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Connecting understandings of weather and climate: steps towards co-production of knowledge and collaborative environmental management in Inuit Nunangat[1]

Shari Fox, Esa Qillaq, Ilkoo Angutikjuak, Dennis Joseph Tigullaraq, Robert Kautuk, Henry Huntington, Glen E. Liston, and Kelly Elder

Abstract: Inuit hunters and meteorologists alike pay close attention to weather and weather changes, with deep understandings. This paper describes a long-time research project based in Kangiqtugaapik (Clyde River), Nunavut, where a research team of Inuit and visiting scientists have combined information and knowledge from a community-based weather station network, on-going interviews and discussions, and extensive travel (both Arctic fieldwork and visits to southern universities) to co-produce knowledge related to human–weather relationships and weather information needs and uses in one Nunavut community. The project uses the concept of "HREVs", *human-relevant environmental variables* — complex, synthesis variables that, used in conjunction with a host of social variables, assist in informing safe land travel and activities. This work, including linking Inuit knowledge and environmental modeling, can be expanded to not only understand human–weather relationships more broadly and in other locations but also provide insights into the process of building diverse research teams and knowledge co-production.

Inuit angunasuktiit amma silalirijiit tamarmik ujjiqsuttiasuunguvut silamit amma silaup asijjiqpallianingani, tukisiumaniqarjuaqłutik. Una paippaangujuq unikkaarivuq akuniujumi qaujitasaqtaunirmut piliriangujumi Kangiqtugaapik (Clyde River), Nunavummi, qaujisaqtiujuni katinngajuni Inungni amma pularaqtunut qaujisaqtiujunut katirisimajuni uqausiksani amma qaujimaniujumi nunalingni–tunngavilingmi silalirivvingmi tusaumatittiniujumi, apiqsuqtaunginnaqtuni amma uqallangniujuni, amma aullaaqsimarjuaqłutik (tamakkit Ukiuqtaqtumi iniujumi piliriniujumi amma pulararniujunut qallunaat nunanganni silattuqsarvigjuangujunut) saqqitittiqatigiingnirmut qaujimaniujumi pijjutiqaqtumut inungnut–silamut piliriqatigiingniujuni amma silamut uqausiksani pijariaqarniujunut amma aturniujunut atausirmi Nunavummi nunaliujumi. Piliriangujuq atusuunguvuq isumagijauniujumi "HREVs", inungnut-atuutilingnut avatimut

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ajjigiinnginniujunut – nalunaqtuni, katinniujuni isumagijauniujuni aaqqiksinirnut piliri–jusiujumi ajjigiinnginniujuni, atuqatiqaqłuni ilagijaujumi inuuqatigiingujunut ajjigiinnginniujunit, ikajuqsuisuunguvuq aaqqiksuinirmi attananngittumi nunami aullaarniujumi amma qanuiliurniujunut. Una piliriniujuq ilaqaqtumi kasuqatiqarnirmi inuit qaujimajanginni amma avatimut uukturautiqarnirmi, angigligiaqtaujunnaqpuq tukisiumanituangunngittumi inungt-silamut piliriqatigiingniujumi tauvunngaujjiniujumi ammalu asinginni iniujunut, kisiani tunisijunnaqpuq tukisirjuarniujuni piliriniujuni sananirmut ajjigiinngiruluujaqtuni qaujisaqtiujunut katinngajuni amma qaujimanirmut saqqitittiqatigiingniujumi.

Key words: Inuit, weather, co-production of knowledge, Arctic. Inuit, sila, saqqitittiqatigiingujut qaujimaniujumi, Ukiuqtaqtuq.

Résumé : Les chasseurs inuits et les météorologues portent une attention soutenue à la météo et aux changements de température, avec une profonde compréhension. Cet article décrit un projet de recherche de longue date basé à Kangiqtugaapik (Clyde River), au Nunavut, où une équipe de recherche composée d'Inuits et de scientifiques visiteurs a combiné les informations et les connaissances émanant d'un réseau de stations météorologiques communautaires, d'entretiens et de discussions en continu de même que de nombreux voyages (à la fois des travaux sur le terrain dans l'Arctique et des visites dans les universités au sud) pour coproduire des connaissances sur les relations entre l'humain et la température ainsi que sur les besoins et l'utilisation des informations météorologiques dans une communauté du Nunavut. Le projet utilise le concept de variables environnementales pertinentes pour l'humain (HREV, *human-relevant environmental variables*) - des variables complexes et synthétiques qui, utilisées conjointement avec de nombreuses variables sociales, aident à informer les parties prenantes sur la sécurité des déplacements et des activités terrestres. Ce travail, qui consiste notamment à relier le savoir inuit et la modélisation environnementale, peut être étendu pour non seulement comprendre les relations entre l'humain et le climat de manière plus générale et dans d'autres lieux, mais aussi pour donner un aperçu du processus de constitution de diverses équipes de recherche et de coproduction de connaissances. [Traduit par la Rédaction]

Mots-clés : Inuits, météo, coproduction de connaissances, Arctique.

Introduction

Inuit hunters pay close attention to weather, with detailed terminology that reflects deep and detailed understandings (Watt-Cloutier 2018) and make decisions large and small on the basis of their weather observations and understandings (Pfeifer 2018). Meteorologists also pay close attention to weather, with detailed terminology that reflects deep and detailed understandings (e.g., AMS 2019) creating information that many people use to make decisions large and small (e.g., Stewart et al. 2004; Silve and Kolstø 2016). Our research project, *Silalirijiit* ("those who work with weather"), now in its 10th year, explores relationships between Inuit and visiting scientists' understandings of weather and also the ways in which Inuit access and use weather information to make decisions. Our experience sheds light not just on weather but also on the process of knowledge co-production (e.g., Lemos and Morehouse 2005; Meadow et al. 2015).

Weather is a perennial topic of conversation around the world, and Inuit conversations are no exception. Wind, snow, ice, waves, and other aspects of weather conditions may be described in exacting detail, using a rich vocabulary and also a shared understanding of how different facets of weather combine to create the specific conditions of interest or concern, especially as it relates to travel and harvesting on the land. For example, wind direction in summer can make the difference between favourable conditions for boat travel or great hazards on the water. In winter, a light wind in one location may indicate fierce winds, blowing snow, and poor visibility a few kilometres away.

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Connecting Inuit understandings with meteorological descriptors is complicated (Gearheard et al. 2010). Furthermore, weather is only one of many factors in Inuit decisions (e.g., other factors may include if there are children travelling in a group, obligations back in the community, etc.), making it difficult to link weather conditions to specific outcomes (e.g., Huntington et al. 2013), although some researchers have had success in identifying and modeling thresholds for travel and hunting in Inuit communities (e.g., Kapsch et al. 2010; Ford et al. 2019).

In this paper, we describe: (a) our efforts to connect Inuit science and understandings of weather with parameters measured by meteorological instruments and used in models by meteorologists, (b) our attempts to provide useful weather information in near-real time and to co-produce concepts capturing weather information that are relevant to Inuit and their decisions and activities, and (c) our resulting insights into the co-production of knowledge. The emphasis in this paper is on the approach we have taken in our project, with examples of the kinds of insights we have gained. Full results will be presented elsewhere when our work is completed.

Methods

Silalirijiit has been based in and led by the Inuit community of Clyde River (Kangiqtugaapik), Nunavut, since 2009. Clyde River (70°29′N, 68°83′W) is situated at the head of Patricia Bay, tucked inside the mouth of Clyde Inlet, a 100 km long fjord on the eastern coast of Baffin Island (Fig. 1). The population of ~1000 is 95% Inuit (Statistics Canada 2016), and subsistence hunting is a major activity. Ringed seals are the primary food species, with arctic char, polar bear, narwhal, and caribou making up the major sources of country food, with some small amounts of bearded seal, arctic hare and migratory waterfowl and their eggs rounding out a yearly diet (Wenzel 2000). The settlement of Clyde River is located on a relatively flat plain next to the ocean, but rolling hills, deep fjords, and some of the world's tallest cliffs are located nearby. The complex mountain and fjord environment of eastern Baffin Island makes up Clyde River's backyard and influences the regional and local climate.

Over the course of the project, we have conducted workshops, interviews, participatory mapping sessions, and focus groups to document Inuit knowledge of weather and bring people together to compare terminologies and conduct data analysis (e.g., methods taken from Huntington 2000). For example, we have conducted weather workshops with Elders, hunters, and youth during which we documented Inuit knowledge and terminology of winds, changes in wind and snow patterns, and impacts of changing weather on travel conditions and practices. Participatory mapping approaches have been an important part of our methods, meeting with expert hunters and Elders to map key weather patterns and features of the community and surrounding areas such as how winds are channeled in the complex topography of the region and places where snow accumulates or is normally blown away. In another part of the project, two hunters from the community kept weather and hunting diaries, tracking where they were hunting, means of hunting, weather conditions, and what weather information they accessed and observed themselves. We have worked with experts in the community who were identified by the community (for example, by the local Hunters and Trappers Association, Elders, and hunters). Our approach was not to strive for a public poll, but rather gain insight and knowledge from recognized experts in the areas of weather and climate.

To gather instrumental meteorological data from locations more relevant to travel and hunting than the existing station at the airport, we have installed four remote automated weather stations (two in June 2010, one in September 2010, and the latest in April 2019) (Fig. 1). An additional station is planned for installation in April 2020. Locations for the

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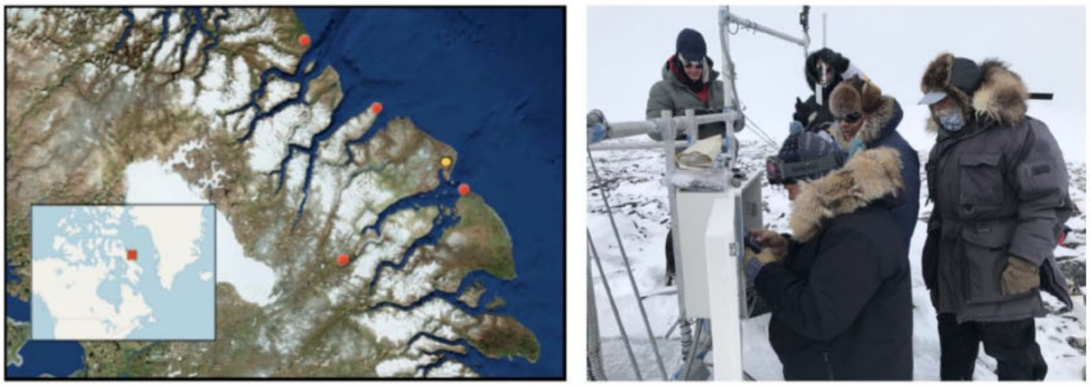
Fig. 1. (Left) Map showing Baffin Island and the Clyde River (Kangiqtugaapik) area in Nunavut, Canada, along with location of the community (yellow dot) and the weather stations (red dots) (created with ESRI ArcGIS online with a Blue Marble layer base with points made by GPS of weather stations; from clyderiverweather.org). (Right) Members of the research team installing the Nattiqsujuq weather station (farthest North on the map) in April 2019. From left: Henry Huntington, DJ Tigullaraq, Kelly Elder, Esa Qillaq, and Glen Liston. Photo by Shari Fox.



stations were chosen in consultation with the community, Hamlet Council, and especially hunters and the Hunters and Trappers Association, while being relatively accessible for annual service. The weather stations were designed with three concepts in mind: (a) a robust design that would survive the harsh ambient conditions, (b) availability of data in near-real time, and (c) presentation of information from places of importance and of chief interest to Inuit hunters and community members in readily accessible formats. The weather station design is documented in Elder et al. (2012) and is based on an unconventional structure with conventional commercially available instrumentation, and on-site solar power and battery storage (Fig. 2). Data transfer to users uses the ARGOS satellite system and ultimately produces web-based, hourly weather information with a data latency of usually less than 2 h from the time of measurement. Weather parameters collected include air temperature, relative humidity, wind speed, wind direction, barometric pressure, incoming and reflected solar radiation, and ground temperature. These data are stored on site with the most critical elements telemetered through the satellite system. All parameters are also stored on site and collected manually during yearly maintenance visits.

Our work with Clyde River community members documents Inuit weather observations, and we use that information, together with data from the four remote weather stations, to match Inuit terminology and understandings with instrumental and modeling terms and understandings. This process of comparison and synthesis has entailed extensive conversations among members of the team, in person and via telephone and email. Although it would be satisfying to point to a specific technique or recipe for synthesis, we have instead found it to be more a matter of together immersing ourselves in our data and experiences, finding frustration in analytical dead ends, and occasionally enjoying a promising insight.

The collaborative process of designing, carrying out, adjusting, analyzing, interpreting, and using the results from research has, in recent years, been called "knowledge co-production." The term spans a range of activities and outcomes, which have in common a collaboration between scientists and practitioners (e.g., Lemos and Morehouse 2005; Meadow et al. 2015). This approach differs from standard scientific research in that decisions concerning research aims, design, methods, conduct, analysis, and outcomes are shared among all the participants rather than being made by the "experts"

Fig. 2. Weather station at Akuliaqattak. Photo by Kelly Elder.

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(e.g., Goodman and Sanders Thompson 2017). Co-production of knowledge can yield conceptual outcomes, such as changes in the way a topic is considered, and instrumental outcomes, which have a direct effect on real-world decisions (e.g., Nutley et al. 2007).

In our project, the co-production approach has meant that, in addition to the formal aspects of our research, our team has spent considerable time together in the field, travelling to and from our weather stations and scouting for additional locations, and in the community sharing meals and other events, as well as travelling to Colorado so that Inuit team members can see and experience where the visiting scientists live and work, too. Cumulatively, this has amounted to months of time together, several thousands of kilometres traveled, and many nights in shared cabins and tents. Unstructured time and interactions leave room to share stories, experience the same weather and snow and ice conditions, learn from one another, tease one another, and simply to become friends. Doing so strengthens the social relationships necessary for knowledge co-production, and also gives us much to discuss concerning weather, travel, decision-making, and more. Collaborative fieldwork is not the only way to achieve such outcomes, but it is an effective one (Huntington et al. 2011). The trips to Colorado by Inuit members of the research team include visiting the southern-based team members at their places of work and in their homes, meeting their family members, as well as co-presenting in local schools and sharing in social events such as horseback riding, professional hockey games, backyard cookouts, and more. Building social relationships in the project, in knowledge co-production projects, and in particular our project, is necessary because trust is needed — from travelling together safely on the land, to being open and willing to listen and consider other worldviews and understandings, and to know when to lead and when to follow in research

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design, analysis, and communication. Our close relationships in the project team, and in the community are what motivate us all to do our best work. We are all motivated to support our project team members and learn from them, offer our best contributions, and together provide a useful information service to the broader community.

Results

Weather stations and data

Data delivery to the Clyde River community has been via local call-in number and radio station for a portion of the study, and via website for the entire period (the community has consistent satellite Internet access). Weather parameters are shown graphically as a time series over the preceding 24 h including the most recent reading, and numerically as the current value. Parameters include measured air temperature, wind direction and speed, relative humidity, barometric pressure, and ground temperature. Sky condition in the form of a cloud fraction is calculated and provided from comparing the measured incoming radiation with a cloud-free model calculation. Pressure tendency (rising, steady, or falling barometer) is calculated from cumulative pressure measurements. A dedicated website hosts data observations from each of the four project weather stations, as well as the Clyde River airport weather station maintained by Environment Canada. Current data may be observed at https://www.clyderiverweather.org, and all information is available in both Inuktitut and English.

Hunters and many other residents access the website from their computers and, as of 2019, their smartphones (the year the community received cell service, and use of phones dramatically increased). Elders and unilingual Inuktitut speakers/readers access the Inuktitut site and community members regularly share information they gather from the site. Often there is discussion of the weather information in combination with other resources regularly accessed such as satellite imagery for sea ice and weather patterns from websites such as windy.ty.

Learning from interviews and discussion

From our discussions in interviews, focus groups, on the land, and around kitchen tables, we have learned about many aspects of weather and relationships to Inuit activities and livelihoods. For example, working with experienced Elders over topographic maps, we heard about changes in wind patterns. The Elders mapped the usual directions for wind patterns in the fjords and then how those winds have changed in recent years. New timing and directions have been observed for different areas in different seasons. Old camp sites that were once used because of their proximity to areas of snow accumulation, are now blown snow-free, and other areas are seeing new accumulation as wind patterns shift. New wind patterns can also create more waves, preventing ice from freezing up, changing the timing of freeze up in some places. Mapping work by the Elders helps to show the different patterns and changes in winds, ocean, and snow, maps that we can align with environmental models that we seek to apply in the research (see Synthesis).

We have also spent a great deal of time documenting Inuktitut terminology for winds and wind strengths in different seasons. For example, in Inuktitut, there are descriptions of various winds and the blowing snow conditions they create, relating to visibility and the ability to travel (Gearheard et al. 2010). These explanations show us that Inuit descriptions of wind strength/wind speed do in fact correspond with what anemometers measure and allow for making more connections between data such as from our weather stations, and Inuit expertise.

As a final example, our discussions and time on the land as a team provided descriptions of how travel decisions are made. We heard and experienced that weather is only one of several factors. There are not simple thresholds in weather conditions beyond which people choose not to travel.

Decisions do include weather, but they also include considerations of other factors such as who is in the travel party, knowledge, and skill levels, reasons for travel and destination, supplies available, and shelter sites available when going from point A to B.

Synthesis

The visiting researchers on the team had initially assumed the existence of weather thresholds for travelling and other activities; for instance, that people would not leave home or camp if wind speeds were above a certain level. In conversation and travel with Inuit on the team, it became apparent that many social and other factors come into play, making it impossible to identify clear thresholds of this kind. The team instead shifted its focus to understanding more about the information Inuit use and how they use it when making decisions, which in turn led to the concept of physically based, complex, synthesis variables — *human-relevant environmental variables* (HREVs; pronounced "H-REVs").

Our work shows that HREVs (e.g., visibility, blowing snow, and wave height) are often more important than individually measured meteorological variables (e.g., air temperature and wind speed). Our studies also indicate that Inuit regularly view the natural system by combining relatively simple pieces of information into more complex variables (i.e., HREVs) that relate directly to hunting, fishing, travel, and safety in all outdoor and livelihood activities. These HREVs, in turn, are used in conjunction with a host of social variables (e.g., who is travelling, what they are travelling for, what else is occurring in their lives) to inform decisions that enable safe, productive, and life-affirming travel on land, open sea, and ice (Gearheard et al. 2010). A common example of an HREV is wind chill, which is a factor of temperature and wind speed together. Both individual parameters are of interest, and their combined effect is familiar to anyone who has been in a wind on a cold day, but the quantification of wind chill allows the effect to be calculated and compared.

HREVs have promise as new value-added products and meteorological metrics that capture and quantify environmental processes that directly impact Inuit lives and livelihoods. The intent is not to replace Inuit analysis of weather information, but to provide information more directly relevant to Inuit decisions and actions. To use the wind chill example, such information may be more useful for selecting one's outdoor clothing than temperature or even temperature and wind, as few people can easily use temperature and wind data to calculate wind chill. Fully understanding Inuit terminology and perspectives, and how Inuit view the environment around them, requires knowing which parameters and variables (and the interplay thereof) are most important to Inuit activities and how these are used in practice. By focusing on HREVs of interest to Inuit, and working together as a diverse team, this work provides a new way to look at human–environment interrelationships; it directly links meteorological metrics with Inuit activities.

As a simple example of what these HREVs could include, consider the finding that boat travel in the open sea during off-shore winds (winds from the west in this area) is discouraged for safety reasons (a boat that loses power will be blown away from safety). Strong onshore winds, on the other hand, pose the risk of being blown into shore amid rough waves, also an unappealing prospect. The HREV model's land-cover and sea-ice datasets could define "open sea" areas, and our coastal meteorological station data defines when on- and off-shore winds occur. Thus, it could generate maps of when and where high waves are likely to be found. Similar analyses and maps can be produced for times when sea ice is present, for example, the occurrence of offshore winds that can produce cracks in sea ice that impede travel and increase the risk of the ice breaking away.

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As another example, Inuit have identified a "whiteout condition" or "flat-light" HREV as critical to travelling safely in snowy landscapes and icescapes. Identifying the potential for flat light conditions requires knowledge of when there is low light, snow cover with no contrast, and a stratus/leaden type of sky that blends into the horizon, often producing very light precipitation. Often you can see a long way, but there is no way to distinguish many terrain features such steep drops over which a traveler might fall.

This example epitomizes the idea of a synthesis variable (an HREV) that requires both landscape (e.g., snow on ground) and atmospheric (e.g., cloud-level) information to create a new, value-added measure that directly relates to safety. An additional point about HREVs is the scale at which they are created and presented. Our travels on the land together have driven home the point that weather conditions matter at very fine scales, as much can change even within a few metres or minutes. HREVs, thus, must be relevant not just in concept, but also at the scale at which they will be used. As another simple example, a single wind-chill figure for Baffin Island for an entire day is far less useful than an hourly estimate for one's specific location. HREVs thus need to take into account the specific features of land and water, including fixed features such as mountains and coasts, as well as variable features such as sea ice cover and snow cover.

Additional outcomes

Our collaborations have produced additional tangible and intangible results. One symbolic instance of increased trust is the willingness of Inuit team members to allow the visitors to tie down *qamutiik* (sled) loads while travelling. Initially, the visitors were steered away so they would not interfere or, worse, botch this important task. Later, the visitors were allowed to try tying the loads down, under careful supervision and often with Inuit team members simply untying and starting over. Eventually, the visitors were allowed to tie down loads themselves.

Alongside this learning, practice, and growing confidence in one another, the team members became more comfortable with each other, through frequent teasing as well as sharing of the joys and sorrows in our lives. The visits to Colorado foster this as well, introducing Inuit team members more fully to the lives of the southern team members, meeting their families, learning their hobbies, and seeing their other interests at and outside work.

On the more tangible side, watching one another in action has helped us all recognize our respective roles in the project. Seeing the work areas at Colorado State University showed Inuit the computing power available there, as well as why writing proposals and papers is so central to the life of research scientists. Travelling on the land in Clyde River with our Inuit research team helped the visitors understand the specific conditions of concern to Inuit when travelling, and also the sources of information people use to understand the weather. For example, certain clouds observed around the top of a local mountain, Angijuqqaaraaluit (Sawtooth Mountain), may indicate bad weather to come. Websites such as windy.ty, the Government of Canada's weather forecasts, and real-time information from the Government of Canada weather station at the airport or the weather stations built by this project all contribute. Inuit do not only consume such information, but also interpret it in light of their own experiences and knowledge of what matters when travelling on the land, such as visibility in winter (flat light being a major hazard) and wave exposure in summer (posing a risk while boating or landing a boat).

Discussion

In our case, HREVs are conceptual outcomes, giving us a new way to think about weather and humans. The weather stations and specifically the website providing near-real-time data are instrumental outcomes, giving Clyde River residents useful and usable

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information with which to make decisions about their activities. Inuit knowledge of weather and weather patterns has been documented by previous studies (e.g., Nelson 1969; MacDonald 1998; Oozeva et al. 2004; Henshaw 2006; Eerkes-Medrano 2017). Recent studies have begun to bridge Inuit knowledge and western science related to Arctic environmental variables such as sea ice (e.g., George et al. 2004; Laidler 2006) and winds (Gearheard et al. 2010). These studies and our own experiences working as a team and with hunters and Elders show the detailed observations and knowledge Inuit have of their environment and how knowledge is built through direct activities in the environment.

Communication among skilled Inuit travellers reflects a deep systems (or HREVs) understanding. The description of a few environmental parameters is often sufficient to convey a far more detailed story from one knowledgeable person to another. For example, if the wind is coming from a certain direction causing choppy wave conditions, boaters may still head out, knowing they will find calm conditions in a nearby fjord that is sheltered from winds from that direction. Using and understanding weather means being aware of the context, as the full set of relationships is rarely stated by skilled Inuit travellers when speaking to their peers.

Although HREVs can be a useful contribution to decision-making, decision-making itself cannot realistically be reduced to single decision points or simple binary questions. We have seen that decisions are sometimes based on basic data such as current wind speed, where a community member will know that the wind speed suggests waves and unsafe boating to go berry picking in the south, so they stay at home or go overland to the north. We have also seen that in spite of harsh weather indicators travel has commenced for complex social reasons or simpler reasons such as running out of favourite supplies at camp. No modeled decision-making process will ever encompass the detail and variance exhibited in complex human behavior. Both rational and irrational human actions are too complicated to understand completely or generalize into a set of decision rules. Instead of trying to understand and model decision making, we have instead re-focused our efforts on the information people use or would like to have.

Providing near-real-time information, such as relevant weather data, may help guide humans in their decision-making and may affect positive outcomes. The use of the Kangiqtugaapik (Clyde River) Weather Station Network website suggests that Inuit do indeed value additional information when making decisions, and that the weather stations and the delivery of information constitute a valuable outcome of the project and the knowledge co-production approach. We have learned about the use of the weather stations mainly through our discussions in the community and continued support for our project from the Hamlet Council and the Hunters and Trappers Association. We have heard from many local hunters that the stations are useful and an added resource to other weather services (like the popular windy.ty) and sea ice satellite images available online. Through Google Analytics, we have observed that the site is used by Clyde River residents most often before weekends and before and after storms. We also observe that some stations are used more often in certain seasons. For example, the Ailaktalik station is used most often in summer, as it is located in an area that provides important information for boating.

Similar approaches are found all around us and have important implications for society outside of the Arctic. For example, the U.S. National Oceanic and Atmospheric Administration (NOAA) creates HREVs to relate weather and other conditions to specific aspects of people's lives. A NOAA snowmelt flood forecast is a combination of predicted above-freezing air temperatures, rain on snow, wind speeds, incoming solar radiation (through things like time of day, time of year, and cloudiness), how much snow is on the ground, whether the ground below the snow is frozen, and other environmental factors that relate to the rate and quantity of snowmelt. Creating such a flood forecast is

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complicated, but each individual contributing variable is of little use by itself. The synthesis of these variables, in contrast, can often be a matter of life and death. Of critical importance in all such cases is a detailed understanding by meteorologists and other experts of what information is needed, on what scales of time and space, and a corresponding understanding by those using the information of the assumptions and uncertainties inherent in the model. Our experience shows that mutual understanding takes time and commitment by both groups, which is justified by the increased utility of the resulting information.

We have found that the knowledge co-production approach entails a high level of commitment on everyone's part, which likely makes it impractical, if not undesirable, for every research project. We have also found that the gains from knowledge co-production are more likely to be modest and incremental rather than a matter of stunning insights. Those modest and incremental gains, however, can add up over the course of a project and relationship to create new and deeper understandings that may be difficult to achieve in other ways. The development of the HREVs concept is one such example. We first had to recognize that modeling decisions was a dead end. Then, we had to consider what we had all observed in our experiences on the land and our conversations in formal and informal settings. Local interest in the data from the weather stations demonstrated that people sought reliable information on parameters of relevance to their activities and knowledge. Further discussions revealed the limitations of simple meteorological parameters such as wind speed or temperature, pointing to the concept of synthetic variables. In this way, the HREVs idea gradually took shape and is still in development as concepts such as boating risks and flat light are to be quantified and modeled.

Collaborative research also involves recognizing and making use of complementary skills, in addition to occasional compromises when various needs do not align. Co-production in this sense is not a matter of cooperation on each step of a project, but instead a way of drawing on respective strengths. Weather stations were a key component of our collaborative work and both the visiting scientists and Inuit had common interests in weather before the project began with specific knowledge and skills in observing and understanding linkages between common parameters such as air temperature, wind speed and direction, and cloud cover. Visiting scientists had previous experience with weather station installation and maintenance in harsh environments, and both visiting scientists and Inuit research team members had extensive experience with general construction methods and electronics. Both groups had skills in Arctic travel and survival, but the Inuit team members have much deeper knowledge and specific skills related to their homeland, on sea ice, local weather and terrain, and route finding. Installation of four weather stations over a 10-year period allowed training of multiple generations in both the scientific and Inuit communities. Ages of installation participants ranged from pre-teen to septuagenarians, all exchanging experience and learning in Arctic travel, weather, construction, instrumentation, language, and culture.

The very locations of the weather stations is another aspect of knowledge co-production. Inuit identified areas for which weather information would be especially useful, in light of travel patterns, providing key information in key places for use and analysis by hunters, and the relative ease or difficulty in extrapolating conditions from one location (e.g., the community) to another (e.g., the head of Clyde Inlet, 115 km distant and on the other side of high mountains). The visiting scientists then helped select specific locations best suited for providing representative weather information (e.g., not sheltered from winds in a certain direction), based on their knowledge of the instruments and the details of micro-scale weather patterns. Indicators of joint success are the widespread use of the project website by Clyde River residents to access real-time weather information (Friday afternoons are an

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especially popular time for doing so), as well as the utility of the compiled weather data for our project and for others interested in Arctic meteorology.

Silalirijiit is, on the one hand, a modest effort at knowledge co-production in the Arctic, based in and led by one community, and utilizing a series of new weather stations. On the other hand, starting with basics allows Inuit experts and visiting scientists to make sure they are indeed talking about the same phenomena and thus building a common understanding; this is an essential basis for effective environmental management. In this sense, *Silalirijiit* offers some insights that may be useful for other projects, in addition to what it contributes to understanding weather and its role in Inuit activities.

Collaborations are essential for going beyond the limitations of individual expertise. A strong team recognizes the respective contributions of its members, and builds on strengths while also sharing knowledge to improve areas of weakness. We can expect the visiting scientists to improve their travel skills, though not to reach Inuit levels of expertise, and we can expect Inuit team members to learn how the weather stations work and how to maintain and fix them, even if computer programming for the data loggers remains largely in the realm of academic arcana. The return visits to Colorado help make the interactions truly a two-way sharing of experiences and life settings, adding to the richness of our interpersonal relationships and understandings. At heart, such an effort depends on spending and enjoying time together, for which there is no substitute or shortcut.

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Qujalijumavugut Kangiqtugaapingmiutanit, Haamlakkut Katimajinginni Kangiqtugaapingmi, ammalu Nammautaq Unganasuktini Mikigiarniaqtinillu Katujjiqatigiingujunut ikajuqsuinginnarniujumi *Silalirijiit* piliriangujumut. Ujannamiiktauq ikajuqsuiniujumi Ilisaqsivit Katujjiqatigiingujunut ammalu Ittaq Piusituqarmi amma Qaujisarvingmi. Ukua sunakkutaat tunngaviqaqput piliriniujuni ikajuqsiqtaujuni Kanatami Qaujisarnirmut Tunngaviujumi uvuuna Tunirrutiit naasautingani OPP 1733688-mi.

Supplementary materials

The Inuktitut syllabic version of the translated Abstract, Key words, and Acknowledgements are included as supplementary material and are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/as-2019-0010.

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