15 pages max, 10 or 11 point font

Arctic Social Science
Solicitation: NSF 21-526

Jon Rosales, PI
Ivan Ramler, Co-PI
Lisa Torrey, Co-PI
Aaron Iverson, Co-PI
Perry Pungowiyi, TEK-Science Expert

Title: Measuring Wind Direction Change on St. Lawrence Island, Alaska with Traditional Ecological Knowledge

Project Background

Kimmerer (2018) offers us an analog for the work proposed below. She explains that as *Nanabozho*, the original person in the *Anishinaabek* tradition, travelled North, he met *wiingaashk* [sweetgrass], "the teacher" (p. 39) and "knowledge holder" (p. 33), and the lessons the grass taught him "could be expressed in two complementary frameworks, in the language of both TEK and Scientific Ecological Knowledge (SEK)" (p. 39). We propose to look to the grasses of the Bering Strait Region as the Siberian Yupik of St. Lawrence Island observe them to learn about changing wind patterns and the lessons the grasses can teach us to strengthen adaptive capacity to a rapidly warming Arctic.

Arctic amplification is well established with warming at twice the global average (AMAP 2017), with data reanalysis studies above that amount (Wang et al. 2022), some modeling studies at nearly four times the global average (Rantanen et al. 2022), and some hotspots up to six times (Huang et al. 2018). These changes have a profound impact on subsistence cultures in the Arctic. Many subsistence practitioners are now left living in an unknown environment accompanied by a sense of solastalgia. Most dramatic to the residents of Savoonga, AK of this study are the effects of changing wind on hunting, travel, settlement patterns, and being able to know their land. Even so, the long-time Indigenous residents of the Arctic offer a way to perceive, understand, and interpret the dramatic changes; in effect, they direct us toward "what to look for and how to look for what is important" (Berkes 2018: 180). While most climate change science is based on instrumental data, traditional knowledge and local observations by subsistence-oriented Indigenous communities offer lengthy and "fine-scale" knowledge of environmental change better suited to developing "effective strategies" for climate change adaptation (Savo et al. 2016: 462).

We propose to measure the traditional ecological knowledge (TEK) in Savoonga, AK that the prevailing wind direction changed from the historical northerly dominated winds 30+ years ago to southerly and easterly dominated winds around St. Lawrence Island (SLI), on which Savoonga is located.[1] We will employ the TEK practice of observing wind dynamics affecting tundra plants. We propose to examine bluejoint reedgrass (*Calamagrostis canadensis*) and tall cottongrass (*Eriophorum angustifolium*), in the sedge family, as indicators of predominant wind direction and wind direction. Hunters and gatherers from Savoonga have taught us to observe the direction these plants lay down after the growing season as proxies for predominant wind direction and wind direction change. They have also taught us to examine wind effects on live plants as they bend in the wind. In doing so, this project applies a new methodology

[1] Please note, wind direction terminology differs in the literature. A *southward* wind means the wind blows to the south and comes out of the north. *Southerly* winds mean the wind is blowing from the south, its origin, and are going north. In this proposal, we describe wind direction from its origin, as in out of the north, or *northerly*, since that is how winds are described by the residents of Savoonga.

that may yield new knowledge about how to detect, measure, and monitor wind direction using grass lay direction. Through the participation of local knowledge-holders, the project can also serve to recalibrate the TEK of wind direction on SLI and perhaps restore the knowledge and practice of observing wind direction that is being lost with a changing Arctic. In addition, the study further develops the field of Indigenous science – to systematically generate evidence about the environment by employing Indigenous practices of observation.

What we have learned with the Alaskans Sharing Indigenous Knowledge (AKSIK) project (explained below) is that in addition to ancient, long-term observational knowledge passed down through elders, TEK is also a *way* of knowing one's current environment. TEK is a knowledge practice of observation of the landscape that enables TEK practitioners to assess and anticipate change in their environment. TEK can also spur new scientific inquiry, as is the case here. TEK complements large-scale Arctic observations, models, and satellite efforts as well as more localized adaptation research since TEK more directly reveals how climate change affects the people living there. As Savo et al. (2016: 470) conclude from their global assessment of TEK observations of climate change:

> Local observations can be combined with other sources of data… to define more precisely the linkages between climatic changes and their direct and indirect effects on the environment. For example, subsistence-oriented communities may note linkages among winds, animal behavior and ice conditions… TEK has the potential to help formal science disentangle the dynamics of social-ecological systems in their responses to climate change.

TEK comes from long-term "immersive experience in a particular place… It is knowledge that undergoes continual generation and regeneration as peoples interact with the environment, observing, learning, and adapting" (Berkes 2018: 180). In this regard, TEK is elder- and practitioner-reviewed on a continuous basis as it is used daily. It is, therefore, a valuable methodology for assessing and observing current environmental change. As Krupnik (2002) observed two decades ago, what is needed in the Western scientific tradition is a form of research that is open to TEK. While great strides have been made bridging TEK and Western science, what we propose is to not treat TEK as another source of information, but as "knowledge in its own right" (Berkes 2002: 344). In our review of climate change knowledge in Savoonga compared to that found in the scientific literature, we find that the TEK there outpaces established scientific knowledge in some significant areas such as changes to ocean currents and coastal sedimentology (Ignatowski and Rosales 2012). Therefore, this project *does not seek to validate the TEK claim that wind direction has changed; it seeks to replicate TEK observation practices to determine how conditions have changed on St. Lawrence Island.*

Of particular importance to the Siberian Yupik of St. Lawrence Island is what they can decipher from observing wind patterns. In his seminal work on TEK weather observational practices on St. Lawrence Island, Krupnik (2002: 174-175) writes:

> A reference to wind is commonly the first and most important feature of the daily observation, and typically leads to many conclusions… Each wind is known to bring a certain type of weather, snow, or ice movement. By identifying or referring to the wind, an observer can make a quick judgment of the situation and even make a basic forecast of upcoming conditions… [These practices] commonly start by referring to the prevailing wind direction.

Understanding potential future wind patterns and current wind patterns on the ground is important for adapting to climate change in Savoonga. Information about climatic trends supports effective climate change adaptation and the lack of such information limits adaptive capacity (IPCC 2022; IPCC 2014). Wayfinding, that is, being able to track and predict weather conditions, is vital for hunters, herders, and gatherers out of the ocean or tundra. Wayfinding advise from elders on how and when to hunt or gather is important as well (Archer et al. 2017) yet few investigations have attempted to quantify local observations in Alaska (Hansen et al. 2013). While several papers document climatic changes on St. Lawrence Island (Ignatowski and Rosales 2013; Noongwook 2000), none have measured change in wind direction on the ground where knowing wind patterns is a matter of safety as well as a critical element to successfully access favored hunting and gathering areas.

While the grass lay component of this project will give us current wind direction data, it alone will not generate information about wind pre-1990 when elders tell us that the historical prevailing direction started to change from the N or NW. To measure that requires a metric that tells us the wind direction from 30+ years ago in a region with no current or historic wind vanes. We propose to compare grass lay direction data to proxy wind data reconstructed, again, in a traditional method. Elders tell us that hunting cabins are built with their doors facing downwind, away from prevailing wind direction. As explained below, we will measure the direction of cabin doors built before 1990 on St. Lawrence Island as a proxy for predominant wind direction at the time the cabins were built.

The methodologies we propose are novel and untested in the scientific community but used since time immemorial in the Siberian Yupik tradition. If successful, the methodologies will enable us to measure wind direction change without erecting an array of weather stations. This new methodology may be of interest to other researchers interested in wind direction and fine scale impacts of atmospheric circulation change affecting people and ecosystems in the Arctic.

Alaskans Sharing Indigenous Knowledge (AKSIK)

This is the latest project of the Alaskans Sharing Indigenous Knowledge program. With the consent of the tribal councils, AKSIK started in 2009 documenting traditional and local knowledge of climate change in Savoonga and Shaktoolik, AK, two indigenous villages in the Bering Sea Region. Through interviews with elders, we identified over 50 distinct climatic changes they have witnessed since roughly 1990 (see Ignatowski and Rosales 2013). We then, via a survey, sorted those changes into the most disruptive elements of change (Rosales and Chapman 2015). Not surprisingly, increased storm intensity, particularly in low lying and highly exposed Shaktoolik, ranked as being the most disruptive element of climatic change for the villages. We therefore began a monitoring program to measure what the villagers told us, that storm intensity was increasing, by mapping driftwood deposits (Rosales, et al. 2021). The next most disruptive element was how weather patterns have changed, particularly the predominant wind direction, which has become more variable and unpredictable. This claim is commonly heard about conditions on St. Lawrence Island and around the Bering Strait Region from its residents that hunt, gather, and herd reindeer.

<If we have room insert study site section here>

AKSIK benefits from several well-developed relationships in Savoonga. First, PI Rosales' mother-in-law is from Savoonga. The fact that PI Rosales is related to her, more than any other reason, has generated trust and a welcoming reception when we return to the village. Second, having a well-respected Village Coordinator, Perry Pungowiyi, enables our work and helps maintain trust with the village. Mr. Pungowiyi is respected in his community as a whaling captain, hunter, and ex-President of the Native Corporation. He is also the primary liaison between AKSIK and the Tribal Council and village residents before and after our field seasons. He is also a careful guide for us, one who knows the landscape extremely well and travels at an inviting pace, taking time to teach us about the island. PI Rosales is in constant contact with Mr. Pungowiyi consulting on current and future projects. Mr. Pungowiyi offers sound advice on how to proceed with the research program. Lastly, AKSIK's research protocol enables trust-building through ongoing engagement. Since its beginning, AKSIK only does research in Savoonga and Shaktoolik, AK. While our engagement with the two communities is limited by funding, the great distance between us, and more recently COVID, we aim to travel to both communities at least once a year if not twice. We start every trip with a meeting with the Tribal Councils seeking their consent to continue our research, report on our findings, and to identify the important questions to each community. Our protocol follows the free, prior, and informed (FPIC) consent process established in the Universal Declaration on the Rights of Indigenous Peoples (UNDRIP 2007). To that ethic we add 'ongoing' (FPICO) to express commitment to the research program's long-term sole focus on the two communities.

AKSIK's work between 2009 and 2015 was funded through internal grants and department funding at St. Lawrence University. In 2015 AKSIK received an EAGER NSF grant (#1640960) to investigate storm surge in Shaktoolik. More recently in 2022 AKSIK received a planning grant (#2221731) to gather more information to support the current proposal. PI Rosales and a St. Lawrence University student, Amanda Barreto Salguiero, hosted three focus group discussions during the first week of August 2022. The first group consisted of eight elders, the second group of six clan leaders, and the third of two reindeer herders. The intent of the focus group discussions, summarized below, was to get more information on the importance of observing grass lay direction, how grass lay observation is conducted, and how cabin construction factors wind direction into the orientation of the cabin door. Focus groups verified the claims made in this proposal and taught us that tracking wind is much more involved than simply a wayfinding practice as initially believed. We now understand that observing grasses and wind patterns are part of a complex knowledge-practice-belief complex (Berkes 2018) that is part of a way of living and being to the Siberian Yupik of Savoonga.

Climate Change Adaptation

This study is situated within the interdisciplinary field of climate change adaptation, a melding of scientific and place-based inquiry to better meet climate change challenges. The IPCC corroborates our research method where they write, "Drawing on diverse knowledges and cultural values, meaningful participation and inclusive engagement processes—including Indigenous Knowledge, local knowledge, and scientific knowledge—facilitates climate resilient development, builds capacity and allows locally appropriate and socially acceptable solutions. (*high confidence*)" (IPCC 2023: 34). For Indigenous peoples, effective adaptation approaches "are culture-specific, historically informed, and geographically rooted" (Berkes 2018: 200). Effective climate change adaptation is also ecosystem-based, rooted in local environmental conditions (UNEP 2019). While our project is Siberian Yupik and St. Lawrence Island specific. The methods developed here can serve as a model for adaptation efforts elsewhere.

Incorporating TEK is now widely accepted as an effective practice for climate change adaptation (IPCC 2022; IPCC 2014; UNFCCC 2006), in particular as a form of resilience (Pearce et al. 2015) and for policy formation (Ingty 2017). TEK and science working together can yield greater scientific results (King et al. 2010; Lefale 2010; Nakashima et al. 2012; Vogel et al. 2007), although results must be tempered by TEK's context specific application (Huntington et al. 2007). Prescient to the project proposed here, the co-production of knowledge approach is seen as an effective method in detecting regime shifts (IPCC 2019); here we propose to show a shift in wind direction, as measured by the cabin door orientation. The IPCC continues, however, that, "While advancements have been made, the practice of knowledge co-production would benefit from further experimentation and innovation in methodologies" (IPCC 2019: 272). In our review of the climate change literature, adopting TEK as a *scientific methodology* to monitor wind is missing.

In their study of Sachs Harbour in Canada, Berkes and Jolly (2001) conclude that what makes subsistence cultures resilient are their abilities to remain mobile to access food, flexible in the foods they consume, knowledgeable about their local environments, and having robust cultures of sharing. The same can be said for Savoonga. Greater understanding of shifting wind patterns may help Savoonga residents adapt to climate change, to anticipate impacts on subsistence gathering activities, cultural continuity, and food security and healthy food choices. Methods that can generate accurate local knowledge are needed now to match the rapid onset of climate change in the Arctic.

Climate change and wind direction in the Arctic

Arctic amplification affects weather system tracks, most evident in storm tracks. Low-pressure systems, and associated storm tracks, from the North Pacific are expected to continue to drift further north with continued warming (IPCC 2019; Chapman and Walsh 2007; Bengtsson et al. 2006). These larger patterns of atmospheric circulation affect wind patterns in the Bering Strait Region and St. Lawrence Island.

Wind direction affects precipitation patterns and sea ice extent as well, with winds from the south bringing more rain and diminished sea ice extent (Jones et al. 2020). Arctic sea ice loss is well-established (AMAP 2017). Sea ice loss in the Bering Sea continues to decrease at an alarming rate since the 1970s (Erikson et al. 2015) and is affected by the increased heat flux accompanying southerly winds (Woodgate et al. 2006). Local winds increase warm water flow from the North Pacific into the Bering Strait (Woodgate et al. 2021). Winds are strongly associated with shore-fast ice formation (Selyuzhenok et al. 2023). Shore-fast ice, in turn, affects the margins of Arctic coasts – a carbon cycle hotspot and area of intense change from erosion, permafrost melt, marine temperature, and increased primary productivity and anaerobic decay (Irrgang et al. 2022; Gould et al. 2022). Understanding these processes is critical to capturing a clear picture of the carbon cycle in the Arctic and role of the oceans as a sink or source of carbon (Rogge et al. 2022). Developing a method to track the direction of winds on a fine scale, a scale that impacts localized ice formation, may be of interest to other Arctic researchers.

Our method can measure wind direction at any location perennial grasses or sedges are accessible (see methodology section below for more detail). Changing wind patterns from climate change are a primary environmental indicator of that change and can be seen in tundra plants, in their movement while alive and their display patterns after they have died. In short, climate change is on display in these tundra plants, yet it is not fully investigated.

Wind studies incorporating TEK

In their global review of TEK studies of weather observations, Savo et al. (2016) conclude that there are geographical gaps in knowledge, often from remote areas, and from where climate change is having the greatest impact. They also conclude that wind was among the least reported observation. Other ethnographic investigations around the world have, for example, documented traditional and indigenous practice of noting wind direction to forecast precipitation in India (Pareek and Trivedi 2011), Uganda (Orlove et al. 2010), and Tanzania (Elia et al. 2014; Chang'a et al. 2010). Changes in wind direction have been observed locally in Kiribati (Kuruppu and Liverman 2011). Other investigations have brought scientists and TEK holders together in workshops to assess environmental change, including wind direction change in Sápmi (Riseth et al. 2010).

Closer to Alaska, MacDonald (1998) and Archer et al. (2017) document how the Inuit closely monitor the wind, its intensity, variability, and direction to guide hunting decisions and how they use snowdrifts for navigation knowing they are shaped by the prevailing winds and experienced observers can note changes to prevailing wind patterns in snowdrifts. Knowing the importance of snow formations to monitor wind patterns, Gearheard et al. (2010) investigated the wind direction claims made by the Inuit of Clyde River, Nunavut. They describe difficulties blending TEK and instrumentation data, concluding that the two sets of information may be incompatible, that is, TEK holders and anemometers may be noting different phenomena (e.g., TEK holders focused on wind variability as it affects hunting practices and anemometer measured average wind directions). Elsewhere in Canada, TEK observers in Nunavut observed seasonal changes to prevailing wind direction (Prno et al. 2011), as subsistence practitioners note in Savoonga.

These are important elements to consider and another reason we do not want to study wind direction with weather stations, rather, we want to investigate wind direction as TEK practitioners study the patterns, by looking at its effect on tundra grasses and sedges.

As with the Arctic in general wind data in the Bering Strait Region of Alaska is lacking, inconsistent, or discontinuous (NOAA 2020). Uncertainty remains on wind forecasting as the complexity of climate change disrupts temperature gradients and jet stream consistency, storm and low-pressure weather systems (IPCC 2012). Savoonga is commonly thought to experience westerly-southwesterly to easterly-northeasterly winds in the summer months and northerly-northeasterly winds during the fall (USGS 2015). Some investigations, however, find evidence of weakening winds from the north (Woodgate et al. 2006) and that increased wind speeds off the coast of Wainright, AK impacts subsistence activities (Hansen et al. 2013). These studies partly support the claim made by TEK holders in Savoonga that the predominant winds have changed.

These dramatic changes have an outsized impact on subsistence cultures, however, particularly on those dependent on hunting mammals in the northern Bering Sea Region (Bering Sea Elders Group n.d.). As one elder put it in our focus groups, “everybody was so sad because there was no ice,” expressing a feeling of solastalgia due to the loss of an important aspect of everyday life and subsistence in Savoonga. Another elder said “the weather is changing more rapidly than ever,” especially the wind which used to be calm for long periods of time. This person added that the wind is more “aggressive” now, impacting their lives and livelihoods. Elders in our focus group again verified the claim that the prevailing winds have changed from the northerly to southerly and easterly directions. Even though elders in Savoonga know the predominant wind direction has changed, it compromises their abilities to decipher weather conditions and brings in complex changes to their livelihoods, especially for hunting sea mammals that we did not fully understand before.

The totality of change

In our initial investigation seeking to document climatic changes in Savoonga we learned that noting the direction dead grass lays is a wayfinding method used there in case one becomes lost or disoriented while on the tundra (Ignatowski and Rosales 2013). Elders in Savoonga tell younger hunters, herders, and gatherers that should they become lost on the island, say in a snowstorm, they should dig down in the snow and look at the direction the grass lays as a wayfinding practice to determine a cardinal axis bearing. Once that is determined, they are taught to head toward the coast to find their way home. Elders in our focus group confirmed these practices, but we also learned that wayfinding is *just one* element of grass lay observations. In fact, wayfinding is a relatively minor and rare observation compared to the much larger composite of daily practices observing tundra plants plays in weather observations for hunting, gathering, and herding.

As documented in Oozeva et al. (2004), one of the first things they note is the wind and wind direction, and then on how those winds play out on the landscape, especially how the wind affects sea ice, where most of their subsistence hunting activities happens. Wind observations embody concerns about safety, hunting and gathering success, cultural continuity, connection to their land, and much more (Table 1). What we heard in our focus groups is consistent with Yua et al. (2022: 1) where they conclude, “Indigenous Peoples' knowledge systems hold methodologies and assessment processes that provide pathways for knowing and understanding the Arctic, which address all aspects of life, including the spiritual, cultural, and ecological, all in interlinked and supporting ways.”

Table 1: Wind as part of a wider complex of knowledge and observations practices by realm for TEK holders in Savoonga, AK

Realm	Indicators
Sky	Cloud types and layers; cloud movements, direction, and sheer; lower clouds are most important for weather prediction; puffy clouds mean good, calm weather; low ceiling means calm weather; white clouds mean warm weather; dark clouds with sharp edges mean windy or bad weather is coming; dark and light clouds together mean a windy day; S winds with dark clouds over the mountains means winds are changing quickly; shape of clouds over mountains indicate imminent wind speed and direction; color of clouds (black clouds in the East mean unfavorable weather, favorable in the West); stars (navigation); sun as a navigation tool; sundogs used to mean wind is coming, but they look different now; note direction birds are flying (e.g. puffins generally fly toward the E when on the southside of SLI); mirage over open water or leads
Land	Wind in live grasses and sedges (wind direction, variability, intensity); dead grasses and sedges (for orientation laying downwind from prevailing wind direction); landmarks (mountains, points, cabins) for orientation; mirage over distant lakes
Ocean	Currents, direction and speed; suspended dust or sediment particles near ocean surface appear before wind changes; appearance and direction of riffles on the water; swells appearing are a 1-6 hour indicator of wave changes; waves change before winds; fog means fairly steady conditions that can linger for days; ocean current on N side of SLU changes twice daily from E to W and back; note wind conditions for how they affect sea ice flows, opening and closing of polynyas, and to predict where sea ice can shelter a boat from wind
Self	Note wind on face, its intensity, direction, and variability; when in a boat, note direction of sea spray on your body and on your crew
Online	Weather service sources are "pretty good"

Wayfinding by observing tundra plants and their lay direction is but one indicator used for navigation. Ocean current direction and intensity, along with fog direction and snowdrift formations are other wayfinding elements taught by the elders. Elders in the focus groups said that predicting how wind patterns will produce ice formations that can shelter you while traveling on the ocean is important to know to return home safely. Knowledge of ice reflections in the sky can direct a hunter toward open water or ice, and on the tundra a mirage in the distance indicates a lake. Being able to read the indicators of wind on the landscape is vital, especially being able to anticipate wind direction change that may bring in severe, and dangerous, weather conditions. Close attention is given to cloud types, their movement, and shape as they travel across the landscape, especially across the mountain peaks south of Savoonga. Several elders taught us that “the water moves before the wind,” so they watch the surface water to see how it is moving and especially for granulated sediments in the water column as an indicator of wind direction change.

Focus group elders stressed that “safety” and acquiring food are of primary importance engaging in subsistence activities. Elders stressed that younger people need to be trained in how to be safe. They maintain that safety, and hunting and gathering success, are based on observation – people must learn how to observe the weather, learn how it works, react when it changes, and anticipate change and the direction of change, to worsening or improving conditions. Such observations are based on daily observations, scanning the whole environment. As one elder put it, this is how you “take care of your family.” Developing these skills is as important as wearing proper clothing and being prepared with a compass, radio, proper gas supplies, and communication with other hunters – “Their words will tell you where to go,” as one elder said.

Grass observations are part of what Krupnik (2002) calls a culturally rich environmental package, or what Berkes (2018) calls a knowledge-practice-belief complex, or what Savo et al. (2016) simply call “multidimensional relationships" with linked changes and spillover effects. Grass observations by the Siberian Yupik in Savoonga can be understood, then, as part of a larger totality of cultural practices, and one component of scanning many signals to ensure safety and success while out on the tundra, and/or deciding on when and where to venture on the ocean. From these observations they know when and where to travel, and whether to travel or not.

Stronger winds and storms coming from an unfamiliar southerly direction, however, now push ice around more making it difficult to discern when and where to go hunting and be safe. Stronger winds change the position of leads in the sea ice more quickly and unpredictably making safe passage to hunting sites and return home more dangerous. As revered whaling captain Chester Noongwook describes in Oozeva et al. (2004: 93):

> I would like to talk about our ice. It has changed from since I became aware of things long ago. Over the past 45 or more years, from change caused by wind, our ice is getting thinner and there are more ridges and the pieces are getting smaller… That is how it has become, and it may be getting thinner and easier to melt. Maybe the current from far south has started to get around the island.

During the focus groups, even though participants were prompted to talk about their grass lay observations, many focused on the marine activities and sea changes. Their focus on the marine environment coheres with the high importance of sea hunting, fishing, and other marine activities to the village of Savoonga. Of particular importance is a consistent northerly wind for several weeks to a month to blow ice to the shore to create solid shorefast ice. Shorefast ice of up to a mile is needed for whaling (in Krupnik 2002). Therefore, the TEK practiced by subsistence practitioners in Savoonga can teach us *how to study* wind patterns within its broader context of subsistence cultural practices and global change in the Arctic.

How to look at wind patterns

When out hunting, subsistence practitioners from Savoonga keep track of the signs of changing weather and react in a timely manner so as not be stranded. Knowing the predominant wind direction is akin to carrying a compass in your hand where that knowledge can save lives, and take care of those of who do not possess or adhere to what they have been taught by the elders. The winds affect ocean currents and move sea ice, opening and closing leads. Sea ice is used as a barrier to protect hunters from large waves or swells. Not being able to track and predict wind direction can lead to hunters being caught in open water or pinned between pieces of sea ice. For example, in the spring of 2020, the wind direction suddenly changed on the north side of St. Lawrence Island, caught hunters by surprise, and locked their boat up in between two ice flows. Thankfully, other hunters were able to rescue them and help tow their boat over the ice to safety. The new predominant and warmer SE winds hamper sea ice development and/or producing thinner ice. Villagers tell us it has been hard to adapt to these changes; it still requires constant attention, but with new interpretations of the wind patterns, and looking out for fellow hunters, herders, herders, and gatherers.

Some people are better than others at watching and interpreting the weather (Krupnik 2002) securing their social standing while alive and legacy once they have passed. The names of particularly knowledgeable and gifted weather watchers remain in the minds of the TEK practitioners in Savoonga. Elders in the focus groups stressed the importance of possessing and retaining the skills of their gifted elders to interpret the weather by sensory perception of existential conditions that surround them. As one elder put of skills taught to him by his elders, "back then we had no instruments we relied on ourselves." This statement highlights the importance of autonomous skill development independent of technological instruments such as GPS, cell or satellite phones, and even CB radio. Many stressed that those technologies may fail to bring people back to safety. As another elder put it, "TEK does not run out of batteries." As with expert tracking skills for hunting success, abilities to read and predict weather conditions in live time as essential to Savoonga hunters, herders, and gatherers. One elder spoke about how this skill is about interpreting the reality around them and being able to interpret it accurately, or truthfully. "We have to all speak the truth, otherwise we put people in jeopardy" he said. An important element of truth telling, that is the ability to accurately interpret one's surroundings, is also the ability and sensitivity to communicate those perceptions to others who may be out on the land. Much communication happens by CB radio, but communication also happens non-verbally. Boat captains, for example, take routes on the ocean that other boats see so others know where you are heading.

We have learned that watching the weather in Savoonga is an everyday practice to ensure overall wellbeing of the community, from providing food to arriving home safely. From our focus groups we can summarize the importance of watching the weather for subsistence activities in Savoonga, AK:

- To decide on where and when to go out on the landscape;
- For safety while out hunting, traveling, herding, joyriding, and gathering;
- To return home safely;
- For hunting and gathering success;
- So they "do not forget" their ancestral teachings, to keep the TEK memory alive, and pass it on to the next generation in their village;
- To not get over reliant on instruments instead relying on themselves and their own abilities; and
- To be able to communicate observations to others who are also out on the landscape.

Caveats

Several elders, however, warned that dead grass bent down has some pitfalls as an indicator of wind change. Variables such as the direction of the last freezing rain event or direction of snowmelt, they said, can influence the position these grasses display. These elders then said that it is important to carry knowledge of previous weather events, such as storms or icing events, to know that the grass lay direction could have been affected by an event other than predominant wind direction.

While some elders taught us that shoreline grasses are stiffer and have longer stems, and herders said grasses on the tundra are softer and preferred by reindeer, no one in the focus groups had detailed knowledge of grass species or parts of the plants. Both reindeer herders could identify the grasses the animals prefer ("the taller grasses") and where those grasses exist on the island. One elder intimated that the Siberian Yupik terms for those grasses is now forgotten. Most focus group participants referred to grasses in general, as opposed to specific grass or sedge types, when referring to wind patterns. One elder stated flatly, "Any grass will tell you the wind direction," suggesting differentiating species is not that important when assessing wind direction.

To document the current predominant wind direction and grass lay direction offers us the opportunity to, as one elder put it, "recalibrate" and "restore" their traditional knowledge and to possibly equip them with new knowledge for climate change adaptation.

TEK Restoration

Hunters, herders, gatherers, and elders in Savoonga are trying to "catch up to climate change" (Pungowiyi 2021). They feel some of their TEK does not apply anymore and needs to be "updated" or "recalibrated." Elders tell us they feel like "children" not being able to advise on or make sense of weather patterns, and perhaps for losing what their ancestors taught them (Ignatowski and Rosales 2013) or even what they knew when they were younger. Nevertheless, as several elders said, their ancestors warned them about climatic changes. Climate change challenges the adaptive capacity of subsistence hunters. Again, the feeling of solastalgia is apparent as climate change strips them "of their considerable knowledge, predictive ability, and self-confidence in making a living from their resources. This may ultimately leave them as strangers on their own land" (Berkes 2018: 201).

As with any knowledge system, TEK evolves with new knowledge combined with the old. Being able to read the landscape, in this case, the grass lay direction and wind in sedges, can serve as a marker to read the new landscape that is forming around Savoonga. When asked, "Why watch the weather?" one elder said, "So we don't forget." So they do not forget how to engage in subsistence activities and maintain their culture and identity, and lose their TEK.

This project, then, is largely about supporting the residents of St. Lawrence Island, and elsewhere in the Arctic, in reclaiming the detailed knowledge about observing tundra plants that is now lost or being lost; it is also about documenting new knowledge about the St. Lawrence Island landscape that may be incorporated in to their TEK if it is useful to them. TEK knowledge, however, is quickly being lost for Indigenous peoples in Savoonga and "at risk of disappearing, just when it is most needed" (Kimmerer 2018: 25). As one elder put it, the "GPS has taken over" and another on how hunters "listen more to the radio weather forecast than to us." Disconnection from the land, and in this case, tundra plants, reduces subsistence practitioner's abilities to detect environmental change and leaves them more vulnerable in the face of climate change.

Even so, re-education of TEK can lead to revitalization of cultures for their sovereignty, self-determination, and empowerment (Berkes 2018). As Kimmerer (2018) writes, ecological and cultural restoration happens by "re-engaging people with the land, renewing place-based connections, and supporting cultural practices that sustain the land" (p. 41). She also sees hope even though this knowledge may be forgotten or uncertain, the knowledge is still there, in the land and in the plants. "The plants can be teachers, but we have to learn how to be students" (Kimmerer 2018: 43). As requested by the elders in our focus group, this project aims to "retrieve the knowledge" held in the plants on St. Lawrence Island and share that knowledge with the community in Savoonga.

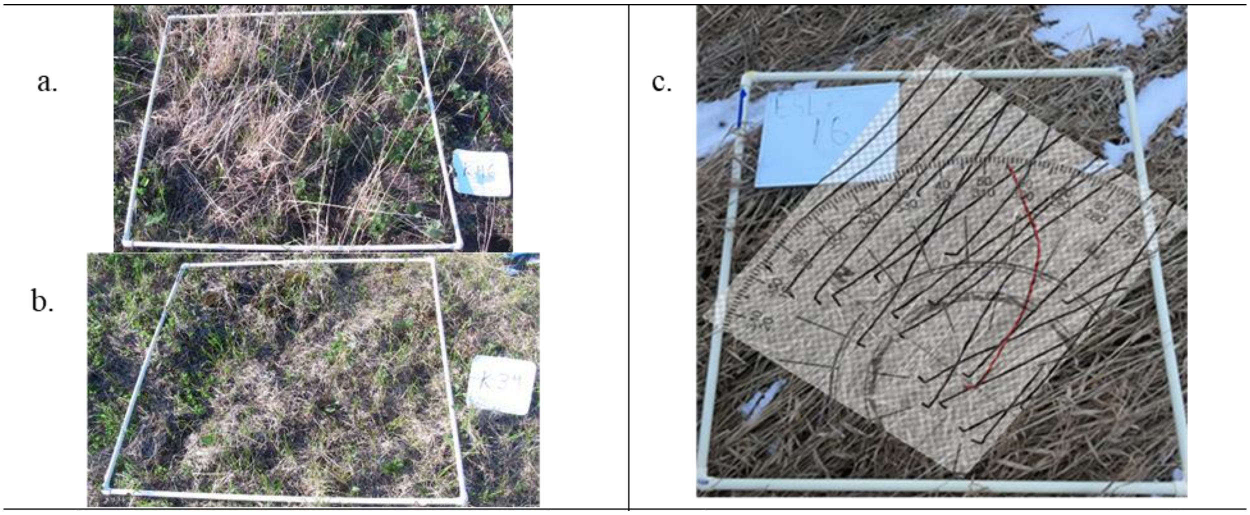
Said differently, this project can also support several goals of the broader Arctic Research Plan for 2022-2026 of the Interagency Arctic Research Policy Committee (IARPC 2021); to, "Enhance our ability to observe, understand, predict, and project the Arctic's dynamic interconnected systems and their links to the Earth system" and to focus on Arctic communities' resilience and adaptive capacity.

Project description

Previous work

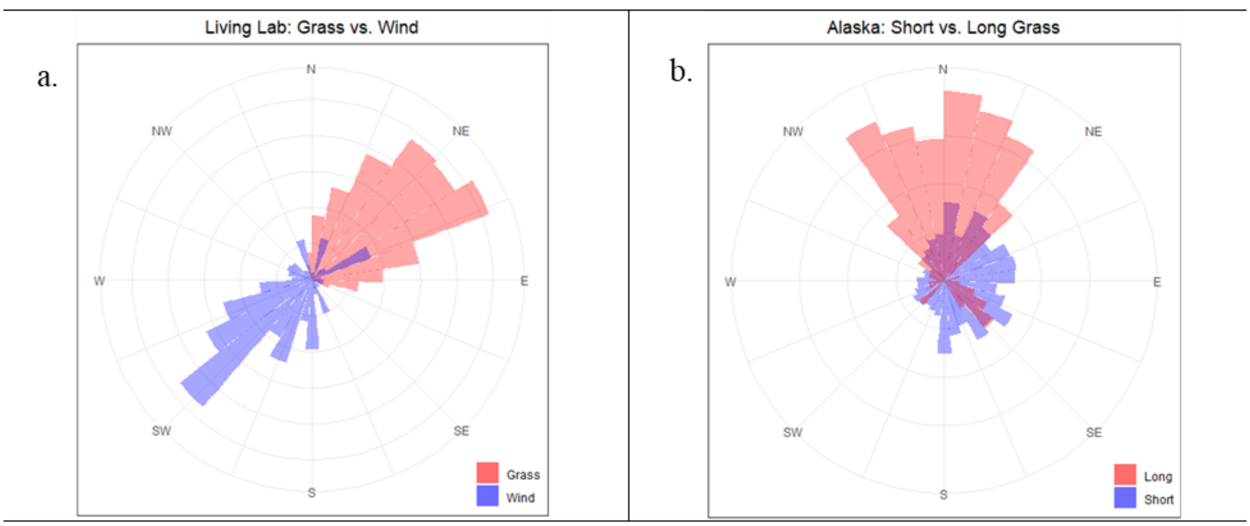
Preliminary work on this project began in 2016 with 60 plots taken east of Savoonga on an exposed tundra slope near the old village site called Kookoolik, about 10 miles east of Savoonga. Meter-by-meter quadrat sampling, outlined with PVC pipe, were placed on the ground oriented North (Figure 1). The quadrats were then photographed, and grass lay direction sketched in using Photoshop software with a compass layer added on top (Figure 1c). We found that the taller Arctic polargrass *(Arctagrostis latifolia)* laid down in a uniform pattern (Figure 1a) as compared to unidentified entangled and matted shorter grasses (Figure 1b). Taller grasses are more exposed to wind blowing across the landscape and have a stronger directional signal than the shorter grasses (see Figure 2b).

Figure 1. Plots of taller Arctic polargrass (*Arctagrostis latifolia*) (1a) and unidentified shorter grasses (1b). Overhead photograph with grass lay sketches using Photoshop (1c).



In 2017, we measured tall (~2 meters) reed canary grass (*Phalaris arundinacea*) at our Living Laboratory at St. Lawrence University in 20 plots (Figure 2a) and compared its grass lay direction to the prevailing winds as measured by an adjacent weather station. The purpose of this experiment was to determine the association of grass lay direction and wind direction in an area with instrumental wind data. We are confident that, *inter alia*, reed canary grass lays itself down in the fall time downwind perhaps encouraged by the bent shape of its large seed heads that point downwind during their development (the large seed heads visibly point an observer in the direction of the prevailing winds).

Figure 2. Grass lay direction for reed canary grass (*Phalaris arundinacea*) and prevailing wind direction in 2017 at the Living Laboratory at St. Lawrence University (a), and for Arctic polargrass (*Arctagrostis latifolia*), shown in red, and unidentigied shorter grasses in blue on St. Lawrence Island (b).



For the Alaska plots at Kookoolik, the longer polargrass laid down in an NW to NE direction, with a mean direction of 3.9 degrees and a strong mean resultant length ($\bar{R}$) of 0.65, suggesting southerly winds (Figure 2b). The shorter grasses were far more varied with $\bar{R} = 0.24$ being uniformly distributed on the eastern half of the compass (blue plot, right panel). For the tall canary grass at our Living Laboratory, grass lay direction was to the NNE to ENE (left panel) and wind direction coinciding with southwesterly winds as measured by a local weather station (left panel, blue plot).

In the summer of 2023 PI Rosales and co-PI Iverson surveyed the coast along the north side of SLI both east and west of Savoonga (NSF grant #2221731). The survey's intent was to confirm with a couple elders the weather and wind observations practices we learned about over the last year, to establish the field methodologies, and to identify indicative plant species to measure.

New proposed work

We seek funding to replicate the TEK practice of noting the direction bluejoint reedgrass (Poaceae: *Calamagrostis canadensis*) and tall cottongrass (Cyperaceae: *Eriophorum angustifolium*) lay down on St. Lawrence Island (SLI) to determine current prevailing wind direction. We will establish pre-1990 wind patterns by observing cabin door orientations built before 1990 when climate changes started to become obvious in Savoonga (Rosales and Chapman 2015). We propose to do this work in four ways over three years on St. Lawrence Island and at our Living Laboratory, each explained below.

On SLI we propose to:

1. Measure on the ground grass lay direction directly on SLI at key subsistence sites on the coast.
2. Measure cabin door orientation at the same subsistence sites on the coast of SLI.

At SLU's Living Laboratory, we propose to:

1. Continue to measure wind and grass lay direction at our Living Laboratory over the duration of the grant.
2. Refine grass lay direction on aerial drone photography via image processing at the Living Laboratory and apply to images from SLI.

Proposed work on SLI

1. Grass lay direction on SLI

Typically, TEK holders assumed the grass would lay downwind of prevailing winds from a northerly direction, with dead grass laying in a southerly direction. With no wind vanes on the island except near the Savoonga airport, we propose to measure the grass lay direction where most of subsistence activities occur.

As mentioned above, previous work taught us that the taller Arctic polargrass (*Arctagrostis latifolia*), that grows 60-100cm on SLI, displays a more consistent lay pattern than shorter grasses that end up matted and difficult to untangle the direction (see Figure 1). Our survey in 2023 showed us that Arctic polargrass is not as prevalent on the island as we once believed. Bluejoint reedgrass (*Calamagrostis canadensis*) is more widespread and tall enough (growing to 30-45cm by mid-summer on SLI) to be affected by the wind, with enough leaf litter from the previous year to assess. Bluejoint reedgrass also has clear culm nodes that appear to be quite plastic—likely bending in response to environmental stimuli. During our survey in the summer of 2023, we could not make it to lower-lying areas of the island (where there are many marshes, etc.) due to outboard engine problems, but given the prevalence of bluejoint reedgrass elsewhere, it seems probable that it will be present across the island. Another abundant plant that can serve as an indicator of wind direction is tall cottongrass (*Eriophorum angustifolium*), in the sedge family, that exists in thick patches leaving behind ample examples of last-year's growth on the ground. Live tall cottongrass also appears to lean in the direction of prevailing winds, while the distinctive cotton heads sway in the wind, potentially being a good indicator of instantaneous wind speed/direction. Given that it is more widespread, bluejoint reedgrass is a leading option to assess grass lay direction. Arctic polargrass is less common, though locally abundant. It is usually in dense patches, and often pure stands, where it occurs. It may not be ideal to assess the previous year's residue since the current year's growth is dense and hard to see through to the dead grass from the previous year. The other grasses we surveyed and identified such as American dunegrass (*Leymus mollis*) grows in patches right along the coast is common, but only present in distinct patches within a few meters of the shoreline is not a good candidate for assessing grass lay direction. Most other grasses we observed, e.g. few flower bluegrass (*Poa paucispicula*) are shorter and more dispersed, thus not the best candidates to be affected by wind.

We therefore propose to focus solely on the bluejoint reedgrass or tall cottongrass patches for this study. We will measure grass lay direction at the end of July when new grass plants are formed and the old grasses from the previous year are still visible underneath.

We are cognizant of the possibility that snowmelt may alter the direction grass lays, as an elder mentioned could occur under some conditions. Therefore, in the summer of 2023 we surveyed a few different areas to see if the previous year's grass lay direction is influenced by slope, e.g., melting snow creating ice/water flows that would push the grass downhill. We did not observe evidence of this after looking at several south-facing slopes of varying degrees of steepness where we might see grass lay direction to the south pushed downhill by snowmelt (and opposite of prevailing winds). Even in these areas, grasses and sedges still lay to the north suggesting wind is the dominant influence on grass lay direction, not snowmelt. We also observed that snowmelt penetrates slopes as groundwater, not surface water, in the porous volcanic stratum on SLI. Nevertheless, our field protocols looking at grass lay direction should avoid steep or moderate slopes.

Grass sampling protocol

We propose to sample grass lay direction across 11 sites on SLI, two on the south side and nine on the north side (Figure 2, left panel). Residents of Savoonga use all these sites, which fall under the Native Village of Savoonga's jurisdiction and cultural practice (residents from Gambell, the only other village on SLI, use other sites on the west side of the island). These sites were chosen for their socio-ecological importance as existing camps for hunting, herding, gathering, vacationing, and/or are former settlement sites where people would have interacted with the landscape and developed the TEK of reading the grass direction. Site #1, for example, is a whaling camp where hunters and elders on shore monitor wind direction as they navigate ice flows while on the water. During the summer of 2023 it became apparent that travel to these sites is safest and most efficient by boat as opposed to ATV.[2]

The physical features (e.g. topography, coastline proximity/direction, landforms) that could affect wind direction will be documented at each site, as well as the direction of cabin thresholds. Village Coordinator Pungowiyi estimates roughly 32 cabins at these 11 sites (Figure 3, right panel). Grass measurements will be taken as near cabins with good landing beaches along the coast. Exposed patches of grasses or sedges to 360-degree winds will

Figure 3: Study sites on St. Lawrence Island.

[2] ATV trails on the tundra are now very wet with innumerable pools of water and mud due to permafrost melt.

Site	Name	#cabins
1	Powooiliak Camp	10
2	Koozata Lagoon	2
3	Kangee Camp	2
4	Ataaka’s Camp	1
5	Iveetok	1
6	Ongoveyuk Lagoon	2
7	Tomname Lagoon (W)	3
8	Tomname Lagoon (E)	3
9	Sevak Camp	3
10	Kitnagak	3
11	Camp Kulowiye	3
	Total	**33**

be chosen to ensure that physical obstacles such as rock outcroppings or hills do not differentially affect grass morphology and direction.

To sample the direction of grass lay, we will employ a modified line-point intersect methodology. Point-intercepts are a commonly applied approach to objectively sample vegetative cover or biomass with many replicates (Bonham 2013; Herrick et al. 2009; Jonasson 1988). These techniques estimate plant species cover by dropping or lowering a pin (or other object or laser) through the vegetation and counting the proportion of times each plant species is touched by the object along a transect or grid (Karl et al. 2017; Godinez-Alvarez et al 2009). Transects will be set perpendicular to the shoreline following a compass reading and by using a 100m tape. Transects will start at the first patch of bluejoint reedgrass that is $\geq 1m^2$. Evaluators will then walk a minimum of 3m along the 100m transect until the next patch meeting the criteria of 1) being within 2m of the transect tape and 2) reaching the threshold of $\geq 1m^2$ in size is located. The team will place a $0.5m^2$ quadrat in middle of each patch and XXX.
A total of 10 plots will assessed per transect. At least five transects separated by at least 20m will be taken at each cabin location.

GPS points will be taken at each transect plot and ground markers left so that the team can return to the same locations for three successive years. After doing preliminary analysis of the first year’s data, we may expand to more sample sites.

2. Cabin door orientation

As stated above, the grass lay component of this project will give us current wind direction data, but it will not be able to answer if wind direction has changed on the island since 1990. To do that requires a metric that tells us the wind direction from 30+ years ago, again, in an area with no current or historic wind vane data. When this science problem was posed to elders in Savoonga in 2016, our Village Coordinator, Perry Pungowiyi, thought we could measure the direction cabins face on the island. Traditionally, he tells us, people built their doorways facing downwind to keep the cold air and snow out of the cabins. This claim was verified by clan leaders during a focus group meeting in 2022. Clan leaders are familiar with the cabins used by their clans and are the most likely people to remember when and how the cabins were built. We will therefore measure the direction of cabin doors during the first field season.

Although many cabins were built by relatives who are now deceased, all clan leaders agreed that cabin doors generally face downwind unless there is an obstruction in the way, such as a rock outcropping, that would change the impact of wind on the cabin. In fact, the question of cabin door placement downwind appeared to be too obvious to them causing some confusion as to why we would assume otherwise. As one clan leader said, “you have to know the prevailing winds” to properly build a cabin, and another “everyone knows it” to face cabin doors downwind. Another clan leader expressed that they are taught by their elders to “use nature as your helper” implying that one must pay attention to the surrounding natural environment to avoid hazards such as wind, storm surge, floods, and to maximize energy efficiency, warmth. Cabin door orientation is part of these considerations.

We learned that nuclear families and their relatives use particular cabins and that most cabins were built by the clan leader’s fathers or grandfathers. Cabins are built at locations that are good for hunting seals, fishing, trapping, and/or leisure. We also learned that there are several cabins at each location, some cabins being newer and other cabins in disrepair and older. Most are close to a lagoon or the coast. Most clan leaders could give us a rough estimate of within a couple decades of when cabins were built. Older cabins were built circa 1930 and newer cabins in the 1970s. Clan leaders indicated that most of their cabins were built before 1990 with some newer cabins been built further inland with eroding shorelines and increased wave activity, or away from eroding permafrost. Since there are multiple cabins at each site and some have been moved, we will take pictures of the cabins we measure and verify the age and orientation of the cabin with clan leaders.

Clan leaders granted us consent to measure their cabin doorframes, but they also pointed out that anyone can use the cabins for safe travel. Cabin doors are unlocked and well stocked with provisions to “help save lives.” Consent to do this work was also granted by the Savoonga Tribal Council in 2022 (see attached letter of support).

Proposed work at SLU’s Living Laboratory

The TEK practice of observing wind and tundra grasses and sedges on SLI generates multiple lines of evidence enabling us to generate detailed knowledge of the dynamics between wind and tundra plants at our Living Laboratory in Canton, NY in several ways.

1. On-the-ground grass lay measurements at St. Lawrence University

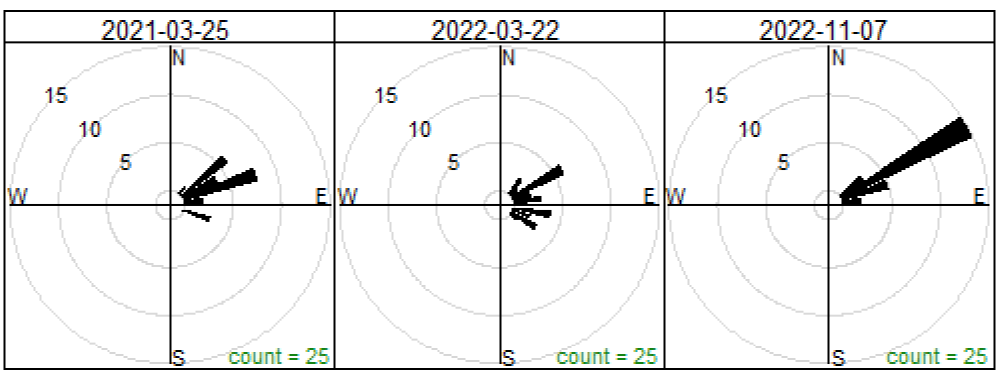
Starting in 2021 we installed a small weather station with an anemometer and wind vane at our Living Laboratory where we measure grass lay direction along a North-South transect running with 25 plots (Figure 4). The weather station and sampling plots intersect a large patch of smooth brome grass (*Bromus inermis*). The site also allows us to test our sampling methodology explained above. Data will be gathered at the Living Laboratory for the duration of the grant in order to independently examine the relationship between wind and grass lay direction.

Figure 4. Grass lay study site at the Living Laboratory. Weather station in the center with 25 plots running north-south (dashed line). Visible grass lay direction (solid line).

Analysis in the winter of 2023 provide preliminary data on the relationship between wind and grass lay direction at the Living Laboratory. On-the-ground manual measurements were taken in March 2021, March 2022, and November 2022 at the same 25 plots. The first set captures grass lay direction from the 2020 growing season. The second from the 2021 growing season, and the third, although not in the spring and affected by winter snow fall and rain, captures the 2023 growing season. We therefore have three years of post-growing season grass lay direction data from the Living Laboratory (Figure 5).

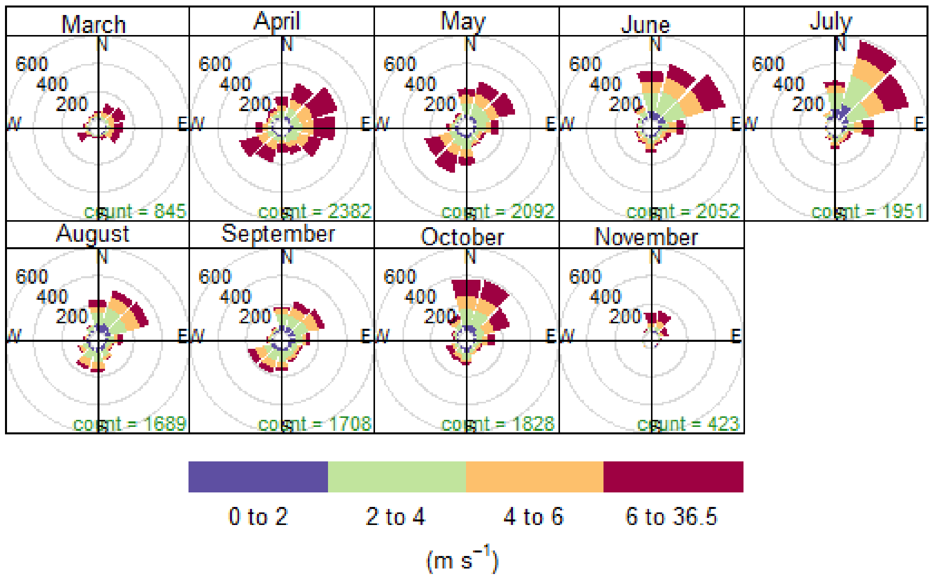
Some notable trends include grass lay direction consistently laying to the E-NE (~68 degrees), like 11/07/2022 data in Figure 5, right panel. November measurements were 2-3 times less variable than March measurements perhaps indicating some grass lay direction change over the winter months, a fact that will be important to determine going forward for the subsistence practitioners in Savoonga. Nevertheless, grass lay direction measurements at the Living Laboratory do not change substantially over the course of a growing season (March to November) with less variability around the mean of 63.2 degrees.

Figure 5. Living Laboratory grass lay directions over three growing seasons. Black wedges refer to the number of plots with that direction.



Wind direction measurements from our weather station at the Living Laboratory by month from March 2022 to November 2022, during the growing and or snow-free period of the year, indicate that August and September most closely match November 2022 grass lay direction (Figure 6). This might suggest that grass lay direction in the fall is determined by the predominant wind direction in the months prior to when the grass dies and lays down. Again, this will be an important fact to discern and communicate to the villagers of Savoonga.

Figure 5. Circular histogram (wind rose) of downwind directions at the Living Laboratory for the 2022 growing season. Color corresponds to wind speed.



2. Aerial photography analysis

In addition to on-the-ground measurements, we seek funding to continue refining our analysis of aerial photography of grasses. Measuring grasses with drone photography enables us to rise off the ground to eye level, or higher, and sample grasses on a larger scale. Previous work sketched out lines using Photoshop, as described above, which is heavily labor intensive. Co-PI Torrey is developing a method to use image processing software that can detect some grass blades in photographs (Figure 7). Using tools provided by a Python image processing library (Van der Walt et al. 2014), a line-detection algorithm called a Hough transform (Galamhos et al. 1999) can detect line segments in photographs (Figure 7, center panel marked in blue). We seek funding to continue processing images in such a manner, trying to ascertain the amount of complexity, i.e., the number of grass blades, that image processing can detect accurately. We will ground truth this analysis with the on-the-ground measurements described above.

We also may be able to apply other algorithms to detect grass blade orientation, such as a method developed for detecting pedestrians (Dalal and Triggs 2005). This method applied to grass lay direction produces histograms of oriented gradients detected in a grid of cells called "pinwheels" (Figure 7, right panel). The “pinwheels” in each cell can then be analyzed for direction (the brighter the line in each pinwheel the stronger the gradient detected each cell). If these existing methods do not offer a strong association with our ground truth measurements, we could then turn to machine learning techniques where we train the computer with grass blades traced by humans. These techniques have been used successfully in potentially related applications, such as tracing blood vessels in retina images (Luo et al. 2019).

Figure 7. Aerial image of 2016 plot near Kookoolik with Hough transformation (blue lines, center panel) with histogram of oriented gradients (right panel).

Circular data

Given the directional nature of the data proposed in this project, standard statistical methods designed for linear data (e.g., t-tests) are not applicable. Instead, grass direction data obtained from the aerial photography analysis will be analyzed using methods applicable to circular data. More specifically, Co-PI Ramler will develop bias-corrected bootstrap confidence intervals for the mean wind and grass direction (Pewsey et al. 2013). For comparing cabin door orientation at SLI camps, we will develop a randomization version of Moore’s Test for Paired Circular (Moore 1980) – supplementing it with correlation coefficients developed for circular-circular associations (Jammalamadaka and Sengupta 2001).

Outreach

An important element of TEK restoration will be to communicate and deliver our results back to the community. With the continued consent from the Tribal Council every year, in years two and three of the study, results will be presented at community meetings. The research team traveling to Savoonga in those years (PI Rosales, SLU student researchers, Village Coordinator Pungowiyi, and a younger subsistence practitioner from Savoonga) will lead those meetings. Special attention will be given to inviting focus group members as well as more women who practice gathering.

Outreach to the broader Arctic research community will be done by establishing a new partnership with the Exchange for Local Observations and Knowledge of the Arctic (ELOKA). ELOKA’s ethical approach to their work aligns with AKSIK’s research ethic, to work toward the collective benefit of the village and research community and to retain consent over what knowledge and information is distributed over the Internet. PI Rosales will meet with ELOKA personnel at the next IASSA conference in the summer of 2024.