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The Best of Both Worlds: Connecting Remote Sensing and Arctic Communities for Safe Sea Ice Travel

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DETAILED DESCRIPTION OF OBSERVED CHANGES

All interviewees agreed that the ice surface changed annually and that this was normal. Kugluktuk participants agreed that recent years had rougher sea ice, though in 2017 it was relatively smooth.

Interviewees described warmer water temperatures, different snowfall patterns, and different currents, all impacting sea ice thickness. A majority of participants from both communities observed that sea ice is thinner than in the past. Hunters recalled seeing open water in mid-winter in locations not previously seen. Open water often results in a need to hug the shoreline instead of traversing offshore areas. For example, the Cape Krusenstern area north of Kugluktuk is becoming more hazardous. It used to be traversable in winter when people traveled by dogsled, estimated as in the 1960s and 1970s. Inuit started noticing thin ice in the 1980s and 1990s, then thin ice and open water year-round in the 1990s – 2000s, and now there is usually a year-round polynya. Interviewees discussed changes in slush under the sea ice that also affect thickness. Thickness in fall was regarded as recognizable by its colouration: dark grey areas are very thin, and the ice becomes lighter grey as ice gets thicker. While it is possible to travel on dark grey sea ice in cold temperatures if there is a supportive layer of slush under the sea ice, this layer of slush is not developing in the same way as it did in the past because of the warmer water temperatures. Consequently, in order to be supportive, the sea ice needs to be thicker to make up for the lack of under-ice slush.

In both communities, the ice-free season was described as approximately a month longer than in the past. Kugluktuk Inuit described this change as potentially beneficial for hunters who have boats, but not for hunters who want to collect goose eggs or hunt caribou. Both communities were nearly unanimous in observing that the timing of freeze-up is variable but becoming later; however, two young Cambridge Bay hunters recalled normal variation in freeze-up dates. Several participants from both communities mentioned that air temperatures tend to fluctuate more than they used to around freeze-up, which also delays freeze-up and makes the sea ice more difficult to read because of melted snow covering the sea ice. Two hunters hypothesized separately that the sea ice is now thinner later in the year and that, while the winds likely haven't changed, freeze-up occurs during a later, windier period.

The timing of sea ice breakup was described as more variable than freeze-up, with participants from both communities observing earlier trends. Numerous interviewees from both communities observed that breakup is about a month earlier than when they were young, and several discussed rapid sea ice breakup in recent years. Others described adjusting their travel timing by 2–3 weeks in order to avoid breakup conditions.

River ice (Inuinnaqtun: *kuukkam hikua*) and lower salinity brackish ice (Inuinnaqtun: *taryukittuq hiku*) was found to impact sea ice access and travel. Near Kugluktuk, river break-up impacts sea ice use by causing over-ice flooding, blocking access to the sea ice, and enhancing melt. Early river breakup and the resulting difficulty accessing sea ice ruined the spring hunt for many Kugluktuk Inuit in 2017. Several interviewees pointed to earlier river movement now, attributed in part to a large amount of snowfall (also common in the 1960s and 1970s) and warm winds melting snow. One hunter noted that the local definition of river breakup is the first day that a boat can be taken from town up the river to the Bloody Falls; this typically occurs sometime in June, with an average around 21 June. In 2017, the river began moving around 22 May and broke on 2 June 2017. The river broke quickly and while people were still out on the sea ice. Consequently, locals had to meet hunters who had been snowmobiling on the sea ice and pick them up by boat at the sandbar just offshore and bring them back to town. In contrast, the melt season

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was considered late in 2018, with people observing that the timing was reminiscent of the 1970s–80s.

Gerry Atatahak from Kugluktuk noted that "those [cracks] are all normal though, people from around here more or less expect to see the same crack year after year, because that's the way, they generally don't change." However, others have observed interannual changes in the locations of ice discontinuities. For example, one Kugluktuk hunter has seen the cracks move,

> a few hundred metres away from their traditional areas, because the waters are warming and changing, so the currents are not exactly where they used to be you know 30 years ago. They've gone a little bit more north. But they're pretty much still right where they've always been. And [the sea ice bridges used to cross the cracks] are almost always in the same location, within a few hundred…feet of each other. Why [do] I know this? I've been taking GPS points of some of them in the Locker Point area.
>
> Kugluktuk hunter

Another Kugluktuk Inuit described a large crack near Walker Point not seen before. A Cambridge Bay hunter observed that cracks are not as straight as in the past and tend to zigzag. Pressure ridges were also noted to have changed. Sea ice adjacent to Kugluktuk was considered smooth in the 1960s and 1970s, with lots of pressure ridges in the past 10–15 years. In Cambridge Bay, two hunters observed that while pressure ridges used to go straight across the ocean from Long Point to the mainland, they have recently been observed oriented perpendicular to their normal orientation, meaning that they now need to be crossed. Other hunters from both communities noted that they were unsure whether cracks or pressure ridges had changed over time.

GERRY ATATAHAK'S INTERPRETATION OF FALL AND WINTER IMAGES

Okay, well you have two different images here [Fig. S1], one is taken in November [when the sea ice is] still all moving around…You have all these white areas here where the ice has accumulated and that have broken up… This dark area [Cape Krustenstern to Locker Point] is fast moving current water, it moves back and forth. And this [bright area in northwest Coronation Gulf/north of Kugluktuk] is where all the ice has accumulated over here, from the southeast winds. […The dark southern shore area],

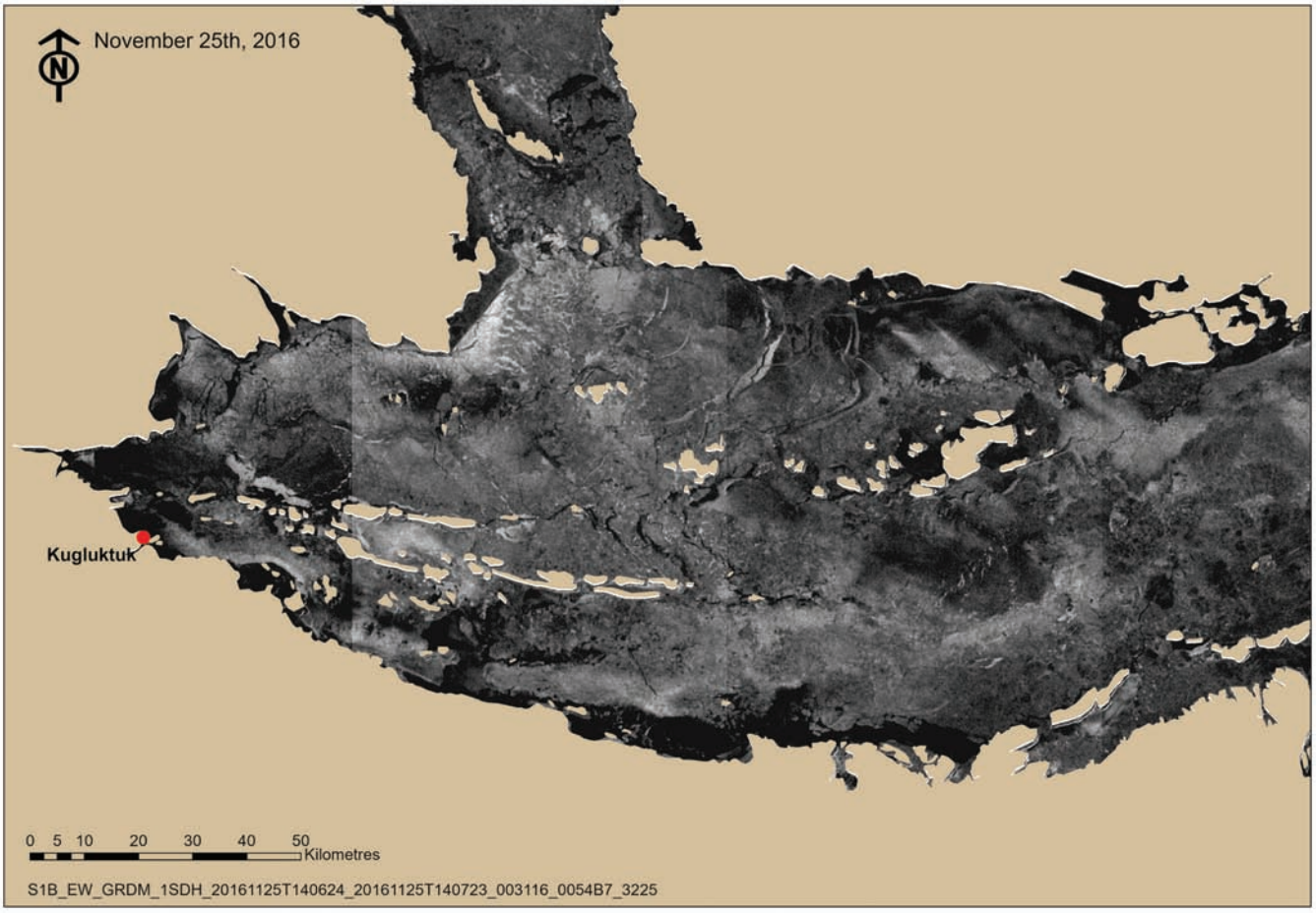

FIG. S1. Sentinel-1 SAR map of the Kugluktuk area from 25 November 2016, used in interviews conducted from 25 May 25 to 8 June 2017.

that's more or less open water. [It] did not freeze until late December.

Now you look at this, the February the 23rd map [Fig. S2], this is set ice—it's solid, it's frozen. But, you can actually see where all the jumbled up ice is, where it's all gathered together. [It's] huge… north of Lambert Island and Douglas Island [because] this is all fast moving water, it moves back and forth… Also, you can tell that the prevailing winds were from the west…When it gets really extremely cold [the prevailing wind] is more or less from the west and that is why most of the ice is over here [east] now.

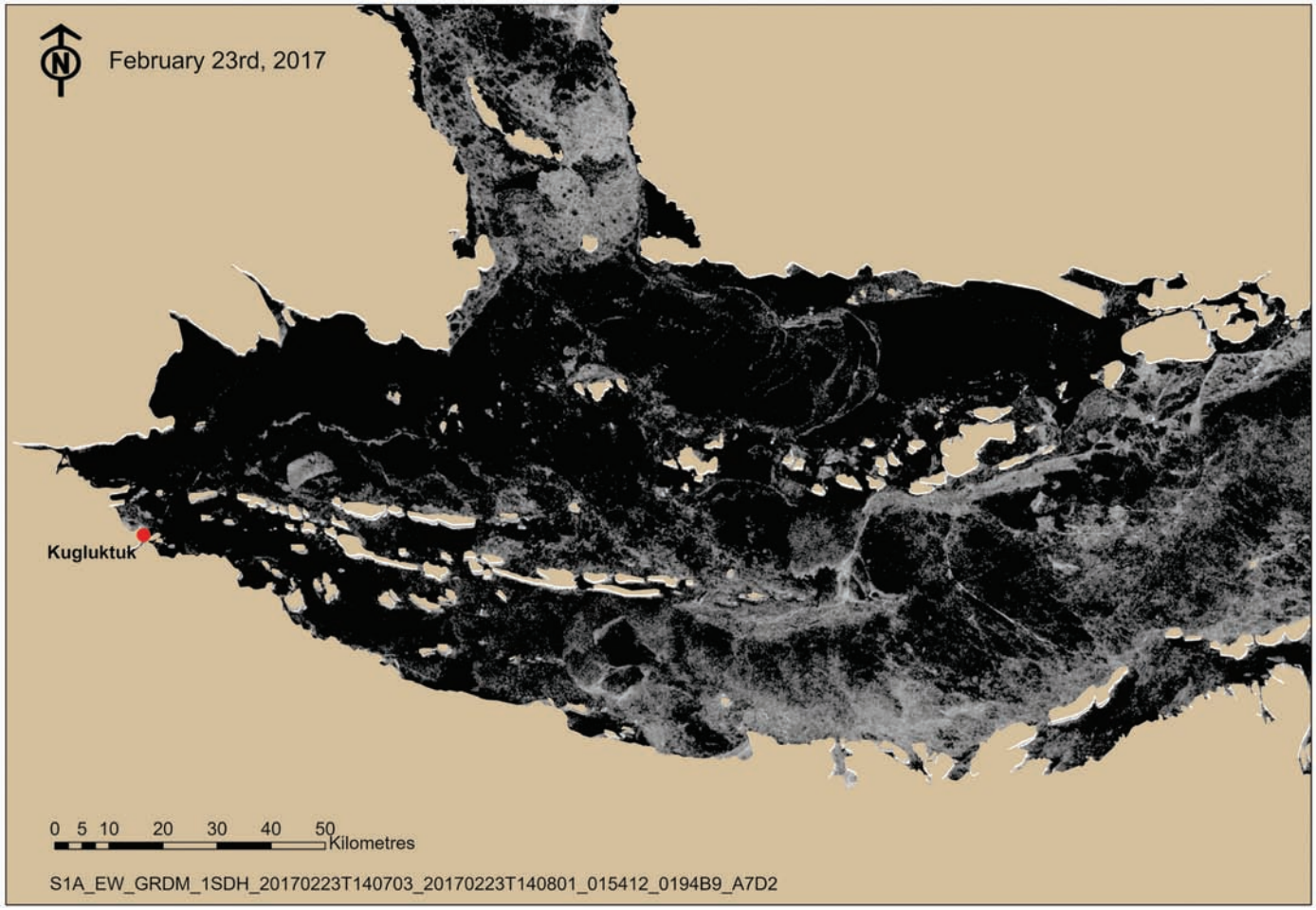

FIG. S2. Sentinel-1 SAR map of the Kugluktuk area from 23 February 2017, used in interviews conducted from 25 May 25 to 8 June 2017.

TABLE S1. Semi-structured interview question guideline for May–June 2017 field. Questions became more specific for later field seasons.

Themes	Follow-up questions
Experience	• Do you, or did you, travel on the sea ice? Why do people travel on sea ice? • Is there anything else you want me to know about sea ice and/or travel?

Hazard identification and technology	• How do you choose travel routes?
	• How much do your routes change from year to year?
	• Using a map/image, can you point out:
	  • Routes that are good for travel/have high traffic?
	  • Areas where travel does not happen. Why?
	• What are the features that make an area good for travel? Poor for travel? Unsafe?
	• Can you point to (or draw) areas on this map where this feature is found?
	• What are the main hazards for travel? Impediments to travel?
	  • How do they vary by season?
	• What features (or ice conditions) would be useful to know about when making travel plans?
	• Do you already use remote sensing images to aid your travel? If so, what information do you use from them?
	• Are there areas where remote sensing information would be very useful (i.e., areas I should focus on)?
	  • How do you think remote sensing images/analysis can help with this?
	• What impact does technology have on travel?

Spatiotemporal sea ice use and change	• Where do people travel to/from Kugluktuk/Cambridge Bay?
	  • Does this depend on the season?
	• When does a normal season for sea ice travel start/end?
	• Have you noticed any changes in sea ice that impact travel?
	  • Where?
	  • When? Over the past 3, 5, or 20 years?
	  • Is it changing more lately?
	  • Are the changes related to seasons?
	  • Who do they impact?
	• What features would be useful to know about when tracking change (or lack of change) over long time periods?
	  • Do you think remote sensing can help us look at changes in sea ice conditions? What would be helpful to track?
	• Is there anything in addition to or instead of remote sensing data that would be helpful? (e.g., web cam, met station data).

Site-specific questions	• What is interesting here? • What part of this image/map/photo is important? • Explain what you see? • What is significant about this area, feature, or process? • How does this kind of feature impact you? The community? Travel or safety? • Is this a normal sea ice feature?

TABLE S2. Information about the Sentinel-1 products processed and used in maps brought to the communities. Where indicated (*), classified maps were also created. S = Sentinel; Des = descending; Asc = ascending; and EW = extended wide-swath. All images are in ground range-detected (GRD) format.

Platform (Direction/Mode)	Date	Orbit (Track)	ID	Location
S1A (Des/EW)	12 March 2018*	020983 (86)	56B6	Kugluktuk
S1A (Des/EW)	5 March 2018	020881 (159)	970B	Kugluktuk
S1A (Des/EW)	20 February 2018*	020691 (144)	BD41	Cambridge Bay
S1A (Des/EW)	11 January 2018	020108 (86)	3D38	Kugluktuk
S1A (Des/EW)	4 January 2018	020006 (159)	E84A	Kugluktuk
S1B (Asc/EW)	4 January 2018	009022 (71)	859F	Cambridge Bay
S1A (Des/EW)	3 January 2018	019991 (144)	1C50	Cambridge Bay
S1A (Des/EW)	4 November 2017	019116 (144)	DAF2	Cambridge Bay
S1B (Asc/EW)	7 November 2017	008176 (100)	1813	Cambridge Bay
S1B (Asc/EW)	1 July 2017	006295 (144)	FC51	Cambridge Bay
S1B (Asc/EW)	22 June 2017	006164 (13)	92F3	Kugluktuk
S1A (Des/EW)	30 March 2017*	015922 (100)	90B7	Victoria Strait
S1A (Des/EW)	28 March 2017*	015893 (71)	3595	Cambridge Bay
S1B (Asc/EW)	18 March 2017*	004764 (13)	57E5	Kugluktuk
S1B (Des/EW)	17 March 2017	004749 (173)	0AE8	Cambridge Bay
S1A (Des/EW)	23 February 2017	015412 (115)	A7D2	Kugluktuk
S1B (Des/EW)	25 November 2016	003116 (115)	3225	Kugluktuk
S1A (Des/EW)	21 April 2016	010920 (173)	317F	Cambridge Bay
S1A (Des/EW)	9 April 2016*	010745 (173)	132B	Cambridge Bay
S1A (Des/EW)	12 March 2016*	010337 (115)	DD0B	Kugluktuk