 2018

CONTACT
Coastal Marine Institute
University of Alaska Fairbanks
College of Fisheries and Ocean Sciences
P.O. Box 757220, Fairbanks, AK 99775-7220
Email: UAF-CMI@alaska.edu

REPORT AVAILABILITY
Administration of the University of Alaska Coastal Marine Institute is funded in part by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM) through Cooperative Agreement M13AC00003 between the BOEM Alaska Outer Continental Shelf Region and the University of Alaska Fairbanks. This report, OCS Study BOEM 2017-076, is available through the Coastal Marine Institute and select federal depository libraries. It can be accessed electronically from the BOEM Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/) and the National Technical Reports Library (https://ntrl.ntis.gov/NTRL/).

CITATION
Kasper, J.L., Mahoney, A.R., Arsenau, J., Winsor, P., Sybrandy, A., Dobbins, E., Irving, B., 2018. Development and Testing of a Low-Cost Satellite-tracked Ice Drifter for Arctic Alaska. Final Report, Bureau of Ocean Energy Management, OCS Study BOEM 2017-076.

Contents

List of Figures

List of Tables

Abstract

The IceTracker project successfully demonstrated the durability, longevity, and utility of simple, low-cost IceTracker buoys. During the course of the project, the IceTracker platform, equipped with a GPS sensor for accurate positioning and an Iridium communications chip for data transmission, proved to be robust and functional in the challenging Arctic environment. IceTrackers were safely and easily deployed by snowmobile and helicopter. Of the 25 trackers deployed between March 2015 and May 2017, one tracker operated for over two years, and multiple units persisted through at least one cycle of break-up and refreezing. The longest surviving tracker transited ~8034 km from its starting point north of Point Barrow and transmitted its position continuously from March 2015 until its batteries ran out in May 2017. Several trackers deployed during the course of the project were beached and subsequently deactivated. Thirteen trackers stopped transmitting data before their battery voltage dropped below the critical transmission level (~7 V) and were presumably crushed by ice. Based on the deployments in this study, it appears that the trackers have sufficient energy in their battery packs to last more than two years at low data transmission rates (12-hour sampling interval). On average, the trackers lasted for 147 (+/- 144) days (median deployment length of 122 days) and had an average speed of $12x10^{-2}$ (+/- 6.2) m s^{-1}. The average distance traveled by the 25 trackers was 1750 (+/- 1745) km (median displacement of 1237 km).

Trackers were deployed in a variety of geographical locales and ice conditions during the project. The initial set of five trackers was deployed in March 2015, via snowmobile, onto a nearshore strip of landfast ice on the Chukchi Sea adjacent to Utqiaġvik (Barrow). Two of these trackers ended up on the Russian Chukchi Sea coast near Wrangell Island after drifting across the Chukchi Sea. One of these trackers was entrained in the Siberian Coastal Current and drifted south towards the Bering Sea.

In April 2015, two sets of trackers (five per set) were deployed, via helicopter, in two distinct pentagons patterns on mixed first-year and multi-year pack ice (mobile sea ice) north of Utqiaġvik in the Beaufort Sea. Drop tests were performed at this time to test the resiliency of the trackers when dropped from a helicopter hovering up to ~13 m over the sea ice. All of the trackers that were dropped continued to transmit without interruption. Shortly after deployment, a storm led to the rapid dispersal and intermingling of the ice these sets of trackers were deployed on. These clusters of trackers were used in a novel application of ice tagging; differences in deformation between multi-year and first-year ice were identified using the tracker positions and analysis of corresponding SAR imagery along the drifters' tracks.

In May 2015, five trackers were deployed on the landfast ice cover of Harrison Bay, via snowmobile, in conjunction with field work for the Arctic Nearshore Impact Monitoring in a Drilling Area (ANIMIDA) III project. The trackers were fitted with low-cost accelerometers to test if they can be used to discern whether the trackers are on ice or floating in open water. More conventional means of determining when a buoy is in the water, such a contact sensor, are not well suited for integration into a package designed to survive being dropped onto the ice from a

helicopter or fixed-wing aircraft. The same set of trackers was also fitted with temperature thermistors. A final set of five trackers was equipped with accelerometers and deployed in Elson Lagoon northeast of Utqiaġvik, via snowmobile, in March 2017. Further testing and/or additional information obtained from external sources such as Synthetic Aperture Radar (SAR) imagery is necessary before we can conclude whether accelerometers are effective as results were ambiguous in this regard.

Deployment of the first 15 trackers in March and April 2015 were deliberately undertaken via snowmobile and helicopter to demonstrate the feasibility of specific deployment methods (helicopter, snowmobile, and/or by residents). Tracker deployments in Harrison Bay and Elson Lagoon were undertaken to leverage logistics (Harrison Bay) and for logistical ease (Elson Lagoon) and to develop new information on the fate of landfast ice in these areas.

Driven by an easterly wind event shortly after the breakup of the landfast ice, trackers deployed in Harrison Bay beached on the west side of the bay. In contrast, the trackers deployed in Elson Lagoon were exported out of the lagoon and made their way north and east into the Chukchi Sea or the Beaufort Gyre. In the past, inferences have been made on the fate of nearshore ice using satellite measurements and/or geochemical tracers. This is the first project that we are aware of that deliberately "tagged" and then tracked landfast ice, including prominent features such as ridges, via buoys. The buoys also fortuitously captured the dynamics of a breakout event off of Utqiaġvik. While drift trajectories and analyses of divergence, relative vorticity, and deformation of landfast ice are novel, ambiguity about whether, and for what duration, the trackers remained on the sea ice limits inferences we can make on the fate and dynamics of the sea ice from this set of measurements.

This project also included a successful outreach component. The UA Museum of the North (UAMN) developed and delivered a university-credit course, "Engineering on Ice: Sea ice science and STEM lessons," (UAF Course ED 593) focused on the trackers and the engineering design process. UAMN also incorporated the course materials into a "check-out kit" as a resource for teachers. Finally, during the field portion of this project, principal investigators Jeremy Kasper and Andy Mahoney participated in the filming of a video broadcast on public television and incorporated into a children's book (Frontier Scientists, Anchorage, AK).

Overall, the project was a very successful demonstration of the low-cost IceTracker technology. By utilizing commercial off-the-shelf (COTS) batteries (tested by dropping from a building), Pacific Gyre was able to significantly reduce the cost of the IceTrackers compared to similar technologies. The overall robustness of the IceTracker package was demonstrated through field-testing. Despite the rough topography typical of sea ice, data return from the IceTrackers was an extraordinary 100%. This is the strongest indicator that the IceTrackers are suitable for deployment in varying ice conditions. The small number of data points generated by this project limits statistical support for conclusions about differences in the movement, deformation, or fate of differing types of sea ice (e.g., landfast, first-year, multi-year, etc.). However, similar to other Lagrangian buoy technologies, given sufficient deployments and a reliable means of determining whether the buoys remain on the ice, IceTrackers could be a robust method for gathering the data needed to support conclusions about ice deformation and ice fate. Most importantly, the low cost of the IceTrackers compared to existing International Arctic Buoy Program (IABP)-type buoys makes it reasonable to deploy sufficient numbers of IceTrackers to make statistically robust inferences about ice deformation, movement, fate, etc. Moreover, because they are simple to deploy, IceTrackers are well-suited for use by first responders in the event of an incident such as oil spill in mixed ice conditions or a small vessel adrift in sea ice. At this point, it does not appear possible to distinguish when the IceTrackers are in open water versus on ice. Improving upon this aspect of the IceTrackers would significantly enhance utility for a variety of studies and applications.

Introduction

Sea-ice covers the waters of Arctic Alaska for up to nine months of the year. Patterns of sea-ice movement can be very complex. For example, observations from residents and measurements made by the UAF ice radar in Utqiaġvik, Alaska (Figure 1) indicate that nearshore ice motion can vary significantly over small spatial and temporal scales (Jones et al. 2016; Mahoney et al. 2015). Small-scale measurements of ice motion are important for guiding marine activities, building better computer models of ice drift (Kulchitsky et al. 2017), and understanding the ice environment inhabited by marine mammals. High spatial and temporal resolution data from the UAF ice radar in Utqiaġvik reveal complex patterns of coastal ice drift, including shear zones, eddies, and anisotropy (Jones 2013). This is consistent with observations from local ice experts (Druckenmiller et al. 2009) but differs significantly from the isotropic stress distribution and motion of the central pack (Weingartner et al. 2003).

In light of reductions in Arctic sea ice extent in recent years and the growing need for operational ice forecasts due to increasing marine activities, it is imperative to develop new technologies that improve our ability to document and track the fate of offshore mobile sea ice and inshore landfast sea ice so we can advance our understanding of these small-scale sea ice motions. Further, knowledge of the effects of small-scale patterns of ice motion is potentially relevant to understanding ocean currents in the water column underlying sea ice, which would help predict oil, sediment, and contaminant trajectories in the nearshore more accurately. For example, high-resolution satellite measurements of coastal sea ice vorticity show that the magnitude of nearshore sea ice vorticity is comparable to that in the underlying water column (Weingartner et al. 2010). Accordingly, when mobile ice is present, the correlation between ocean velocities under the sea ice and the overlying sea ice is high (Weingartner et al. 2010). However, the presence of mobile sea ice inhibits the reporting of under-ice current measurements in real-time. New technologies, such as the IceTrackers, for tracking such small-scale ice motions fill a critical information gap. New data on ice motion from closely spaced clusters of buoys also adds to datasets on the divergence of drifting ice (Hutchings and Hibler 2008). Such data sets are especially sparse along the shear zones between landfast ice and the mobile pack ice farther offshore.

Overall, the data and scientific understanding resulting from this study support BOEM information needs concerning the permitting process for offshore oil and gas development in the Chukchi and Beaufort Seas and contribute to the acquisition of new fundamental knowledge about small-scale sea ice dynamics. The IceTrackers are also highly relevant as a response tool in an area where marine operations are increasing. A case in point is the Northern Transportation Company fuel barge that was adrift in the Beaufort and Chukchi Sea in 2014. While responders were able to place a satellite AIS tracker on the vessel, they did not have a method of tracking ice around the vessel in the event of oil spilling onto the ice. As a flexible, low-cost platform, IceTrackers are ideally suited to such situations.

Methods

In conjunction with the University of Alaska Fairbanks (UAF), Pacific Gyre, Inc. (PGI) designed the IceTracker package to be compact (~0.45 x ~0.30 m), lightweight (~4.5 kg), and able to survive rough deployments (e.g., dropped from a helicopter). The IceTrackers were also designed to provide more accurate positioning than an Iridium-based position alone by employing precision GPS antennas. Each IceTracker consisted of the following components: an antennae enclosure, a PGI controller including Iridium 9602 SBD modem, a uBlox LE GPS receiver, a 12V 15aH alkaline battery pack, and a magnetic switch. Components were all enclosed by polyethylene foam (Figure 1). The GPS receiver (accurate to >+/-7 m) improved upon the Iridium positioning (accurate to 10s of km), while the alkaline battery pack reduced overall cost (total cost was $2,000 per unit). Trackers could also be equipped with a 3-axis accelerometer and a thermistor. In the basic configuration (without the temperature thermistor) each tracker reported its position, battery voltage, GPS quality (a flag), the variance of the accelerometer, and the time of each measurement.

The exterior of the trackers is shown in Figure 1 (right). Each unit was 0.45 m tall and 0.25 m at the widest point. The trackers shipped in individual cardboard boxes for easy handling and fit in a large day-pack; thus, they were easily deployable by hand and snowmobile or other means.

The Iridium modem allowed for two-way communication which means the sampling rate of the tracker could be adjusted remotely from 5 minutes to 12 hours. The 12v 15aH alkaline battery packs had sufficient energy to power the IceTracker for >24 months at the lowest sampling rate of 12 hours. Commercial-off-the-shelf (COTS) alkaline batteries were drop tested before incorporation into the final IceTracker design. The use of COTS alkaline batteries reduced costs of the units. The units were activated via Pacific Gyre's website before deployment. At deployment time, removal of the magnetic switch started the IceTracker transmitting. The electronics were encased in a watertight package inside of a white polyethylene foam casing which provides impact protection and buoyancy (Figure 1, right). The shape of the foam casing was designed to ensure the GPS and Iridium antennae maintain their skyward look angles for reliable communication. The foam case also constrained the distance the buoy would roll; the unit inscribed a circle (radius < 3 m) when forced by wind or pushed.

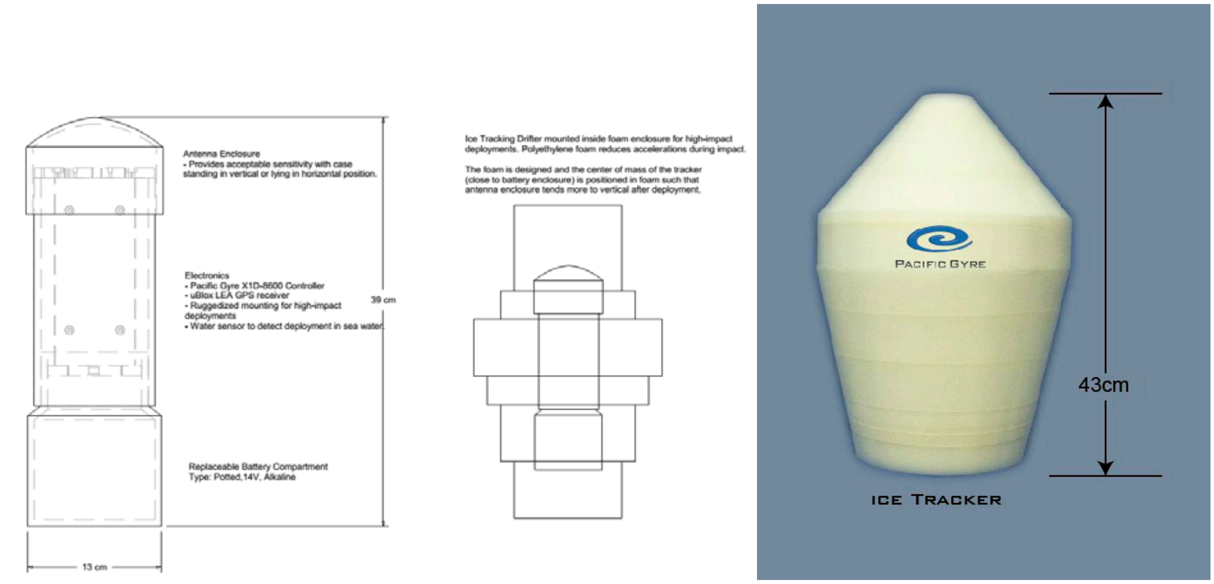


Figure 1. Initial design of IceTracker electronics enclosure, foam casing, and IceTracker final design. Left and middle: initial design of IceTracker electronics enclosure and foam casing. Right: Final design of the IceTracker.

After an initial redesign (Figure 1), twenty-five trackers were deployed during the project.

1) Five trackers were deployed March– April 2015 within the mask of the UAF ice-radar at Utqiaġvik. Deployments were made by residents using snowmobiles.
2) Ten trackers (two sets) were deployed from a helicopter onto sea ice of varying age class (first and multi-year sea ice) in April 2015.
3) Five trackers (each equipped with a thermistor and an accelerometer) were deployed via snowmobile onto landfast sea ice in Harrison Bay, May–June 2015.
4) Five trackers (each equipped with an accelerometer) were deployed via snowmobile onto landfast ice in Elson Lagoon in April 2017.

The last five trackers deployed (Elson Lagoon) were set to sample once every 12 hours to minimize Iridium data expenses. Prior to this, trackers were set to report their position once an hour unless higher-resolution data was required for testing purposes (e.g., testing battery lifespans).

3-axis accelerometers (NXP Semiconductors model MMA8452Q) and thermistors were tested on several of the trackers (this was an addition to the original scope of the project). The use of accelerometers, included on trackers 16–25 in Harrison Bay and Elson Lagoon, was conceived as a low-cost means of discriminating whether trackers are floating in open-water or on sea ice. To minimize Iridium telemetry costs, only the variance of the acceleration was sampled. This method was adapted after bench and tank tests (by Pacific Gyre) indicated that the variance of the acceleration provided a reasonable indication of whether an IceTracker was on a fixed bench or bobbing in a tank. The accelerometer chip location is shown in Figure 2 (right).

Thermistors were also included on trackers 16–20 in Harrison Bay. The location of the thermistor is shown in Figure 2 (left). Thermistors were located within the tracker electronics enclosure and measured the ambient temperature inside the unit, not the medium (water or air). The lack of a subsurface drogue, the shape of the buoys (the buoys roll continuously in water), and the need for a rugged, drop-resistant foam shell capable of surviving large impact forces limited application of an external thermistor in the shell of the buoy. Such placement was unlikely to be successful and unlikely to consistently measure water temperature due to the dynamic motion of the buoys in water. Thus, the thermistors were placed internal to the protective shell. The application of an internal thermistor is a standard diagnostic tool for the health of a variety of oceanic drifters. Here, we attempted to glean additional information, at no additional cost, by using the information from this internal thermistor.

Figure 2. Thermistor stinger and accelerometer locations on an IceTtracker. Left: Thermistor stinger location on the bottom plate of the electronics (red box). Right: the red box indicates the location of the bottom plate in relation to the rest of the electronics, and the yellow box indicates the location of the rest of the electronics including the accelerometer. The entire electronics package (including batteries) is enclosed in a water-tight container embedded in the foam outer casing.

Position data for the IceTrackers was made available through an application programming interface (API, developed by Pacific Gyre). This data was then made available in real-time through the project websites using a Google Maps® interface (icetrackers.org). Figure 3 shows an example of drifter tracks displayed on the webpage. A second webpage was created for redundancy and testing purposes (http://www.ims.uaf.edu/artlab/projects/IceTrackers/).

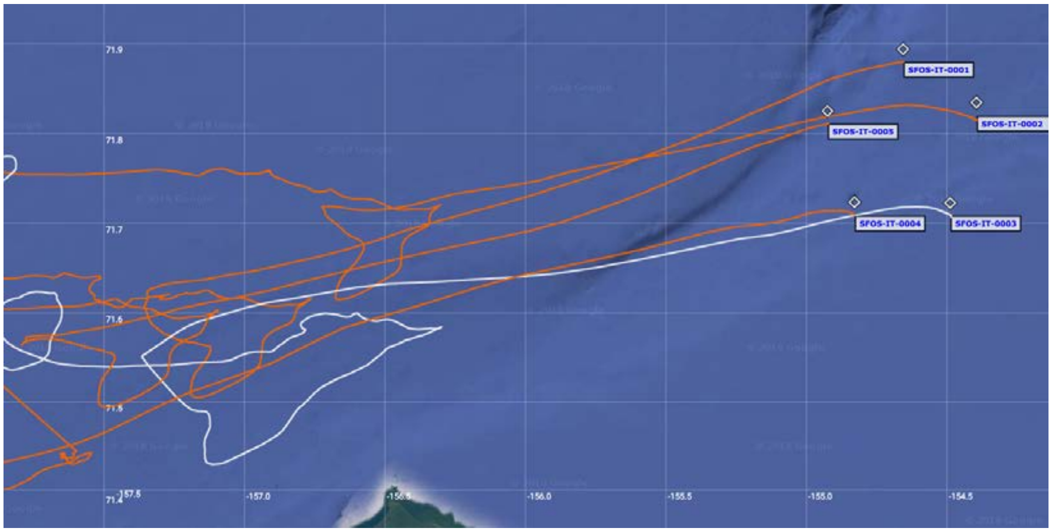


Figure 3. An example map from the project webpage showing the tracks for IceTrackers 1–5 (Cluster B, described below). White diamonds indicate the starting location. A white track line indicates deployment on multi-year ice while a red track line indicates deployment on first-year ice.

2015 Utqiaġvik Deployments

Three clusters of IceTrackers (five in each) were deployed west and north of Utqiaġvik during spring 2015. Two clusters (A and B) were deployed on drifting pack ice composed of a mix of first-year and multi-year ice floes north of Utqiaġvik. The third cluster was deployed on the landfast ice west of Utqiaġvik. The deployment locations for each buoy and the arrangement of each cluster are shown in Figure 4, and deployment details are provided in Tables 1 and 2. To test survivability, single trackers were dropped from a helicopter while hovering at 8, 10, and 13 m above the ice.

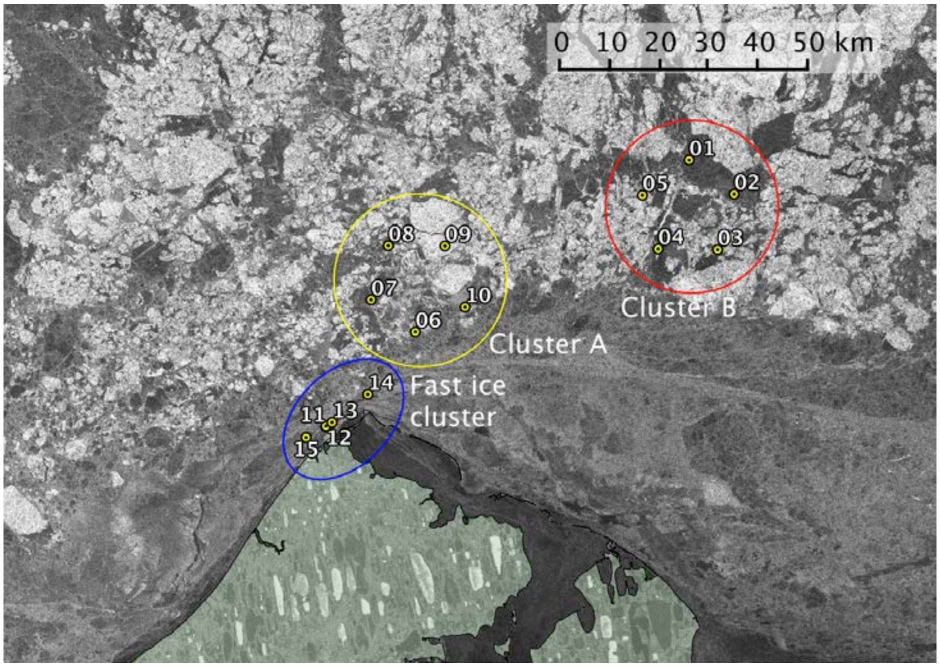


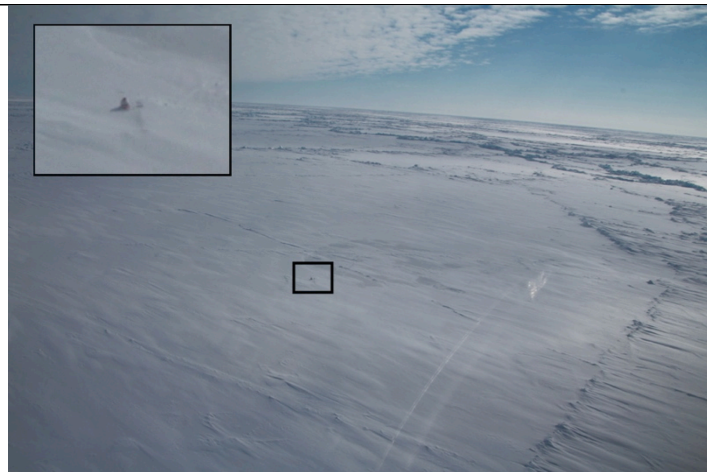
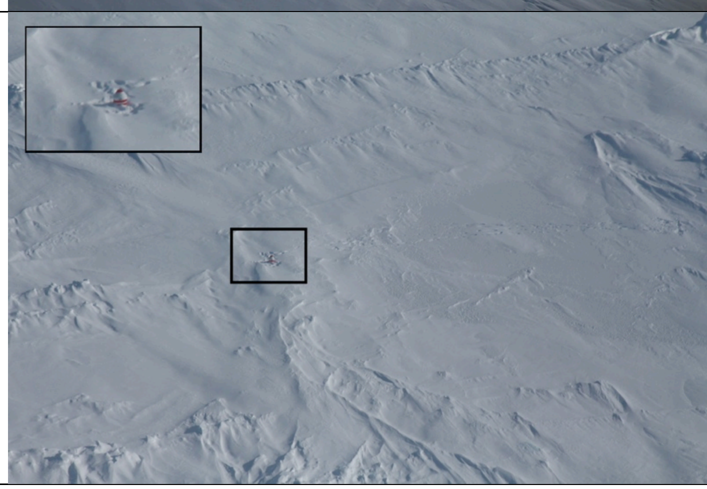
Figure 4. Deployment locations of the 15 IceTrackers deployed in March and April 2015 and the arrangement of the three clusters. The background image is a Radarsat2 SAR image acquired on April 15, 2015.

Table 1. Deployment details for IceTrackers deployed in March and April 2015. (- indicates not measured)

Drifter	Cluster	Deployment time and location: Date	Lat	Lon	Ice Thickness (m)	Snow depth (m)	Free-board (m)	Ice type
0001	B1	4/16/15	71.87924	-154.6554	1.39	0.08	-	First-year ice
0002	B2	4/16/15	71.81497	-154.39394	1.41	0.15	-	First-year ice
0003	B3	4/16/15	71.70872	-154.48643	1.79	0.19	-	Multi-year ice
0004	B4	4/16/15	71.70899	-154.82829	1.69	0.09	-	First-year ice
0005	B5	4/16/15	71.81108	-154.92317	1.29	0.13	0.11	First-year ice
0006	A1	4/14/15	71.54031	-156.20682	2.18	0.19	0.22	Multi-year ice
0007	A2	4/15/15	71.5985	-156.46554	1.47	0.03	-	First-year ice
0008	A3	4/15/15	71.70281	-156.37858	1.47	0.04	-	First-year ice
0009	A4	4/15/15	71.70576	-156.05303	2.96	0.20	-	Multi-year ice
0010	A5	4/15/15	71.59057	-155.92735	-	0.22	-	Multi-year ice
0011	Fast ice 1	3/26/15	71.35366	-156.69529	-	-	-	Barrow fast ice
0012	Fast ice 2	3/26/15	71.35486	-156.69443	-	-	-	Barrow fast ice
0013	Fast ice 3	3/27/15	71.36229	-156.66079	-	-	-	Barrow fast ice
0014	Fast ice 4	4/17/15	71.41823	-156.46443	-	-	-	Barrow fast ice
0015	Fast ice 5	4/16/15	71.33165	-156.8036	-	-	-	Barrow fast ice

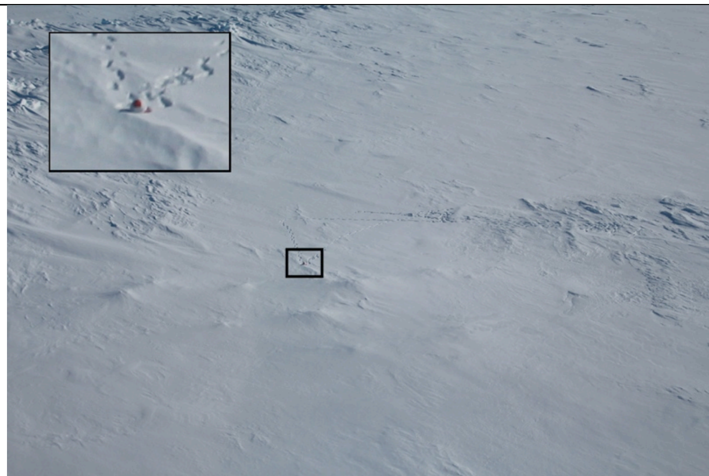
The following table lists photographs and deployment notes for each drifter deployed between March and April 2015. If the battery voltages indicated sufficient voltage to transmit just prior to the end of the buoy's life, fate is listed as “Crushed by ice?” in Tables 2 and 4. If the buoy was beached and subsequently deactivated or appeared to have reached the end of its battery life (voltage below ~7.5V), its fate is indicated as “beached” or “end of battery life,” respectively.

Table 2. Deployment photographs and notes for each IceTracker deployed in March and April 2015 (- indicates not measured).

Buoy	Photo
SFOS-IT-0001 Cluster B, tracker 1 First-year floe Ice Thickness: 1.39 m Snow depth: 0.08 m *Buoy placed on ice adjacent to the helicopter* Fate: Crushed by ice?	
SFOS-IT-0002 Cluster B, tracker 2 First-year floe Ice Thickness: 1.41 m Snow depth: 0.15 m *Buoy placed on ice adjacent to the helicopter* Fate: Crushed by ice?	

SFOS-IT-0003
Cluster B, tracker 3
Multi-year floe
Ice Thickness: 1.79 m
Snow depth: 0.19 m
Buoy placed on ice adjacent to the helicopter

Fate: End of battery life

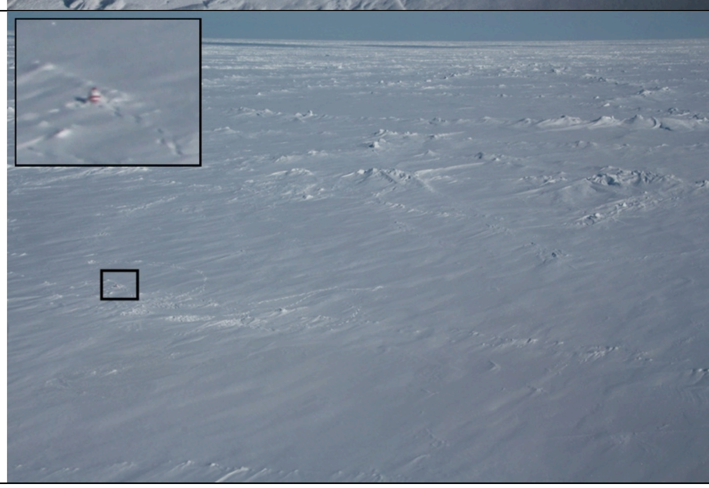


SFOS-IT-0004
Cluster B, tracker 4
First-year floe
Ice Thickness: 1.69 m
Snow depth: 0.09 m
Buoy placed on ice adjacent to the helicopter

Fate: Crushed by ice?

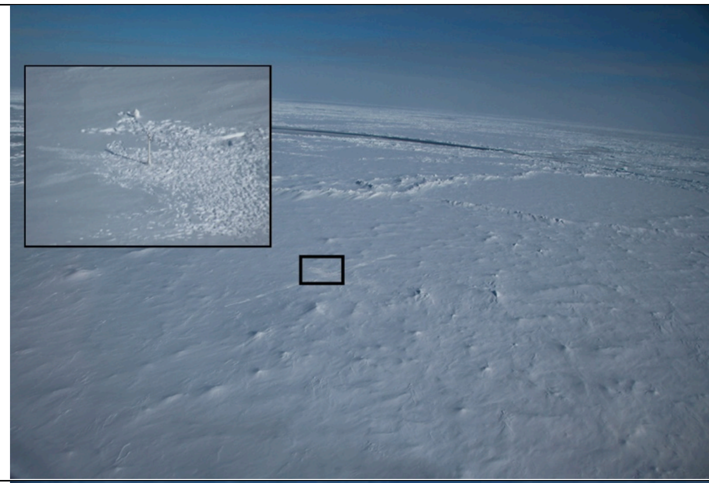
SFOS-IT-0005
Cluster B, tracker 5
Small first-year floe surrounded multi-year ice
Ice Thickness: 1.29 m
Snow depth: 0.13 m
Buoy placed on ice adjacent to the helicopter

Fate: Crushed by Ice?



SFOS-IT-0006
Cluster A, tracker 1
Multi-year ice floe
Ice thickness: 2.18m
Snow depth: 0.19 m
Buoy placed on ice adjacent to seasonal ice mass-balance buoy (SIMB)

Fate: Crushed by Ice?



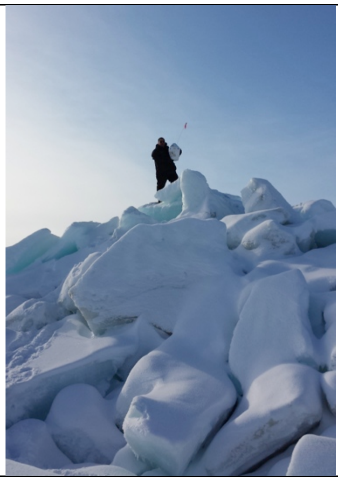
SFOS-IT-0007
Cluster A, tracker 2
First-year floe
Ice thickness: 1.47 m
Snow depth: 0.03
Buoy dropped from a helicopter at 10 m above the ice

Fate: Crushed by Ice?

SFOS-IT-0008
Cluster A, tracker 3
First-year floe
Ice thickness: 1.47 m
Snow depth: 0.04
Buoy dropped from a helicopter at 8 m above the ice

Fate: Crushed by Ice?

No picture available

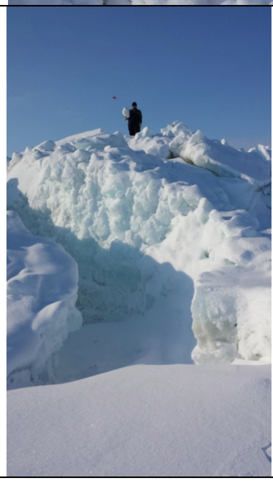
SFOS-IT-0009 <u>Cluster A, tracker 4</u> Multi-year floe Ice thickness: 2.96 m Snow depth: 0.20 m *Buoy dropped from a helicopter at 13 m above the ice* Fate: Crushed by Ice?	
SFOS-IT-0010 <u>Cluster A, tracker 5</u> Multi-year floe Ice thickness: - Snow depth: 0.22 m *Buoy placed on ice adjacent to the helicopter* Fate: Crushed by Ice?	No picture available
SFOS-IT-0011 <u>Fast ice cluster, tracker 1</u> Pressure ridge in landfast ice Ice thickness: - Snow depth: - *Buoy deployed by snow machine by R. Sarren (NSB DWM)* Fate: Beached	

SFOS-IT-0012
Fast ice cluster, tracker 2
Rubble field in landfast ice
Ice thickness: -
Snow depth: -
Buoy deployed by snow machine by R. Sarren (NSB DWM)

Fate: End of battery life

SFOS-IT-0013
Fast ice cluster, tracker 3
Pressure ridge in landfast ice
Ice thickness: -
Snow depth: -
Buoy deployed by snow machine by R. Sarren (NSB DWM)

Fate: End of battery life



SFOS-IT-0014
Fast ice cluster, tracker 4
Pressure ridge in landfast ice
Ice thickness: -
Snow depth: -
Buoy deployed by snow machine by C. George (NSB DWM)

Fate: Crushed by Ice?

SFOS-IT-0015
Fast ice cluster, tracker 5
Pressure ridge in landfast ice
Ice thickness: -
Snow depth: -
Buoy deployed by snow machine by C. George (NSB DWM)

Fate: Crushed by Ice?

2015 Harrison Bay Deployments

Details of the 2015 Harrison Bay IceTracker deployments are shown in Tables 3 and 4 and Figure 5. This set of trackers was deployed on the fast ice covering Harrison Bay, via snowmobile, in conjunction with field efforts for the ANIMIDAIII project May 16–19, 2015, just prior to the breakup of the Colville River.

Table 3. Harrison Bay IceTracker deployment details (- indicates not measured).

		Deployment time and location			**Ice**	**Snow**	**Free-**	
Drifter	**Cluster**	Date	Lat	Lon	**Thickness (m)**	**depth (m)**	**board (m)**	**Ice type**
0016	HB1	5/16/15	70.5804	-150.0101	1.55	-	0.1	Harrison Bay fast ice (first-year ice)
0017	HB2	5/17/15	70.5991	-150.0107	1.70	-	-	Harrison Bay fast ice (first-year ice)
0018	HB3	5/17/15	70.5917	-150.0578	-	-	-	Harrison Bay fast ice (first-year ice)
0019	HB4	5/17/15	70.6013	-150.2369	1.70	-	0.10	Harrison Bay fast ice (first-year ice)
0020	HB5	5/20/15	70.6145	-150.2490	-	-	-	Harrison Bay fast ice (first-year ice)

Table 4. Deployment photographs and notes for the Harrison Bay IceTrackers (- indicates not measured).

SFOS-IT-0016 Harrison Bay cluster tracker 1 Smooth landfast ice Ice thickness: 1.55 m Snow depth: - *Buoy deployed by snowmobile by J. Kasper.* Fate: beached	
SFOS-IT-0017 Harrison Bay cluster tracker 2 Smooth landfast ice Ice thickness: 1.70 m Snow depth: - *Buoy deployed by snowmobile by J. Kasper* Fate: beached	
SFOS-IT-0018 Harrison Bay cluster, tracker 3 Smooth landfast ice Ice thickness: - Snow depth: - *Buoy deployed by snowmobile by J. Kasper* Fate: beached	
SFOS-IT-0019 Harrison Bay cluster, tracker 4 Smooth landfast ice Ice thickness: 1.7 Snow depth: not measured *Buoy deployed by snowmobile by J. Kasper* Fate: Crushed by Ice?	

SFOS-IT-0020
Harrison Bay cluster, tracker 5
Smooth landfast ice
Ice thickness: not measured
Snow depth: not measured
Buoy deployed by snowmobile
by G. Lawley/M. Savoie (KLI)

Fate: beached

No picture available

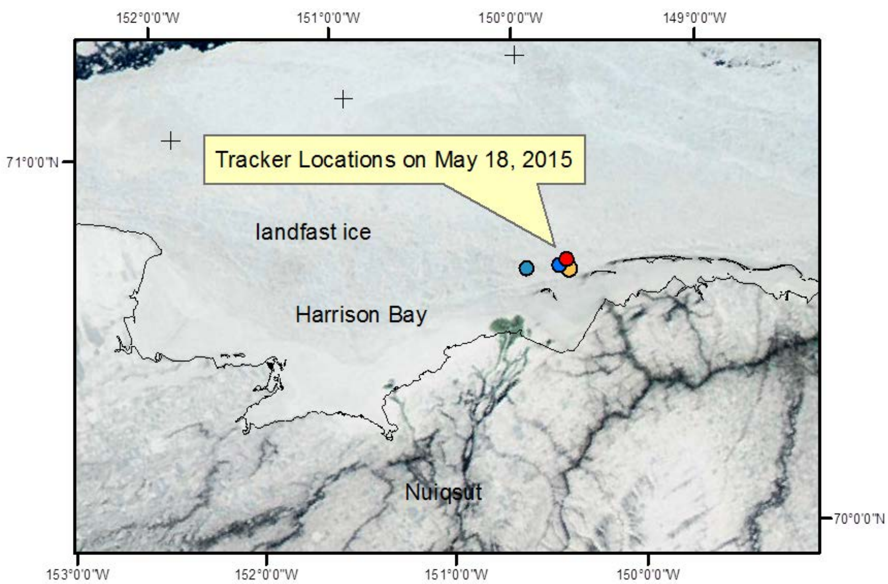


Figure 5. MODIS image from May 18, 2015, showing the initial location of the IceTrackers in Harrison Bay.

All trackers deployed in Harrison Bay were deployed on smooth patches of landfast ice (Figure 5). The locations were chosen because they were accessible by snowmobile and sampling was occurring at these locations for other projects. No river water or overflood waters were present at the locations where the trackers were deployed. However, surface ice melt was present at the deployment sites several days after deployment (Figure 6).

Figure 6. Ice conditions at the site of IceTracker 0016 on May 23, 2015. Significant surface melting had taken place between deployment and the time that this picture was taken. There was no river overflooding present at the location of the IceTrackers (as indicated by MODIS imagery and CTD measurements taken at the same time as the photo above).

2017 Elson Lagoon Deployments

IceTrackers were deployed in Elson Lagoon on 3/1/2017 by Ukpeaġvik Iñupiat Corporation (UIC) staff via snowmobile. There are no pictures available from this deployment. Initial tracker locations are shown overlaid on a MODIS image (from https://worldview.earthdata.nasa.gov/) in Figure 7. Deployment details are included in Table 4.

Table 5. Deployment details for the Elson Lagoon IceTrackers.

Drifter	Cluster	Deployment time and location			Ice Thickness (m)	Snow depth (m)	Free-board (m)	Ice type
		Date	Lat	Lon				
0021	EL1	4/1/17	71.3636	-156.2415	-	-	-	Elson Lagoon fast ice (first-year ice)
0022	EL2	4/1/17	71.3491	-156.2418	-	-	-	Elson Lagoon fast ice (first-year ice)
0023	EL3	4/1/17	71.3351	-156.242	-	-	-	Elson Lagoon fast ice (first-year ice)
0024	EL44	4/1/17	71.3201	-156.2481	-	-	-	Elson Lagoon fast ice (first-year ice)
0025	EL55	4/1/17	71.3052	-156.2505	-	-	-	Elson Lagoon fast ice (first-year ice)

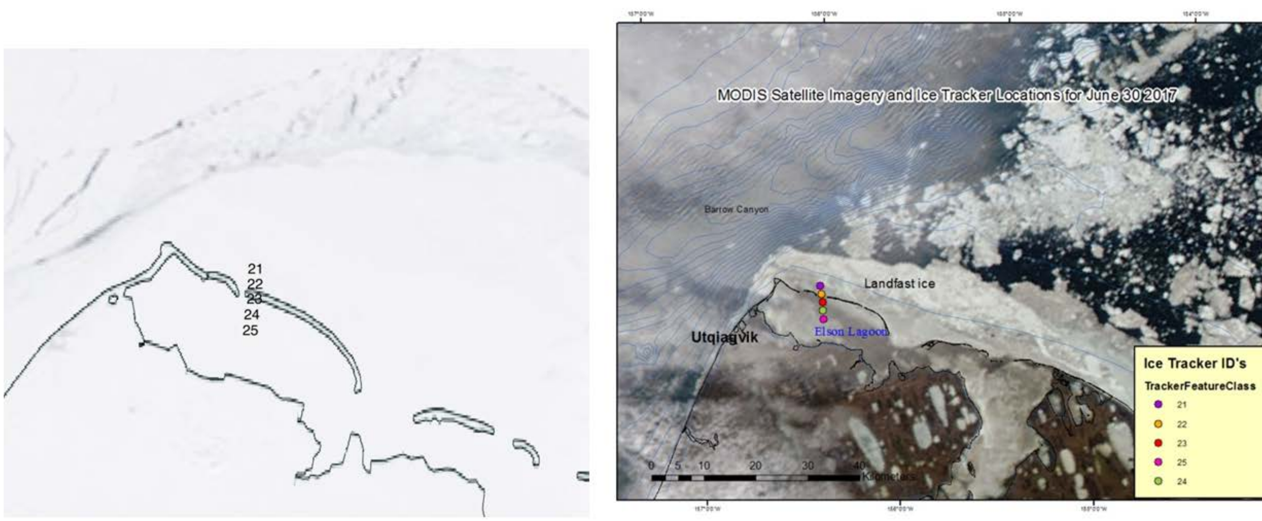


Figure 7. Initial locations of the Elson Lagoon trackers. Left: MODIS image from 04/01/2017 and Right: wider area MODIS image from 06/30/2017 with features labeled (courtesy of W. Horowitz).

Results

The average life of the trackers was 147 days (median of 122 days) and the average distance traveled was 1749 km (median of 1237 km). The longest-lived tracker survived 768 days and traveled a distance of ~8035 km. Note that the last five trackers deployed were turned off due to budget limitations, so the average life and distance traveled may be biased by the inclusion of these trackers. Only one of these trackers was destroyed prior to the deactivation in September 2017, 209 days after their deployment.

Data return was exceptional (100% return rate) during this demonstration project (# of good positions/# samples). The three trackers dropped from a hovering helicopter (8, 10 and 13 m above the ice) showed no negative effects and continued to operate for at least 107 days (186 days in the case of tracker 0007 dropped from 10 m). The remaining trackers were individually placed on the ice. Thirteen trackers ceased communication when their battery voltages were seemingly sufficient for them to continue to transmit their position (voltage above ~7 V). It is assumed these 13 trackers were crushed by ice.

While these gross statistics capture important information on the longevity and durability of the trackers, they do not provide insight into the differences in ice conditions or the sea ice dynamics for the ice floes that the trackers were deployed on. For this information, we turn to satellite imagery and analysis of drifter tracks and winds along the path of the trackers.

Deployment on Mixed First-year and Multi-year Ice Floes

Trackers deployed from a helicopter in April 2015 were deployed in two hexagons (Cluster A and Cluster B, Figure 8) on a mix of multi-year ice and first-year ice. The deformations of these hexagons were tracked through time using SAR imagery and supporting data collected from the trackers.

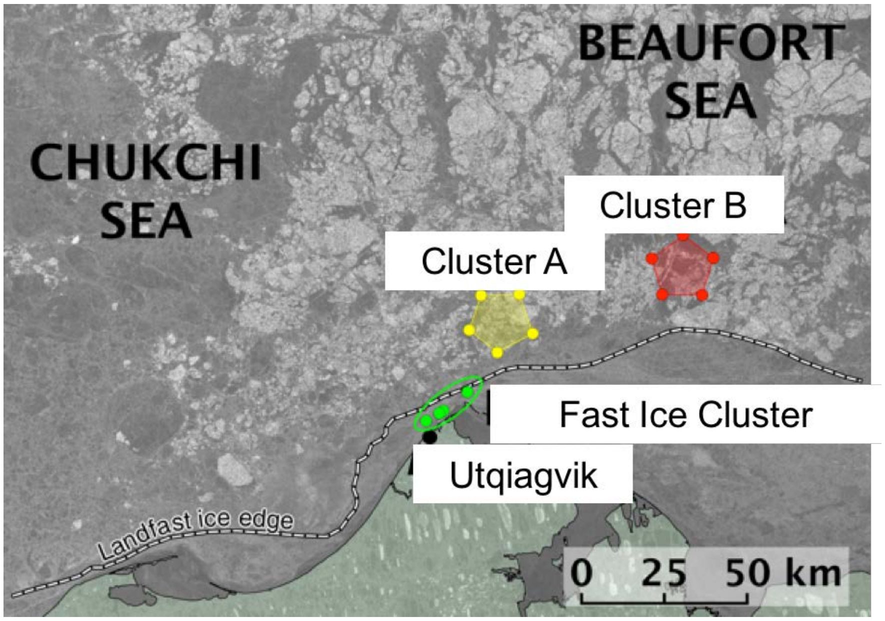


Figure 8. Initial deployment locations of IceTrackers surrounding Utqiaġvik.

Ice motion in the study region was effectively zero during deployment, but two days later the IceTrackers captured a rapid transport event in which multi-year ice from the Beaufort Sea was flushed into the Chukchi Sea across Barrow Canyon. During this event, westward ice motion began in the Chukchi Sea and propagated eastward. This created new openings in the ice and led to rapid elongation of the clusters as the westernmost buoys accelerated away from their neighbors to the east. The buoys tracked ice velocities of over 1.5 m s^{-1} with the fastest motion occurring closest to the coast, indicating strong current shear (Figure 9). Three days later, ice motion reversed and the two clusters became intermingled.

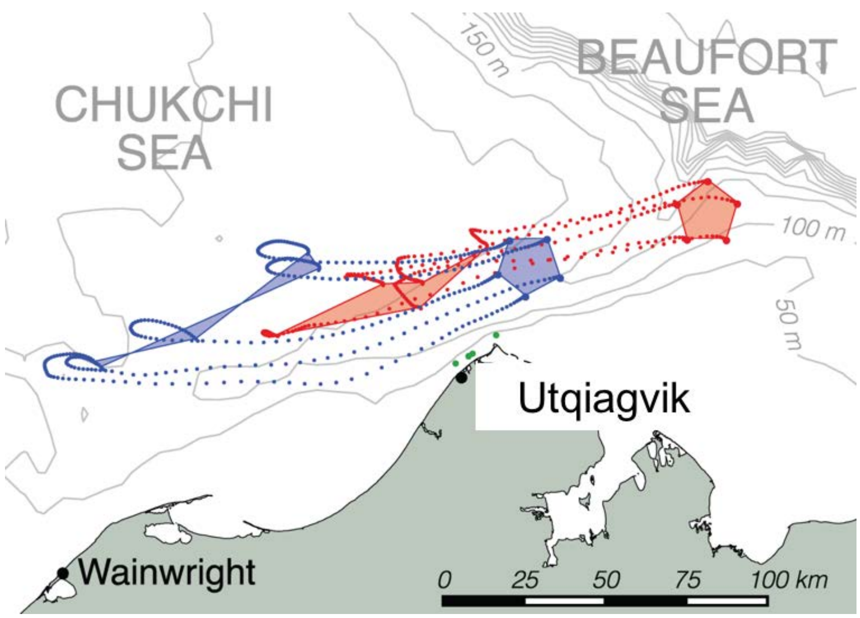


Figure 9. Deformation and translation of Cluster A and Cluster B during a storm event.

The data show no detectable difference in velocity between first-year and multi-year ice floes; however, Lagrangian time series of SAR imagery (Figure 10) centered on each buoy show that first-year ice underwent significant small-scale deformation during the event. To our knowledge, this is the first time an ice buoy has been used in conjunction with SAR to track deformation along the path of a drifting ice element.

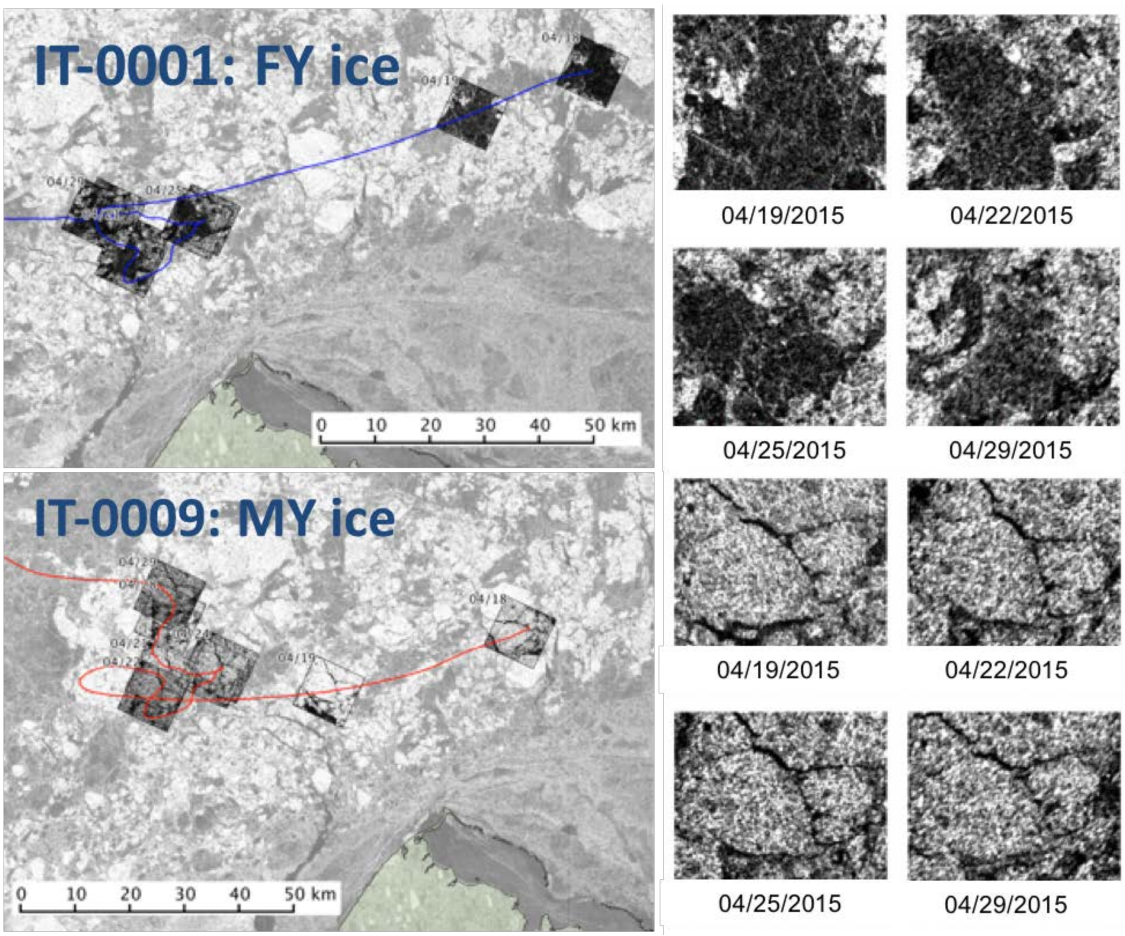


Figure 10. Synthetic Aperture Radar (SAR) data centered on IceTrackers. SAR provides a Lagrangian view of ice deformation. IT-000X indicates the IceTracker number, FY indicates first-year ice, and MY indicates multi-year ice.

Time series of ice velocity, wind velocity, wind factor, and turning angle shown in Figure 11 illustrate that, during the event shown in Figure 9 and Figure 10, the sea ice was in free-drift as the coastal flaw lead opened (i.e., internal stresses between the ice floes the trackers were located on were minimal because of the open water to the west). Along-track winds were taken from the North American Regional Reanalysis and interpolated to the drifter position following Weingartner et al., 2015. High wind factors and turning angles (angle between the wind and sea ice) indicate the presence of strong, complex currents in the flaw zone.

Overall, this event illustrates that (1) multi-year ice from the Beaufort Sea can be entrained into the Chukchi Sea during coastal flaw lead events, (2) significant deformation and mixing of ice can take place at seaward edge of flaw zone, and (3) deformation takes place primarily in first-year ice around the multi-year ice floes.

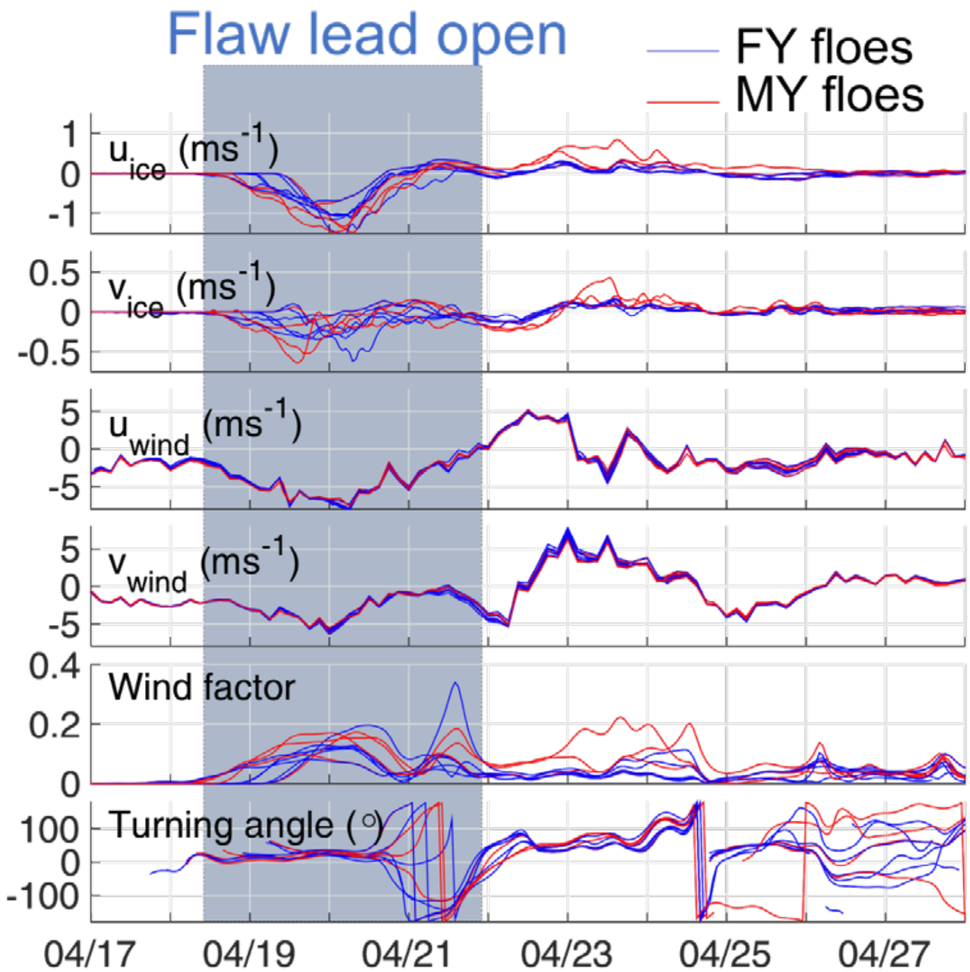


Figure 11. Ice (top; from the IceTrackers) and wind (middle) velocities along the drifter tracks with wind factor and turning angles (bottom) computed from IceTracker NARR velocities. For both the ice and winds, u (m s^{-1}) is east-west velocity (positive to the West).For both the ice and winds, u (m s^{-1}) is east-west velocity (positive to the West).

In addition to their utility for tracking discrete ice features such as multi-year or first-year sea ice, the trackers allow us to carry out standard analyses of the ice motion and to calculate dynamically relevant parameters such as divergence, relative vorticity, and deformation. These calculations are illustrated below using position data from several of the tracker clusters. Calculations follow Weingartner et al., 2015. Such calculations are straightforward to carry out for each cluster. However, for brevity, we only show a few separate analyses for each cluster.

Utqiaġvik Fast Ice Cluster

We begin by looking at the five trackers deployed on the landfast ice along the Chukchi Sea coast, west of Utqiaġvik. The correlation of the motion of this set of drifters with local winds was low; the correlation of R^2=0.058 between the NARR 10-m wind velocity interpolated to the drifter position and drifter velocities was not significant.

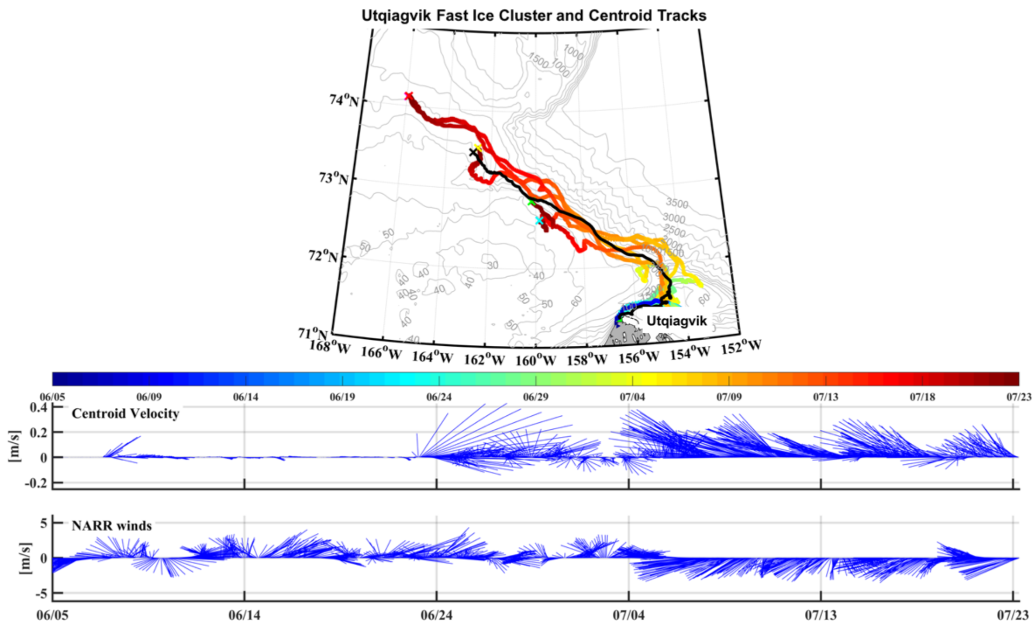


Figure 12. Map of the Utqiaġvik fast ice cluster and cluster centroid tracks (top), and centroid velocity (m s^{-1}) and NARR wind velocity (m s^{-1}) along the centroid track (bottom). Positive wind (centroid) velocities indicate winds to the east (drifter motion to the west).

Diagnostic quantities such as dispersion can also be calculated from the tracker positions. An example of this calculation is shown in Figure 13 for the Utqiaġvik fast ice cluster. For each term, the dispersion remained small until the breakup of the fast ice at the beginning of May 2015. After this, all dispersion terms peaked and then declined again until early July when the trackers quickly dispersed to the west along the Chukchi Sea shelfbreak.

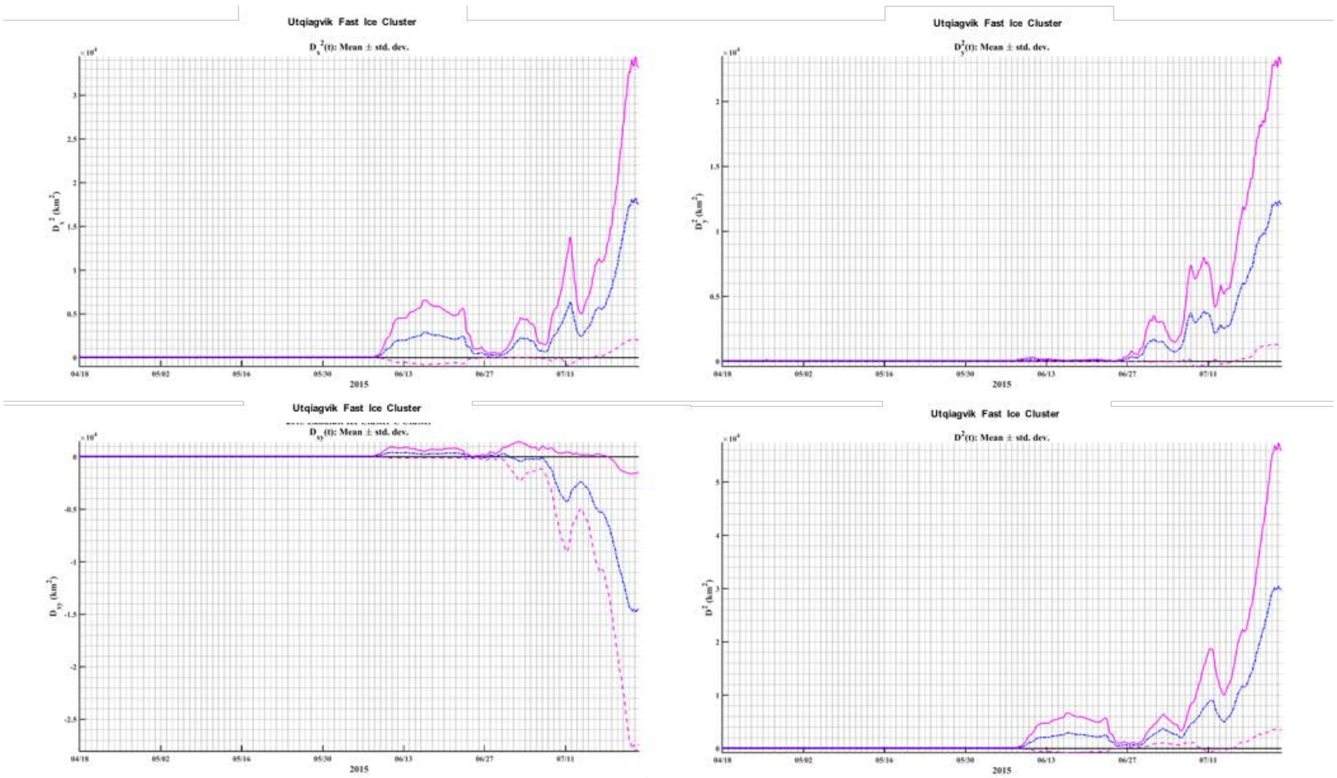


Figure 13. Time series of relative zonal (top left) and meridional (top right) dispersion, the cross-correlation in relative dispersion (bottom left), and the relative dispersion (bottom right) for the Utqiaġvik Fast Ice Cluster. Units are km^2.

Elson Lagoon Cluster

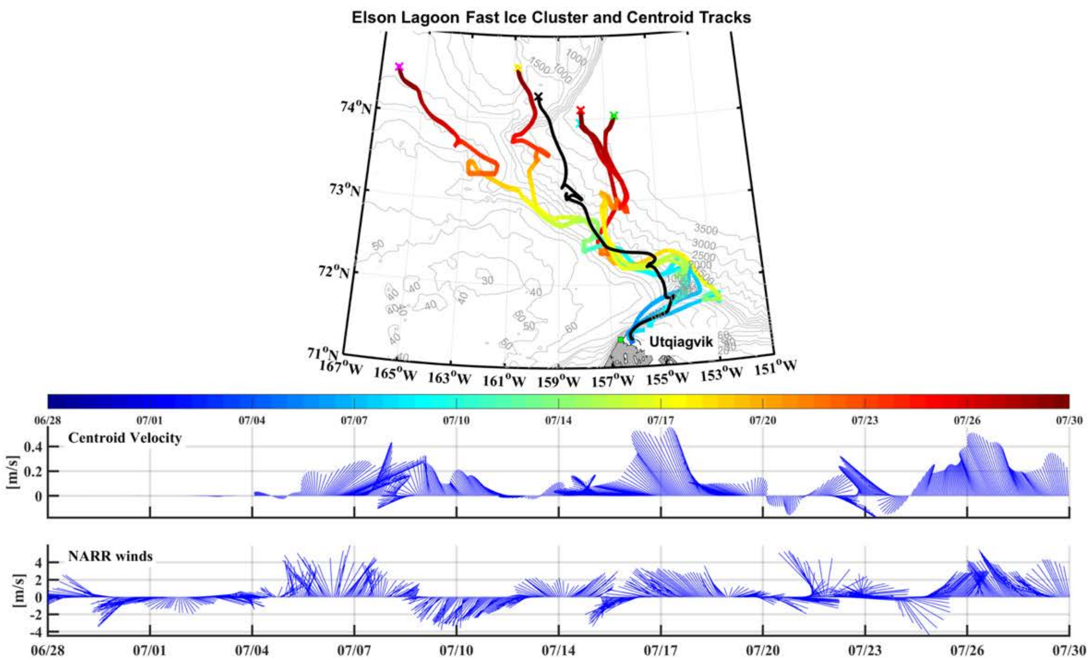


Figure 14. Map of the Elson Lagoon cluster and cluster centroid tracks (top), and centroid velocity (m s^{-1}) and NARR wind velocity (m s^{-1}) along the centroid track (bottom). NARR wind speed is interpolated to the centroid location.

As with the Utqiaġvik fast ice cluster, the correlation of the motion of the Elson Lagoon set of drifters with local winds was low; correlation of R^2=0.111 between the NARR 10-m wind velocity interpolated to the drifter position and drifter velocities was not significant (Figure 14).

Similar to the analysis of ocean drifters, it is often of interest to diagnose the movement of individual drifters, the translation of the cluster centroid, and other dynamical terms such as divergence, vorticity, and deformation. An example of such calculations for the Elson Lagoon cluster is shown in Figure 15.

For the Elson Lagoon trackers, the divergence, vorticity, and deformation are negligible until the breakup of the fast ice cover. On 07/03, divergence, vorticity, and deformation rapidly increase as the fast ice begins to break up and the trackers are flushed out of Elson Lagoon. Although not shown, the variance of the acceleration increases slightly with the onset of drifter motion on 07/04.

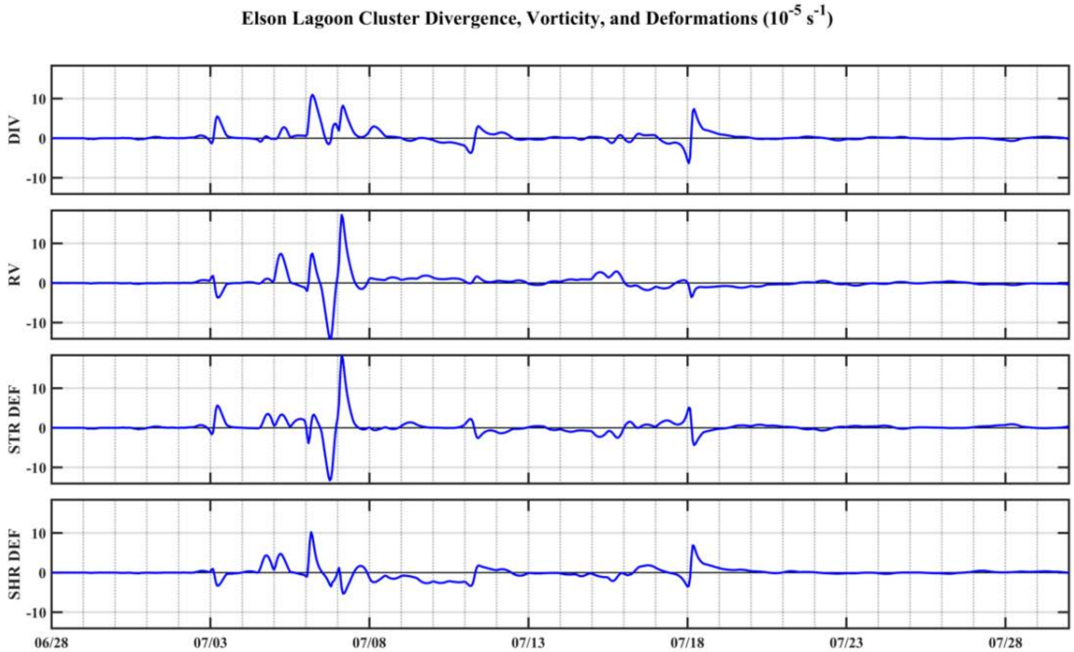


Figure 15. Time series of horizontal divergence (top), relative vorticity (second from the top), stretching deformation (third from the top), and shearing deformation (bottom) for the Elson Lagoon Cluster. Units are 10^{-5} s^{-1}.

The positions of the Elson Lagoon trackers are shown overlain on MODIS imagery on three separate days for which there are MODIS images with minimal cloud cover (Figure 16). The trackers remained stationary at their initial location for ~3 months before rapidly flushing out of the lagoon beginning on 7/03. On 7/11 trackers 24 and 25 appeared to be in open water, but it is difficult to tell from available MODIS imagery whether the remaining trackers were on ice or in water. These trackers appeared to be rapidly flushed out of Barrow Canyon and caught up in the Chukchi Slope Current (Corlett and Pickart, 2017) or another adjacent circulation system.

Figure 16. MODIS imagery with approximate tracker positions from 4/01–7/11, 2017.

Transport of Material by Sea Ice: Harrison Bay Cluster

In addition to using the trackers for dynamical analysis, the trackers may be useful for inferring the fate of sea ice and any material transported by the ice. BOEM is interested in improving their understanding of sea ice as an agent for cross- and along-shore transport of material. In the case of Harrison Bay, specifically, there is interest in the fate of contaminants and other chemical constituents contained in the ice that may be transported by the nearshore ice after breakup.

Figure 17 shows a sequence of MODIS images from Harrison Bay from May–July 2015. These trackers were deployed May 18–21 (Table 3), immediately prior to the spring freshet, and remained stationary until ~June 23, 2015 (Figure 18). After this, the trackers were rapidly blown with the wind to the western edge of the bay.

Multiple MODIS images between May 18 and ~ June 21 help to visualize changes in ice (especially nearshore where the ice melts the most rapidly), but the ice the drifters were on was stationary during this period. Once the ice adjacent to the coast melted out, the ice farther offshore moved into the open water closer to shore.

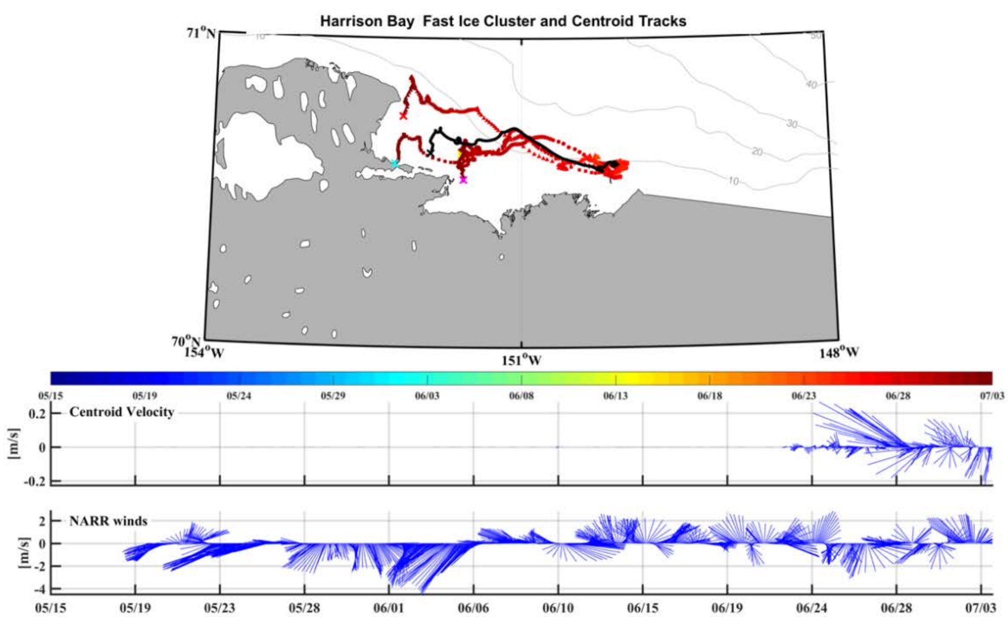


Figure 17. Map of the Harrison Bay fast ice cluster and cluster centroid tracks (top), and centroid velocity (m s-1) and NARR wind velocity (m s-1) along the centroid track (bottom).

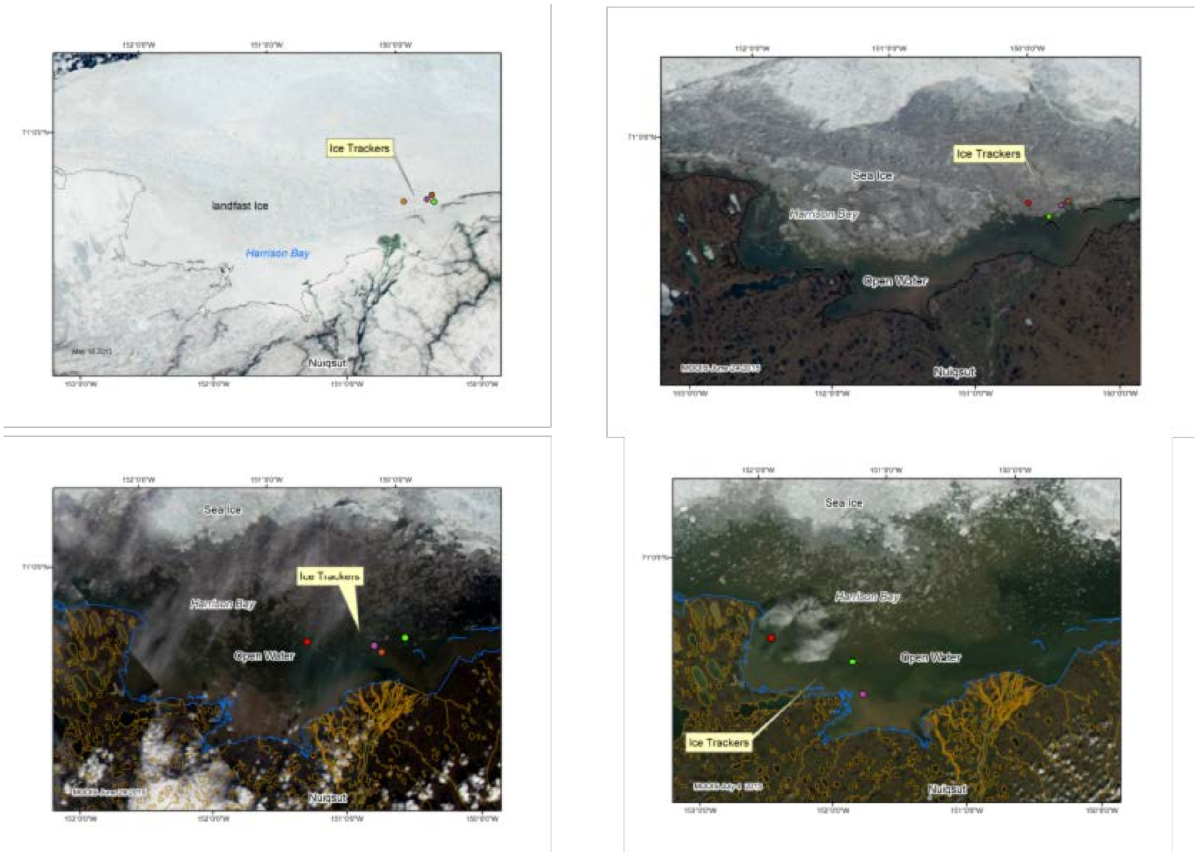


Figure 18. IceTracker positions overlaid on MODIS imagery. Upper left (May 18 2015): IceTrackers on landfast ice; Upper Right (June 24 2015): lceTracker locations just prior to moving into open water created by the melting of inshore landfast ice; Lower left (June 29 2015): IceTrackers are drifting to the southwest in open water within Harrison Bay; Lower Right (July 4, 2015): IceTrackers begin to ground along the shore of Harrison Bay after moving from the east side of the bay.

Utility of Accelerometers and Temperature Sensors in Discriminating between Open Water and Sea Ice

Figures of tracker position overlaid on MODIS satellite imagery appear to indicate that, based the variance of the accelerometer alone, we cannot discern between when the trackers are floating versus when they are on the ice. For example, based on MODIS imagery, tracker 0016, one of the Harrison Bay trackers, appears to have been floating in open water for several days before beaching; a MODIS image from 6/29/2015 (Figure 18, bottom left panel) appears to show open water surrounding the tracker. Similarly, a MODIS image from 7/4/2015 shows no sign of sea ice around tracker 18 (Figure 19). The variance of the acceleration for tracker 0016 does not appear to change at all until 6/27 and then it only briefly exceeds 1.8×10^3 before settling below 1×10^3 again until just prior to the tracker beaching on 7/5 (Figure 20). Not shown, National Weather Service analysis from this period indicates the buoys were in open water as early as 6/29/2015.

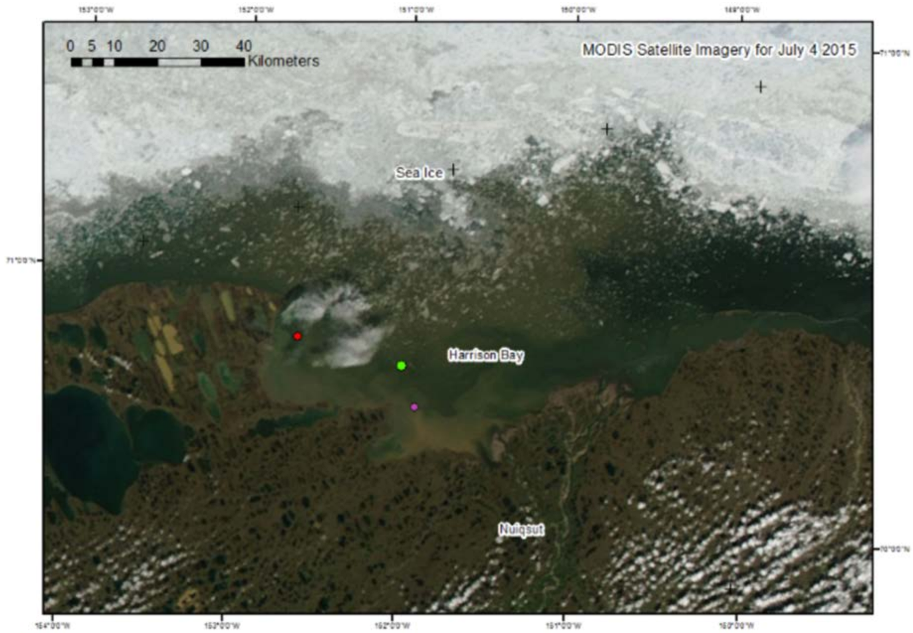


Figure 19. MODIS image from 7/4/2015 with IceTracker locations.

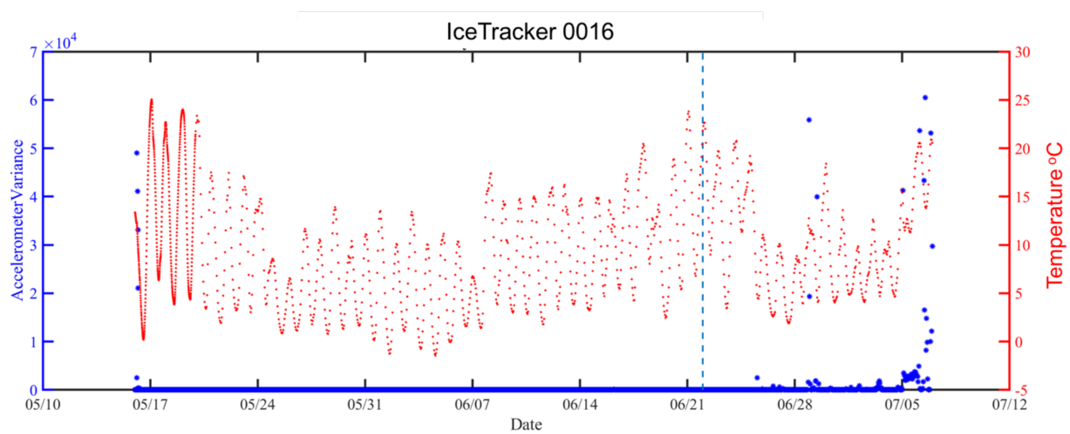


Figure 20. Variance of accelerometer and temperature time series (^{0}C) recorded by tracker 0016.

The temperature sensor alone does not appear to be indicative of when a tracker is in the water versus on the ice. From the image shown in Figure 6, we know the tracker was on the ice on May 23. According to the temperature sensor in the buoy, the temperature within the tracker on this day ranged between ~0 and ~20^{0}C. There are several periods when the daily fluctuations in temperature within the tracker are smaller: 5/24, 6/07, and after 6/27. We might expect smaller daily temperature fluctuations when the buoy is submerged because of the high heat capacity of water. The variance of the accelerometer begins to increase only after 6/27, when the daily variations of temperature are smaller compared to earlier in the record. Thus, sampling both the variance of the temperature and the variance of the acceleration may be necessary to determine when the buoys are submerged or on sea ice. Further controlled field and lab tests, briefly described in the Summary and Conclusions, could address the utility of a combination of sensors in determining when the trackers are on ice or in open water.

IceTracker Applicability in Search and Rescue Operations

The return rate of the Elson Lagoon trackers was increased in summer 2017 to assist a search and rescue effort off Utqiaġvik. During a brief period, the five trackers, initially deployed in Elson Lagoon, were set to report their position every five minutes, their maximum reporting period. Tracker positions were relayed to UIC staff on-site. While it is not clear whether the trackers were close enough to aid in the successful rescue effort (they were several hundred kilometers removed from the drifting vessel), their reliability and adaptability were demonstrated during this incident and over the course of the project.

Discussion

The IceTrackers have a low-cost advantage over other ice tracking technologies and are clearly a useful platform for specific situations (i.e., those in which a compact, rugged, and easily and rapidly deployable buoy for tracking sea ice is required). For example, IceTracker characteristics make them well-suited for search and rescue operations, spill response in mixed ice conditions, and campaigns where a large number of buoys are deployed on sea ice from aircraft. These are just some of the situations for which IceTrackers, rugged platforms with a long shelf-life, are well-suited. Campaigns which re-seed the ice with drifters each year are another application where the low-cost and durability of the IceTrackers makes them a good fit.

The design requirements to create a rugged and low-cost platform limit the ability to add some features that may be desirable in certain situations. For example, an external thermistor for tracking surface water temperatures may be desirable as a means of inferring the presence of sea ice around a floating buoy, but it would be difficult to incorporate such a sensor without compromising the impact resistance and cost of the IceTrackers. Similarly, a standard method of determining whether an ocean buoy is submerged is to utilize a “contact” sensor that completes an electrical circuit when submerged (Johnson et al. 2012). Integrating such a sensor into the IceTracker platform would be complicated and may not be possible in a buoy designed to survive the significant impact forces of being deployed from an aircraft. These design constraints mean that IceTrackers alone may not be well-suited to deployment situations where there is an expectation that the ice could melt in place (e.g., adjacent to the Colville River).

During the course of the project, an accelerometer was incorporated into the IceTracker in order to test whether this low-cost sensor was useful in determining whether the trackers were immersed. The ability to remotely determine whether a tracker is floating or frozen into sea ice would greatly expand the utility of the IceTrackers. To reduce the volume of data transmitted, the variance of the acceleration was sampled and telemetered via an Iridium modem at the same rate as the position information. From the results presented above, it is not clear that the variance of the acceleration is adequate for determining whether the IceTrackers are immersed. MODIS imagery from 6/29/2015 appears to show that the IceTrackers are immersed; however, there was no clear signal in the variance of the acceleration. There is considerable ambiguity in these comparisons since the exact timing the MODIS overflight can only be estimated from satellite flight tracks and each MODIS image pixel represents $\geq$30 m. High-resolution SAR imagery along the track of buoy, similar to that shown in Figure 10, may be more useful for diagnosing the utility the accelerometers and temperature sensors as aids for determining whether the buoys remain on the ice. However, such an undertaking was beyond the scope of this project, and the need for such costly satellite products (e.g., from Radarsat 2) was not anticipated in the proposal stage. Similarly, the incorporation of an accelerometer as a means of determining whether the buoys were floating was not a part of the original proposed effort, but it was hoped that it would be a means to overcome some the other design constraints.

In the case of the Harrison Bay deployment, the IceTrackers appear to have functioned as surface drifters as they moved within the open water environment south of the eroding landfast ice edge. As seen in the MODIS image from 07/04/2015 (Figure 19), their movements were likely impacted by local winds and the local discharge of fresh water from the Colville River. In this situation, the buoys provided valuable and new information on the breakup of the nearshore ice. All of the ice within the bay appears to have melted in-place and, thus, all of the material frozen into the ice was retained within the bay, at least temporarily.

In the case of the Chukchi Sea landfast ice deployments, all of the IceTrackers were advected across the Chukchi Shelf or north into the Beaufort Sea. Presumably, this ice did not survive more than one ice season given the extensive melt of ice in the region in recent years. Similarly, landfast ice from Elson Lagoon was caught up in a westward circulation pattern along the Chukchi slope. In these cases, the ice and any material transported with the ice presumably melted out as the sea ice melted along its trajectory. Based on this information, if there was a spill in the Elson Lagoon, contaminants could conceivably be advected far from their point of origin. In the case of Harrison Bay, contaminants during the early summer months (June, July) would likely be retained locally. Note that these conclusions are based on very limited information and are not statistically validated.

For specific types of studies, it may make sense to deploy IceTrackers in combination with other types of drifters. For example, beginning in the spring, standard, drogued ocean drifters (e.g., those used by Weingartner et al. 2015) could be deployed in combination with IceTrackers on the landfast ice to track the seasonal evolution of stratification in the Beaufort Sea in a method similar to the pilot effort that was undertaken in Harrison Bay (described herein). Such a deployment would provide a rich amount of data on the changes in seasonal stratification, mixing of freshwater, and the potential for the dispersal of sediments and/or contaminants in the event of a spill. It is unlikely such information could be obtained by other means. The use of supplemental standard ocean drifters would provide important information on immersion, mixing of water masses, water distribution over multiple vertical levels, and the relative differences in motion of these different water masses. In such a scenario, the IceTrackers would provide robust redundancy to the more standard ocean drifters in challenging mixed ice conditions. Such a study would also provide valuable comparisons between the performance of the IceTrackers and standard ocean drifters.

Finally, just as with standard ocean drifters, to gain new insight and reach meaningful conclusions about the fate of landfast ice and/or the dynamics between pack and landfast ice along the shear zones, IceTrackers will need to be deployed repeatedly, over multiple seasons and years, in sufficient numbers to make statistically robust inferences (Weingartner et al. 2015). If it can be demonstrated that IceTrackers can survive impacts with the ice at higher rates of speed than were tested in this project, fixed-wing aircraft flights are likely the most economical means of large-scale deployments of IceTrackers. (Note: Subsequent to this project, several IceTrackers were successfully deployed from a C-130 aircraft). If we are not able to develop a means of determining whether the IceTrackers are immersed, then such deployments will be best undertaken in combination with extensive SAR analysis (e.g., in collaboration with the National Weather Service Ice Desk) beyond that undertaken here. Such analysis would likely provide a means of tracking immersion of the IceTrackers.

Conclusions

Summary

Twenty-five IceTrackers were deployed during the course of this three-year study. Overall, this demonstration project was highly successful, and the technology has been demonstrated to be well suited for large-scale deployments in the Arctic as a robust response tool for increasing domain awareness and as a low-cost means of collecting high-quality scientific data including information on ice dynamics, the fate of ice, and sea ice dispersion. Additional work needs to be done on the IceTrackers to enhance their capability to track whether they are sitting or drifting on ice or in open water. These devices could be used by National Weather Service to enhance their ice analysts' capability to track ice movement and, potentially, to differentiate between stable landfast ice and mobile pack ice.

New information on the fate of landfast ice was gathered during the project including from the Chukchi and Beaufort Seas from Elson Lagoon and Harrison Bay. The fate of landfast ice appears to vary in each case: landfast ice from the Chukchi Sea drifted westward after detaching from the coast, landfast ice from Elson Lagoon drifted north and west, and landfast ice from Harrison Bay was retained locally on the western side of the bay. In addition to generating new information on the fate of landfast ice, we demonstrated a novel technique for analyzing deformation along a drifter track using SAR imagery.

This project generated significant interest in the community of Utqiaġvik and accomplished successful outreach initiatives with K-12 teachers and in partner projects with Frontier Scientists.

Recommendations for Further Study

IceTrackers were demonstrated to be a versatile and lower-cost tool for studying sea ice dynamics including in the under-studied but dynamically complex landfast ice zone where there is currently a paucity of data. As demonstrated herein, the trackers can be used to great effect to "tag" different ice types (landfast, first-year, multi-year, etc.) and subsequently to track the evolution and fate of the tagged ice. The low cost and ease of deployment of the IceTrackers mean that field campaigns to understand ice dynamics can be undertaken with less effort, cost, and logistical complexity than with other, existing technologies. This facilitates making larger or more frequent deployments to further our knowledge of small-scale ice dynamics, work that was previously limited by cost. Thus, we recommend that IceTrackers be considered for future studies where understanding the fate and transport of material (sediment, contaminants, etc.) by sea ice are a priority or in studies where an improved understanding of sea ice dynamics is the desired outcome. Overall, the trackers appear to be relevant to a number of studies comparing buoy trajectories to modeled sea ice trajectories may be a useful application of the data generated from the trackers. Indeed, more expensive buoys have been used extensively for this purpose in the past (e.g., Hutchings and Hibler 2008).

The utility of the IceTrackers would be further improved if a reliable means of determining when the trackers are submerged can be developed. If a means of discriminating when trackers are submerged or frozen into ice (or on top of an ice floe) can be demonstrated, then the trackers may prove useful for studies of freeze-up (and break-up). The combination of an accelerometer and a temperature sensor appears to have promise in this application. We, therefore, recommend a follow-up study to develop this aspect of the trackers. A series of experiments in increasingly complex environments could help to develop quantitative metrics for determining when the trackers are on (or frozen into) sea ice. For example, metrics based on the variance of the accelerometer and the variance of the temperature sensor may be appropriate. One could envision an experimental setup in a climate-controlled chamber where trackers were frozen into a growing ice sheet alongside a control tracker that was not in the water. This same experiment could be repeated in a local lake during freeze-up. Finally, trackers could be frozen into a lagoon or another semi-enclosed body of water, where there is a reasonable expectation that the trackers would not be lost to open water during the experiment. In each case, synchronous video would assist in understanding the progression of the experiment and the evolution of the temperature and accelerometer measurements.

Study Products

Outreach

The UA Museum of the North (UAMN) created a curriculum focused on sea ice, climate, the engineering design process and the development of ice drifters in this project, and the resulting data obtained. Hands-on activities and resources were shared with teachers through an intensive 1.5-day workshop. The free workshop provided background information, engagement with activities and materials, an opportunity to speak directly with scientists involved in the project, and an option for professional development credit for teachers. Participants received a kit of materials for classroom use.

Activity themes included:

- Albedo
- Sea Ice & Shorelines (coastal erosion)
- Local Knowledge
- Ice and ships (historical drifters)
- Ice ridges
- Ocean currents, sea ice, and climate
- Ice drifter design
- Engineering Design Process
- Data analysis and graphing
- Drifter movements (Arctic ocean circulations and geography)

A Fairbanks-based workshop was planned for May 11 and 13, 2017. Thirteen Fairbanks North Star Borough teachers registered and seven actually attended, participated fully, and received credit (Figure 21). Participants included teachers from six schools, ranging from preschool to middle school, and one retired teacher who teaches as a substitute. Each participant submitted a reflection on how they would implement activities with students. Feedback was very positive when asked what was most valuable about the course:

> "The combination of the research data being collected using the drifters with the design challenges."
>
> "Seeing and realizing the changes are real and having Jeremy and Andy present to provide actual experiences."
>
> "It was a great price, excellent useful information, and unbelievable materials to take away. It was very well organized. Excellent binder, great resource lists."
>
> "Offer this class again."
>
> "It was fun, engaging and connects to our NGSS that we are learning to adopt."
>
> "Awesome time and hands-on work and to learn from the study—ice drifts, geography, and science."
>
> "I would highly recommend this course—great resources, clear and organized presentation; scientist explanation added diverse ideas for preparation of material. Material will allow for fantastic thematic units."

Figure 21. Teachers and instructors participating in the Fairbanks teacher workshop.

After contacting the superintendent and all principals in the North Slope Borough School District, a workshop was planned for Utqiaġvik on March 30 and April 2, 2017. The workshop was canceled due to non-attendance, and a resource kit and activity binder were left at the school. Several teachers commented that travel funding was a limiting factor.

Other project-related outreach activities had a broader distribution. While carrying out fieldwork for this project, Drs. Mahoney and Kasper were filmed by the Frontier Scientists production team. Material from filmed interviews and field work was incorporated into Frontier Scientists videos (http://frontierscientists.com/projects/ocean-sea-ice-science/sea-ice/) and later incorporated into a half-hour segment that was broadcast on KAKM TV in Anchorage (https://www.youtube.com/watch?v=r6RWwE5Ugpc). The video was included as an "Additional Resource" in a new pop-up children's book "The Adventures of Apun the Arctic Fox" produced by Frontier Scientists. In addition, to inform community members about the project, Drs. Mahoney and Kasper developed a "flyer" distributed around Utqiaġvik (Figure 22). Finally, project results and IceTracker trajectories were displayed on two project webpages (icetrackers.org; http://www.ims.uaf.edu/artlab/projects/IceTrackers/).

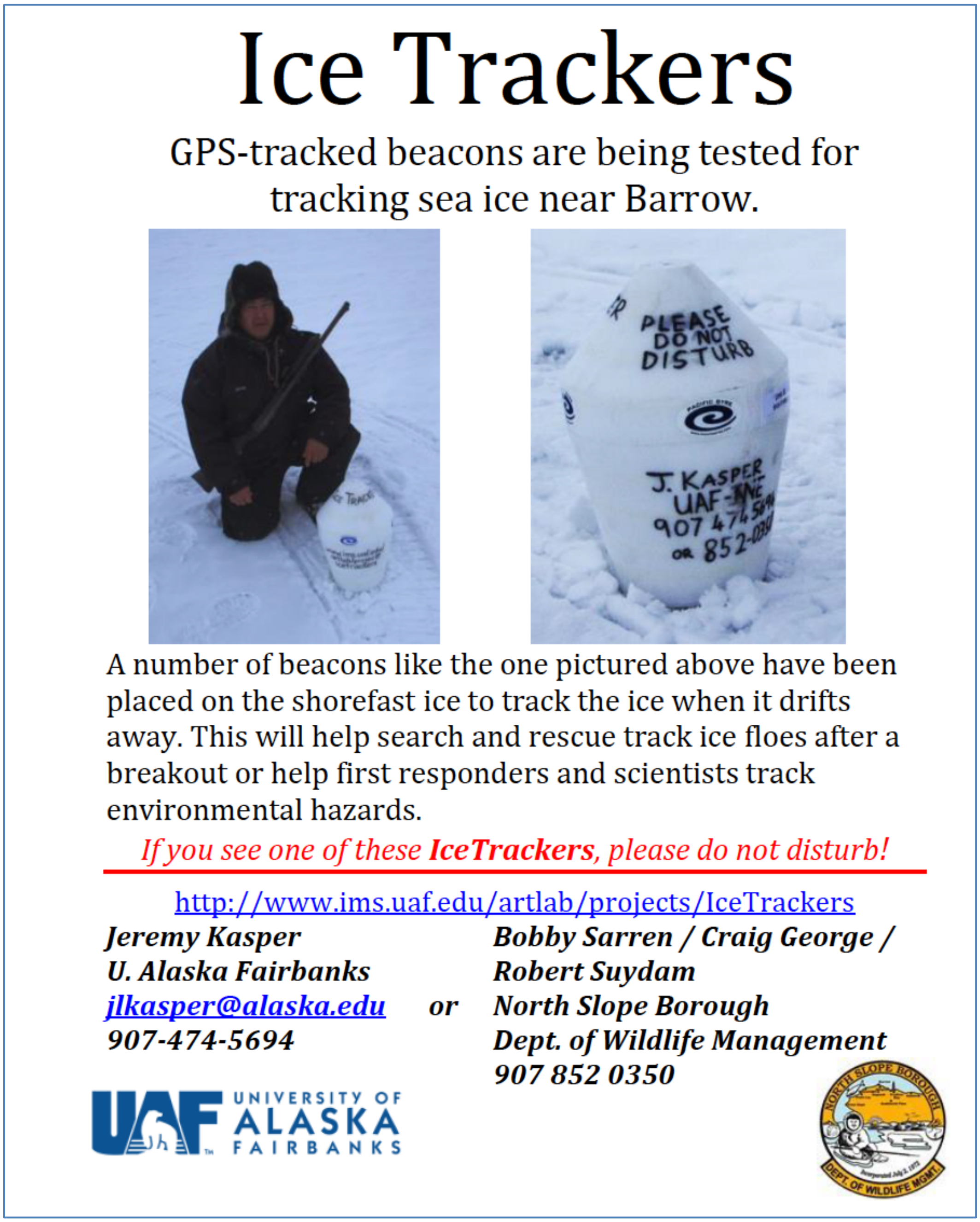


Figure 22. Outreach flyer distributed around Utqiaġvik.

Presentations/Publications

"Ice Trackers," CMI Annual Review, Anchorage, AK, 2015. Oral Presentation

"Ice Trackers: low-cost tracking of sea ice in remote environments," Alaska Oil Spill Technology Symposium, Fairbanks, AK, 2015. Poster Presentation

"Ice Trackers," International Arctic Buoy Program Annual Meeting, 2015, Oral Presentation

Mahoney, A., J. Kasper, and P. Winsor, 2015, Multi-year ice transport and small-scale sea ice deformation near the Alaska coast measured by air-deployable Ice Trackers. American Geophysical Union Fall Meeting Abstracts.

Kasper, J., J. Trefry, A. Fox, M. Savoie, S. Fox, G. Lawley, R. Trocine, and P. Shipton, 2016, The 2015 Spring Freshet and Its Effects on the Alaskan Beaufort Sea. Ocean Sciences Abstracts.

Mahoney, A., J. Kasper, and P. Winsor, 2016, Multi-year ice transport and small-scale sea ice deformation near the Alaska coast measured by air-deployable Ice Trackers. Alaska Marine Science Symposium Abstracts.

"IceTrackers: low-cost tracking of sea ice in remote environments," CMI Annual Review, Anchorage, AK, 2016. Oral Presentation

"IceTrackers: low-cost tracking of sea ice in remote environments," CMI Annual Review, Anchorage, AK, 2017. Oral Presentation

Kasper, J., A. Mahoney, and P. Winsor, 2016, IceTrackers. Alaska Marine Science Symposium Abstracts.

Acknowledgments

This project was a partnership with the North Slope Borough, Pacific Gyre LLC (IceTracker manufacturer), the University of Alaska Fairbanks, and the Bureau of Ocean Energy Management through the University of Alaska Coastal Marine Institute. Study Collaboration and funding were provided by the U.S. Department of the Interior, Bureau of Ocean Energy and Management, Environmental Studies Program, under Cooperative Agreement Number M14AC00019 through the University of Alaska Coastal Marine Institute. Matching funds for this study were provided by the Shell North Slope Borough Baseline Studies Program, Pacific Gyre, Inc. and by the University of Alaska Fairbanks. Robert Suydam, John Craighead George and Robert Sarren with the North Slope Borough Department of Wildlife Biology and Nagruk Harcharek with UIC were integral to the success of this project. We would also like to acknowledge the support of the BOEM Program Officer, Warren Horowitz, and Heather Crowley, the BOEM Program Manager. Finally, we would like to acknowledge Liz O'Connell and Frontier Scientists for their work to publicize the results of this study.

References

Corlett, W. B., and R.S. Pickart (2017), The Chukchi slope current. Progress in Oceanography (153), 50–65. doi:10.1016/j.pocean.2017.04.005.

Druckenmiller, M. L., H. Eicken, M. A. Johnson, D. J. Pringle, and C. C. Williams (2009), Toward an integrated coastal sea-ice observatory: System components and a case study at Barrow, Alaska. Cold Regions Science and Technology 56(2-3), 61-72.

Hutchings, J. K., and W. D. Hibler (2008), Small-scale sea ice deformation in the Beaufort Sea seasonal ice zone. Journal of Geophysical Research-Oceans 113(C8). doi:10.1029/2006JC003971

Johnson, D., R. Stocker, R. Head, J. Imberger, and C. Pattiaratchi (2012), A Compact, low-cost GPS drifter for use in the oceanic nearshore zone, lakes, and estuaries. Journal of Atmospheric and Oceanic Technology (20), 1880–1885.

Jones, J. (2013), Landfast Sea Ice Formation and Deformation Near Barrow, Alaska: Variability and Implications for Ice Stability. M.S. Thesis, University of Alaska Fairbanks, Fairbanks, AK.

Jones, J., H. Eicken, A. Mahoney, MV Rohith, C. Kambhamettu, Y. Fukamachi, K. Ohshima, and J. Craig George (2016), Landfast sea ice breakouts: Stabilizing ice features, oceanic and atmospheric forcing at Barrow, Alaska. Continental Shelf Research (126), 50–63. doi:10.1016/j.csr.2016.07.015.

Kulchitsky, A., J. Hutchings, J. Johnson, and B. Lewis (2017), Siku Sea Ice Discrete Element Method Model. Final Report, Bureau of Ocean Energy Management, OCS Study BOEM 2017-043.

Mahoney, A., H. Eicken, Y. Fukamacha, K. Ohshima, D. Simizu, C. Kambamettu, M. Rohith, S. Hendricks, and J. Jones (2015), Taking a look at both sides of the ice: comparison of ice thickness and drift speed as observed from moored, airborne and shore-based instruments near Barrow, Alaska. Annals of Glaciology 56(69). doi:10.3189/2015AoG69A565

Weingartner T.J., and MBC Applied Environmental Sciences (2003), Physical Oceanography of the Beaufort Sea - Workshop Proceedings. Final Report, Minerals Management Service, OCS Study MMS 2003-045.

Weingartner, T.J., R.S. Pickart, and M.A. Johnson (2010), Recommended Physical Oceanographic Studies in the Alaskan Beaufort Sea, Final Report, Minerals Management Service, OCS Study MMS 2010-018.

Weingartner, T.J., C. Irvine, E. Dobbins, S. Danielson, L. DeSousa, B. Adams, R. Suydam, and W. Neatok (2015), Satellite-tracked Drifter Measurements in the Chukchi and Beaufort Seas, Final Report, Bureau of Ocean Energy Management, OCS Study BOEM 2015-022.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the sound use of our land and water resources, protecting our fish, wildlife and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island communities.

The Bureau of Ocean Energy Management

The Bureau of Ocean Energy Management (BOEM) works to manage the exploration and development of the nation's offshore resources in a way that appropriately balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.