Slush-ice berms on the west coast of Alaska: Development of a conceptual model of formation based on input from and work with local observers in Shaktoolik, Gambell and Shishmaref, Alaska

by

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M.Sc., Universidad Nacional Autonoma de Mexico, 1988

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Supervisory Committee

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Abstract

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Bering Sea storms regularly bring adverse environmental conditions, including large waves and storm surges of up to 4 m, to the west coast of Alaska. These conditions can cause flooding, erosion and other damage that affects marine subsistence activities and infrastructure in the low-lying coastal communities. Storm impacts also include interactions with sea ice in various states: large floes, shore-fast ice, the acceleration of sea-ice formation in frazil or slush state, and the formation of slush-ice berms. Slush-ice berms are accumulations of slush ice that develop under the right wind, water level, water and air temperature, and snow conditions. During a strong wind event, large amounts of slush may be formed and pushed onto the shore, where the slush can accumulate, solidify and protect communities from flooding and erosion. Slush ice berms can also be problematic, restricting access to the coast and presenting other hazards. Residents of Shishmaref and Shaktoolik, communities on the west coast of Alaska, observed the formation of slush-ice berms during storms that occurred in 2007, 2009 and 2011. These formations are important to the

communities, and it would be useful to develop the capacity to predict their occurrence. However, scientific work has not been conducted on this phenomenon, with the result that a physical conceptual model describing the formation of slush-ice berms does not exist. In recognition of this need, a project thesis was designed, and had as its main objective to identify and document the environmental and synoptic weather conditions that lead to these types of events, and to develop a descriptive physical conceptual model of slush-ice berm formation. A key to this work was the engagement of traditional knowledge holders and local observers to gather data and information about slush ice and slush-ice berm formation, along with the specific dates when these events took place. This dissertation is organized around three major elements: development of a conceptual model of slush-ice berm formation; presenting the traditional knowledge gathered that led to the development of this model; and documenting the methods and tools used to engage traditional knowledge holders and local observers in this process. In this dissertation, the knowledge from traditional knowledge holders on slush ice formation is presented in the context of feeding into a physical scientific process – specifically, developing a descriptive physical conceptual model of slush-ice berm formation. It is expected that this type of research will contribute to slush-ice berm forecasting which would aid communities' safety by improving assessment of environmental risk.

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Acknowledgements

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This dissertation was funded by the Western Alaska Landscape Conservation Cooperative (WALCC) and the National Oceanic and Atmospheric Administration (NOAA) to conduct a study based on work with community observers to develop a conceptual model of slush-ice berm formation and to identify the impacts of storms and adverse weather on community activities and infrastructure. Funding support by the National Science Foundation of the SIZONet project is gratefully acknowledged. I appreciate the important contributions by community-based ice observers and the Exchange of Local Knowledge of the Arctic in the completion of this work.

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Marjorie, you are like a family to me. To my family in Mexico, Canada, and Europe, specially my mom and Dafne. It has been fun sharing this experience with you. Many thanks!

Dedication

To John Eerkes-Medrano, for your love and support. You left way too soon but the memories will go on.

1 Introduction

The coast of western Alaska extends for over 1,200 km from north to south, from Wainwright to Bristol Bay. This region is characterized by permafrost-dominated tundra and river deltas (Terenzi, 2014). It has an abundance of salmon runs, seabirds and waterfowl in the coastal areas and caribou, moose, bears and wolves on land. This area also includes some threatened species such as sea otters and walruses (WALCC, 2016). Five native groups inhabit this area: Unangax or Aleuts, Alutiiq or Pacific Eskimo, Central Yupik or Southwestern Eskimo, Siberian Yupik or Bering Sea Eskimo and Inupiaq or Northern Eskimo (GAO, 2009). This region is sparsely populated. Residents live in villages generally with a current population of a couple of hundred people, that were originally inhabited by their ancestors. They practice subsistence activities including fishing, hunting and gathering of plants (GAO, 2009). Most communities have basic infrastructure, including school, health clinic, store, church, post office, washateria, and city and tribal offices (GAO, 2009). They are typically situated in low-lying, flat areas such as sandspits, river deltas, and barrier islands. These locations were selected to meet subsistence needs, including fishing and hunting and to build schools – a requirement imposed on them in the 1920s by the federal Bureau of Indian Affairs (Bearded, T. 2008; USACE, 2008b; Marino, 2012). Western Alaska is not accessible by road, so the locations for villages had to be accesible for barges to navigate and offload school building materials. The transportation and cultural/subsistence advantages offered by these locations are offset by the disadvantage of being particularly vulnerable to storm surge impacts such as flooding and erosion. These impacts are expected to worsen as storms in the region increase in frequency and intensity and sea ice retreats as a result of global climate change (McCabe et al., 2001; Terenzi et al., 2014).

Global climate change in arctic regions shows a trend of generally increasing air temperature over the 100-year period 1905–2006 that is almost twice the global average change of 0.74 degrees Celsius (IPCC, 2007). Since the 1960s and 1970s, the average temperature increase in arctic regions has been 1°C to 2°C, and this trend is expected to continue (Anisimov et al., 2007). At the same time, and consistent with this warming, sea ice in arctic regions has shown a decrease in extent, thickness and length of season (Vihma, 2014). In the Pacific Arctic region, Eicken and Mahoney (2014) indicate that over the past three decades the length of the ice season has decreased by about a month.

In the northern part of the Bering Sea basin, sea ice normally forms in situ, along the coast, in October and November, when cold northeasterly winds from arctic high-pressure systems dominate the region, driving this ice towards the south and southwest portion of the Seward Peninsula and St. Lawrence Island (Pease, Schoenberg and Overland, 1982). This ice advance can be interrupted by low-pressure systems that move into the Bering Sea, bringing moist warm air with southerly wind. Any increase in frequency of cyclonic activity and westerly cyclone tracks due to global warming could reduce the total duration of northeasterly winds, and consequently of the ice growth, during the fall storm season (Overland and Pease, 1982).

A reduction in the extent and thickness of shore-fast ice during the storm season leaves the communities on the coast of Alaska more vulnerable to destructive waves and storm-related impacts. Atkinson et al. (2011) describe an incidence of severe damage to a local cannery in the Bristol Bay area, resulting from a storm surge acting on ice that had formed on the structure's wharf facility. Sea ice can also provide protection to communities in different ways. Shore-fast ice armours the coast, increasing its resistance to erosion (Eicken et al., 2009; Atkinson et al., 2011), and large pieces of floating ice can dampen wave energy and mitigate the transfer of wind energy into the water. However, as shore-fast ice becomes thinner, it is more prone to melting, deforming and disappearing (Vihma, 2014), and its damping effect on wave action is reduced. Less shore-fast ice results in winds propagating longer distances over the water (longer fetch) creating higher amplitude waves during the fall storm season (Atkinson, 2005; Francis and Atkinson, 2012).

Storms that reach western Alaska and the Bering Sea have usually originated and intensified in the western North Pacific, east of Japan, over the warm western boundary of the Kuroshio Current (Serreze, 1995; McCabe et al., 2001; Rodionov, 2007; Mesquita et al., 2010). This is one of the most active storm tracks in the northern hemisphere. Storms travel northeastward and develop into mature cyclones near the international dateline, which is also the centre of the Aleutian Low. Most of these storms continue eastward into the Gulf of Alaska or the eastern North Pacific, where their peak potential slowly weakens; some others travel northward into the seas off western Alaska (Mesquita et al., 2010). Storms can stall or remain stationary for a few days, resulting in moderate to strong winds blowing from the same direction for extended periods of time (Rodionov, 2007). However, these storms can also intensify further in the fall due to the temperature gradient between the cold Siberian continental air mass and the relatively warm ocean air over the Bering Sea (Rodionov, 2007). The resultant strong winds of long duration, combined with long open-water fetches, generate large waves that can reach up to 8 m and drive water-level surges of as much as 3 m into shallow coastal areas. In the absence of sea ice, these waves and surges can cause significant negative impacts to the coastal zone (Chapman et al., 2009; Terenzi et al., 2014; Erikson et al., 2015).

Atkinson (2005) outlines geomorphological, ecological and infrastructure impacts on coastal arctic regions as a result of storm-induced waves. Such impacts were evident in Shaktoolik, Shishmaref, and Gambell and provided a rationale for selecting these communities for the project. Houses in Shishmaref have been relocated as a result of storm impacts in 2005 (Figure 1.1). In Shaktoolik, electrical power lines were left exposed as a result of coastal erosion during the 2013 storm (Figure 1.2), and there were concerns about salt water contamination of the town's drinking supply if the waves reached the river, which supplies the town's drinking water (Figure 1.3). In Gambell, during the 2013 storm, the waves carried the gravel from the beach onto the airstrip, forcing the town to close the airport, the community's only means of year-round access to the mainland, leaving the town isolated in case of emergency (Figure 1.4).

When sea-ice is in the early stages of formation, frazil or slush ice can be produced in large quantities and driven by storm winds onto the shore, where it piles up in the nearshore area. If this slush-ice accumulation has an opportunity to consolidate through in-situ freezing, it may form solid structures that can greatly limit the adverse impact of surges, as has been witnessed by local ice experts and residents in communities such as Unalakleet, Golovin, Shishmaref and Wales (Eicken, 2010; Eicken et al., 2014). More recently, in 2009, and 2011, storms threatened Shaktoolik and other communities at the eastern end of Norton Sound with floods from the anticipated storm surges. However, slush ice was driven ashore, solidified and formed a natural defensive barrier (a "berm") that mitigated the impact of storm surges (observations from the community as reported in USACE, 2011; National

Weather Service pers. comm. 2009). Similar findings have been reported for the Bering Strait region (Eicken et al., 2014). These types of occurrences prompted Atkinson and Eicken to apply for funding to investigate the weather and sea-ice conditions that lead to berm formations. Although slush-ice berms can protect communities from storm impacts, once they have solidified they can also impede travel and access to the sea. When they are not frozen solid, they can also be hazardous to anyone trying to cross them. This potential to both protect and hamper makes understanding the occurrence of slush-ice berms of particular interest. Atkinson recognized that while these berm occurrences should be part of an operational forecasting regime, no scientific work had been conducted on these phenomena, and a physical model describing the formation of slush-ice berms during storms did not exist. Eerkes-Medrano undertook this project, and established objectives and methodology, with the intention of developing a physical conceptual model.

The nature of slush-ice berm formation precludes simple monitoring with an instrument as is done, for example, with air temperature – there is no simple way to observe this phenomenon. Slush ice berms are also episodic and spatially discontinuous, further hampering their analysis. However, recognizing that local knowledge holders in Indigenous communities live in a close relationship with the land and sea, and have a deep understanding of their environment and its conditions – knowledge that is critical to their survival – Eerkes-Medrano engaged local residents in Shishmaref, Gambell and Shaktoolik to gather information and data on slush ice and slush-ice berm formation processes. The aim was to develop a schematic/conceptual physical model of slush-ice berm formation utilizing data gathered from these traditional knowledge holders. The following are the specific main objectives:

1. Develop a conceptual model of slush-ice berm formation. This included:

a) Establishing a formalized nomenclature that represents the range of coastal slush-ice berm types.
b) Identifying the synoptic weather conditions that led to these types of events
c) Examining the broader meteorological context in which slush-ice berms occur.

2. Document the specific traditional knowledge that was gathered for this project concerning slush ice and slush-ice berm formation processes. This included:

a) Gathering and distilling this knowledge to identify the parameters conducive to slush and slush-ice berm formation in the communities of study.
b) Collecting comments on the advantages and disadvantages that slush-ice berms present for communities.

The intent was to examine the nature of the comments in their original form to capture how raw community comments fed into the development of the physical process model outlined in objective 1.

3. Describe the process by which traditional knowledge holders are engaged. This included:

a) Documenting the methods used to conduct interviews and to develop and build trust.
b) Describing the tools used before and during the project to gather information to bridge the cultures and narrow the gap that often exists between scientists and local residents.

The intent was to present the insights gained and lessons learned during this process.

Traditional and Indigenous knowledge holders are those who maintain a cumulative and dynamic body of knowledge based on a long history of interaction with the natural environment and with each other. This knowledge is generally held collectively (UNESCO, 2006). Realizing the depth of knowledge possessed by these Indigenous and local experts, scientists working on the west coast of Alaska have increasingly engaged Inupiaq and Yupik residents to examine and monitor natural processes. Their local observations and knowledge have been very relevant in informing, guiding and complementing scientific studies that aim to understand physical and environmental processes, and have resulted in scientific contributions to hazard assessment and emergency response (Eicken, 2010).

In this project, Indigenous knowledge holders from Gambell, Shaktoolik and Shishmaref were asked to identify specific dates and times of slush-ice berm occurrence during the storms of 2009, 2011 and 2013. Once these specific dates were identified it was possible to conduct the following:

- Indigenous knowledge holders' specific information on dates and times of event occurrence was complemented with information from the Sea Ice Zone Observations Network (SIZONet/Eloka) database, which consists of community-based observations by Indigenous sea-ice experts (SIZONet, 2008; Apangalook et al., 2013; Eicken et al., 2014). The database also contains short narratives on sea ice, weather and other significant features relevant to residents. The information has been tagged by the SIZONet/Eloka staff for easy access according to sea ice, weather, boating, and whale, polar bear, caribou, and seal observation categories. The information can be filtered by observer, location, date, etc. All the information gathered from local observers in the communities of study and from the SIZONet/Eloka database, was then interpreted, classified, and synthesized by the authors resulting in a nomenclature that better represents the range of slush-ice berm formation processes (Objective 1.a).

- The chronology in which events occurred was relevant to conduct the synoptic weather analysis required to identify the specific weather conditions that led to the formation of the slush-ice berm episodes of 2009, 2011 and 2013 (Objective 1.b).
- Finally, based on local observers' input and synoptic weather analysis, it was possible to conduct an examination of the broader meteorological conditions under which the various types of slush-berm formation occurred and to develop a conceptual model of slush-ice berm formation (Objective 1.c).

The results of objective 1 are presented in Chapter 2, "Slush-Ice Berm Formation on the West Coast of Alaska" (in press, journal Arctic).

The specific comments, descriptions and observations gathered from Indigenous knowledge holders on slush and slush ice berm formation processes are presented in raw form in Chapter 3. Inupiaq and Siberian Yupik Perspectives on Slush-Ice and Slush-Ice Berm formation on the West Coast of Alaska (written as a manuscript to be submitted). This approach was chosen to preserve and convey the insights and quality of the local knowledge and to compare and contrast the knowledge held by residents in different communities. The objective is to show how traditional knowledge is a type of science – based on hundreds of years of observation required for the people's survival – that can be interpreted from a western science perspective and integrated in western science projects (Hobson, 1992).

The methods used to engage Indigenous and local observers in this project are documented in Chapter 4, Engaging Community and Stakeholders in Slush-Ice Berm Formation and Impactful Weather Events Research in Alaska, USA (to be submitted). This chapter presents the many issues and challenges encountered when engaging communities and local observers in this kind of scientific research. It includes a description of the preparatory work required before contacting communities, the approaches and tools used to conduct interviews, and the challenges encountered during site visits including cancellation of public meetings or the absence of interview participants who leave town to go hunting if the day is good. Chapter 5, "Conclusion," includes a summary of main results and suggestions for future work.

1.1 Research Motivation

To understand the occurrence of a specific weather or sea ice phenomenon such as the formation of slush ice and a slush-ice berm, and its impact on a specific community, requires an understanding of the antecedent environmental conditions in the days up to and during slush ice berm formation. Environmental conditions include air temperatures, wind speed and direction, length and duration of the fetch of the wind, storm conditions, and snow and sea ice conditions among others. In a place such as the western coast of Alaska, this information is hard to obtain as weather stations are sparse and sometimes intermittent (Cassano et al., 2011; McBean et al., 2005). Scientists, land managers and policy makers trying to understand these events and their impacts do not have sufficient station data to explore the climate drivers, and therefore they need to rely on different sources of information. Working with traditional knowledge holders and local observers was the only realistic way to understand the processes, conditions, uncertainty and variability associated with the slush-ice and slush-ice berm formation episodes and in order to develop the knowledge, nomenclature and conceptual model of slush-ice berm formation that will form the basis for future research in this area and, eventually, the ability to forecast the formation of these berms during storm episodes.

Figures:

Figure 1.1 Shishmaref: Abandoned house sits on the beach after sliding off during the 2005 fall storm. Credit: Diana Haecker/AP

Figure 1.2 Shaktoolik: Old power house.
Wire exposed in the old power house. Photo taken after the storm of November 9, 2013. Credit: Gloria Andrew

Figure 1.3 Shaktoolik: Concerns about drinking water quality.
View of town (left) and water intake infrastructure, first bend, Tagoomenick River (right). There is a concern about saline intrusion into the drinking water supply as the waves are able to reach the river, that supplies the town’s drinking water. Credit: USACE, BEA, 2009 (picture left), LEM 2013 (picture right)

Figure 1.4 Gambell: Airstrip.
Waves carried the gravel from the beach onto the airstrip during 2013 storm. Credit: USACE, 2008

2 Slush-ice berm formation on the west coast of Alaska

2.1 Article information

This chapter consists of a manuscript (in press) to be published in Arctic Journal. Figures are the same as those submitted with the paper, but they have been renumbered for consistency in this dissertation. References have also been reformatted for consistency.

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2.1.2 Author's and coauthors'contributions

Eerkes-Medrano developed project objectives and methodology to engage local residents, conducted site visits and synoptic weather analysis, collected photographic material, created figures and tables and wrote the manuscript. Atkinson edited figures and reviewed and edited the manuscript. Eicken reviewed and edited sections of the manuscript and facilitated access to the SIZONet database. Weyapuk has been a local observer and regular contributor to the SIZONet database with observations on slush and ice formation. Weyapuk, Nayokpuk, Ungott and Sookiayak provided information and reviewed sections of the manuscript.

2.2 Abstract

Some coastal communities in Western Alaska have observed the occurrence of "slush-ice berms". These are features that form typically during freeze up when ice crystal-laden water accumulates in piles on the shore. Slush-ice berms can protect towns from storm surge, and they can limit access to the water. Local observations from the communities of Gambell, Shaktoolik, and Shishmaref, and Wales were synthesized to develop a taxonomy of slush-ice berm types and a conceptual process model that describes how they form and decay. Results indicated two types of slush-ice berm formation processes: *in-situ* (forming in place), and *advective* (pushed in by storm winds). Several formation mechanisms were noted for the crystals that comprise in situ berms. Cold air temperatures cool the surface of the water; crystal formation is aided by the occurrence of winds that translate surface cooling through a greater depth. Snow landing in the water cools via melt of the snow and the contribution of crystals directly to the water. A negative surge can expose the wet beach to cold air, allowing crystals to form on the beach, which are then picked up by waves.

Slush crystals for advective berm events form offshore. Winds move the slush towards shore where it accumulates and where wind-induced waves move it up onto the beach.

2.3 Introduction

Coastal western Alaska, defined for this study as the northern Bering and southern Chukchi Sea between the Yukon-Kuskokwim Delta and the area just north of Bering Strait (Fig. 2.1), is home to numerous villages and several larger hub communities. Almost all of these communities are situated on the coast, and in some cases on sand or gravel bars – a necessity imposed by transport and subsistence needs, which include low, flat ground for airstrips and access to the water for hunting and fishing and to receive sea-lift barges. This region experiences annual sea-ice cover formation, which, at its maximum extent, reaches well south into the Bering Sea (Fig.2.1). In recent decades the sea-ice cover has been forming later in the fall. This has lengthened the ice-free season, resulted in a less stable ice cover and has exposed increasingly larger areas to storm impacts (Frey et al., 2014; pers. comm. with Shaktoolik residents, 2013).

Coastal western Alaska sees regular incursions of storms moving up from the western North Pacific, a spur off one of the most active storm tracks in the Northern Hemisphere, which stretches across the North Pacific Ocean from regions off eastern Asia to the northeast towards the Aleutian Islands and Gulf of Alaska (Mesquita et al., 2010). Often when storms reach these regions they are in the mature phase of their life cycle and their potential for peak impact is slowly weakening. Storms that move into the seas off western Alaska can stall, remaining stationary for days, resulting in moderate to strong winds blowing from the same direction for extended periods of time. In some cases, however, when upper air conditions are favorable, these storms can re-energize. The resultant strong winds from slow-moving, long-duration weather systems, when combined with long open-water fetches, can generate large waves that can reach up to 8 m and drive water-level surges of as much as 3 m into shallow coastal areas (Chapman et al., 2009; Terenzi et al., 2014; Erikson et al., 2015). Surges and wave action cause inundation and erosion that damages both infrastructure and subsistence forage areas (e.g., berry-picking areas), and can cut-off communities.

Sea ice too can cause major damage. Atkinson et al. (2011) described an incidence of severe damage to a local cannery in the Bristol Bay area which occurred as a result of storm surge acting upon ice that had formed on the structure's wharf facility. However, sea ice can also protect communities from surge and wave action in several ways. Large pieces of floating ice dampen wave energy and prevent the wind transfer of energy into the water, and land-fast ice armors the coast increasing its resistance to erosion (Eicken et al., 2009; Atkinson et al., 2011). In the early sea-ice formation stages, frazil or slush ice can be driven onto shore and pile up in the nearshore area by storm winds. If slush ice accumulating on the beach has an opportunity to consolidate through in situ freezing, it may form solid defensive structures and can greatly limit the adverse impact of surges, as has been witnessed by local ice experts and residents in communities such as Unalakleet, Shishmaref and Wales (Eicken, 2010; Eicken et al., 2014). In 2009 a storm threatened Shaktoolik and other communities at the eastern end of Norton Sound with floods from an anticipated storm surge. However, slush ice was driven ashore, solidified, and formed a natural defensive barrier (a "berm") that mitigated storm surge impact (observations from the community as reported in USACE 2011). Similar findings have been reported for the Bering Strait region (Eicken et al., 2014). In Shishmaref, where key infrastructure is threatened by coastal erosion (GAO, 2009), and where ice threatens the integrity of engineered revetments put in place to protect structures, ice berms may be at least as effective in mitigating storm impacts. Once solidified, slush-ice berms can also impede travel and access to the sea and, in an unfrozen state, be hazardous to anyone trying to cross them. This potential to both protect and hamper makes understanding the occurrence of slush-ice berms of particular interest.

While slush ice and berm formation are part of the traditional knowledge system of indigenous ice experts and residents of coastal communities in western Alaska, the topic has been addressed only a few times in scientific literature and reports. Slush ice in the coastal zone has been studied by Wiseman (1973) and Reimnitz and Kempema (1987). More recently, a post-storm analysis of the November 2011 strom provided detailed descriptions of berm formation in the coastal zone, but the intent of the report was not to analyze causal mechanisms for the berms (Kinsman and DeRaps, 2012). These studies did not provide a detailed breakdown of the weather controls that need to be in place for its formation. To address this, we undertook a study that combines analysis of eight years of ice observations by Inupiaq and Yupik experts with field visits to gather traditional knowledge and local observations of slush and slush-ice berm formation in three communities: Shishmaref, Shaktoolik, and Gambell. Our goal for this paper was to develop a conceptual model of slush-ice berm formation based on observations and comments provided by local experts, as supported by an analysis of the synoptic weather conditions and the meteorological context that lead to these types of events. Specific elements of the traditional knowledge on slush ice and slush-ice berm formation gathered for this project will be presented in a separate paper.

2.4 Methods

2.4.1 Study sites

Three communities – Gambell, Shaktoolik, and Shishmaref – were locations that were visited by some of the authors for this particular project. Although not visited, Wales is included because it has numerous entries in the community observation database called the Seasonal Ice Zone Observing Network (SIZONet), which provided additional useful observations and examples.

Gambell is a community of 681 people (U.S. Census Bureau, 2010), situated on the northwest cape of St. Lawrence Island, 200 miles southwest of Nome. The community is on a gravel spit which is constantly moved by waves and currents. Gambell's nearshore environment is categorized in this paper as "deep," which means it slopes rapidly down, reaching a depth of 30+ m at 6 km from shore. It has a small tidal range, approximately 0.5m between high and low tide. The spit is periodically eroded along the north and west shorelines by storm-generated waves (USACE, 2008). The isolation of Gambell has helped residents maintain their traditional St. Lawrence Yupik culture, their language, and their subsistence lifestyle, which is based on marine mammals. Gambell subsists largely on harvests from the sea -- seal, walrus, fish, and bowhead and gray whales (Gambell, 2012).

Shaktoolik is a community of 251 people (U.S. Census Bureau, 2010) situated near the north end of a sandspit in Alaska's Norton Sound. Shaktoolik has a "shallow" beachfront, reaching only ~6 m at 6 km distance from the coast. Shaktoolik has a slightly larger tidal range than Gambell or Shishmaref, approximately 1.5 m. With the Tagoomenik River to the east and Norton Sound to the west, the community has water on two sides. The community has been relocated twice, once in 1933 and again in 1967 because these sites were prone to severe storms and winds. The present location faces similar problems. The local economy is mixed, based on commercial fishing, traditional subsistence activities, and local jobs (Shaktoolik, 2013).

Shishmaref is a community of 563 people (U.S. Census Bureau, 2010), located on Sarichef Island along the northern coast of Seward Peninsula on the Chukchi Sea. Shishmaref is also a shallow beachfront, also reaching ~7 m at 6 km from shore. Shishmaref also has a small tidal range of approximately 0.5 m. The Island is exposed to severe fall storms. In this community, as many others on the west coast of Alaska, state flood disaster declarations have been issued in 1988, 1997, 2001, 2002, 2005, and 2011 (Alaska Department of Military and Veterans Affairs [ADMVA], 2008; Parnell, 2011). According to Kawerak (2012) the bluff on the north shore of the island erodes at an average of one to one-and-a-half meters a year. Several engineered structures have been built to lessen shoreline erosion (Mason et al., 1998). However, there are no engineered flood protection measures in place (FEMA, 2009). It is a traditional Inupiat Eskimo village with a fishing and subsistence lifestyle (Shishmaref, 2012).

Wales is a community of 145 people (U.S. Census Bureau, 2010), located near Cape Prince of Wales defining the eastern boundary of Bering Strait. The village is located in low-lying areas of unconsolidated sediments below Cape Mountain; its nearshore zone may be categorized as deep, reaching ~40 m at a distance of 6 km from shore. Wales also has a small tidal range of approximately 0.7 m. Strong winds and currents result in dynamic ice conditions beyond a narrow belt of shorefast ice forming in December or January (Weyapuk, in Apangalook et al., 2013). It is a traditional Inupiat Eskimo village with a fishing and subsistence lifestyle.

Observational data about slush ice berm occurrence were obtained from two sources. The first consisted of dedicated site visits to the communities of Shishmaref, Shaktoolik, and Gambell. Two site visits were conducted in each community. Visits to Shishmaref took place in August and October 2013. Visits to Gambell and Shaktoolik occurred in November 2013 and August 2014. The November 2013 visit was particularly well timed because a strong storm was in progress at the time, which afforded an opportunity to observe the process of berm formation first-hand. During the first visit, five semi-directed interviews with local observers were held to gather information about slush-ice berm event occurrence and the environmental context of their formation, including specific dates. Interview data consisted of raw written notes and audio recordings from the interviews. Discussions with community members also resulted in the acquisition of photographs. All raw interview data were reduced by an initial hand transcription followed by a search through the transcribed notes and other sources for information of relevance to berm occurrence. During the second visit to Shaktoolik and Gambell, the five interviewees were also asked to comment on photographs taken by the authors of the *in-situ* slush-ice berm formed in November 2013, and on photographs taken by residents, of the *advective* slush-ice berm formed during the storm of 2009.

The second source consisted of an existing database of community-based observations by indigenous sea-ice experts established by the Seasonal Ice Zone Observing Network (SIZONet; Apangalook et al., 2013; Eicken et al., 2014). The database holds a large number of near-daily observations, for several communities along the west coast of Alaska, including Gambell and Wales beginning in fall of 2006. Observers are recognized indigenous sea-ice and environmental experts from the respective communities recording ice and weather conditions relevant to local uses of the ice cover and associated hazards.

Specific dates for berm occurrence were important and came from observations and interviews, and guided the analysis of the synoptic (weather) patterns that prevailed for the periods preceding, during, and following berm occurrence. Data concerning weather patterns was obtained from an online portal and tool system maintained by Earth Systems Research Laboratory (ESRL), operated by the US National Oceanic and Atmospheric Administration (NOAA). This site uses "reanalysis" data – grids of weather variables generated by weather forecast models run for past time periods using observational data available at those times – and a selection and display portal that allows the user to easily plot variables of interest. Two specific reanalysis datasets were used: NCEP/NCAR global reanalysis (Kalnay et al., 1996) for rapid, general assessment and, when more detail was required, the higher-resolution North America Regional Reanalysis. Maps of pressure, wind, and temperature parameters were produced and then qualitatively analyzed to look for explanatory patterns. The NOAA/ESRL portal may be found at http://www.esrl.noaa.gov/psd/data/composites/hour/. After initial analysis of community observations and weather information, a second visit to each community took place to present the findings to the community, to ensure veracity and obtain feedback from them.

2.5 Results and Discussion

2.5.1 Types of Berms

Three types of berms were identified – based on mode of formation – that can protect communities from storms and are relevant in the context of coastal dynamics: 1) *shoved-ice* – non-slush berms consisting of slabs and boulders of ice piled up through an ice shove. Because this is not a slush-ice berm, it is only mentioned briefly as it is the first type of berm that come to residents' mind; 2) *in-situ slush-ice* –berms consisting of slush ice formed in place and/or freezing of seawater in exposed parts of the beach; and 3) *advective slush-ice* –slush-ice berms composed of slush ice, frazil and/or small ice aggregates moved in from somewhere else. The most essential condition for slush-ice berm formation (whether *in-situ* or *advective)* is water temperature that is at or below the freezing point (-1.8°C for ocean waters in the region). Note that we are distinguishing between ice berms based on mode of formation, rather than berm structure. This approach is in line with the goals of this study, relating specific environmental conditions to formation of ice berms. A classification based on structure would cut across the different formation modes, and would need to differentiate berms in terms of the size of individual aggregates (e.g., frazil grain, aggregated slush flocs, ice gravel, ice block, ice raft).

Shoved-ice Berms: Shoved ice is the most common type of berm mentioned by people in the communities. This type of berm forms when well-established sea ice is driven ashore by wind and/or currents (Mahoney et al., 2004), can form very rapidly, reaching a height of up to 10 m to 13 m, and can form "anywhere" when the conditions are right during the fall season (Eddie Ungott, pers. comm., Gambell, November 2013; Roy Ashenfelter, pers. comm., April 2014). Shoved-ice berms are common throughout the area, but typically occur later in the season when the offshore ice pack is compact enough to transmit stress over longer distances (Mahoney et al., 2004). This type of berm is not the subject of this study, but is mentioned here to make the distinction clear.

In-situ slush-ice berms: These berms form primarily on the beach closest to the water under appropriate conditions of air and water temperature, wind, and wave conditions. A berm can form in a matter of hours in response to air and water temperatures below freezing (typically below –1.8°C for ocean waters in the region). The height of in-situ type berms is usually no more than 1 m and is determined by wave splash height. Berm width is determined by the distance between the high and low tideline, in the following manner. After a drop in air temperature, at low tide the beach is exposed to cold air which allows ice crystals to form in interstitial water and at the surface of beach sediments. As the tide moves in, the water picks up the crystals which form an ice crystal water slurry, termed slush, and builds successive berms culminating with a relatively large berm at the high tideline. As the tide goes out, it continues piling berms until it reaches the low tideline (Fig. 2.2). Community observations also indicate that the slush ice accompanying the berm can extend up to roughly 1.5 km offshore, depending on weather conditions. This occurs under the persistent action of waves, which continues to push slush towards the shore. When the slush associated with the berm extends offshore to a distance of 0.5 km or more wave action is attenuated, reducing wave energy at the shore. The in-situ berm formation process can be accelerated by snow falling on the water: melting of the snow can increase the rate of cooling of the water, and the introduction of ice crystals provides nuclei onto which larger sea ice crystals can grow, speeding the process of sea ice crystal formation (Osterkamp, 1978). Once the in-situ berm has reached a certain height and width and is large enough to remain in place, if the winds intensify and waves spill onto and over the berm the water will freeze when it comes in contact with the berm, creating a solid surface; but the interior of the berm will still remain unfrozen until enough time has passed for it to solidify completely.

Community residents related their observations that slush-ice berms form faster in areas where the nearshore coastal environment is shallow, such as at Nome. They noticed that, as the waves break close to the shore (surf zone), the water continues moving up on the sloping beach and, if it is cold, when the water recedes (backwashes) it will start to form ice crystals (slush) on the beach. When exposed to cold air the beach cools enough that it can rapidly freeze the water that washes over it during successive waves. In addition, slush will also begin to form in the shallow surf zone. When the waves come in, they lift the ice crystals from the beach and push this, along with the slush in the surf zone, onto the beach where it will start to accumulate forming a berm. Each successive wave brings a new slush deposition, increasing the berm's height and thickness, and the berm continues to form as long as there is wave action. A drop in sea level – negative surge – will enhance the slush-ice berm formation process by exposing more water-saturated beach to cold air.

Along deep coastal areas, such as those near Gambell, residents observed that slush takes longer to form and slush-ice berm formation starts only when the water is cold and a large number of crystals form in the nearshore zone, giving surface waters the consistency of "oatmeal" (a mixture of water and ice crystals). This ice in the water will rise to the surface, and if the slush layer is a few centimeters thick, it is able to dampen smaller waves and breakers, which reduces the movement of slush towards the shore. Therefore, waves of greater amplitude – often non-locally generated swell waves –are required to overcome the inertia conferred by the presence of the slush layer and lift the slush up and push it to the shore, where it will start piling up. As with the in-situ berm, each subsequent swell will continue the process of piling the slush onto the shore.

Three examples of *in-situ* slush ice berm formation and their associated weather context are presented. Two occurred in Wales – the first on 8 November 2007, and the second on 10 November 2012 (based on observations by Weyapuk, in Apangalook et al., 2013) – and the third occurred in Shaktoolik on 15 November 2013 (L. Eerkes-Medrano, pers. obs.).

Observations of the ice berms formed at Wales are limited to indications of physical dimension. Wind analysis for the first two events show a general east/north easterly direction and speeds of about 4 to 8 m/s. Both events are associated with a low-pressure system over the Aleutian Islands (e.g. Fig. 2.3). The position of this low explains the air flow direction, indicating that the low pressure system was drawing relatively cold continental air from over the Alaska mainland to the east, resulting in a reduction of temperatures in the vicinity of Wales. In the day leading up to the slush ice berm formation events air temperatures of approximately –3 °C to –4 °C dropped to approximately –8 °C over a period of about a day as the low pressure systems moved in (Fig. 2.4). In both cases, Weyapuk reported an associated slush-ice zone extending for over 0.4 km from shore.

The *in-situ* slush-ice berm started to form on the beach, along the low-tide line, on 15 November. The observed mean maximum temperature that day was –7 °C and the mean minimum –11 °C. Temperatures in this range continued during the week. Community members mentioned that 15 November was the first day of cold weather after a series of storms struck the town, bringing warm, humid air (7, 9, and 13 November) and the first day of slush-ice berm formation. The berm disappeared in the afternoon, when the temperature rose, and it formed again the next day. This diurnal cycle of formation and decay continued for the next three days; on the fourth day, two slush-ice berms had formed parallel to each other – one along the low-tide line and one along the high-tide line. Slush had also accumulated between these two berms and was starting to solidify (Fig. 2.2). There was also slush offshore extending for about 200 m. Winds during this event were moderate out of the north/northwest. Unlike the first two events described, this event was not associated with a low pressure system but rather a general pressure pattern that favored a northerly flow (Fig. 2.5). Despite different causes, these weather conditions are similar to those observed during the first two events discussed above: low to moderate wind speeds (< 8 m/s) bringing weak wave conditions and temperatures dropping to approximately –8 °C/–9 °C.

Advective slush-ice berm: The essential process distinguishing an *advective* slush-ice berm type from the *in-situ* type is that the slush is moved in from elsewhere – advected – by strong winds or onshore currents.

Reimnitz and Kempema (1987) observed large volumes of slush-ice forming during storms in the shallow areas of the Beaufort Sea. They theorized that during these storms, a large quantity of heat is removed from the surface water in a very short time, facilitating the formation of a large volume of slush ice, consisting of frazil ice crystals from 1 to 5 mm in diameter (Martin,1981), that rises to the surface. Reimnitz and Kempema (1987) refer to the sea turning into "applesauce" during these storm episodes. Because of the constant agitation of the slush ice by waves, the formation of pancake ice, the first stage of a solid ice cover, is uncommon. This slush production was observed to occur only when the wind velocity was at least 10 m/s and the air temperature about –10°C or less. The thickness of the water-saturated slush can range from a few centimeters to several meters; when the storm subsides, the slush freezes from the surface down, slowing or stopping wave motion (Reimnitz and Kempema, 1987). Once the slush solidifies, it usually breaks again due to tension or shearing, resulting in geometric ice shapes which are pushed by the waves and currents against the shore (Morecki 1965; Reimnitz and Dunton, 1979). During the strong 2009 storm in Shaktoolik that resulted in a large berm, residents observed that the temperature was not cold at the time of the storm, that slush was not present in the water before the storm, and that they had no idea where the slush came from; it was snowing and the sea conditions were very rough. After the storm residents observed bands of crushed slush/frazil ice aligned obliquely to the beach, indicating compression by wave fronts (Fig. 2.6). These observations from Shaktoolik support the idea of rapid heat loss, suggested by Reimnitz and Kempema (1987), and the solidification process suggested by Morecki (1965), and Reimnitz and Dunton (1979). In Gambell, residents also mentioned that when there is a fall storm, the slush-ice berm forms immediately, and that as long as the wind continues to blow, the accumulation continues to grow and solidify. If the wind-driven motion is directed offshore, the slush will be blown away from the beach.

Slush-ice moves with the wind- and current-driven surface water until it is piled up against stationary ice or land (Reimnitz and Kempema, 1987). If pushed against sheets of solid ice the slush ice will be driven down and can accumulate to a thickness of more than 4 m (Bauer and Martin, 1983). Once the wind dies down, the slush-ice, along with dislodged anchor-ice “ice boulders,” rises to the surface, where it can mix with snow and slush ice, and it can be pushed against the beach (Reimnitz and Kempema, 1987). Reimnitz and Maurer (1979) mention ice “boulders”, or wide, flat pans up to 5 m in diameter being deposited along the Alaskan Beaufort Sea coast during a westerly storm in September 1970. Short and Wiseman (1974) noted that on Pingok Island, after a late fall storm, ice pans less than 10 m in diameter and 60 cm thick piled up on the shore along with the slush-ice, but these formation episodes varied in time and place and from year to year. In years without fall storms, such as 1971 and 1985, Reimnitz and Kempema (1987) did not notice the production of large amounts of slush/frazil, but during the fall storm of 1978, the slush-ice berm was 4 m thick.

Similar observations were noted by residents in Shaktoolik during the fall storms of 2009, 2011, and 2013. During the advective slush-ice berm formation episode of 2009, residents mentioned that two berms formed in town. In the first part of the storm episode, the storm surge accompanied by strong wave action pushed the slush ice farther back from shore, onto the shallow part of the beach (in front of the town), to a height of more than 3 m. When the winds subsided, the swells continued to pack the slush against the beach. A few hours later, the wind picked up and the storm surge pushed more slush-ice onto the shallow beach and in front of the old town, where the beach is only slightly deeper than in front of the new town. There it formed an advective slush-ice berm higher than 4 m and deposited large, thick ice pans on the beach, forming a wall (Fig. 2.7). Residents noted that, during the 2009 episode, fall temperatures had been relatively warm before the storm, that the advective slush-ice berm formation was a result of the storm, and that it was snowing heavily at the time. In contrast, during the 2011 storm there was snow and the town was protected by an advective slush-ice berm but there were no large pieces of ice. During the 2013 storm no slush-ice berm was formed.

In Gambell and Shaktoolik residents mentioned that snow and blizzards accelerate the advective slush-ice berm formation process. Osterkamp (1978) mentioned that if it starts to snow heavily, the introduction of snow into the water will aid ice crystal growth as mentioned previously. Under the right conditions, the ice nuclei grow rapidly but are broken up by flow turbulence and collisions (Martin 1981). The broken pieces act as secondary nuclei for the formation of more ice crystals, and large amounts of slush ice are produced very quickly (Kempema et al., 1990).

Synoptic weather patterns

The NCEP/NCAR reanalysis data for these events reveal the following:

During the 2009 and 2011 episodes, an advective slush-ice berm formed during periods of intense storm activity resulting from a low-pressure system located in the Bering Sea, just to the west of Norton Sound (Figs. 2.8 and 2.9). In both cases, the location of the low-pressure system resulted in west and southwest winds at Shaktoolik, driving waves and slush directly onto the beach. The wind speeds during the 2009 storm were about 14 m/s with gusts of up to 22 m/s, and during 2011 the winds speeds were reaching 18 m/s with gusts of up to 39 m/s (Figs. 2.10 and 2.11). In both events, during the 10 days prior to the storms, temperatures ranged between –5 °C and –10 °C. On 11 November 2009, and 9 November 2011 – the days when the storms hit – the temperatures were about –8 °C and –9 °C, respectively (Figs. 2.12 and 2.13). These two storms may be contrasted with another storm that occurred on 9 November 2013, which did not produce a berm. During this event the air temperatures were above 0 °C, and during the storm episode the air temperatures were 2 °C (Fig. 2.14), not enough to cool the water to produce slush. Although the low-pressure system was west of Norton Sound, it covered a much larger area than the low-pressure systems of 2009 and 2011 and extended from Bristol Bay to the Chukchi Sea (Fig. 2.15). The greater width of the storm meant that the wind direction was from the south and southwest, instead of from the west, and not so directly facing Shaktoolik.

Advective slush-ice berms form in the presence of onshore winds. The particular form they take is determined by two additional environmental conditions – air temperature and presence of a storm surge – that can combine to result in four possible advective slush-ice berm forms.

The first condition, storm surge and cold air, can result in the formation of large advective slush-ice berms farther inland from the shoreline (Fig. 2.16). This type of berm usually forms above the normal high-water mark, is mostly solid, and is higher than about 3 m. It can protect a village from storm action. Once it forms, it solidifies and may remain in place for the duration of the winter.

The second condition, no storm surge and cold air, results in an advective slush-ice berm of moderate height, about 3 m or less, forming near the shore. Because it forms in cold air and with wave action, the resulting berm is quite strong, durable, and larger than an in-situ berm. Note, that in the Bering Strait region moderate height berms are typically less than 1 m high because of significantly smaller fetch and different nearshore bathymetry that impact advective slush-ice berm formation.

The third condition, *storm surge but no cold air,* results in a large, wide advective slush-ice berm that is dangerous to walk on because the air is not cold enough for the berm to be frozen thoroughly. A person can fall through when attempting to walk on it. Residents of Gambell mentioned that with this type of berm, the more a person moves, the deeper and deeper they sink into it, because the slush-ice is like quicksand.

The fourth condition, *no storm surge and no cold air,* results in an advective slush-ice berm of moderate height, not frozen solid and therefore also not strong enough to walk on safely. As with the previous type of berm, a person can sink while attempting to walk on it.

For both *in-situ* and *advective* slush-ice berms, if they form under conditions of warm air (above 0 °C) they will remain in a slushy state; they will be solid enough to remain in place but not to support the weight of a human. If no subsequent wave or surge event acts to melt them, as the air temperatures decrease these berms eventually solidify.

In-Situ Berm Conditions: An issue that came up during this study is the role of beach characteristics in the formation *in-situ* slush-ice berms. In the shallow coastal areas, the *in-situ* slush-ice berm will form as long as there is slush in the surf zone; it will be washed onto the beach and deposited along the low or high tideline, where it can further develop. Along beaches with a steeper profile, community residents mentioned that swell must be occurring in order to push the slush onto the beach. The role of temperature is also identified –if the temperature is too low and there is no wave action, the beach surface may freeze, forming a solid crust, and no slush-ice berm formation will occur. These observations point to the importance of two factors whose detailed consideration are beyond the scope of this study: slope of beach and nearshore zone, as well as the sediment grain size. The steeper gravel beaches of St. Lawrence Island and parts of the North Slope of Alaska exhibit different wave run-up characteristics and because of higher permeability of beach sediments and larger grain size are less likely to form surface ice crusts.

Synoptic weather analysis of *in-situ* slush-ice berms corroborates the community observations that they can form "very rapidly" if there is a rapid drop in temperature. During the days prior to the *in-situ* slush-ice berm formation in Wales (8 November 2007, and 10 November 2012) and Shaktoolik (15 November 2013), the temperatures had been above 0°C, and as soon as temperatures dropped below 0°C the berms formed. The SIZONet database shows that several other episodes of small *in-situ* slush-ice berm formation and disappearance took place every year between 2006 and 2014 during the fall in Wales, Barrow, and Gambell. A total of 53 daily observations out of >5000 reference slush-ice berm formation in these communities for the specified time period. Most of these episodes were observed in Wales, but they were not considered in more detail here because they were too small to protect the town from a storm. However, a cursory synoptic weather analysis suggests that there is no particular association of these smaller events with low-pressure systems, but rather to a general cooling of temperatures associated with the fall season. Also, in Wales, the beach is wider than at Gambell or Barrow, which corroborates observations from residents of Shishmaref that the *in-situ* slush-ice berms formed when there was a sizable beach; in Shishmaref, now that the beach has been eroded, a slush-ice berm does not form. In Gambell, it was mentioned that slush-ice berms form faster on shallow coastal zones and are safer to walk on than those that form on deeper coastal zones.

If the temperature remains low, the berms in shallow water solidify more rapidly and as a result are safer.

Advective Slush-Ice Berm Conditions: An analysis of the synoptic weather conditions that produced an *advective* slush-ice berm in Shaktoolik during the storms of 2009 and 2011 reinforces Reimnitz and Kempema (1987) observations as follows. First, the occurrence of strong winds (> 10 m/s) from an onshore direction allows large wind-driven waves and causes the slush in the nearshore/offshore zone to be pushed directly onto the beach. Second, conditions of low air temperature are important insofar as durable slush-ice berms were only observed at temperatures below –10 °C. Third, the occurrence of snow provides crystals for nucleation and aids in cooling of the surface water layer (Osterkamp, 1978). It was snowing during both of the *advective* slush-berms episodes in Shaktoolik; in both cases as well the wind speed was well above 10 m/s (14 m/s in 2009 and 18 m/s in 2011), and the air temperatures, were about –10 °C. The observation by Osterkamp (1978) of the contribution of snow in seeding the water and accelerating the slush formation process was corroborated by residents in all three communities. One additional community observation is that the weather patterns conducive to the formation of an *advective* slush-ice berm are very limited and site-specific. Short and Wiseman (1974) and community observers have mentioned that this process takes place in a very short period of time when the conditions are adequate.

Effects of Slush-ice Berms on Communities

Slush-ice berms offer both advantages and disadvantages to coastal communities. The most common advantage of slush-ice berms mentioned by interviewees was the protection the berms offer from storm-induced surge or severe marine state, an advantage noted in the following news report:

> "The storm could generate waves of up to 12 feet [3.5 m] and cause localized erosion along the northern coast of the Seward Peninsula as winds gusting up to 40 mph [17.5 m/s] pummel the area, according to the National Weather Service … Shelton Kokeok, whose home is about 30 feet [9 meters] from the sea, said he watched throughout the day as the north wind blew in slush, which turned out to protect Shishmaref" (SanDiegoSource, 2007).

The often-mentioned disadvantages of the slush-ice berms include the following:

- They make hunting for seals difficult, because they block the shore and the seals, after they have been shot, the presence of slush prevents them from being washed all the way to shore.
- They limit onshore access to the beach, with the result that hunters must cut a pass through the berm to haul their boats out to the beach.
- They are not safe to walk on if they have not solidified.

An interesting observation by residents in Shaktoolik was that slush-ice berms used to form in October, when the weather became colder, but (just before freeze-up occurs). Now slush-ice berm formation is happening later in the year, in either November or December, depending on local conditions.

2.6 Conclusion

This project has characterized the two major types of slush-ice berm that can help protect coastal communities in Alaska from storm impacts as well as the synoptic weather patterns associated with these phenomena. It shows that both types of berms – *in situ* and advective slush-ice berms – form in the fall, just before sea-ice forms, under specific weather conditions. The observations of and descriptions from community residents, ice observations by indigenous experts in the SIZONet database, and personal observations were critical in identifying the role that beach characteristics play in the development of *in-situ* slush-ice berms, and previous research results have been reinforced by community observations.

These findings illustrate the benefits derived from collaborative approaches that involve local and indigenous knowledge holders in the scientific collaboration. Their knowledge, combined with observations during community visits, the literature review and synoptic weather analysis, sheds light not only on the two types of berm formation but also on the relationships between weather conditions and slush ice. This information will be valuable in developing future process-models of slush-ice berm formation that could result in incorporation into predictive models. It may also serve as a basis for refining weather parameters and for understanding the dynamic interplay of the weather variables conducive to slush-ice berm formation during storms.

Additional field work is required to more accurately identify specific thresholds and ranges of air temperature, storm surge and wind speed necessary to support the formation of various types of slush-ice berms. Characterization of beach and nearshore morphology and sediment grain size as well as detailed observations of the entire freeze-up season of approximately one month's duration will also be required. However, as Short and Wiseman

(1974) point out, berm formation varies from place to place and from year to year. Once these parameters are identified, the opportunity exists to incorporate these results into routines used by computer modelers to improve slush-ice berm forecasting. The work conducted in this project may also have potential benefit for engineering applications, considering that slush-ice berms appear earlier and form faster in shallow near-shore waters.

2.7 Acknowledgements

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Figures:

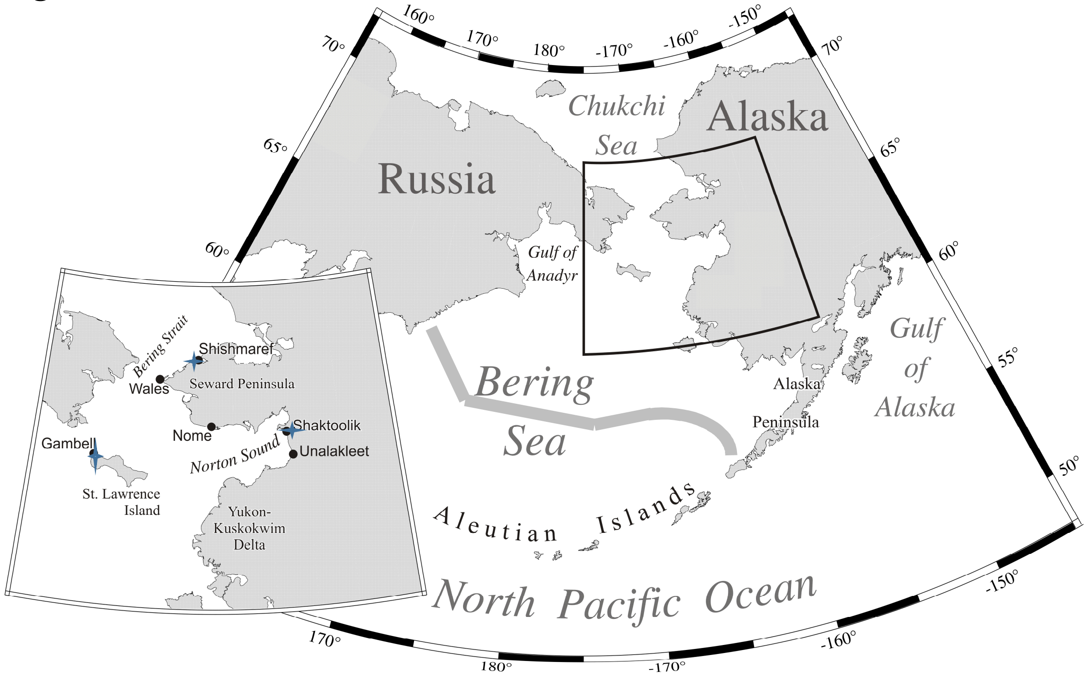

Figure 2.1 Region of study.he broader area is the Bering and Chukchi Sea and their coastal zones. Inset map shows the specific area under consideration. Main map also shows average maximum sea ice extent, 2001-2009 (thick grey line).

Figure 2.2 Two *in-situ* slush-ice berms.
One slush-ice berm along the low-tide line, and the other along the high-tide line. Slush has also accumulated between the two berms, joining them to form a single, large berm. Shaktoolik, November 2013. (photo by L. Eerkes-Medrano).

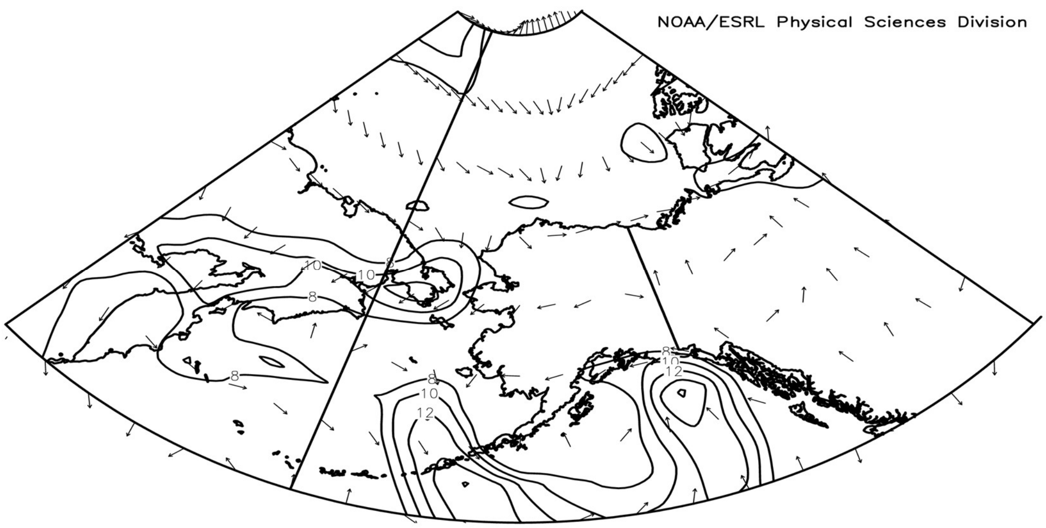

Figure 2.3 Surface winds (10m height) associated with the in situ slush-ice berm event of 10 November 2012 at Wales, Alaska.
Small arrows indicate the direction of the wind. Contour lines indicate speed of the wind in meters per second (m/s). Only wind speeds of 8 m/s or greater are displayed. Contour interval is 2 m/s. Data from NOAA/ESRL.

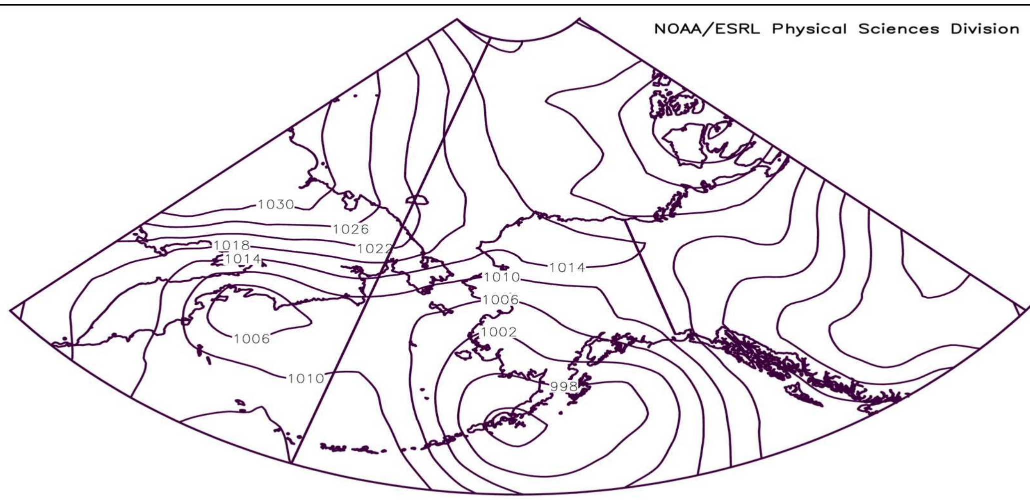

Figure 2.4 Sea level pressure associated with the in situ slush-ice berm event of 10 November 2012 at Wales, Alaska.
Contour lines indicate sea level pressure in millibars (mb). Contour interval is 4 mb. Winds rotate counter-clockwise around areas of low pressure. Data from NOAA/ESRL.

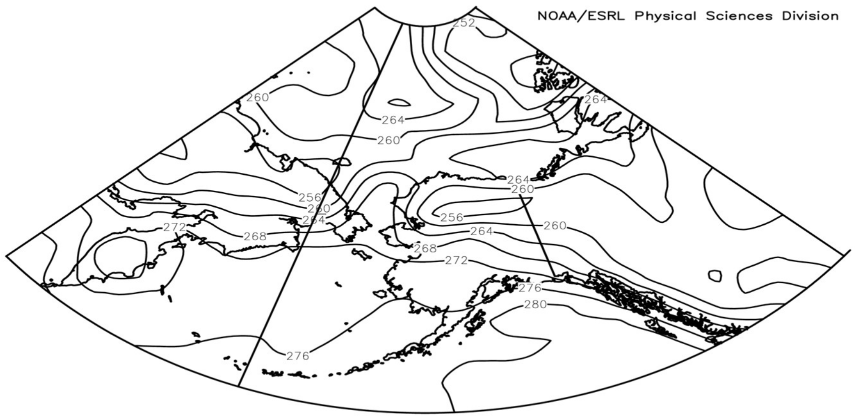

Figure 2.5 Surface air temperature (2 m height) associated with the in situ slush-ice berm event of 10 November 2012 at Wales, Alaska.
Contour lines indicate surface air temperature in Kelvin (K). Subtract 273 to arrive at the equivalent temperature in degrees Celsius (°C). Contour interval is 4 K. Data from NOAA/ESRL.

Figure 2.6 Advective slush-ice berm with ice boulders pushed against a deep beach in the old part of town.
The slush/frazil broken into geometric pieces is aligned obliquely to the beach, Shaktoolik, 2009. (photo by Simon Bekoalok of Shaktoolik)

Figure 2.7 Advective slush-ice berm.
The slush ice is piled up against a shallow beach in front of Shaktoolik, November 2009.
(photo by Agnes Takak of Shaktoolik)

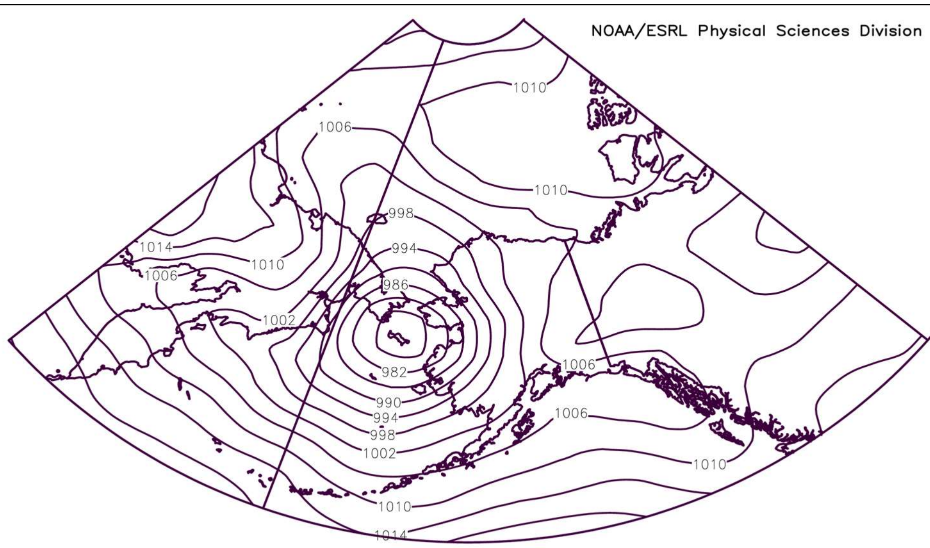

Figure 2.8 Sea level pressure associated with the advective slush-ice berm event of 11 November 2009 at Shaktoolik, Alaska.
Contour lines indicate sea level pressure in millibars (mb). Contour interval is 4 mb. Winds rotate counter-clockwise around areas of low pressure. Data from NOAA/ESRL.

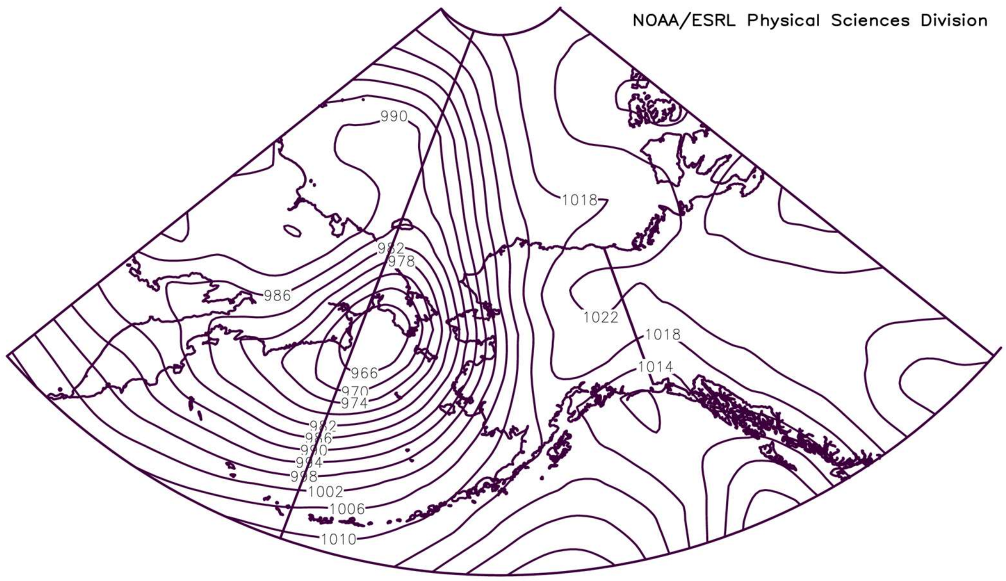

Figure 2.9 : Sea level pressure associated with the advective slush-ice berm event of 9 November 2011 at Shaktoolik, Alaska.
Contour lines indicate sea level pressure in millibars (mb). Contour interval is 4 mb. Winds rotate counter-clockwise around areas of low pressure. Data from NOAA/ESRL.

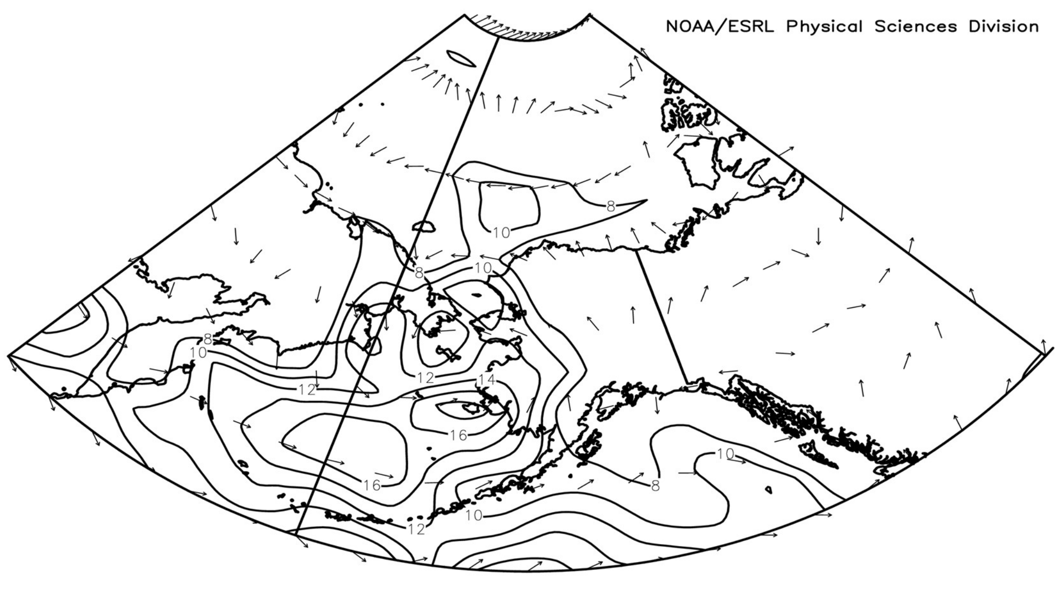

Figure 2.10 Surface winds (10m height) associated with the advective slush-ice berm event of 11 November 2009 at Shaktoolik, Alaska. Small arrows indicate the direction of the wind.
Contour lines indicate speed of the wind in meters per second (m/s). Only wind speeds of 8 m/s or greater are displayed. Contour interval is 2 m/s. Data from NOAA/ESRL.

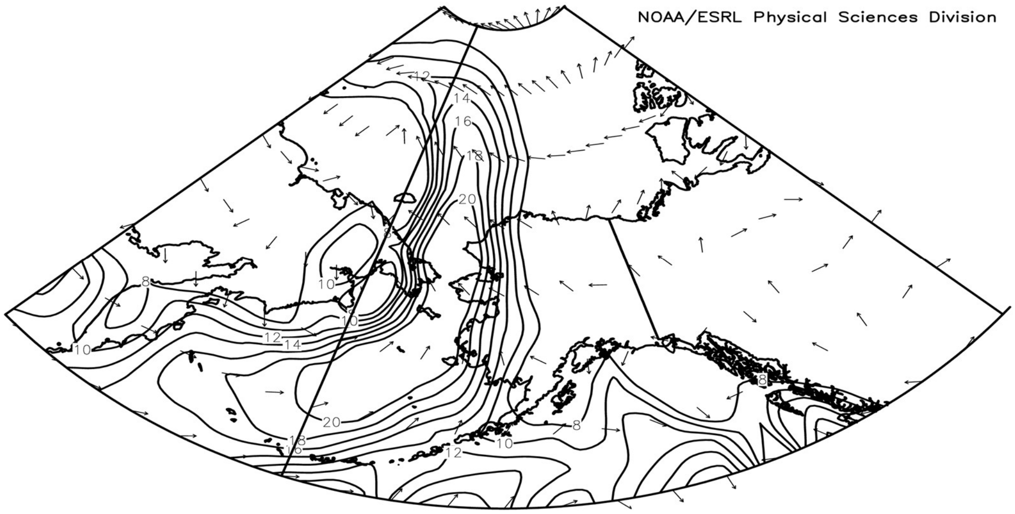

Figure 2.11 Surface winds (10m height) associated with the *advective* slush-ice berm event of 9 November 2011 at Shaktoolik, Alaska. Small arrows indicate the direction of the wind. Contour lines indicate speed of the wind in meters per second (m/s). Only wind speeds of 8 m/s or greater are displayed. Contour interval is 2 m/s. Data from NOAA/ESRL.

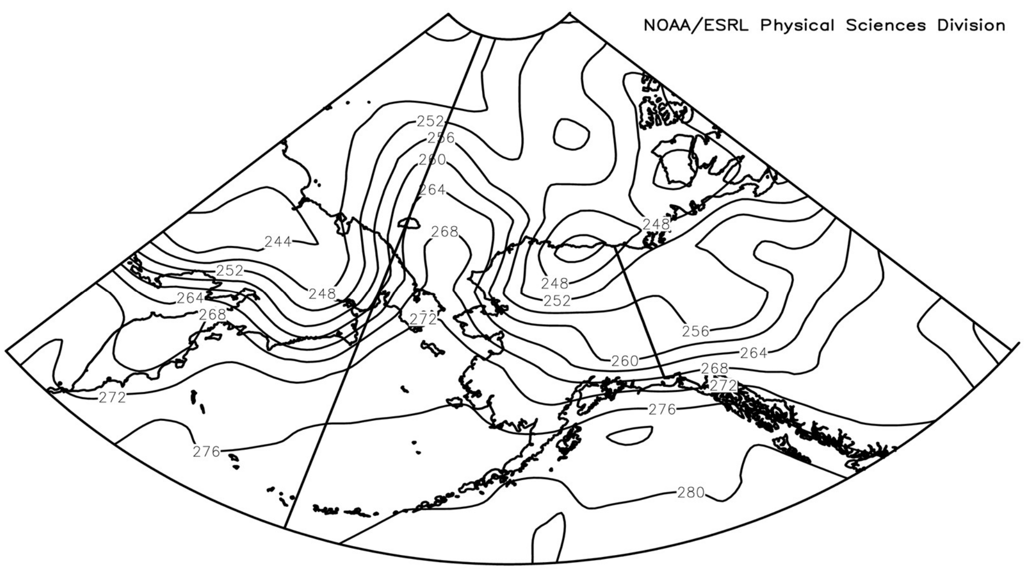

Figure 2.12 Surface air temperature (2 m height) associated with the advective slush-ice berm event of 11 November 2009 at Shaktoolik, Alaska.
Contour lines indicate surface air temperature in Kelvin (K). Subtract 273 to arrive at the equivalent temperature in degrees Celsius (°C). Contour interval is 4 K. Data from NOAA/ESRL.

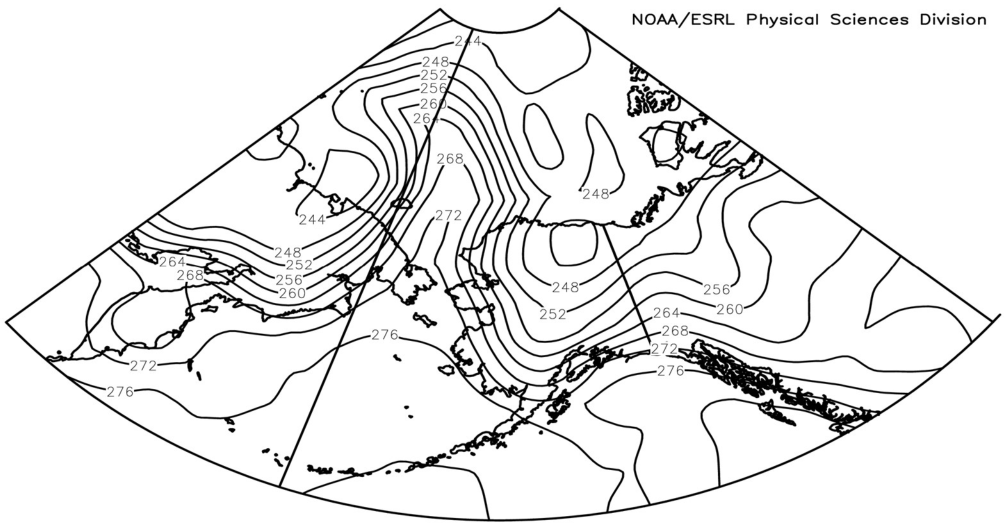

Figure 2.13 Surface air temperature (2 m height) associated with the advective slush-ice berm event of 9 November 2011 at Shaktoolik, Alaska.
Contour lines indicate surface air temperature in Kelvin (K). Subtract 273 to arrive at the equivalent temperature in degrees Celsius (°C). Contour interval is 4 K. Data from NOAA/ESRL.

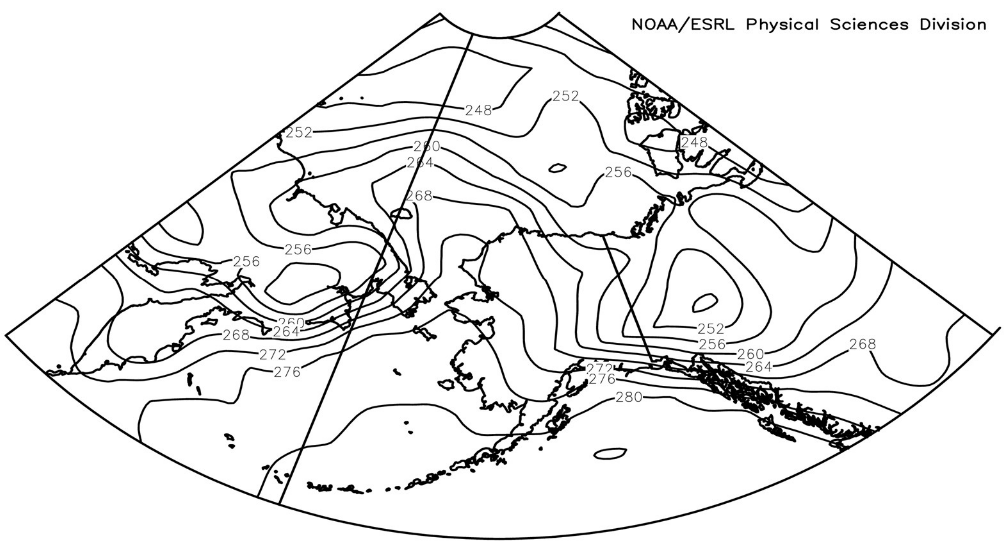

Figure 2.14 Surface air temperature (2 m height) associated with the storm event that did not result in a berm, 9 November 2013 at Shaktoolik, Alaska.
Contour lines indicate surface air temperature in Kelvin (K). Subtract 273 to arrive at the equivalent temperature in degrees Celsius (°C). Contour interval is 4 K. Data from NOAA/ESRL.

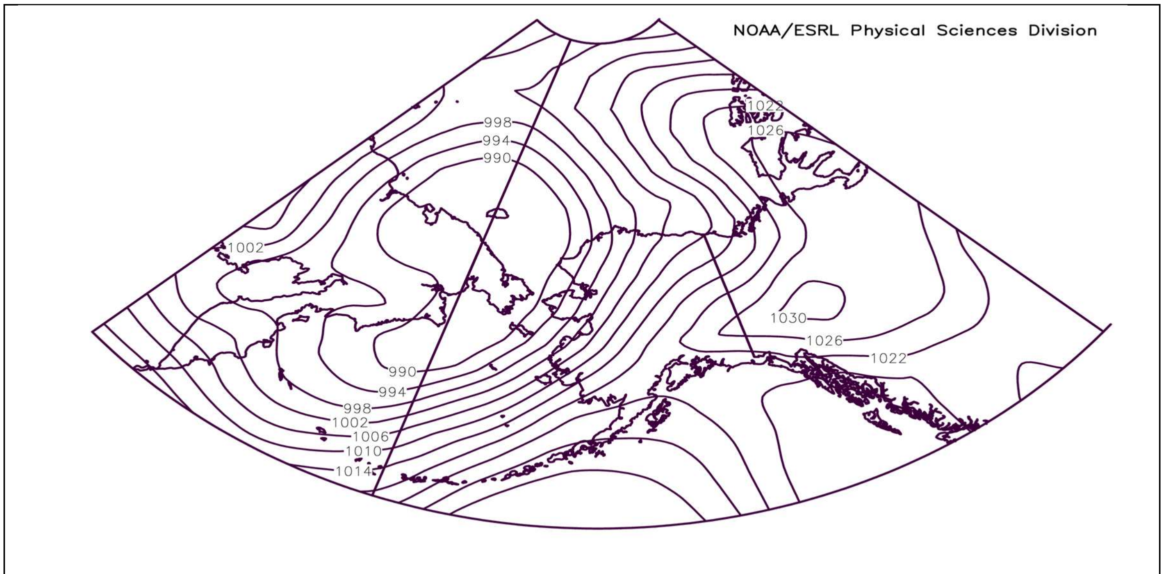

Figure 2.15 Sea level pressure associated with the storm event that did not result in a berm, 9 November 2013 at Shaktoolik, Alaska.
Contour lines indicate sea level pressure in millibars (mb). Contour interval is 4 mb. Winds rotate counter-clockwise around areas of low pressure. Data from NOAA/ESRL.

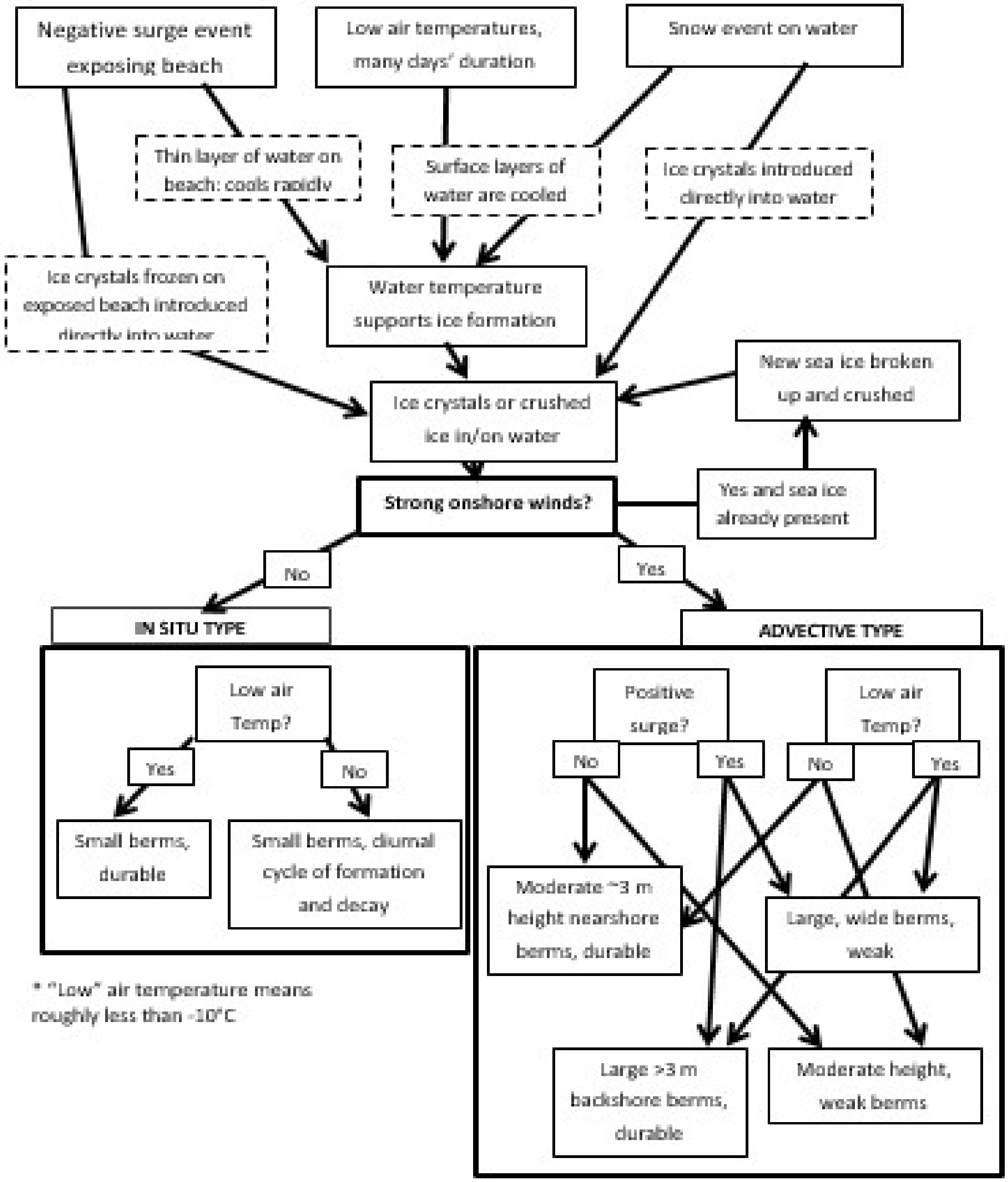

Figure 2.16 General taxonomy of slush-ice berm features.
Solid line boxes indicate an observed feature. Dotted line boxes provide an explanation regarding why the occurrence has the observed outcome. A feature not listed on here is a situation that occurs when there is so much slush ice piled against the shore that wave activity is damped out. In this case, without wave action, the slush does not get up onto the beach to form berms. These near-shore slush ice mats can extend many meters out from shore. Large waves can break through and carry slush up onto the beach, and the action of storm surge can lift and then deposit slush directly onto the beach.

3 Inupiaq and Siberian Yupik perspectives on slush-ice formation on the west coast of Alaska

3.1 Article information

Chapter 3 consists of a manuscript to be submitted for publication.

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3.1.2 Author's and coauthors' contributions

Eerkes-Medrano developed the methodology to engage local residents, conducted site visits and interviews; took photographs; analyzed, organized, synthetized the material; and wrote the manuscript. Atkinson reviewed and edited the manuscript. Additional coauthors provided input, reviewed the manuscript and provided consent for publication.

3.2 Abstract

Most communities on the west coast of Alaska regularly experience storms that can generate surges of up to 4 m, which cause flooding and erosion that disrupt community activities. In some cases, community residents have observed the formation of berms composed of slush ice. These berms can be large enough to protect communities from storm-surge damage and can reach heights of about 4 m. However, their presence can also be disruptive – for example, by hindering access to the ocean.

Despite the importance of slush-ice berms there has been a lack of scientific work on this phenomenon. In this project, the authors worked with Inupiaq Indigenous knowledge holders and local observers in Shaktoolik and Shishmaref as well as with Siberian Yupik Indigenous knowledge holders and local observers in Gambell to understand and describe slush and slush-ice berm types and formation processes. This effort led the author to develop a physical conceptual model of slush-ice berm formationand to establish a nomenclature based on descriptions by the local observers. Two types of berms berms were identified based on residents comments: in situ- it forms in place, and advective – pushed in by storm and winds . This hapter presents Indigenous knowledge holders' comments, descriptions and observations concerning slush and slush-ice berm types and formation processes that was gathered during the process, with the objective of showing exactly how they discuss this phenomenon in their own terms. This includes how different age groups view the phenomenon, and specific details that various knowledge holders focused on. The information and observations on slush-ice and berm formation provided by Indigenous and local observers are then discussed in the context of river related observations of large scale

slush formation, followed by a brief discussion on slush ice and slush-ice berms from a sea-ice services perspective.

3.3 Introduction

The coastal communities of western Alaska (Figure 3.1) are typically situated along the coast to meet cultural, transportation and subsistence needs. These sites require low-lying, flat ground for airports, as well as water access for hunting and fishing, and to accommodate sealift barges (Bearded, T. 2008; USACE, 2008, Marino, 2012).

The low profile leaves these communities exposed to regular winter storms that generate surges of up to 4 m, causing flooding and erosion. For example, a storm in 2013 devastated a large number of communities (SanDiegoSource, 2007).

Sea ice is a significant environmental feature of coastal communities that can protect them from flooding and erosion. The presence of sea ice can have both positive and negative effects, and provides a variety of services (Eicken et al. 2009). For example, sea ice is of benefit when it can be used as a platform on which to camp, or when residents build snowmobile trails on the ice that they use to go whale hunting (Eicken, 2010; Druckenmiller et al., 2010). Sea ice can have negative consequences when it is driven ashore during strong wind events. Atkinson et al. (2011) describe an incidence where a cannery in the Bristol Bay area was severely damaged as a result of a storm surge acting on ice that had attached itself to the cannery's wharf facility. More typically, sea ice protects communities from the impact of fall storms. The presence of ice dampens wave energy, and land-fast ice armours the coast, increasing its resistance to erosion.

The initial stage of sea-ice formation consists of ice crystals suspended in the water column. These crystals, termed frazil, can form if the water is exposed to sub-freezing air temperatures and turbulent conditions (Kempema et al., 1986). Given the right wind, wave and temperature conditions, large amounts of frazil, also termed “slush ice,” can be produced and driven toward the beach, where it is piled up in linear rows, or berms, that are parallel to the water’s edge. Depending on a range of factors, these slush-ice berms can grow to various heights and freeze through to varying extents (Eerkes-Medrano et al., in press, journal Arctic). When solidly frozen, slush-ice berms are formidable structures that can greatly limit flooding associated with storm surges. This has been witnessed, for example, in the communities of Unalakleet and Wales (Eicken, 2010; Eicken et al., 2014). Also, in 2009 and 2011, storms threatened Shaktoolik and other communities at the eastern end of Norton Sound with floods from an anticipated storm surge. Slush ice was driven ashore, solidified into berms and formed large, natural barriers that mitigated storm-surge impact (observations from the community as reported in USACE, 2011; National Weather Service, pers. comm., 2009). Reports of similar but smaller slush-berms formation have come from other locations in the Bering Strait region (Eicken et al., 2014). Despite their protective role, slush-ice berms can also impede travel and access to the sea; when they are not frozen solid, they can also be hazardous to those attempting to cross them. This potential to both protect and disrupt makes the formation of slush-ice berms of particular interest to communities and scientists.

After the storms of 2009 and 2011 in Shaktoolik and other communities in Norton Sound, Atkinson and Eicken decided to investigate the synoptic conditions that led to the formation of these berms and applied for funding to work directly with Indigenous knowledge holders who have observed the events. As such this project to develop a conceptual model of formation of slush-ice berms was undertaken by the author.

To our knowledge, previous work on slush-ice berm formation during the fall storm season is limited to studies: by Wiseman et al. (1973) and Reimnitz and Kempema (1987). These studies focus on the modification of the nearshore region in the Chukchi and Beaufort Seas due to slush formation and sediment transport. Their focus was not the analysis of the synoptic weather conditions required for the formation of large volumes of slush-ice and slush-ice berms during the fall season, nor to categorize different types of berms – based on mode of formation – that can protect communities from storm impacts.

Instrument-based observing networks, ranging from automated weather stations to satellite imagery, are often unable to capture natural phenomena at the local level, especially phenomena that are episodic and spatially discontinuous in occurrence – do not occur in the same place every time and they appear on the shores of some communities but not in others – such as slush ice berms. To fill this gap, and recognizing the depth of knowledge possessed by these Indigenous and local experts, scientists working on the west coast of Alaska have more frequently been engaging Inupiaq and Yupik residents to examine and monitor natural processes. Local observations and knowledge have informed, guided and complemented scientific studies that aim to understand physical and environmental processes, and have made valuable scientific contributions to hazard assessment and emergency response (Eicken, 2010).

This project was undertaken in three communities that had observed slush ice and slush-ice berm formation during storm episodes – Shishmaref, Shaktoolik and Gambell – and included site visits and semi-directed interviews (Huntington, 1998) with five Indigenous and local observers in each community, and the gathering of photographs from community members. In the semi-directed interviews the author had a list of key topics to ask information about and the interviewee was able to follow his train of thought Huntington 1998, Zhang and Wilmuth, 2009). Each interview lasted about one hour This documents the specific traditional knowledge that was gathered for this project concerning slush ice and slush-ice berm formation. It presents Indigenous knowledge holders' comments, descriptions and observations concerning slush ice and slush-ice berm types and formation processes, with the objective of showing exactly how they discuss the phenomenon in their own terms. This includes how different age groups view the phenomenon, and specific details that various knowledge holders focused on. Drawing on the knowledge holders' comments on the mode of formation, the authors identified three types of ice berms: in-situ (slush ice and slush-ice berm forms in place), advective (slush ice is pushed onto the shore from somewhere else) and shoved-ice known as ivu (Inupiaq) or vuusleq (Siberian Yupik) (slabs and boulders of ice are piled up as a result of an ice shove). This third type is not formed by slush, and does not occur only during the fall storm season. It is mentioned here because it is the type of berm most commonly observed by residents.

The information and observations on slush-ice and berm formation provided by Indigenous and local observers are discussed in the context of river-related observations of large-scale slush formation. This is followed by a brief discussion on slush ice and slush-ice berms from a sea-ice services perspective.

The overall effort allowed the authors to identifify two types of berms and formalize their nomenclature as in situ – forms in place, and advective –it is trasnsported from somewhereA critical point is that slush ice–related processes and features are complex phenomena driven by the interplay of various components of the coastal morphology/air/ocean setting that cannot be captured using instruments alone. Researchers wishing to learn about them must rely on long-term human observations (that is, traditional knowledge). This means the input of Indigenous and local observers is invaluable for advancing the knowledge of environmental conditions required for their formation.

The scientific objective of defining slush-berm mechanisms well enough to establish the basic physical model was accomplished in Eerkes-Medrano et al. (in press, journal Arctic). However, the specific traditional knowledge that was gathered, interpreted and synthesized to establish that model is very different from western knowledge of physical mechanisms. This knowledge is developed by people who depend on it for their survival, and it reflects their deep connection with the surrounding environment. Traditional knowledge must be understood in its own context when researchers attempt to fit the knowledge into a western-style framework. This chapter presents the knowledge gathered in Shaktoolik, Shishmaref and Gambell in this context.

Study Sites

Several criteria were used to select the communities of study. One criteria was that residents had observed the formation of slush ice and slush-ice berms during storms. Budget and time consideration played a role in selecting only three communities out of twelve originally planned for this study. Ultimately, Shaktoolik, Shishmaref and Gambell, located along the west coast of Alaska, were chosen for the study (Fig. 1). Shaktoolik was selected because USACE and other researchers had conducted research in this town and suggested it as a good candidate. Residents in this town had also contributed significant sea-ice information to SIZONet. Shishmaref was another site suggested by USACE, and Atkinson had conducted research work and knew the people in town. Gambell was selected because of the residents' extensive participation in sea-ice research projects, such as Oozeva et al. (2004), and their significant contributions to SIZONet. As well, the authors had been in touch with community residents who were offering access to log books covering 30 years of weather observations. Consent for this project was granted by the Tribal Council in Shaktoolik and Gambell, and by the City in Shishmaref.

Shaktoolik is a community of about 250 residents (U.S. Census Bureau, 2010) situated near the north end of a sandspit in Alaska's Norton Sound (Figure 3.1). With the Tagoomenik River to the east and Norton Sound to the west, the community has fresh water on one side and salt water on the other. It has been relocated twice, in 1933 and 1967, because the earlier sites were prone to severe storms and winds. The present location faces similar problems. Shaktoolik's population today is largely Malemiut–Inupiat Eskimo, who have a fishing and subsistence lifestyle. The local economy is mixed, based on commercial fishing, traditional subsistence activities and local jobs (Kawerak, 2013).

Gambell is a community of about 700 people (U.S. Census Bureau, 2010) situated on the northwest cape of St. Lawrence Island, 322 km southwest of Nome (Figure 3.1). The community is on a gravel spit that is constantly shaped by waves and currents. The spit is periodically eroded along its north and west shorelines by storm-generated waves (USACE, 2008). Gambell's isolation has helped its residents maintain their traditional St. Lawrence Yupik culture, language and subsistence lifestyle, which is based on the hunting of marine mammals. Gambell's economy largely relies on subsistence harvests from the sea – walrus, seal, fish and bowhead and gray whales (Kawerak, 2012a).

Shishmaref is a community of about 600 people (U.S. Census Bureau, 2010) on Sarichef Island, a barrier island located along the north coast of the Seward Peninsula on the Chukchi Sea (Figure 3.1). It is a traditional Inupiaq Eskimo village with a fishing and subsistence lifestyle (Kawerak, 2012b). Sarichef Island is exposed to severe fall storms. State flood disasters were declared in 1988, 1997, 2001, 2002, 2005 and 2011 (Alaska Department of Military and Veterans Affairs [ADMVA], 2008; Parnell, 2011). According to Kawerak (2012b), the tribal non-profit organization for the region, the bluff on the north shore of the island erodes at an average of 0.9 to 1.5 m a year. Several shoreline hardening emplacements have been built to lessen coastal erosion (Mason et al. 1998), but no engineered flood-protection measures are in place (FEMA 2009).

The authors found that communities such as Gambell, which depend on hunting sea mammals, such as whale and walrus, during fall and spring migration for subsistence, have a closer interaction with the sea-ice environment than do communities that depend on commercial fishing or other subsistence activities carried out in rivers, lagoons or bays. Shaktoolik residents conduct their commercial fishing in the bay in front of the village and in the mouth of the river. Shishmaref residents hunt most of their seals in the lagoon behind the town and hunt walruses only during the spring migration, at the end of June, when they are close to the village (Curtis Nayokpuk, pers. comm., January 2016). Members of these communities do not go as far out into the ocean as the residents of Gambell, who may travel as far as 110 km north and northeast in their hunt for walruses. This link to the sea-ice environment is an essential part of the Arctic coastal situation: Druckenmiller et al. (2010), Mahoney et al. (2009), Huntington et al. (2011) and Eicken (2010) have noted that residents in Wales and Barrow, who have a close interaction with the sea-ice environment in their daily hunting activities, are also deeply aware of the benefits and challenges that changes in sea ice pose to their livelihoods.

3.4 Methods

The traditional knowledge and observations of slush and slush-ice berm formation processes and the information on the specific dates and times of slush-ice berm formation were gathered through site visits and interviews. Two site visits were conducted in each community. The first visit consisted of public meetings and semi-directed interviews with Indigenous and local observers to present the project and to gather information about the occurrence of slush-ice berms, including specific dates and the environmental context of their formation. Comments were explicitly solicited from "younger" hunters, defined to be less than about 45 years old, and "older" hunters/elders. Interview data consisted of raw written notes and audio recordings from the interviews. Discussions with community members also resulted in the acquisition of photographs. Date information was used to guide the analysis of the synoptic (weather) conditions leading to slush berm formation and is the subject of a separate paper (Eerkes-Medrano et al., in press, journal Arctic).

Following the first visit, data were collated and synthetized and preliminary findings and summaries were extracted. Once this process was complete a second visit took place to present the findings to the communities via a public meeting using a power point presentation followed by discussions with previous interviewees in order to ascertain the accuracy of what had been obtained in the initial interviews and to get residents' responses and input concerning specific events, including the slush-ice berms that formed in 2009, 2011, and 2013. Photographs collected from residents and taken by one of the authors (LEM) during the first visit were used in the second visit to solicit feedback and to guide the interview questions about slush-ice berm formation in Shaktoolik.

3.5 Results and Discussion

The descriptions and comments from knowledge holders presented here have been classified by topic and a brief interpretation from the western science perspective is provided to introduce the descriptions and comments. This approach was chosen to show how traditional knowledge is science (Hobson, 1992) and can be interpreted from a western science perspective while preserving and conveying the insights and quality of the local knowledge. The approach is also useful to compare and contrast the knowledge held by residents in different communities.

The results below are divided into three sections. First are general descriptions of slush-ice and slush-ice berm formation processes obtained from hunters, younger (under about 45 years old) and older. Second are descriptions of environmental factors that contribute to slush-ice and slush-ice berm formation. Third are descriptions of the three berm types – categorized by the authors based on community input – that are able to protect communities from storm impacts. Two of these berm types are slush-ice berms. Based on mechanisms of formation, the authors classified them as *in-situ*, which form in place when seawater and sea spray freeze at the waterline; and *advective*, made up of slush and frazil ice that is formed during a storm and then driven inshore, piling up on the beach. A third type of berm – shoved-ice berms (WMO 2014), – is only included here because it is the most familiar to residents, even though it is not formed by slush ice and can appear during the winter and spring as well as the fall storm season.

3.5.1 Slush-Ice and Slush-Ice Berm Formation Processes

Residents in all three communities mentioned the occurrence of qenu (Siberian Yupik, Krupnik et al., 2010) or qinu (Inupiaq; Weyapuk, Jr. and Krupnik, 2012) – the first slush ice to appear along the shoreline. This ice, as well as sea ice in general, is occurring later and later in the fall season. Similar findings have been documented in Huntington (2000), Huntington et al. (2011), Eicken (2010) and Eicken et al. (2014). Oozeva (pers. comm., August 2014) mentioned that even what he wrote only ten years ago (Oozeva et al., 2004) no longer applies: "Things have changed a lot since." The elders in Gambell and Shishmaref generally relate the timing of slush-ice formation to the season of the year. In their definition, winter becomes official the day the ice pack arrives. Until then it is still fall even if the ground is freezing it is not winter yet Apangalook (pers. comm., August 2014).

> In the fall the slush forms from underground and comes to the surface. Qenu is the first-forming ice, when it's wintertime. If the north wind is not blowing hard, then it begins to become ice and it's safe to walk on. (Conrad Oozeva, Gambell, August 2014)
>
> Slush comes with the freeze-up. (Paul Apangalook, Gambell, November 2013)
>
> In the fall, when slush builds up and there was a beach, we were protected. Nowadays the slush does not protect the same way. The waves lift it and wash the slush away. (Johnson Eningowuk, Shishmaref, August 2013)
>
> By this time [fall] there would be more north wind and we would have it [slush] in the shallow parts of the island. (Anders Apassingok, Gambell, November 2013)
>
> In late winter, the ice that wind brings from the north is thick ice. Lots of times in some places where it touches the cakes of ice together it forms piles from one side of the beach to the other. That is the time that [it] is down on to the bottom of the sea and it stays here until spring. (Conrad Oozeva, Gambell, August 2014)

In contrast, younger people interviewed tend to relate the timing of the slush formation and other events to the month of the year:

> We should have it by now [second week of November]. Last year it happened late, in early December. It usually happens in October. I remember those days, I used to stay at the camp and see the changes right in my front yard, and to go hunting we needed to look for the lower locations to make a trail. (Melvin Apassingok, Gambell, 2013)

> We usually get rain in mid July, August and part of September but now, this fall, it has been raining in October and part of November. The cold has been real late this year, that is a big change for us (Dale Sookiayak, Shaktoolik, 2013).

Residents in Gambell differentiate between the formation of slush ice in the near-shore zone – *qenu* – and the formation of slush-ice berms on the beach –*sigugneq.* When talking about slush ice and where it forms, shallow water is the first factor that comes to their mind.

> *Qenu* forms first in places where there is shallow water. It forms in Savoonga, and when it's thick the currents bring it here. (Anders Apassingok, Gambell, August 2014)
>
> In places like Nome, when it is cold the slush ice forms faster because it is shallow. (Edmond Apassingok, Gambell, November 2013)
>
> Savoonga gets it sooner because they are shallower over there. (Anders Apassingok, Gambell, November 2013)

Gambell residents (Conrad Oozeva, Melvin Apassingok, Clement Ungott, pers. comm., 2014) also consider *qenu* to be the ice formed during strong wave conditions when ice floes are rapidly broken into small pieces that constantly crush into each other. The result is a mixture of small ice floes and small ice particles (brash ice, WMO, 2014) suspended in the water (Frankenstein et al., 2001).

Residents note that slush does not form in deep water. Similar findings are made by Daly, (1994), who mentioned that temperature stratification plays a very important role. He outlines that if there are weak winds and stratified shallow waters, frazil or slush ice can form rapidly over large areas, however, in the deep oceans where there is convection, slush ice may never form. Residents elaborated on the role of air temperature, water depth and temperature stratification at the surface layer:

> In places like Gambell, where there is no shallow beach, the slush does not form. (Melvin Apassingok, Gambell, November 2013)

> In shallow water it will build fast, but in deeper water, way down deep, it will not form any slush because somewhere there the temperature is going to stay the same. (Edmond Apassingok, Gambell, November 2013)

One Gambell resident commented on slush forming "at the end of the water … towards nowhere" (from the shoreline towards the ocean) and about the difference that the tides (low and high water) make.

> First we get the slush that starts to form at the end of the water on the beach, and it starts to form outwards towards nowhere, and you need low water so that it forms quickly. In deep water it has swells that keep it free from slush. (Clement Ungott, Gambell, August 2014)

Residents also mentioned that during the initial stages of formation, slush is highly mobile. Once it is formed it can be taken away by swells and wind changes, unless it has an anchor.

> *Qenu* can extend on the north side of the island or the west, but as soon as the weather changes it goes away if there is *no anchor* to keep it in place. (Conrad Oozeva, Gambell, August 2014)

> Slush ice moves. The wind from the sea will wash it on the beach and form a high-bank. If the wind direction is from the north, it will form a high bank [on the shore]. They happen every year, they form a high-bank, but if there is wind from the south or southeast and it keeps blowing, it will take it [the slush] away. (Anders Apassingok, Gambell, November 2013)

In Shaktoolik and Gambell, residents mentioned that in several cases slush starts to form at the "bottom of the water," fairly close to the beach, when the land and the beach start to freeze. Then the slush floats up and starts to accumulate. They mention that this process occurs as follows: in a shallow beach area, when the tide recedes, it leaves the land exposed to cold air and it gets colder than the water.

Slush comes from the bottom. The water gets mushy and it flows *up.* (Simon Bekoalok, Shaktoolik, August, 2014)

Qenu is the name for the ice that comes from the bottom of the water and it flows up. Sometimes real thick, a few feet height. (Conrad Oozeva, Gambell, August 2014)

In Gambell, where the beach is deeper, people equate the slush formation with the formation of other types of ice, such as frost, and mentioned the need for a calm day for it to surface. Kempema et al. (1986) identified in laboratory experiments that as long as there is turbulence that overcomes the natural buoyancy of ice crystals, the frazil ice remains in suspension but when the turbulence stops the frazil crystals rise to the surface.

Slush ice is something that forms down below at the bottom of the ocean, and when the weather turns cold it forms down there. The same way frost forms when it's cold. It's like wet snow down there. The bottom of the sea is cold and then when it becomes thick down there, on a calm day it comes to the surface. At first it would be thin. (Anders Apassingok, Gambell, 2014)

3.5.2 Factors Contributing to Slush-Ice and Slush-Ice Berm Formation

Four factors were identified by residents as most relevant in the formation of slush ice: water depth, temperature, wind, and tides. Although Shaktoolik has a shallow beach, resident Eugene Asicksick mentioned that large amounts of slush ice form first in the shallow areas around Cape Denbigh, which acts as a hook for the slush to accumulate, and then the currents bring it to Shaktoolik (Figure 3.2). Kempema et al., (1986), Schaefer, (1950); Wigle, (1970); Arden and Wigle, (1972), mention only two factors required for frazil ice formation: 1) air at sub-freezing temperatures that will produce supercooling in the water –a condition whereby the water has been cooled below its freezing point without freezing, and when a disturbance is introduced, it can "flash freeze," and 2) turbulence caused by wind generated waves or currents.

For the slush to form, it depends on how cold it is and on the currents. If the temperature drops, in half a day you can get slush. Now [in November] we are starting to have slush forming. If it stays like this [0˚C], by tomorrow the slush will be further out. (Roy Panaptchuk, Shaktoolik, November 2013)

On the shallow part north of Gambell, when the slush fills up, it gets thick in this area and the current brings that slush ice here. We are very deep here, so we are the last ones to get it. Temperature is what determines its formation. (Anders Apassingok, Gambell, November 2013)

You need about 20˚F to 30˚F [–6.5˚C to 1˚C] for slush to form out there. If there is no wind it will stay because it will give it time to freeze. (Carole Sookiayak, Shaktoolik, November 2013)

Sometimes the slush comes in calm weather with 5-knot winds, and it will be pushed in and will form around the beaches. (Clement Ungott, Gambell, August 2014)

In the northern part of the Bering Sea basin sea ice normally forms in-situ in October and November when northeasterly winds from arctic high pressure systems dominate and drive this ice towards the southwest and south to the Seward peninsula and St. Lawrence Island (Pease et al., 1982). The northerly winds bring the cold air temperatures that Gambell residents identify as a factor in the slush-ice berm formation.

The land gets cold enough and slush starts to come to the surface from the bottom. The slush ice forms on the bottom near the shore, and it will float to the surface, and that helps form the slush-ice buildup. It thickens – it does not necessarily freeze, but it thickens. At the same time on the shoreline, the waterline will start to freeze and that will [also] create it. Even before the berm forms, if enough slush ice floats up, that forms new ice. As it gets colder, the beach will start to freeze and the soft frozen slush will start to build up on the shoreline, on the ground. The slush will build up as long as there are breakers. (Paul Apangalook, Gambell, November 2013)

It forms on the beach on a cold day – *qenu* – on the high tide. It forms with northerly wind. If the north wind is not blowing hard [and it's cold enough] the slush begins to solidify (Conrad Oozeva, Gambell, August 2014)

When talking about slush-ice *berms*, a resident in Shaktoolik mentioned the first criterion for berm formation:

> We need slush to form a berm (Carole Sookiayak, Shaktoolik, November 2013)

Other residents in Gambell mentioned the role that pack ice and currents play in pushing the thick slush from adjacent shallow areas, such as from Savoonga (on the north east St. Lawrence Island) onto the shores to form the berm.

> The pack ice pushes the smaller pieces of ice and slush in. As it [the slush] is being pushed, it comes to the shore and stays along the tideline. If there is wind, it will keep blowing it away. (Anders Apassingok, Gambell, November 2013)

In these communities, residents mentioned that in addition to the previously identified factors for slush-ice berm formation (water depth, temperature, wind, and tides), the presence of storms, snow, blizzards, swells and breakers also play a role in berm formation.

> As long as we get blowing snow and a blizzard, we should have them. We do not get them in October, we get them when it gets colder and colder. (Iver Campbell, Gambell, November 2013)

> If there are storms it [the berm] quickly builds up. If a storm hits, it will build right away. (Paul Apangalook, Gambell, November 2013)

> It is formed by a combination of snowfall and slush, and it will get thicker on top. [Due to] the wind and the beach and the wave-action crashing, it will start to build and build. On some areas it will be higher than the beach itself. If the storm comes, it will act as a natural barrier, and the waves will crash on the slush barrier. (Edmond Apassingok, Gambell, November 2013)

> For the berms to form you have to have the swells coming in. (Melvin Apassingok, Gambell, November 2013)

The above noted comments reveal the depth of understanding of physical process such as slush and slush-ice berm formation that is woven into traditional knowledge. The deep knowledge held by residents is based on years of observation focusing on the development of these processes in ocean conditions and on the role that snow plays in this process. This type of information cannot be gathered from instrument-based observing networks which are often unable to capture natural phenomena at the local level, particularly in the case of episodic and spatially discontinuous events such as slush-ice and slush-ice berm formation. In this case, traditional knowledge provides the ocean perspective that complements scientific studies on the role that snow plays in the formation of slush-ice formation in fast-flowing fresh-water rivers; e.g., Osterkamp (1978) mentions that if it starts to snow heavily, the introduction of snow into the water will aid ice crystal growth and, under the right conditions, the ice nuclei can grow rapidly and be broken up by flow turbulence and collisions (Martin 1981). The broken pieces act as secondary nuclei for the formation of more ice crystals, and large amounts of slush ice are produced very quickly (Kempema et al. 1990).

3.5.3 Types of Berms

During the interviews, residents mentioned that some slush accumulates into a berm near or at the place it was formed. On other occasions, slush is transported from one place to another by wind and currents, sometimes on its own and sometimes along with broken ice or larger pieces of ice. In Gambell residents outlined that wind direction will determine where it will accumulate, as slush is mobile.

> Slush ice moves. The wind from the sea will wash it on the beach and form a high bank. If the wind direction is from the north, it will form a high bank. It happens every year; it forms a high bank. (Anders Apassingok, Gambell, November 2013)
>
> That slush ice when the wind blows will bring the heavier ice from elsewhere, and it will crush it in from the land and make it thick. (Anders Apassingok, Gambell, November 2013)
>
> The north side of the island is deep and the west is shallower. The [slush-ice berm] ridge starts to form on the north side, and it gets higher. (Clement Ungott, Gambell, August 2014)

Drawing on personal observations, data gathered from SIZONet, reviews of interviewees' comments, feedback from public meetings and a literature review, three types of berms were identified in this project, that can protect communities from storms. Only two of them are made up of slush and are therefore the focus of this study. The third type is comprised of ice but is mentioned here only for reference purposes because communities refer to it as the most common berm that forms:

1. *In-situ* ice berms – in which slush ice forms in place; referred to as *sigugneq* (Siberian Yupik) or *qaimguq* (Inupiaq);
2. *Advective* ice berms – in which large amounts of slush ice is transported from somewhere else; based on interviews no distinction was made in Siberian Yupik or Inupiaq between this type of berm and in situ berms;
3. Shoved-Ice berm (WMO 2014)– in which slabs and boulders of ice pile up (Eerkes-Medrano et al., in press, journal Arctic); referred to as *vuusleq* (Siberian Yupik) or *ivu* (Inupiaq; note that ivu is a broader term that refers to ice ridging and ice push events).

A ***sigugneq* manifested as an *in-situ slush-ice berm*** (Figure 3.3) forms on the beach (Oozeva et al., 2004) with little movement involved, low to moderate wind speeds (< 8m/s) bringing weak wave conditions and air temperatures dropping to approximately –8°C/–9°C (Eerkes-Medrano et al., in press, journal Arctic). The height of this berm is no more than 1 m. This berm can be associated with slush that extends for up to about a mile from shore, depending on local weather conditions. The formation of the *sigugneq* or *in-situ* berm can happen in a matter of hours in response to low air temperature, around -10°C.

The lead author observed the formation of in-situ slush-ice berms on November 15, 2013. In this particular case, the observed mean maximum temperature that day was –7°C and the mean minimum –11°C. The berm disappeared in the afternoon, when the temperature rose, and it formed again the next day. Temperatures in this range continued during the week and the berm's diurnal cycle of formation and decay continued for the next three days. On the fourth day, two slush-ice berms had formed parallel to each other – one along the low-tide line and one along the high-tide line. Slush had also accumulated between these two berms and was starting to solidify (Figure 3.3). There was also slush offshore extending for about 200 m. Winds during this event were moderate out of the north/northwest. This event was not associated with a storm system but rather a general pressure pattern that favored a moderate wind from a northerly direction.

In Shaktoolik, a resident mentioned that the in-situ berm is not formed by storms but mostly by the high-tide action along the shore, and if the berm is not yet frozen, large waves can take it away.

> When the tide comes in, the small waves push up some slush and build [it] up on the beach. It can go back out [be taken away] with a large tide or with a storm. (Simon Bekoalok, Shaktoolik, September 2014)

> The small [*in-situ*] berms form in relatively calm weather, when it is cold and there is high tide and when the waves are anywhere from 6 inches to 3 feet [15 to 90 cm]. If the waves are higher, the berm will be higher. During the high tide you get a higher berm because the high tide and the small waves push it [the slush] in. It forms on the [beach] surface, and with the waves it builds it up and freezes to the bottom. (Simon Bekoalok, Shaktoolik, August 2014)

Typically slush-ice berms on the coast of Alaska are composed only of marine ice. In Shaktoolik, however, the local proximity of fresh water coming from the river means that *in-situ* slush-ice berms usually include small bodies of fresh water ice "ice cakes" within the berms, that form as river water solidifies on the beach. Fresh water freezes at 0°C degrees while seawater freezes at about -1.8°C, because of the salt in it (NOAA 2014). An additional characteristic mentioned by residents in Shaktoolik is that this type of slush berm is a mixture of ice cakes and slush that will stay put if the weather is cold:

> We get ice cakes because they float around, and they get pushed on. They can come up from offshore. If it's cold, the berm keeps on freezing and extending, and if there is a storm it can wash out. But if it's solid enough it can stay during the storm and can stay there the entire winter, until spring. (Simon Bekoalok, Shaktoolik, August 2014)

> If there is a big storm and the waves are big enough it does move the ice cakes, but in a normal time without the storm, typically [the ice cake] just sits on the bottom of the sea bed or else it drifts around and it can be pushed up. But it does not move much because sand is heavier than ice, so it still stays low. (Simon Bekoalok, Shaktoolik, August 2014)

Advective slush-ice berms are the result of large quantities of slush formed out at sea during storms and then carried by the wind and currents towards the beach, where they pile up (Figure 3.4) Their occurrence was observed and documented by Kempema et al. (1986), Reimnitz et al. (1986), and Reimnitz and Kempema (1987), on the shallow beaches of the Beaufort Sea during storms. These authors outline that slush-ice moves with the wind- and current-driven surface water until it is piled up against stationary ice or land. In Shaktoolik, during the 2011 storm, this type of berm (Figure 3.5) reached up to 7 m in height (Kinsman and De Raps, 2012).

> The slush-ice berm, when it gets in, it hits [the beach] and the waves go back again. Then the swells/waves collapse right on the berm and the waves slow down. That is what happened to Nome. The waves with slush hit the beach, deposit the slush and go back. One-way wind will form [them], right from the north, and the swells will keep on splashing and splashing over and over until it is formed. When slush ice starts to form and the swells keep pushing it into the shoreline, it builds over and over. It gets thicker and thicker, and the swells do not go anymore; the winds collapse right then and it slows them [the waves/swell] down. It could also disappear if the temperature rises. (Melvin Apassingok, Gambell, November 2013)

> The waves deposited slush and then receded, and then the next wave would bring a new deposit, more slush, and receded. That was [what happened] during the storm [the first part]; the waves were anywhere from 5 to 12 feet [about 1.5 to 3.6 m] in height. (Simon Bekoalok, Shaktoolik, September 2014)

Bauer and Martin (1983) mention that during the storms the wind can drive slush ice downward, pushing it underneath sheets of solid ice, where it can accumulate to a thickness of more than 4 m. This slush accumulation in deep water is outlined by a Shaktoolik resident.

> The bigger chunks need deep water to form, because for the ice to be beaten you need deeper water to form it. Also, the shape of the land affects how the sea ice will form. For example, by Cape Denbigh, the slush is built up there and moves toward the town with the current, the wind and waves. Also, where there is more slush, the waves are smaller and do not make as much impact as they did over the old town. (Simon Bekoalok, Shaktoolik, September 2014)

Reimnitz and Kempema (1987), outline that when the wind dies down the slush-ice, along with dislodged anchor-ice "ice boulders," rises to the surface where it can mix with snow and slush ice and be pushed against the beach. In Shaktoolik a resident mentioned that ice boulders (Figures 3.6 and 3.7) were deposited during the second part of the storm – there were two storms, one after another. After the first one, when the wind died down, the ice boulders "chunks of ice" rose to the surface during the high tide.

> During the early part of the storm the slush did not extend as far out to sea and the waves were a lot bigger and more liquid; they did not have as much slush. They pushed in the slush and receded, and the slush was deposited, and as more slush came in it got deposited first against the berm [scarp] on the undercut part. The wind speed was about 45 to 60 miles per hour blowing from offshore. Then there was a low and the water [surf] receded and the wind dropped. Then the tide came in and rushed sometime during the night when the storm hit and built up the rest [of the slush berm]. During the storm, the slush berm formed first and the big chunks of ice came in after. It was an extremely high tide [that pushed the boulders up], and the waves were impacting the top soil, the top part of the berm. The waves were 20 to 25 feet [6 to 7 m] high. There are

typically two tides, and the larger one occurs in the evening. The high tide came in and rushed sometime during the night [with the storm], and built up the rest [of the berm, including the boulders] and extended [the slush] for a few hundred feet out. Those chunks were from a combination of surge and tide. The slush went all the way to the sea bed, 20 feet [6 m] deep. (Simon Bekoalok, Shaktoolik, August 2014)

A wide range of variation was noted in terms of the presence of ice boulders during the advective berms formed in Shaktoolik during the storms of 2009 (Figures 3.6, and 3.7), 2011 (Figure 3.5), and 2013 (Figure 3.3).

> A slush berm was formed during the storm of November 2009, and it had slush-ice chunks. There was a big storm on November 9, 2011, and there was a slush-ice berm – but the ice chunks were not there. During 2013 there was hardly any slush; that is why we got the logs taken away in front of the village. (Simon Bekoalok, Shaktoolik, September 2014)
>
> The wall formations are occasional, but I have never seen anything like that [in 2009] – it's like the Great Wall of China. I have seen *ivus*, or ice piled up, but those are solid ice rather than slush. (Simon Bekoalok, Shaktoolik, September 2014)

A ***shoved-ice,*** *vuusleq* (Siberian Yupik) or *ivu* (Inupiaq), formed from pushed-up ice, is the most common type mentioned when people in communities are asked about ice berms. This type of berm – better referred to as a ridge in compliance with World Meteorological Organization sea ice nomenclature (WMO, 2014) – forms when sheet or pack ice is transported and driven ashore by winds and/or currents. Its formation is not confined to the freeze-up period, but can occur at any point throughout the winter when a sea-ice cover is in place. One common characteristic mentioned by residents is that it can form very rapidly, sometimes reaching a height of 10 to 13 m, and can form "anywhere" when the conditions are right during the fall or spring (Roy Ashenfelter, pers. comm., 2013; Eddie Ungott, Clement Ungott, Melvin Apassingok, pers. comm., 2014).

> When there are storms they [vuusleq] start flushing against the beaches, and it starts forming higher and higher. *Vuusleq* is a ridge pushed by the wind and the current together. Any current and any wind will form it, as long as they keep pushing. (Clement Ungott, Gambell, August 2014)
>
> You get the big chunks with the wind and the swells. During the storms we do not get slush, we get crushed ice because of the highs sea and it becomes *qenu*. If it starts to form the cake ice, once the swells get too high they'll start to crush it. It will be crushed like in a blender. You know when you blend a chunk of ice into a powder? The same thing happens with wind and swell, and it becomes like a blender and the big chunks are formed here along the beaches. We get them chipped off from the beaches and then they are blown away, but the wind brings them back. If we see some rocks among them, then we know that they have been formed in the beaches somewhere. If they have gravel, they have been formed on a beach and not on the ocean. (Clement Ungott, Gambell, August 26, 2014)

There were various explanations from residents in Gambell about *vuusleq*, which is commonly observed on Saint Lawrence Island. *Vuusleq* happen every year in Gambell – during fall, winter, and spring – and can occur both along the shoreline or out in the sea.

> For a *vuusleq* to push in, it's hard to tell when or how it will form. One winter the condition would be this way, but next year or next season the condition would not be like that at the time. There are several ways in which it can happen. (Conrad Oozeva, Gambell, August 2014)
>
> Every year is a different year with the sea and ice conditions, but we have all the conditions. Some years formations do not happen as much as the first year; nowadays, we hardly have the ice piled up and stay in one place – vuusleq – but farther out in the sea, sometimes they form. (Conrad Oozeva, Gambell, August 2014)

Often the *vuusleq* becomes the anchor that holds the ice around St. Lawerence Island:

> On the west side of the island if the *vuusleq* forms, sometimes the ice will not move. It will be anchored by a big *vuusleq*. Sometimes when the big pack ice hits [the beach], that makes the slush extend further out. Like this year, we had one on the west side. And it became too big one time, from high tide and rough sea, and it broke it off. (Conrad Oozeva, Gambell, August 2014)

3.5.4 Slush ice berm formation mechanisms

The work in this project provided specific dates and times of slush-ice berm formation and gathered information from Indigenous knowledge holders and local observers on slush-ice and slush-ice berm formation processes. Based on this information, the authors classified berms that protect communities from storms into three categories: in-situ, advective, and shoved-ice. Although the three communities are very familiar with the shoved-ice berms – *ivus* or *vuusleq*– because they happen anywhere and anytime during the fall, winter, and spring, the descriptions of slush ice and slush-ice berm formation reflect some differences, particularly between Gambell and Shaktoolik.

Residents in these communities identified the variables required for slush and slush-ice berm formation. In Gambell, residents mentioned that the initial formation of slush requires shallow waters, cold temperatures and wind of < 2.5 m/s for its formation, and outlined that in deeper waters slush does not form. A wind speed of (2.5 m/s) would result in gentle waves producing layers of slush ice referred to grease ice (WMO 2014). Similar findings are presented by Daly (1984), who outlines the role of temperature stratification. He mentions that under weak winds conditions and stratified shallow waters, frazil or slush ice can form rapidly over large areas, and in the deep oceans where there is convection, slush ice may never form.

For the in-situ berm to form, the high tide and waves were the relevant factors mentioned by residents. The lead author also observed the formation of this type of berm in Shatkoolik under conditions of air temperatures of about –8°C/–9°C and low to moderate wind speeds of < 8m/s, which bring weak wave conditions.

In Shaktoolik residents mentioned that an advective slush-ice berm requires large amounts of slush for it to form and this will depend on snow, stormy conditions, high tide, temperatures between –6.5˚C to -1˚C, and offshore wind with speeds of 18 m/s to 27 m/s. This wind speed would produce 6 m high waves. These observations are similar to research findings in the sea ice literature. Osterkamp (1978) notes the contribution of snow in seeding the water and accelerating the slush formation process, and Daly (1984) documents studies of slush ice forming in rivers and streams, and states that for large amounts of slush ice to form, supercooling of the surface water and turbulence are necessary. The degree of supercooling required is based on models by Carstens (1966), and Osterkamp et al. (1974), who mention that supercooling of 0.1˚C is sufficient to initiate the production of slush ice. The turbulence would then be created by the wind, however, these authors did not conduct analysis of the synoptic weather conditions required for the formation of large volumes of slush ice.

Reimnitz et al. (1986) document the production of large volumes of slush under stormy conditions with 15 m/s winds and temperatures of -5˚C. They posit that storms lasting several days can cool the ocean, allowing the formation of large amounts of frazil ice. Eerkes-Medrano et al., (in press, journal Arctic*)* identified the synoptic weather conditions that produced the *advective* slush-ice berms formed during the storms of 2009 and 2011 in Shaktoolik. In both cases, a low pressure system located in the Bering Sea, just to the west of Norton Sound resulted in winds at Shaktoolik with average speeds of 14 m/s in 2009 and 18 m/s in 2011, driving the waves directly onto the beach. The air temperatures during these events ranged between –5°C and –10°C. These conditions allowed the formations of large amounts of slush-ice that was pushed onto the shore forming the unusually large advective berms that protected the town.

The observation by Shaktoolik residents of how a high tide favours the creation of frazil and slush can be explained in the context of supercooling of the entire water layer. Most scientific studies of slush/frazil ice production at the surface layer refer to observations of fast flowing rivers. Arden and Wigle (1972) observed slush formation on the Niagara River and noted that, as the river cools from the surface down, the ice crystals on the surface are submerged to greater depths by turbulence. After a few hours of supercooling from above, the frazil ice extended to a depth of 7 m. Matsumura and Oshima (2015), conducted a numerical model of frazil ice formation in the ocean. They mention that slush/frazil ice crystals formed at the surface tend to melt as they go down and absorb latent heat from surrounding water. As this process takes place, there is also an upward flux of latent heat. As time progresses, if the supply of frazil ice from above continues, this causes the entire water column to be supercooled to the local freezing point, resulting in a large amount of slush/frazil ice being produced. In this regard, the 18m/s to 27 m/s winds and temperatures of -6.5°C to -1°C, experienced in Shaktoolik during the November 2009 storm, likely caused supercooling of the ocean surface and the production of slush that was submerged by turbulence for a number of hours. This effect, in addition to storm surges and tides of up to about 2 m, resulted in supercooling of an entire water layer and the production of large amounts of slush ice. This ice was then pushed in onto the shore by the strong waves and surge and formed the large berm that reached up to 7 m in height. An advective berm of similar magnitude was formed in Shaktoolik during the 2011storm.

3.5.5 Advantages and Disadvantages from a sea-ice services perspective

Comments from residents also identified additional advantages and disadvantages presented by ice berms. While these berms protected Shaktoolik from flooding and erosion, additional advantages and disadvantages were identified by residents in the communities of study. The advantages can fall under the sea ice services categories identified by Eicken et al. (2009) who considers the benefits of sea ice as part of ecosystem services, as follows: 1) climate regulator, marine hazard and coastal buffer; 2) transportation and use as a platform, 3) cultural services from the "icescape"; and 4) support for food webs and biological diversity.

In terms of a coastal buffer residents mentioned that during storms the slush-ice berms protect the houses from the wind and swells that cause shoreline erosion and affect local infrastructure (Figure 3.8). The berms also serve as a platform to hook their fishing nets. By hooking a fishing net at the end of the berm, residents can extend their nets farther out into the ocean (Eugene Asicksik, pers. comm. August 2014). Finally, Shaktoolik residents mentioned that during the 2013 storm a slush-berm was not present, allowing a large area of land to be flooded. This affected the biological diversity because the tundra was heavily damaged; also, no berries grew in that area for several years after the flood (Eugene Asicksik, Arlene Sookiayak, pers. Communication, August, 2014).

The main disadvantages of slush-ice berms mentioned by residents were related to: seal-hunting activities; safety while travelling by boat or walking on a berm; and to the difficulty in accessing the beach to get the boats out when going hunting. Residents of Shaktoolik and Shishmaref hunt seals by snowmobile from the shore. If there is slush on the shore usually the seal will get stuck in the slush and will not wash in on the shore (Paul

Apangalook, Gambell, November 2013). Residents mentioned that while travelling by boat, the boats can get caught in slush produced during strong winds –slush produced during strong winds is sticky and is called active, while slush produced under calm conditions is not sticky and is called passive (Kempema and Ettema 2015).

Elders in Gambell mentioned the need to use a stick to test how safe the slush-ice berm is to walk on. They emphasized that the top layer may freeze giving the impression of being safe to walk on but underneath, the slush is porous by nature and unstable. Druckenmiller et al. (2010) mention that slush-ice formations lack the drainage of salt water that is typical of thermodynamic ice processes and therefore; this inhibits solidification of slush-ice berms, rendering them potentially unstable.

This understanding of advantages and disadvantages of coastal sea ice to Indigenous and local people plus the site specific knowledge of slush and slush-ice berm formation gathered through this work points to the benefits of engaging Indigenous knowledge holders in scientific research. This characterization of slush-ice berms by type and conditions of formation using Traditional Knowledge provides a foundation to further advance scientific work on this complex topic, which represents an interplay of site-specific atmosphere and ocean conditions.

3.6 Conclusion

The findings in this project reflect the benefits of a collaborative approach with Indigenous knowledge holders and local observers and illustrate how Traditional Knowledge data in its most basic form was then translated into information that was used to create a physical model of slush-ice berm formation processes (Eerkes-Medrano et al. in press, journal Arctic).

It is important to note that rarely were more than a few individuals able to provide observations for any particular berm type. Typically, an "observation" is a single datum placed into a statistical context that requires a certain quantity of data in order to arrive at a reasonable capacity to extract a result. However, in the case of traditional knowledge holders, a single comment from them represents years of observational data gathering. The starting point for this research is not the community comments, but rather the years of observation that support each comment. Thus, this is a corollary to a prescribed statistical approach. In this case we count on the large number of experimental or observational repeats have already been conducted by the traditional knowledge holder. It is interesting that in no case was doubt expressed when hearing local observers describe processes they had witnessed. Rather, they simply stated how things worked.

In particular, traditional knowledge holders not only provided information that led to the identification of the two types of slush-ice berm formation that occur along the western coast of Alaska, but they also provided descriptive details of how these berms form as well as the role that other factors, such as, depth of the nearshore zone or atmospheric processes, play in the formation of slush ice and slush-ice berms. The residents' knowledge and observations allowed the authors to understand and identify conditions most relevant in each type of slush-ice berm formation, such as the role that the shallowness of the beach plays in the formation of *in-situ* slush-ice berms, while storm and snow conditions were more relevant for *advective* berms and the deposition of ice boulders.

The authors observed that the degree of residents' interaction with sea ice as they conduct their daily activities determines the extent to which they observe subtleties in slush-ice and slush-ice berm formation, when and where they form, and the variables at play. In communities where there is traditional hunting for whales and walruses during the fall and winter, local observers provided more detail in slush-ice and slush-ice berm formation processes than in communities where there is no traditional hunting in the fall. The daily interaction also determines whether residents see the slush-ice berm as a protective measure from natural phenomena, such as storms, or as an obstacle to conducting their daily activities, such as when they go seal hunting in the fall by snowmobile and the seals will not wash in. The findings also point to the differences in how elders and young hunters see the slush-ice berm formation processes taking place. These observations are also relevant when choosing potential interviewees as their depth of knowledge of slush ice and types of slush-ice berms varies according to their cultural backgrounds.

While there is a great amount of information gathered from working with Indigenous knowledge holders and local observers, there is the potential to continue working with them in gathering additional information on specific thresholds and ranges of air temperature, storm surge and wind speed as well as interactions with freshwater and tides to support the formation of various types of slush-ice berms. Given the difficulty in making observations of water temperatures, then the engagement of local observers in scientific work becomes a crucial step in the understanding of these process.

To our knowledge, this is the first time that a formalized nomenclature of slush-ice berm types has been established based on in-situ observations from Indigenous and local observers. This is also the first time that in-situ observations of unusually large advective berms have been presented in the context of scientific observations. This research reflects how traditional knowledge is a science that can complement physical scientific studies (Hobson 1992) to arrive at results that would not have been possible with using either paradigm on its own.

Figures:

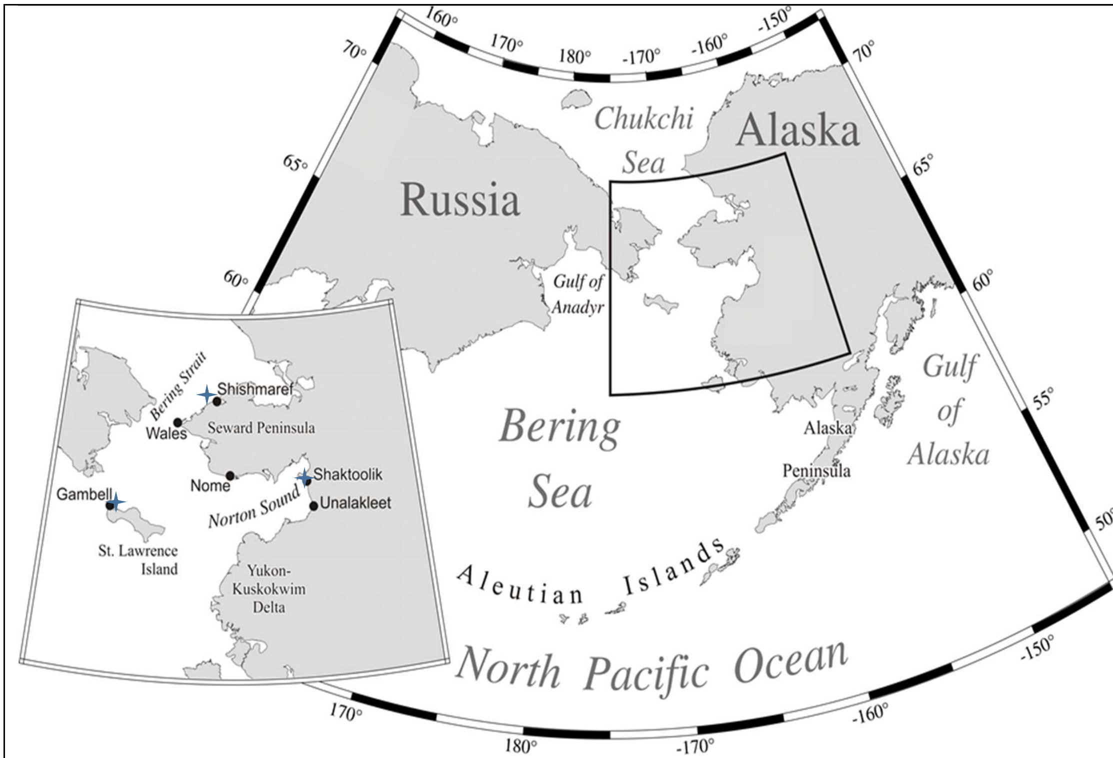

Figure 3.1 Region of study.
The broader area is the Bering and Chukchi Sea and their coastal zones. Inset map shows the study sites.

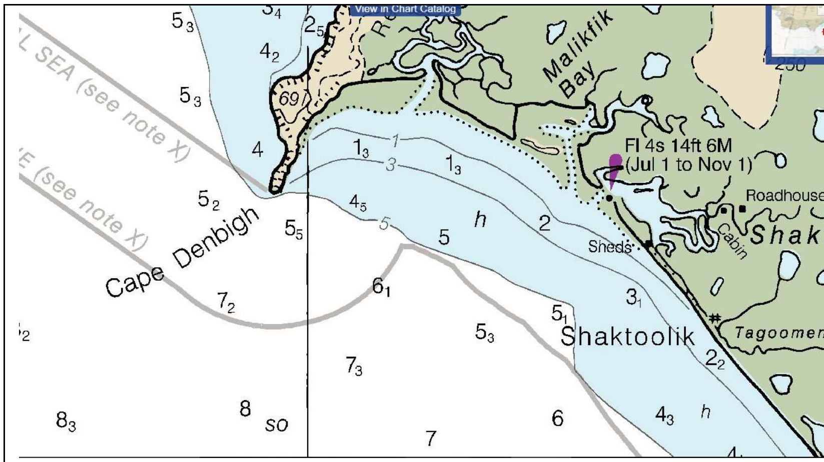

Figure 3.2 The shallow areas around Cape Denbigh act as a hook for the slush to accumulate.
The currents bring the slush to Shaktoolik. (Eugene Asicksick, Shaktoolik, August, 2014) (Chart 16200. Norton Sound:Golovin Bay. General Chart. Scale 1:400,000, Edition 15. 10/1/2014- Source:http://www.charts.noaa.gov/OnLineViewer/16200.shtml)

Figure 3.3 Two in-situ slush-ice berms at Shaktoolik, November 2013.
One berm is along the low-tide line (on the right), and the other along the high-tide line (on the left). Slush has also accumulated between the two berms, joining them to form a single large berm. (Photo by L. Eerkes-Medrano)

Figure 3.4 Advective slush-ice berm in front of the new town of Shaktoolik, November 2009.
The angular shapes in the slush are caused by wave action. This berm reached a height of about 7 m in certain areas. (Photo by Agnes R. Takak)

Figure 3.5 Advective slush-ice berm.
Formed in from of the new town in Shaktoolik. November 2011Kinsman and De Raps, 2012 (Credit: Gloria Andrew)

Figure 3.6 Ice boulders on top of the slush-ice berm in the old town of Shaktoolik.
Large ice boulders were deposited on top of the berm in November 2009. (Photo by Gary Bekoalok). The ice boulder is about about 3 to 3.5 m. From the beach to the top of the ice bolder the height was about 7.5 m. (personal communication with Simon Bekoalok, Shaktoolik, September 2014)

Figure 3.7 Ice boulders.
These boulders were deposited on top of the slush-ice berm in the old part of town during the *advective* slush-ice berm formation episode at Shaktoolik in 2009. (Photo by Simon Bekoalok)

Figure 3.8 Shoreline erosion.
Erosion of the shoreline took place in the absence of a slush-ice berm formation during a storm episode. Shaktoolik, November 2013. (Credit: Gloria Andrew)

4 Engaging community and stakeholders in slush-ice berm formation and impactful weather events research in Alaska, USA: A community-centered and feedback-based adaptive approach

4.1 Article information

This chapter consists of a manuscript to be submitted for publication. Tables are the same ones that will be submitted with the manuscript. References have been reformatted for consistency in this dissertation.

4.1.1 Authors' names and affiliations

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4.1.2 Author's and coauthors' contributions

Eerkes-Medrano developed the approach to engage local observers, conducted site visits and interviews and wrote the manuscript. Atkinson reviewed and edited the manuscript.

4.2 Abstract

Local observers from the communities of Gambell, Shaktoolik and Shishmaref, on the west coast of Alaska, were engaged in projects that included identifying specific dates and times of impactful weather events and describing slush-ice berm formation processes that affected their communities' economic and subsistence activities, coastal infrastructure, and personal safety. Local observers and communities in Arctic regions have been engaged in scientific research to understand environmental processes and change since the late

1990s. This study builds on these earlier initiatives with a focus on how impactful weather affects subsistence activities, and on the formation of slush and slush ice berms during storms. By providing a description of the process and methods followed, this paper aims to make a contribution the broader knowledge and methods that can be used when engaging local indigenous residents in scientific research Various methods were used to gather information and record observations. Interviews were most successful when they included calendars, maps, pen and paper because local residents' connection with their environment is best reflected when they can draw on a map or paper placed in front of them.

The authors aimed to make the project fully community-centered by: a) focusing on impactful weather events identified by community residents; b) making clear to residents that they were there to learn from them about weather events and impacts of these events; c) making a priority to address the stated project related needs of community residents; and c) by reflecting on community feedback to take the project in unanticipated directions in response to unexpected situations, conditions and challenges encountered. Residents in Gambell and Shaktoolik commented on the sense of empowerment they felt as a result of having scientist coming to their communities to "learn" from them and acknowledging them as experts. They were appreciative of having a project focusing on the impacts of weather variables affecting them such the winds in May, in Gambell, during the walrus hunting season or the rain in July, in Shaktoolik, during the commercial fishing season. This chapter describes the methods used before and during the project to bridge cultures and narrow the gap that often exists between scientist and local residents. It also presents the insights gained, and lessons learned during this process.

4.3 Introduction

Local residents live in a close relationship with the land and sea, and therefore develop a good understanding of their environment and its conditions (Huntington, 2000, Gearheard et al. 2010). Numerous studies have engaged local residents in scientific research, using different methods to incorporate local knowledge (also known as experience-based knowledge, local Indigenous knowledge, and traditional ecological knowledge), particularly in the areas of resource management, vulnerability, and adaptation to climate change (Berkes and Jolly, 2002; Ford and Smith, 2004; Nickels et al., 2006; Furgal and Prowse, 2008). Recently, several scientific studies have used local knowledge to understand the relationship between sea ice and climate (George et al., 2004; Laidler, 2006; Ignatowski and Rosales, 2013). Researchers have demonstrated the value of direct community engagement when gathering information for physical impacts analysis (Oozeva et al., 2004; Eicken, 2010; USACE, 2011) and for understanding how communities are vulnerable to climate change (Krupnik and Jolly, 2002; Loring and Gerlach, 2010). For example, Gearheard et al. (2010) outline the relevance of connecting Indigenous observations and scientific knowledge. They examine how Inuit observations of changing wind patterns contribute to the understanding of changing sea-ice conditions, which in turn affect subsistence activities. The usefulness of these studies depends on the acquisition of reliable data. To obtain the best observations of environmental conditions affecting coastal communities, especially those which may be difficult to measure with instruments, it is essential to communicate directly with communities, as every community is affected differently depending on its unique geographical and cultural conditions.

Huntington et al. (2011) outline the greater access to information and insight that results from working in partnerships with local residents. They also outline the benefit of working with teams that have expertise in both social science training, which helps facilitate effective cross-cultural communication, and natural science training, which ensures researchers recognize key observations and can help the social scientists understand what locals are trying to communicate. Kendrick (2003) and Huntington et al. (2010) emphasize the importance of cross-cultural communication to develop trust and build common ground. Early and ongoing collaboration with communities and a considerable investment of time are required to build trust, discuss research objectives, and collect data and synthetize results. Such collaboration takes into account a social interplay (Huntington et al., 2009). In this case, the interplay involved personalities, backgrounds, religious adherence, family clan, age, education, gender, and roles that people play in their community.

Studies examining the relationship between sea ice and climate are relevant on the west coast of Alaska, where the weather largely determines the ability of residents to conduct their daily subsistence activities and thus exerts a significant impact on the livelihood and well-being of native people. The west coast of Alaska, between Bristol Bay and Wainwright on the Bering and Chukchi seas (Figure 4.1), is home to numerous villages and several larger hub communities (GAO, 2009). Almost all of these communities are situated on the coast, and in some cases on sand or gravel bars – a location imposed by transport and subsistence needs, which require low-lying flat ground for airstrips; access to the water for hunting and fishing and to receive sealift barges (Bearded, T. 2008; USACE, 2008b; Marino, 2012). This region experiences annual sea-ice formation, which at its maximum extent reaches well south into the Bering Sea (Pease, Schoenberg and Overland, 1982) (Figure 4.2). In recent decades the sea-ice cover has been thinning and forming later in the season, resulting in a less stable ice cover and exposing increasingly larger areas to storm impacts (Frey et al. 2014; Carole Sookiayak and residents, pers. comm. 2013). Storms frequently move into the region from the western North Pacific (Serreze, 1995; McCabe et al., 2001; Rodionov, 2007; Mesquita et al., 2010), and storm surges (up to 4 m) and wave action can cause flooding and erosion that damages both infrastructure and subsistence forage areas (Terenzi, et al., 2014),(e.g., berry-picking areas), potentially limiting access to country food sources. Storms that occurred in October 2004, September 2005, November 2009, November 2011 and November 2013 are prime examples of occasions when the storm-driven winds set up wave action and surge that resulted in extensive erosion and damage to coastal infrastructure, with ensuing major disruption to community life (Hufford and Partain, 2004; Mesquita et al, 2010; Terenzi et al., 2014, Pingree-Shippee et al., 2015).

The surge associated with the storms of November 2009 and November 2011 was several meters, which would normally cause damage to the communities at the end of Norton Sound (Burke, 2009; Samenow, 2011). However, ice crystals in the water – the very early stages of sea-ice formation, which are known as qenu (Siberian Yupik, Krupnik et al., 2010), qinu (Inupiaq; Weyapuk, Jr. and Krupnik, 2012) or "slush ice" – were piled high on the beach, solidified and formed a natural solid barrier – a "berm" – that mitigated surge impact. Authors Atkinson and Eicken decided to investigate the synoptic conditions that led to the formation of these berms- and applied for funding to work directly with Indigenous knowledge holders who had observed the dates and times when the events occurred. Atkinson thought that adding the possibility of berm formation to the weather-forecasting regime would be a useful product for residents. However, there are no instruments capable of recording these events, and little scientific research had been conducted on this phenomenon, with the result that a conceptual model of slush ice berm formation, upon which a physical model could be developed, does not exist.

To produce a conceptual model, researchers need information about the weather and other environmental conditions in which these features have formed – information that can best be obtained on site visits to communities to gather specific observations from local residents, who observe and have a deep knowledge of what takes place in their environment (Hobson, 1992) in observing and understanding what goes on in their areas. A second project parallel to the slush-ice berm – although not the main objective of this dissertation – was the identification of the impactful weather events that affect subsistence activities in these communities. The intent of this project was also to conduct synoptic weather analysis of these events with the same objective of adding the possibility of their occurrence to the weather-forecasting regime. This second project is only mentioned here because it was an important component of community engagement during the sites visits. This project also included the provision and installation of a small weather station in each community of study.

The type of research conducted in these projects is important for three reasons beyond its direct, day-to-day utility to residents. First, western Alaska is a region experiencing what are arguably some of the most rapid rates of environmental change anywhere on the planet (Larsen et al., 2008). If the sea ice retreats even a little, residents here feel it first. Second, the general effects of weather stressors on these communities are not well known; this lack of knowledge is compounded by the differences between communities, which makes a "one size fits all" approach to adaptation of little use. Third, this research intersects with other projects currently underway on the west coast of Alaska, and the results from this study will be relevant to policy makers, planners and decision makers at the local, state and federal level.

This current chapter focuses on the methods of community engagement that allowed the necessary information to be gathered. In particular, it describes the approach taken to build trust and respect. While the main focus is on the slush-ice berm project, insights gained from the author's work in the impactful weather events project will be mentioned when relevant, such that this document presents a set of practices that worked for this project and identifies pitfalls encountered, all of which could be useful to individuals and groups conducting research with communities. in which the residents are treated as equal science partners.

Pulling this information together is important because it is apparent from the authors' experiences in this and other community-based projects, and from hearing of other researcher's projects over the years, that there are many opportunities for failure, and that failure takes a variety of forms. Some communities have come to distrust researchers or feel frustrated by their involvement in research projects because they don't feel they receive tangible benefits from their participation in projects, they feel they are being taken advantage of (Nadasdy, 1999; Simpson, 2001), or they have a sense that the knowledge they have shared has been stolen (Shiva, 1997; Brook et al., 2015). With these concerns in mind, the authors made an effort to establish a relationship of mutual trust and respect with local people. The authors tried to ensure they met their commitments and kept community residents in the loop by reporting regularly on their progress in bi-monthly phone calls, and by planning a second visit to report on their activities and the next steps in the research.

This paper does not follow a classic Introduction/Methods/Results/Conclusions format. Instead, it presents a discussion and analysis of methodological approaches. The organization is chronological, following the project through all stages of community engagement, from background preparation, through initial contact and selection, to all aspects of the interview and data analysis process.

4.3.1 Preparatory work – Become community focused

Before starting work, the authors developed an awareness and understanding of the communities in order to facilitate building a relationship during subsequent conference calls. They achieved this awareness and understanding by taking the following steps:

a) Immersing themselves in the cultural, political, and economic aspects of the potential partner communities.
b) Becoming aware of previous and ongoing research related to climate, weather, erosion, and sea-ice.
c) Talking to other scientists conducting research in these communities in order to a) ask what was working and what was not working; b) identify the key participants; and c) discuss the main issues to consider in every community from the perspective of research capacity.
d) Checking social media outlets, including Facebook, blogs, and YouTube videos, to become aware of current community activities and events.
e) Using Google to learn about community residents the authors would be talking to and meeting with. For example, the authors looked at senate committee minutes to see what issues had been discussed in the different communities and by whom. It

was important for the authors to understand the key residents' engagements, such as events they were involved with, priorities they were handling, etc.

f) Reading local economic development plans and becoming familiar with the vision, values and priorities of the community.

g) Contacting community members – suggested by scientists in point c), above – who had been involved in research related to climate, erosion and sea ice to hear about their experiences with scientists and politicians, and to establish additional contacts in the community.

h) Contacting key community members – for example the ones named on senate committee minutes – to learn more about their work and to find out about life in town, as well as their interests, family, etc. The intention here was to learn more about the people and the community and to ask what researchers could bring for the individuals or their family, and to determine what kind of door prizes and food the community would like during public meetings.

i) Contacting community residents to ask what kind of craft material they could use. After obtaining this information, the authors asked family and friends for donations of these items – i.e., quilted fabric or beads that women can use in their arts and crafts – to take to the communities. (These gifts have been greatly appreciated as door prizes during public meetings.)

j) Contacting local schools and offering to present information about the research project to students.

Eight months before starting any site visits, the authors held individual conference calls with a variety of federal and state departments, including staff from the Fairbanks

Weather Forecast Office of NOAA's National Weather Service; Kawerak; the Denali Commission; the Local Environmental Observers (LEO) program, operated by the Alaska Native Tribal Health Consortium (ANTHC); US Army Corps of Engineers, Community and Regional Affairs Division; University of Alaska Fairbanks Sea Grant Program; and Glenn Gray Associates, among others. The objective of the conference calls was to obtain information about similar or related projects in these communities in order to coordinate activities, look for synergies, and avoid overlap. The authors also asked about any negative and positive research experiences staff at these entities were aware of having taken place.

4.3.2 Inviting communities

Candidate communities were identified based on the following: a) classification as vulnerable to impactful weather and storm activity, based on a list provided by Kawerak, a regional non-profit corporation that provides services in the Bering Strait Region and The Denali Commission; b) identification by staff at the U.S. Army Corps of Engineers (USACE), Alaska Region, as a community in need of support; c) information gleaned from a literature review, including references to slush-ice formation during storms; and/or d) communities' interest in participating in this project. Considerations of budget and time played a role in narrowing the selection from a list of 12 potential candidates to three communities: Shaktoolik, Shishmaref and Gambell, located along the west coast of Alaska (Fig. 1). Shaktoolik was selected because USACE (2011 and pers. communication 2013) and Ignatowski and Rosales (2013) had conducted research in this town and suggested it as a good candidate. Residents in this town had also contributed significant sea-ice information to SIZONet. Shishmaref was also suggested by USACE (pers. Communication 2013), and Atkinson had conducted research work there and knew the people in town. Gambell was selected because of residents' extensive participation in sea-ice research projects such as Oozeva et al. (2004) and for its significant contributions to SIZONet. In addition, the authors had been in touch with a resident of Gambell who offered access to her husband's log books covering 30 years of weather observations. Consent for this project was granted by the Tribal Council in Shaktoolik and Gambell, and by the City in Shishmaref.

Despite fairly close proximity, the communities present a range of geographic and cultural aspects. These differences determine the type and degree of impact that weather events have on subsistence activities. For example, in Shishmaref, residents usually conduct subsistence activities in the lagoon behind the town or on the ocean close to the island. In Shaktoolik, residents fish commercially in the bay in front of town and up the Tagoomenik River, and they go inland to hunt caribou. Residents in these two communities usually do not venture as far out into the ocean as people in Gambell, where residents regularly travel up to 70 miles north in the Bering Strait in 16 to 18-foot aluminum boats to hunt for walruses; they do not fish on the same scale as residents of Shaktoolik or Shishmaref or caribou hunting. Also, Gambell residents depend more on the winds to conduct their walrus-hunting activities. In the fall, the wind will bring the ice with the walrus; in the spring, however, the wind might bring the sea ice and pile it up along the shoreline, preventing residents from taking their boats out to hunt.

Once identified, communities then had to be approached for participation. First contact can be established through the tribal councils. Kawerak has a good web site with contact information for the communities in the Bering Strait region. Face-to-face is the best method to invite communities to participate in a project. This can be done by requesting an opportunity to add a project presentation to the agenda of a council meeting already scheduled. However, the authors in this project are based in Victoria, B.C., Canada and travelling to the communities to assess their interest was not a viable option. The next best approach was to talk to people over phone.

When the authors contacted the tribal council and the city representatives in the three candidate communities to invite them to participate in the project, they encountered three types of responses. Gambell expressed an interest in taking part because residents had been unable to conduct the spring walrus hunt due to bad weather and sea-ice conditions; the town was in the process of declaring a state of emergency, and residents felt the authors' research could benefit them. Shishmaref was generally receptive because one of the authors (Atkinson) had previously worked there, so a positive connection was already established. Shaktoolik was not interested in engaging in any new research because the town had been working with several researchers and had seen few tangible benefits.

When they contacted tribal council representatives in Shaktoolik, the authors were able to rely on the knowledge they had gained from their preparatory work to acknowledge the frustration the community was feeling and to connect with them through a dialogue that reflected an understanding and respect of their frustration and reluctance to participate in the project. Then the authors moved the focus of the conversation to hearing from residents how they were being affected by impactful weather events. They alsolistened to the concerns about flooding and erosion from storm surges and their experiences with slush-ice berms. It was important to acknowledge the common interest in impactful weather from the residents and authors perspective as residents would potentially benefit from this project. The authors then talked about how this project included the installation of a small weather station for community use and how the results of the project would hopefully be used in improving the forecasting of impactful weather events that would help the community to be better prepared for such occurrences. After this discussion, community representatives became interested in participating in the project.

4.3.3 Discussing the Project

A key feature of the impactful weather events project is that the local residents identify the types of weather events that are of most concern to them – such as the winds piling up the ice along the shore in Gambell, preventing residents to go out hunting for walrus in May – which means the primary research goals are largely articulated by the community. To this end, numerous conference calls took place between the authors and community representatives after community selection, but six to eight months before commencing any fieldwork. The objective of the conference calls was to 1) discuss the project' goals and objectives; 2) seek the communities' input on problematic weather affecting their activities and impacting infrastructure; 3) discuss dates for sites visits during times when the community residents would be in town, i.e., and not when residents are engaged in subsistence and hunting activities; 4) discuss the venue where the researchers would present the project and the process they would use to engage residents (each community representative had particular suggestions about the process to be followed); and 5) seek approval for the content of any printed material used in public announcements and interviews. It was very important that the language used during interviews and in printed material was targeted to the audience: clear and free of scientific jargon. E-mail communication was avoided because residents asked to be called in person and if documents needed to be reviewed, communities usually request that the information be faxed to them.

It was found to be relevant to share previous research experiences with the communities, especially experiences that laid a groundwork of credibility in northern and/or community engagement work. One of the authors (Atkinson) has years of experience working on impactful weather events affecting other communities on the west coast of Alaska. During the calls he was able to share the benefits of his work with community representatives, who became more trusting of the research team and the intent of the project.

During the calls, the authors emphasized that this project could only take place with local observer collaboration in identifying specific dates of event occurrence rather than elder's observations on climate change. The identification of specific dates and times of occurrence of impactful weather events was critical in identifying the synoptic weather conditions that lead to the events. Young hunters – under 45 years old –who go out to hunt and experience weather impacts would be good candidates for interviewees. The project did not have a budget to compensate for interviewees' participation.

Two visits to each community were planned. The first visit would be a data-gathering effort designed to a) seek information about the formation of slush-ice berms, and b) hear about and gather information on specific dates and times of impacts of storms, sea ice, and severe weather events on infrastructure and subsistence activities. In each community, semi-directed interviews (details below) would take place with five to nine local observers in order to gather information about slush-ice berm formation processes.

The second visit was designed to report preliminary findings to the community, verify results, and make corrections as needed. This visit was deemed critical to the success of the project because the authors were able to deliver on their commitment of installing a weather station and to seek residents input.

4.3.4 Interviewing methods

Two interviewing methods, semi-directed and unstructured, have been successful when gathering traditional ecological knowledge and when conducting collaborative research with Indigenous people. In the semi-directed interviews the interviewer usually has a list of topics to discuss and guides the participant to freely follow his/her train of thought (Huntington 1998). The participant can add or skip topics and there is no limit on the time for the interview (Huntington 1998). The interviewer can add questions or change the sequence based on interviewee's response (Zhang and Wildemuth, 2009). The unstructured interview is more of a listening technique (Bernard 1995), where the participants are asked to share their knowledge on a specific topic (Fox 2002, Corbin and Morse 2003). In this type of interview the questions are not predetermined but they are spontaneous and generated based on the interaction (Minichello et al., 2009, Zhang and Wildemuth, 2009). In this project, the semi-directed interview approach was used, but unlike the case in studies gathering traditional ecological knowledge, the interviewees were carefully guided to remember specific dates and times when impactful weather events took place.

Leading questions, such as "do you have more storms in recent years than in the past?" or "is the NW wind the prevailing wind in the fall?" were avoided, as this type of questions will likely lead to a positive response because from an Inuit elder's perspective, the statement may reflect the interviewer's knowledge, and it is disrespectful to openly disagree with what another person believes (Bernard, 1995, Fox, 2002, Ferguson and Messier, 2009).

Before commencing the interview process, the authors initiated a rapport by first observing the interviewee state – did he/ she seem to be in a rush? distracted? looking tired? did he/she seem cold? Was he/she wet from the rain? – in order to initiate regular conversation. This conversation could focus on asking how they were doing, the current weather, the family, or inquiring about something interesting about the town or people. These interactions would allow the interviewee to see that the interviewer is not only focusing on him as a subject to be interviewed but as a human being. The interviewee would be able to respond with knowledge and reflect his identity. The author, based on her personal and professional background has learned to pay close attention to body language, to what both her and others are communicating. Considering that about 65 percent of communication is non-verbal (Mehrabian 1972), while establishing this rapport, the author took care of observing interviewees' body language. Were the interviewees sitting back or leaning forward in their chairs? Which way were their bodies leaning? Some gestures such as smiling are universal while others have a cultural connotation (Table 4.1). On one occasion, despite having gotten the approval to tape the session, the interviewee leaned back and got tense. It was important to clarify how important it was for the author to pay full attention to the interviewee and not to be distracted by taking notes. The author also clarified how the information would be used. The interviewee agreed and slowly relaxed again as the conversation continued focusing in important issues happening in town. Other keys to look for are outlined in Table 1. Sometimes mirroring behavior is a good idea but not always. It all depends on the interviewee needs and the situation. These needs can vary not only by culture but by the education, age, or gender of individuals, and they can also vary during the course of the interview. Depending on the situation, the author would, change the topic to something that would be more of an interest to the interviewee, or get up – if sitting down – and prepare tea and offer the interviewee something to drink or eat, or approach the topic of conversation using different words, tone of voice or gestures. Every community and every person is different.

Once an initial rapport had been established, the authors proceeded with the semi-structured interview moving on to the discussion of impactful weather events and eventually to talking about the specific date and time when the events occurred. Usually the interview would start with questions such as: "tell me how the storm is affecting the town?" or "how does it affect you?" Once the storms component was covered, the authors explored other impactful weather events with questions such as "what kind of weather keeps you from going hunting?" The intent of these questions was to elicit memories of times of impactful weather events. To continue the dialogue the authors tried to tune in to the interviewee's world by echoing how they must have felt, what they might have seen or heard, and by trying to be with them and empathizing in that moment and understand what it must have been like. The authors demonstrated to the interviewee that they were listening and trying to understand what was said by reflecting the interviewee's verbal message—i.e., by paraphrasing or restating the words of interviewees and by encouraging them to continue talking using empathy, curiosity, and a willingness to learn from the interviewee's experiences.

Interviewees normally would talk about weather changes they had observed. A sequence of question and response between authors and interviewee during the semi-directed interview might be as follows. If an interviewee made an observation such as the "weather has been too wet lately!" a potential follow up comment would be: "was this unusual?" to which a potential reply would be: "Yes, it was more wet." A follow up would be "how did it affect you or the community?" and their response could be "we couldn't pick any berries; it was too wet." The authors might follow with "what month do you pick berries?" to which the interviewee could reply "end of August". At this point the authors would use a calendar and ask the interviewee to tell them what social or family things they did that month such as visits to the doctor. The idea was to facilitate a process of recalling specific events that took place during that month. Once that is done, then interviewers asked when their picking took place that month and tried to identify the specific dates of the "wet" events to see how they would fit with the social or family activities. This approach allowed the authors to corroborate information by triangulating with other events that happen at the time and thus to ensure there is some accuracy in the recollection of events.

During the interview, the authors also invited the interviewee to sketch something related to what he or she was saying such as the coast line and how they were navigating when coming back to town and the wind started to blow and or the position of their boat while they were fishing in relation to the movement of the currents. This approach was very useful because the act of "sketching something" helped the interviewee to focus on the issue at hand, to bring back the memory, and to reinstate the context (pers. observation, Gambell, August 2014, Memon et al. 2010) which then helps interviewees in terms of remembering specific dates and times.

The interview approach the authors followed was similar to the process of "peeling an onion." The authors commenced with general questions to build rapport and then using either words, tone of voice, expressions, gestures, or question that would allow them to maintain the interviewees' attention, moved on to help interviewees get mentally closer to times when bad weather events occurred, so that they could remember an "aha" moment. Every question is like a layer of an onion. The authors showed that they were listening and connecting before moving on to the next layer. Sometimes negative emotions are associated with bad weather events, such as an accident which may trigger sadness or negative emotions, therefore it is imperative to have respect, empathy and to be in the interviewee's shoes and help them move out of that state before finishing an interview session.

Body Language	Possible Non-Native Meanings	Possible Native Meanings
Nodding head	I understand what you're saying.	I hear what you are saying.
Raised eyebrows	I'm surprised by what I am seeing or hearing.	Yes; I agree with what you are saying.
Furrowed brow	I'm listening very carefully to what you are saying. I question the truth in what I am seeing or hearing.	No. I'm displeased with you.
Tapping pencil	I am distracted.	I am impatient.
Sighing	I am tired.	I am bored.
Arms tight to body	I am cold.	I want to maintain an impersonal distance.
No eye contact	I am lying to you.	I respect you.

Table 4.1 Cross-cultural communication.
Mary Wolcoff, 1989.

Important Mainstream American Cultural Values	Important Inupiat Values
Ownership	Sharing
Equality in social relations	Respect for others
Competitiveness	Cooperation
	Respect for elders
Love for children	Love for children
Achievement	Hard work
	Knowledge of family tree
Directness in communication	Avoid conflict
Human superior to nature	Respect for nature
Formal religion	Spirituality
Humor	Humor
Nuclear family	Extended family
Material possessions	Hunter success
	Domestic skills
Achievement-oriented	Humility
Individualism	Responsibility to tribe

Table 4.2 Inupiat and American values.
Laura J. Noland, 1989.

Non-Natives:	Natives:
Early demonstration of learning. Seek to please.	Early age—respect through silence, observation.
Speaks to many people who give perspective to life; no need to talk to those he is close to; companionship.	Converse at length with those he's close to; watch and give respect to those he does not know well.
Values conversation as a way to get to know others.	Values observance as a way of getting to know others.
Learn through trial and error.	Children listen and learn; don't answer questions or demonstrate skills unless they know the answer or are adept at the skill.
Teacher expects Native students to demonstrate knowledge.	Difficult to meet expectations of non-Native teachers due to way of learning.
"Puts best foot forward." Presents positive self-image and high hopes for the future.	Not acceptable to "boast" nor to speak of future (makes it difficult for job interviews).
Interprets Native's not boasting or speaking of future as lack of self-confidence.	
Rapid communication.	Thinking before answering. Longer pauses.
Must have closure for courtesy.	No closure (e.g. may hang up at the end of a telephone conversation without saying good-bye).
Direct messages.	Indirect messages.

Table 4.2.a Inupiat and American values.
Laura J. Noland, 1989.

What's Confusing to English Speakers about Athapaskans	What's Confusing to Athapaskans about English Speakers
The Presentation of Self	
They do not speak.	They talk too much.
They keep silent.	They always talk first.
They avoid situations of talking.	They talk to strangers or people they don't know.
They play down their abilities.	They brag about themselves.
They act as if they expect things to be given to them.	They don't help people even when they can.
They deny planning.	They always talk about what is going to happen later.
The Distribution of Talk	
They avoid direct questions.	They ask too many questions.
They never start a conversation.	They always interrupt.
They talk off the topic.	They only talk about what they are interested in.
They never say anything about themselves.	They don't give others a chance to talk.
They are slow to take a turn in talking.	They just go on and on when they talk.
The Contents of Talk	
They are too indirect, too inexplicit.	They aren't careful about how they talk about people or things.
They don't make sense.	
They just leave without saying anything.	They have to say good-bye even when they see you are leaving.

Table 4.3 Differences in communication between Alaska natives and non-natives.
Bea Shavada, 1989.

4.3.5 Site Visits

First Site Visit to Shishmaref

The first visit to Shishmaref, was scheduled from August 24 to 28, 2013, following advice from the Mayor and tribal council. By this time, residents would be back from camping because the kids go back to school. Initial contact between authors and community representatives was scheduled to take place upon the authors' arrival, on Saturday August 24, to discuss the schedule for meetings and interviews. There would be a project presentation and discussion with the tribal and Elders' council, followed by semi-directed interviews with key individuals. Upon arrival on August 24, the authors learned that their contacts were not in town. The community had experienced three weeks of rainy weather, and the authors' date of arrival was the first sunny day, which gave the residents an opportunity to finally go caribou hunting. The authors were informed that their contacts would likely be back three days later, on August 27, a day before the authors' scheduled departure. After recovering from the shock, the authors reflected on the fact that the community subsistence hunting was more important to the residents than this project. Based on this feedback and as a way to adapt to circumstances and move on with the project (feedback-based adaptive approach), the authors decided to learn what they could from interactions with the remaining residents over the three days by taking the following approach:

1. <u>Interact with the locals who remained in town, the artisans, store clerks, etc.</u> As soon as the authors arrived in town, several residents offered them their artwork for sale. The authors engaged in conversation with these residents, informing them about the project and listening to their concerns and experiences with bad weather

events when conducting regular subsistence activities. Also, the authors visited the two stores in the community to learn about what products were available and their prices. The authors shared with the clerk the purpose of the visit and engaged in a dialogue about impactful weather events: bad weather prevents planes from flying and therefore affects supply delivery to the stores.

2. Walk the streets and meet people. In the authors' experience, a very good way to introduce the project and start building trust is to go for walks in town and greet as many residents as possible. The community is the residents' home, and the researchers are visitors. Greeting every resident is a way to acknowledge them and show respect. In most of these communities, kids are extremely friendly and curious. They are very interested in visitors and happy to hear about what the visitors are doing. The authors have found that, during public meetings, some parents are already informed about the project because they have listened to their kids talking about what they've learned while talking and playing with the visitors. While walking the streets, the authors met some hunters who had returned from the caribou hunt. When approached, these hunter's reaction was that they did not want to be interrupted and they had to butcher their animal as soon as possible. The authors reflected on the fact that hunters needed to do their butchering first and adapted their approach accordingly. When they met the next young hunters who had returned with their caribou the authors offered to help butchering the caribou. The hunters were glad to have some help. The authors joined these hunters in butchering the caribou and learned about the good and bad weather conditions that they had experienced while hunting during the year. The authors

were invited to come back the next day to continue butchering, join the main hunter and his family for dinner, talk to them about the research project, and interview this hunter. The authors were aware that their objective was irrelevant to the residents, so they made the residents' objective their priority. The authors' willingness to be present in the moment with the hunter's needs and to help with the butchering allowed the hunter to complete his task and to be willing to share his knowledge on weather impacts once the main priority was accomplished.

3. Join community activities and events. The authors took every opportunity to join in community activities. For example, there were several women picking berries at the end of town, and the authors offered to pick berries for them. This interaction gave the authors an opportunity to learn about weather conditions affecting the berry harvest that year, and to hear from these women about their husbands' experiences with problematic weather events during the hunting season. The authors were invited to join in the Sunday church service. Since many of the residents attend the service, this was a good opportunity to meet them. Once the service was over, the pastor welcomed the authors to town and invited them to explain the purpose of the visit and invited residents to cooperate. This was a good opportunity to let them know the intent of the visit and the authors' interest in learning from the residents' experiences with ice-berm formation and impactful weather events. After the service, some residents invited the authors to their homes for tea so they could talk about their research and conduct their interviews.
4. Learning from the women in the community. As the week started, the authors went to government offices and talked to women they had contacted during the

preparatory work. The intent was to learn about their experiences with bad weather during community or family events. In the authors' experience, women and men tend to remember events differently. Because of their roles in the society, women tend to remember social and family events more easily than men and can place weather events in this context. For example, women remember impactful weather events such as storms or floods that took place while they were preparing a potluck. They also remember the occurrence of bad weather when they were planning to take kids to the doctor in Nome, as planes are usually affected by bad weather.

When community representatives returned from the caribou hunt on the afternoon of August 26, meetings were set up for Tuesday afternoon (August 27) with the Elders and IRA council. The feedback from council members complemented responses gathered from interviews with women and young hunters. The actions by the authors when their original plans were disrupted by the residents' absence from the community, and their adaptability to changing circumstances, allowed them to make full use of their site visit and to gather relevant information before departing on the morning of Wednesday August 28. Visits with local artists, shop owners, women, children, hunters, and elders enabled the authors to gain a more complete picture of how impactful weather affected different community activities.

The work done prior to the site visits gave the authors an opportunity to connect early on with key community residents, who they could then meet during the site visit. The authors visited these residents in their homes and talked about the slush-ice berm formation and impactful weather events. It was a rewarding experience to meet the key contacts' families and build relationships. While in Shishmaref, home visits were an excellent setting for interviewing residents because the interviewees were more relaxed. Every community and interviewee is different and it was important to ask interviewees about their preferences to ensure that the setting was conducive to a productive interview session.

First Site Visit to Gambell and Shaktoolik

Based on the visit to Shishmaref during August, when the residents' frame of mind was not focused on storms or slush-ice berm formation, in preparation for the trip to Gambell and Shaktoolik the authors did more research to locate additional information relating to slush-ice formation during storms. The authors sifted through print and online media (*Nome Nugget*, UAF journal class reports of storm impacts on western Alaska communities, *Alaska Daily News*, personal Christian and sports blogs), where families would inform friends and relatives of what they experienced during storms. The authors searched the internet for video-clip examples of slush-ice berm formation that could be used in helping residents to *recognize* specific impactful weather events and then to *remember/recall* the specific date and time of when the events happened. It has been documented that a process of recognizing an image is much simpler than remembering an event, as remembering involves multiple mental processes (Tulving and Thomson, 1973). A video clip was identified where residents in Shaktoolik described a berm protecting the town during a storm (http:aksik.org).

The visits to Gambell and Shaktoolik were scheduled from November 7 to 17, to coincide with the storm season and to facilitate setting an environmental context where residents could easily recall storm conditions and specific dates and times of occurrence of slush-ice formation during storms. While it is not possible to retrace a storm or an impactful weather event, it is possible to recall, or facilitate access to the mental picture of the environment or context which will lead to a memory of, the specific date and time of the event (Smith and Vela, 2001) by setting the dates of site visits and interviews to coincide with the fall storm season. It is easier to remember events and situations if the environments are similar (Eich, 1980; Godden and Baddeley, 1975). As it happened, three storms hit Shaktoolik and Gambell on November 7, 9, and 13. The November 9 storm was the most intense, causing severe erosion, flooding, and removal of large quantities of driftwood in Shaktoolik. During the November 9 storm, the authors were able to witness how Gambell experienced 25 feet of erosion along the north beach. As a result, some machinery left there from the Second World War was unearthed, causing fear of water pollution among the residents. The visit to these communities had to be extended until November 20 because storm conditions affected flight schedules between Gambell and Shaktoolik.

In these two towns, community representatives requested that the authors present the project at a public meeting. In Gambell, the authors were asked to bring food (which had to be brought in from Anchorage) and door prizes. The authors were assigned a liaison person paid by the IRA to help organize the public meetings and to select interview candidates for the semi-directed interviews that would follow the meetings.

Public meetings are an opportunity to initiate interpersonal communications and build relationships. These meetings involve the sharing of food, which is an important trust-building activity because it relates to the community's core values (see table 4.2). Preparing the food before the event with the help of a liaison person gave the authors an opportunity to find out about key issues affecting the town, who to expect at the meeting, who is who in town, and to get more information about the town activities. Scheduling time for socializing and eating before the meeting allowed participants to relax as they were not sure what to expect from the meeting. It also gave authors time to greet every resident, learn something about them, and establish an initial connection. Public meetings were also an opportunity to memorize participants' names, identify from the participants potential meeting facilitators, and acknowledge the presence of the different community representatives—e.g., people speaking on behalf of the city, native tribal council, corporation, etc.

During a brief self-introduction starting with their name, role and institution, the authors moved on to talk about their interest in working in the community and with the people in the community. They highlighted the value of the residents' observations and emphasized how much the authors were there to learn from the residents' knowledge and how this knowledge would inform the scientific project. The authors avoided any references to academic degrees and focused on the role they play and responsibility they have in the project. The approach used by the authors to introduce the project was to first engage participants through an event or story currently affecting the community. For example, the authors mentioned the community's concerns about the vulnerability of the electric infrastructure or the potential for sea water entering the river and contaminating drinking water in Shaktoolik. They also mentioned how the slush berm in 2009 saved the community from major storm impacts and how beneficial it would be for the community to know if slush-ice berms would form during the storms, e.g. some type of berm forecasting. From here, they moved on to project objectives and continued the dialogue with the community residents – about 30 attendees – mentioning how it would also be beneficial for the community to have more data about meteorological conditions such as wind speed and direction when building a case to apply for financial assistance to deal with storm impacts such as erosion and damage to infrastructure. Placing community interests first and then linking them to research objectives helps to build trust because it shows that the authors have taken the time to learn about what is relevant to the community. It also shows that the project will have a direct link to something that the communities are concerned about.

Receptivity to cultural differences and communication styles was important at the individual and group level. At the individual level, the authors paid attention to verbal tone, body gestures, speech rate, pitch, silences, and humour, and adjusted their own style appropriately to match the speakers' style and create rapport (see Tables 4.2, and 4.2.a). For example the authors lowered their pitch, slowed their talking speed, and used more pauses and silences when addressing elders. At the group level, checking the mood in the room and being receptive to body language, eye movements, and resident's comments was very important in addressing participant's needs. For example, in one community the authors were introducing the project's benefits which included improving weather forecasting. A resident asked the authors: "what is God's view about this weather forecasting?" The authors realized that a cultural practice is to commence meetings with a prayer, and participants were feeling uncomfortable about having a meeting without having said a prayer. The authors asked for a volunteer to say a prayer. After the prayer, the residents were more relaxed and accepting of the authors and the project. They asked questions, smiled or nodded and commenced to talk about the impacts of the storm taking place during the meeting. Prayers before and after the session are part of the cultural tradition in some communities. It became apparent that in these communities it was important to apply the axiom: "Do unto others as they'd like done unto them" (Alessandra, 1996).

The time of the year also affects the outcome from public meetings. In contrast to the site visit to Shishmaref, which took place during nice weather in August, when people were caribou hunting, the public meeting in Gambell took place while storms were hitting the town and the governor had declared a state of emergency for the communities on the west coast of Alaska. In Shaktoolik, the storm had just passed, having caused severe floods. At the end of the public meetings in Gambell and Shaktoolik, the residents were so concerned about storm impacts that they drew up action plans based on what they wanted to see happening to address storm impacts, and discussed potential funding sources. In Shaktoolik, the impacts were so severe that the mood in the community was of serious concern, and the mayor asked one of the authors to join him on a tour so he could show her the storm impacts on infrastructure.

During the sessions it was very useful to receive men's comments about infrastructure damage and women's views about flood impacts on sewage backing up in the toilets. Men in general focused on storm impacts on town infrastructure, and women focused on impacts to their houses, the berry patches, the grass areas that were flooded, etc. These comments reflected the roles people play in the community. Women gather berries, weave baskets using grass, and take care of the household while men go fishing and hunting.

In Gambell, the semi-directed interviews were facilitated by the liaison person, who selected the interviewees, determined the place to conduct the interviews, and provided refreshments. No women were selected, only elders and young hunters, because the town's main concern is the walrus hunt which is primarily practiced by men. The time allowed for each interview was one hour. In some cases, elders and young hunters were grouped for the interviews, and the authors were able to take an observer role (Huntington 1998). This was possible as long as the two people were talking about the same event, reminding each other of what had happened on that occasion, and helping each other remember specific dates. As observed in Shishmaref, the elders contributed their traditional knowledge of climate and weather changes, and their knowledge of sea ice and slush-ice formation. The young hunters complemented this information with material about specific locations where slush-ice–berm formation had taken place and their experience of the impacts of bad weather conditions while they were out hunting. Maps and calendars were very useful tools to help interviewees recall the specific dates, times, and locations when events happened. The authors also provided interviewees with pens and paper so they could draw the coastline areas where they had experienced an incident, or town areas where infrastructure had been affected by storms and impactful weather events. Interviewees and facilitator were compensated by the IRA for their time.

Unbeknownst to the authors, the facility used for interviews in Gambell had not been approved by the building authorities. In addition, some interviewees had not been approved by the IRA council to participate in the interviews but had been suggested by the liaison person because they were relatives. These situations were addressed as soon as the authors became aware of them to ensure that they did not undermine the future of the research project. In coordination with the community representative, the authors offered apologies and reparation to the respective authorities for the unauthorized use of facilities and supplies.

In Shaktoolik the liaison person became ill and was not able to facilitate the selection of interviewees, so other residents helped the authors find interview candidates. These interviewees were respected elders who were willing to share their traditional knowledge about changes in climate but were not active hunters, however, they were not the best candidates to provide information for the project as they were not active hunters. After these interviews the authors asked the tribal council for permission to interview some women who were featured in a climate change video. The women had seen the slush-ice berm and taken pictures of it, and they were willing to share these pictures and information about the slush-ice berm and impactful weather events. As the intent was to identify "specific dates and times" of the formation of slush-ice berms and impactful weather events, these women were perfect candidates. They also suggested other people who could be interviewed, an example of the snowball sampling approach in selecting interview participants (Bradshaw & Stratford 2000).

With the pictures in hand, residents immediately recognized the slush-ice berm and remembered the conditions leading to the berm's formation. Women were particularly astute when remembering dates and times as they were able to relate the events to the time of their wedding anniversary or a birthday celebration. Men, on the other hand, contributed information about the height of the berm—e.g., how many "Hondas" tall the berm was, how far into the ocean it extended and when it formed. In terms of impactful weather events, there were differences in what men and women were able to contribute. Young hunters in general were good at focusing on the short term, what is happening here, today, and tended not to remember negative impacts of weather events while conducting activities. Women would remind their husbands about accidents they had while bad weather was happening.

This has been documented in Beyer (1998), who points out that, unlike men, women tend to recall more mistakes and negative experiences.

4.3.6 Second site visits

Follow-up visits were scheduled to report back to each community on preliminary findings from the interviews as well as to share results from the analysis of impactful weather events. This allowed the communities to continue their engagement in the research process, verify results, and provide feedback. These visits were critical to the success of the project and the broader process of scientific engagement with communities; they were a response to the often-heard complaint that researchers seldom return to present their findings.

Each community decided how results should be presented. In Shishmaref, the results were presented directly to interviewees. In Gambell and Shaktoolik, a public meeting was requested and the results were presented using a power point presentation, followed by sessions with individual interviewees.

In Shishmaref there was no request for a public meeting to show project results. Results were discussed directly with interviewees.

In Gambell, the plan was that residents and authors would cook the meals to be served at the public meeting. The community representative was facilitating residents' involvement in meal preparation and had hired locals to gather berries for the pastries to be served. The public meeting was scheduled to take place on a Saturday afternoon, a day after the authors' arrival. The details for the meeting would be discussed between the authors and the community representative once the authors arrived in town.

The day the authors arrived was the first sunny day after a period of rain that prevented residents from going hunting. As a result, everyone was out hunting, including the authors' key contact person. The authors were informed that their contact would be back from hunting three days later. The next day the authors learned that their contact had arrived in the middle of the night but left again because a resident had an accident while coming back from the hunt. Residents play different roles in the community, including search and rescue, hunters, presidents of native organization, store managers, etc. At this point, the authors did not know if residents had collected berries as planned, and it was unclear when or if the public meeting would happen.

Once again, the authors reflected on the fact that community's priorities were first and adapted their approach to the situation, working with other council members to arrange to have a building available for the public meeting, hoping it could still take place the next Monday. They also identified alternative residents who could help with meal preparation and gathering berries. These substitutions were possible because the authors had developed strong relationships in the community, so even though the key representative was not available, there were other residents willing to work with the authors to ensure that the public meeting took place. The key contact came back on Sunday morning and agreed that the meeting could take place the next Monday

With the residents' help, the food was ready the evening before the public meeting was scheduled. However, early on Monday morning a death occurred. According to the cultural practices of Gambell residents, when someone dies, public events are postponed until after the funeral. The authors donated the food to the grieving family and decided to meet with residents individually to discuss findings and invite them to provide feedback on project results. Each interviewee selected a place for meeting with the authors, and each received compensation from the research project for their participation. During this second visit, interviewees were compensated by the project.

During the initial site visit to Shaktoolik, the authors had gathered photographs showing the different types of slush-ice berm formation. This graphic material was key for residents in Gambell to identify types of slush and slush ice berm formation processes they have observed, helping them to recall specific dates and times when slush-ice berm formation had occurred. The authors sometimes encountered interviewees in these communities who refused to provide feedback. The first approach used by the authors was to be in the moment with the person refusing them and to put the resident's needs first, and later to reflect on what was going on for the individual. For example, being asked to go away may have been due to the person being really busy and engaged in something that required his/her full attention, or maybe she/he had had a bad day during their hunt or with their family or maybe the setting was not convenient. The TVs are often on in homes and if the person is hard of hearing he/she may prefer not to talk over the background noise. Using the feedback-based adaptive approach, the authors realized once again that their priority was not the residents' priority. As such, the authors acknowledged and respected this decision and went away for the day. The next day this resident was at a different setting, having a relaxed elder's lunch. The authors took the opportunity to approach the resident to just deliver a specific gift brought to him/her from Victoria to show appreciation for his/her previous participation. Nothing else was expected from him/her. As a result, the resident changed his/her mind and asked the authors how he/she could answer their questions and explained that the previous day the TV was on and he/she is hard of hearing so he/she was not willing to talk to the authors. The right setting is very important. These gifts were brought to residents for two reasons. In the authors tradition the custom is to bring a small present to the host when one is visiting family or friends. It is also a sign of gratitude and appreciation. Prior to the trip, the authors had asked council representatives and key people in the community about their preferences in regards to food, coffee or tea. They also inquired about their family members and ages and they had brought small gifts for them and their families. Usually residents realized that the authors were not just seeking their own benefit but that they care about each individual in the community as human beings. In all cases the outcome was an invitation to return and to continue working with the community. This approach allowed the authors to connect with the residents and build a relationship that resulted in their continued participation in the project.

Two days after the resident's death the funeral was still not scheduled, and the authors had to go to the next community. The authors walked the streets, distributing to residents the door prizes they had brought for the public meeting, as the meeting was not going to take place. At some point, the IRA made an exception to their cultural tradition and called its members for a special meeting to provide project feedback to the team. The authors were grateful that the town supported their research objectives during the town visit.

In Shaktoolik, the authors had been in discussion with the tribal council for several months before their trip, making plans to set up the public meeting. Upon arrival, the authors were informed that a new leader had been in place for three months and they should get in touch with her. The authors were not provided with contact information for the new leader. When they did get in touch with the new leader, she told the authors that she had no information about their visit and no interest in a public meeting. She also said the town leaders were going camping for four days and would return the evening before the authors' scheduled departure. The authors asked if they could hold a public meeting upon council's return, but the new president made no commitments. That left little hope that they would present the project at a public meeting.

Once again, the authors had to reflect on the fact that the community has to focus on their main priority and based on the situation's feedback adapted their approach. They decided to seek feedback from interviewees using the photographs gathered during the previous visit. Interviewees in general were very generous with their time and provided valuable feedback on the photographs. In one instance, a resident was suspicious of the authors. The town had recently had religious visitors who created division in the community and made residents suspicious of strangers, and he/she feared the authors belonged to a religious organization. He/she saw the authors from behind through a side window as they were knocking at her door. However, the authors' dress code apparently did not fit that of religious visitors, and the authors' persistence in knocking at the door, combined with the residents' curiosity, overcame suspicion. The authors were eventually invited in. The authors also made presentations to the school and received support from some community members to prepare food in the hope that council would be back early enough and would be willing to hold a public meeting the evening before the authors' departure.

The authors had purchased cloud berries in Gambell, as they knew Shaktoolik had not had a good berry crop due to lack of rain. At 4.50 p.m., the authors had the food ready for the meeting but there was no word of the council being back. The authors decided to distribute the food and the door prizes to residents, walking on the streets and going house to house. As the authors were heading out, council returned from their camping trip. It was

5 pm when the authors got a call from council agreeing to hold a public meeting at 7 pm, as long as it did not take longer than 20 minutes. A public meeting was called and it ran for more than an hour and a half. One resident noted inaccuracies in observations and provided specific feedback to clarify information. This resident became one of the main observers for the project and remains in regular contact with the authors, providing information on weather events. Residents were very pleased with the results of the research, and the new leader and council were so impressed with the authors' work and the project's benefits to the community that they asked the authors to come back to town and feel free to put forward any resolution to either have the project continue or to support any project the authors would like to put forward. It turned out to be a rewarding experience.

4.3.7 After the Project

Several outcomes resulted from the first visit to Gambell and Shaktoolik as follows: a local observer was recruited in each community. Since then, the authors have been making weekly or biweekly calls to ask how the weather has affected the communities and have been documenting this information; in Gambell, the IRA council made the walrus hunting logbooks available to the authors. This information could be linked by the authors in studies of synoptic weather. Also, the authors were fortunate to obtain permission to copy the Leonard Apangalook logbooks. Leonard Apangalook made careful observations of weather and ocean conditions in Gambell for about 30 years, and his wife made the logbooks available to the authors when they visited her at her home in Anchorage.

4.4 Discussion

These examples of community collaboration portray the adjustment that scientists from the south must make before and particularly during a project when conducting research in remote communities, the challenges encountered before and during the project, and the community and interview-centered and feedback-based approach taken to address them. Before project commencement, the two main types of challenges encountered were the communities' reluctance to participate in the project, and the communities' expectations for presenting the project. During the project, main issues fell into four categories: 1) logistics; 2) the role of the liaison person and interviewee selection; 3) power and authority; and 4) research methodology.

4.4.1 Issues encountered – Before Project Commencement

Reluctance to Participate

It is relatively easy to commence a research project when a relationship with the community already exists or when the community has had good previous experiences working with scientists. When a community has had a negative experience with scientists, it can be reluctant to participate in future studies. In this project, when the authors encountered a community reluctant to participate, they shifted their approach from trying to engage the community to first focus on the community needs, on understanding the residents' frustration, and on expressing empathy. After listening, empathizing, and reflecting on the community's feedback, they used the knowledge gained through their preparatory research to highlight critical weather related areas of concern to the residents and provided examples of how by working together in this project, there would be a benefit to the community. The authors were able to get past the reluctance by sparking a mutual interest in the project due to their interest in understanding the community's issues and needs, and their intent in having a project that would be of service to the community.

Meeting Community Expectations

Proper initial project budget allocation has to include the cost of at least two site visits –in order to inform the community about the results of the research and the next steps, the provision of food and door prizes for public meetings, compensation to interview participants, cost of changing flights due to unexpected situations, etc. –that is, contingencies. Several communities have their own guidelines in terms of compensation to participants. However, in the authors' experience, if the community is interested in the project, there is always flexibility in terms of the amount of compensation to be provided. An open dialogue, combined with the researchers and community representatives' objective to have a project that ultimately will be of service to the community, is more of a priority than the benefit to a specific interviewee.

Food at Public Meetings. Communities had certain expectations in terms of the type of food made available at public meetings. When the authors had budgetary and logistical constraints in meeting these expectations, they found that the best approach was to discuss and be clear on what could be done to accommodate expectations before the project began.

The stores in the communities visited have a limited food selection, so the food for meetings had to be flown in from Victoria, BC, or Anchorage, AK, to Nome, AK, and from Nome to Gambell or Shaktoolik. Thanks to the work conducted before starting the project, the authors had the support of a community member who now lives in Anchorage and guided them on what food to purchase in Victoria and what food to purchase in Anchorage. This resident advised on communities' food preferences and also provided freezer storage space.

The authors were only able to transport the food to Shaktoolik because Kawerak staff stored the food in their office and had it delivered to the airport in Nome for the authors to pick up on their way to Shaktoolik. Without this support from Kawerak, the authors would not have had time to pick up the food at Kawerak's office, as they were behind schedule to catch the Shaktoolik flight due to delays caused by storms.

The support from residents and Kawerak would not have happened without early contacts to community members and work done by the authors. When conducting projects in northern communities, researchers cannot assume there will be the same access to food as there is in the south. Also, they cannot assume residents in these communities have the same food preferences as people in the south. An interesting point was how unpalatable the Canadian snacks were in some communities. Canadian snacks are considered "too salty."

Employment and compensation. When participating in collaborative projects, community members are not only focused on project outcomes but also on the legacy and benefits for the community. The most immediate benefit they see is the economic benefit of one or two people being hired by the project, and compensation to participants being interviewed. Several studies mention the opportunity to create employment by hiring a local facilitator to run meetings and identify candidates for interviews (Wolfe et al. 2011, Gearheard and Shirley 2007, Pierce et al. 2009), and as a way to build relationships. Many scientists have hired a local facilitator or liaison person, so a precedent exists in many communities. This project did not require hiring a guide or an individual to facilitate the meetings. These expectations were discussed with community representatives before the project commenced, to avoid conflict.

Provision of equipment. One benefit of this project to the community was the installation of a small weather station for community use. The stations were installed during the second trip, after communities indicated an appropriate location for them — a very desirable outcome, as communities are struggling with changing weather patterns and a lack of accurate weather forecasting when conducting subsistence activities. One of the communities expected to receive a large instrument. By focusing on the needs of the community and how the equipment, although not large, would meet their needs and serve the project, the authors were able to continue working and maintaining the trust of the community.

4.4.2 Issues encountered – During Project Delivery

i. Logistics

Meetings cancelled or postponed. In two communities the authors had their public meetings cancelled, but in both cases, and sometimes contrary to tradition, community representatives called for impromptu council meetings to make sure the authors were able to present the project and receive community and council's feedback before departing. The site visits were always an opportunity to reflect on the reality of the people in the communities versus scientist expectations and modus operandi. By using a feedback-based adaptive-approach, the authors were able to identify options to meet with people, either by walking or join them while picking berries. When meetings were cancelled, the authors proceeded with their plans of preparing food, and distributed the food and door prizes to the people irrespective of whether the meetings would take place or not. These simple gestures resulted in relationship, trust, and friendship building in the communities. The authors remembered that their main goal was to be focused on the community needs. If the authors put the residents' needs first, then the research project will turn out eventually because the relationship building, which is the main basis required to work with communities, is already established.

Allowing extra time when scheduling site visits. Air travel to and from the villages can often be compromised and disrupted because of the weather. However other interruptions can also happen: on one trip the author's plane out of Shishmaref was borrowed for half a day to take the school volleyball team to the next village for a tournament. This unscheduled flight delayed the authors return to Nome and led to the authors losing their flight connections back home. At times when the authors arrived late to public meetings due to missed and delayed flights, tribal council representatives have re-scheduled these meetings to accommodate for authors' flight delays. When this has happened, the key contacts have made radio announcements to ensure people attend the public meetings.

Because of the difficulties associated with travel in the north, it is good to build in a lot of extra times for visits. In this project, the authors usually planned to arrive two or three days before the meetings and have a day or two in town after interviews to accommodate for unexpected weather delays. This also gave them time to accommodate requests from the community to spend extra time in town, either to give the researchers a tour of town or show them relevant areas affected by storm impacts.

ii. Role of the Liaison Coordinator and Interviewee Selection

In two cases, interviewee selection did not take place as planned. In the first case the liaison person was not available because the weather was good and he was out hunting with many of the community members. In the second case the liaison person became ill, so was unable to facilitate interviews for the authors. The authors' preparatory work was crucial, as it meant they knew who was who in town and what projects the residents were participating in. This knowledge allowed the authors to approach residents in their home. It was easy for the authors to knock at the door and to express an interest in hearing more about the projects the residents were involved in. Making sure that the interviewees knew that the authors had the community and interviewees' interest first was a key to engage them in the project. Once a common interest was identified, the residents felt confident in sharing information and in participating in interviews. As mentioned earlier, flexibility to let go of expectations in terms of scheduled meetings and interviews and an adaptive approach based on resident's feedback is required in every case as every interviewee is different.

iii. Power and Authority

Two situations were encountered where power and authority were misused. In the first case, the liaison person in Gambell recruited participants who were not active hunters and therefore had no information about impactful weather events while hunting. She also recruited more people than she was allowed by the IRA. Not having the best candidates for the interviews while was not the best scenario, provided some information complementary to the project, however, interviewing candidates who were not approved to participate in the process was detrimental to the project because the IRA representatives had more interviewees who expected to be compensated than it had budgeted for. The only option was to explain the IRA president the encounters with the liaison's relatives had been a house visit and not interviews. The IRA president confronted the liaison person and removed her from the project. Her relatives did not receive compensation.

In the second case, town representatives continued exercising leadership authority even after they had lost an election to another community member. This meant the authors had to restart the process of building a relationship with and gaining the trust of the new elected representatives as soon as they arrived in town. The authors' approach was to continue preparing for the public meetings and interviewing people in the hope that they would gather sufficient data and that meeting opportunities would arise. No matter how well planned the site visits are, challenges will always arise, but they recognize that by reflecting on the feedback of the situation and adapting to the new situation—being flexible and keeping the focus on being of service to the community, the end result has so far been always positive.

iv. Research Methodology

Setting the environmental and mood context. A project task was to identify the "specific" dates and times when slush-ice berms formed during fall storms of 2009 and 2011, and when weather events affected residents' subsistence activities or the community's infrastructure. When scheduling site visits to gather this information, the authors had to be aware of the environmental context and the interviewees' mood. In the authors' experience, it is easier for residents in any community, not only in the north, to remember specific dates and times of weather events when the visits occur at the same time of year and in similar weather conditions.

During the first site visit to Shishmaref, in August 2013, the authors gathered substantial information about impactful weather events that took place that month and in August of the previous year. However, there was no information about fall storms because the "environmental context" of August was not conducive for residents to remember *specific dates and times* of slush-ice berm formation during storms (Gerlach, pers. Comm, Godden and Baddeley, 1995). The best time for a site visit to interview residents to talk about slush-ice berm formation during storms is during the fall storm season, in November.

During this visit, the residents were in a good mood because the weather was perfect for their caribou and seal hunting activities, but this "mood context" was not conducive to remembering negative impacts from past weather events. McCormick (1995) and Lewis and Critchley (2003) have documented that it is easier to remember positive experiences when one is in a good mood and to remember negative experiences, such as impactful weather events, when one is in a low mood. The residents were focused on summer activities, such as fishing and seal and caribou hunting, during August, and their mood was very positive. It was not easy for residents to remember stormy conditions or impactful weather events during a good sunny day.

If the dates of site visits and interviews coincide with bad weather that prevents residents from going out hunting, it is more likely they will remember past dates and times of similar bad weather that prevented them from going out hunting (McCkormick 1995). The visits to Gambell and Shaktoolik took place during a period of severe storms in November 2013, and this facilitated a mood-congruent recollection of events. The conditions were such that the governor declared a state of emergency. This was a perfect example of environmental context and mood context: there was a storm and the people were concerned, so their mood was already in tune to bad weather events and storm impacts. During the public meetings in both communities there was a lengthy discussion about storm impacts on infrastructure, and the residents readily provided information about slush and slush-ice berm formation. During this project the authors found out that residents were motivated to explain what was happening during the storm and how it was affecting them. They expressed an appreciation to the that researchers were there witnessing what they are going through.

Elders and young hunters. Selecting the appropriate interviewees is another critical concern. Shishmaref and Gambell residents have participated in several research projects that focus on documenting traditional ecological knowledge. As such, community representatives assigned elders to be interviewed for this project. The authors emphasized the need to also interview "*young active hunters, under 45 years old*" who could remember "specific dates and times" of impactful events. These young hunters were able to provide information about weather impacts on subsistence activities and elders commented on how the environment has changed over time (traditional ecological knowledge). This traditional knowledge served as a frame of reference for the slush-ice berm study. For example, elders mentioned that the berm used to form in the old days but it does not form anymore because the beach has been taken away. The elder's knowledge was relevant in terms of where the slush used to form and of the general conditions for its formation. The authors noted the role that culture and tradition play in an information exchange. In a situation where elders were unable to participate in a meeting, younger hunters contributed more to the discussions, whereas they would have deferred to the elders otherwise and valuable information from these young hunters would not have been gathered.

Dominant roles and interrupting speakers. When interviewees were selected as group, some individuals took a dominant role even though their input was not particularly relevant to the project. Sometimes the individuals doing a lot of the talking have not been on the land in almost a decade. It is the interviewer's role to draw the conversation to the person who holds relevant information and to allow for a balanced discussion. While it might be considered culturally inappropriate to interrupt the interviewee, in the authors' experience, many interviewees have had enough exposure to westerners and they are used to being asked too many questions and to being interrupted (see Table 2). A feedback-based-approach to gauge what is appropriate in every situation is the best strategy.

Gender Perspectives. Engaging women in interviews along with the husbands was very useful. Women in general showed more ability to recall specific dates. By having to look after the children and social events they are more in tune with the calendar. For example, in Shishmaref women could recall the specific date of a particular storm because it was the day of the potluck and they were cooking in the kitchen and looked through the window and everything was flooded. In Shaktoolik, they talked about the first storm in November 2013, taking place while the kids were in Unalakleet for a baseball tournament. Women would mention how the storm affected the sewage system and led to toilets backing up. The men would show the authors how the water tank, electric generator and other large pieces of infrastructure were affected.

An interesting point is that men and women often have different perspectives about the intensity of impacts and about what to report during interviews. While men may de-emphasize the impact or danger of storms, women seem in some cases to remember more details and focus on potential dangers. Young male hunters may tend to forget or minimize accidents that took place while hunting due to bad weather events, while women are more likely to remember any dates and intensity of accidents and negative experiences (Beyer, 1998) due to bad weather events. Therefore, having women participating with their husbands during the interview process was very useful.

Language and Terminology. Lack of common terminology due to differences in cultural groups or demographics can challenge data gathering. During the project, the authors, elders, and young hunters were sometimes using different terminology. While some elders used Indigenous names to describe slush-ice berms, the younger hunters –who do not speak the native language because they were sent to a residential school, were asked to provide comments about a special feature described in the native language and they could not relate to that term. In this project we had Siberian Yupik and Inuit groups, which have different dialects. This too had to be taken into consideration. The authors, in trying to use a native term, sometimes were using a term from another community e.g. in Gambell residents refer to slush as *qenu* while in Shishmaref the term is *Ki-nu* and the authors were asking about slush-ice. Initially the authors asked for information about "ice-berm" formation, which is not the common term used to refer to slush-ice berms. As such, they were given information about *ivu* events, which refers to ice piled up, and were not receiving specific responses about the timing of "slush-ice berm" events. Also, when talking about impactful weather events, residents sometimes use terms such as "low water level" and "low tide," and "high water level," "high tide," and "storm surge" interchangeably when referring to impacts of weather events. For these reasons, it is important to ensure that all parties are using the use terminology.

Information reliability. Consistency of information varies and is dependent on a number of factors. Often community members expect to be compensated. This can lead to a situation where individuals want to make a contribution even though their comments may not be entirely accurate. Also, sometimes projects are not amenable to community based information; the more the information has to take the form of specific quantification of environmental parameters e.g. storm surge heights or values for "how cold/windy was it," the less likely community observations will be able to work for the project. There is no guarantee of getting accurate information. Sometimes perceptions of impactful weather are subject to bias, mood, or emotions. For example, if it is windy (15-20 knots) and rainy but hunters are determined to go out and get cigarettes, the weather is "not so bad." However, if the fridge has food or they prefer to watch TV, the same event will be considered "really bad."

4.5 Conclusions

This paper reflects the many issues and challenges encountered when engaging communities and local observers in scientific research in the north, communities and the benefits of working "together" with the communities to meet project objectives. The skills applied by the authors included: cultural and self-awareness and interpersonal and communications skills that allowed authors to bridge the gap between "us" and "them" and to work with the residents as a team. The authors moved from the sense that "I need certain information for my project" to a sense that "I can understand what the people's needs are and I can see how the project can be of service to the community; I see how we can work together and look at this project as 'our project.'" This feedback-based adaptive approach was very useful during the many times that meetings and activities were cancelled or re-scheduled. The authors regularly had to reflect and check their assumptions about how things should go, challenge these assumptions and understand that their priorities were not the communities' priorities but that there is always a way to make things work out even though they would only see that at the end.

It's important to emphasize the need to read the situations and the people. To understand not only their personal agendas, but their family and relationships within the community. As we address the questions about how to relate to interviewees from another cultural background, the authors emphasize the need to 1) be aware of interviewees' culture, needs, experiences, thoughts, personalities etc. while still keeping in mind the project goals; and 2) approach the interviewee with mutual equality and respect by dealing with them at the personal level, being fully present and giving full attention. Using this feedback, we can formulate an approach that meets interviewees' needs.

In order to develop community relationships one has to be able to establish a connection through interaction and once the relationship has been established it is important to maintain this relationship by keeping in touch throughout the project either by phone calls, Christmas cards, postcards, Facebook, etc. The residents' participation in this project was an investment of their time and expertise in the hope that it will be of service to their communities. It was also important for the authors to be clear about the outcomes of the project to avoid the risk of betraying community's hopes or undermining the credibility of the residents involved in this project. The residents are participating because it appeals to their cultural tradition of doing what is best for the community.

It is hard to emphasize just how important is to keep residents up to date on progress and to have a second visit to the community. This is crucial to maintain trust. A common concern expressed by residents in all communities was that scientists would not keep the community informed about the progress of the research; would not conduct a second visit to show what the findings were and how the information was being used; and, at the end of the project, would not send participants a copy of the results or show them how their information was being presented and used. When communities do not hear what happened to their knowledge and input, they are left with the feeling of resentment and a sense they have been taken advantage of.

There are two key elements of working with communities, and both involve time. First: commit to spending the necessary time on the ground. It is advisable to plan to spend a few days on site visits to allow for weather delays and other community priorities that may take precedence. Working with the communities in preparing food or bringing food for public meetings and events is always a great idea. Second: be flexible. While researchers arriving in a community have as their main focus the research project, for the people in the community the main priority is to provide for their families. As such if bad weather turns good just when researchers arrive, residents will do what they have to do –go out hunting, camping and so on. The researcher's s priority and previous commitments will be of no relevance in these cases

There is no specific set of skills effective in every situation and no "one size-fits all" approach. Every situation was assessed based on the circumstances, and the authors adapted their behavior in each case to achieve the desired outcome for both parties (feedback-based-approach). The results of this project confirm the findings of Guijt and Shah (1998) and Kanji (2004), who noted that successful cross-cultural collaboration involves a great amount of reflection throughout the research process and the inclusion of different individuals and types of interactions; requires researchers to invest time and share experiences to establish a common ground; and corroborates the value of interdisciplinary research.

FIGURES:

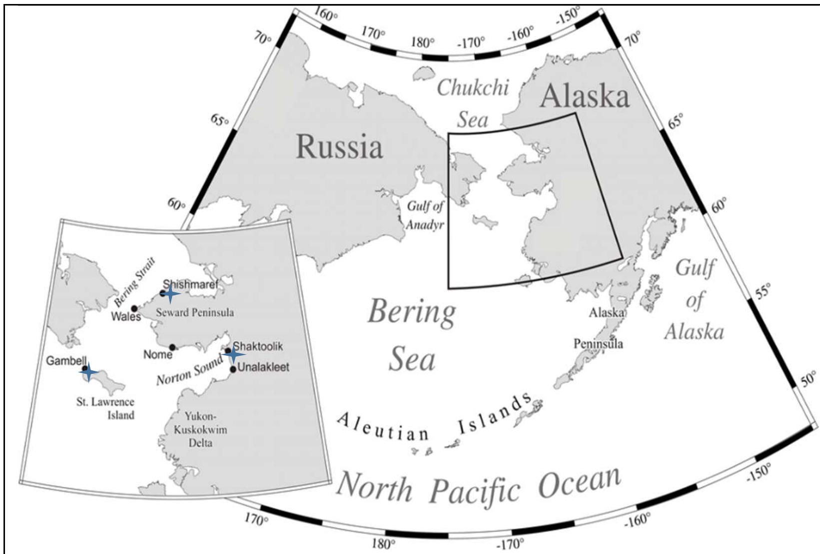

Figure 4.1 Region of study.
The broader area is the Bering and Chukchi Sea and their coastal zones. Inset map shows the study sites.

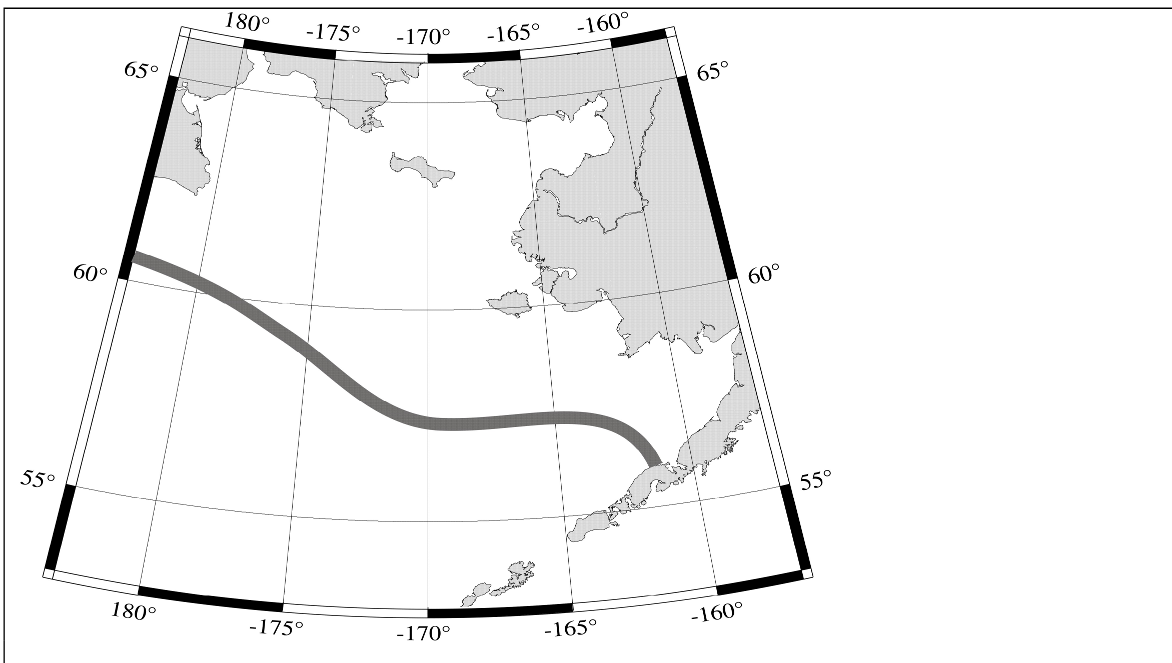

Figure 4.2 Average maximum sea ice extent, 2001-2009.

5 General Conclusions

This study makes use of traditional knowledge and specific local observations of slush and slush-ice berm formation to develop a conceptual model of slush-ice berm formation. In five chapters—an introduction (Chapter 1), three papers prepared for publication (Chapters 2, 3, and 4), and a general conclusion (Chapter 5), this thesis sets out: the taxonomy of slush-ice berms types and the conceptual model of slush-ice berm formation and decay (Chapter 2), the distillation of traditional knowledge gathered (Chapter 3), the methods used to engage Indigenous knowledge holders and local observers from Shishmaref, Gambell, and Shaktoolik, on the west coast of Alaska in this project (Chapter 4), and a summary of main results and suggestions for future work (Chapter 5).

5.1 Main research results

Types of berms. This project characterized two types of slush-ice berms –*in situ* and *advective*– that help protect coastal communities in Alaska from storm impacts and they can also be problematic when conducting subsistence activities. These types of berms form in the fall, just before freeze-up. The in situ-berm forms in place, under conditions of low winds, from slush that has formed in the surf zone. The slush is washed onto the beach and deposited along the low or high tideline where it grows further. The advective berm is formed from slush that has accumulated in the ocean and has then been pushed in onto the beach by storm winds (Chapters 2 and 3). In addition to these two types of slush-ice berms, communities identified shoved-ice berms as the most common type of berm formation. However, this type of berm is largely composed of ice and can form at any point during sea ice season. It is mentioned in this thesis only to clarify the types of berms identified by residents, but because it is not a slush-ice berm, it does not form part of the analysis (Chapter 2 and 3).

Conditions for slush-ice berm formation. The most essential condition identified for either in situ or advective berm formation is sea water temperature that is at or below the freezing point (~ -2.0°C for ocean waters in the region) in addition to cold air temperatures and onshore wind and wave action. The presence of snow can also accelerate slush formation because melting snow increases the cooling rate of the water. When ice crystals from snow enter the water, they provide nuclei onto which larger sea-ice crystals can grow, speeding the process of sea-ice crystal formation, and energy to melt the crystals is extracted from the water, aiding the cooling process (Osterkamp 1978) (Chapters 2 and 3).

In-situ slush-ice berm characteristics and conditions of formation. The height of the in-situ berm is determined by the wave splash; its width is determined by the distance between the high and low tideline. Synoptic weather analysis, residents' traditional knowledge, and personal observations indicate that an in-situ berm will form in the presence of low to moderate wind speeds (< 8 m/s) which bring weak wave conditions, and with air temperatures of about -8°C to -9°C. Synoptic weather analysis did not show a particular association of this type of berm with low pressure systems but rather to a general cooling of temperatures associated with the fall season (Chapters 2 and 3).

In-situ berm formation in shallow coastal areas. Local observers' comments and information from SIZONet indicate that in-situ slush-ice berms form faster in shallow coastal areas such as found off of Nome. In these areas, the beach is exposed to cold air and it cools down enough to rapidly freeze the water that washes over it during successive waves. Slush also forms in the surf zone and as the waves come in, they lift the ice crystals from the beach along with the slush from the surf zone and push it farther up onto the beach, where it starts to accumulate, forming a berm along the high or low tideline (Chapters 2 and 3).

In situ-berm formation in deep coastal areas. In Gambell, where the beach is deeper, residents noted that slush takes longer to form and will require a swell to push it from the surf zone onto the beach (Chapters 2 and 3).

Advective slush-ice berm characteristics and conditions of formation. This type of berm results when large amounts of slush are advected from elsewhere by strong winds or onshore currents. Synoptic weather analyses of two advective slush-ice berm episodes that took place in Shaktoolik during the storms of 2009 and 2011 show that this type of berm requires strong onshore winds (>10 m/s) that will produce large wind-driven waves and will push the slush from the offshore to the nearshore zone and onto the beach; these berms can form with air temperatures below -10°C. Synoptic weather analyses show that these events are associated with low-pressure systems. In the case of the 2009 and 2011 slush-ice berm episodes, the pressure system was located to the West of Norton Sound, resulting in west and southwest (onshore) winds blowing directly at Shaktoolik (Chapters 2 and 3).

Types of advective slush-ice berms identified. Synoptic weather analysis, personal and local observations and traditional knowledge reveal that the combination of air temperature and storm surge produce four types of advective slush-ice berms (Chapter 2):

1. *Storm surge and cold air* – results in large advective berms farther inland from the shoreline. This type of berm is higher than about 3 m and can protect a village from storm action.
2. *No storm surge and cold air* – results in a berm of moderate height, about 3 m or less, forming near the shore.
3. *Storm surge but no cold air* – results in a large, wide berm that is dangerous to walk on because the air is not cold enough for the berm to be thoroughly frozen.
4. *No storm surge and no cold air* – results in an advective berm of moderate height, not frozen solid and therefore not strong enough to walk on safely. As with the previous type of berm, a person can sink while attempting to walk on it.

Traditional knowledge and slush-ice berm mechanisms. Indigenous knowledge holders identified the variables required for slush and slush-ice berm formation. For the in-situ berm, the main variables identified are wind speed of about 2.5 m/s, waves, high tide, and shallow waters. For the advective berm the main conditions are snow, stormy conditions, high tide, temperatures between –6.5˚C to -1˚C, and offshore wind with speeds of 18 m/s to 27 m/s (Chapter 3).

Advantages and disadvantages of slush-ice berms from a sea ice services perspective. Protecting local infrastructure from flooding and erosion during storm episodes was the main advantage of slush-ice berm identified by Indigenous knowledge holders and local observers. This advantage falls under the category of using sea ice as a coastal buffer, identified by Eicken et al. (2009). Additional advantages, under the category of sea ice as a platform, include the ability to hook fishing nets from the berm, which enables residents to extend their nets farther into the ocean. Disadvantages include the fact that berms can limit shore access. Residents will often shoot seals in the water from their snowmobiles; if there is slush or a slush-ice berm, the seal will get stuck in the slush or berm, and the tide or current will not wash it in to the shore. Berms also limit hunters' access to the beach, with the result that they must cut a pass through the berm to haul their boats out. A final disadvantage of berms is that if they have not solidified below the surface, they are not safe to walk on (Chapter 3).

Culture, gender and age differences. A key finding was that in communities where traditional hunting for whales and walruses takes place in the fall, winter, and spring, Indigenous knowledge holders and local observers provided more detail on slush-ice and slush-ice berm formation processes than was the case in communities where there is no traditional hunting in the fall and winter. This common interaction with slush and slush-ice berms also determined whether residents perceive the slush-ice berm as a protective measure or as an obstacle to conducting their daily activities. The findings also highlight gender and generational differences related to the perception of slush-ice berm formation processes; the deference of young hunters to elders when interviewed at the same time, and the detail that women are more likely to remember specific dates and times of events. These observations were relevant when selecting interview candidates (Chapter 3).

Planning considerations. Key to successful field visits and interviews was the development of a relationship based on trust and respect. In the planning stages, discussing the project's goals and objectives within the context of communities' interest and concerns was essential to get the involvement and support from tribal representatives, as was performing preparatory work to become aware of community issues before even initiating contact. Additional considerations are the timing of site visits, budget, and community expectations. It was important to be flexible and to allocate extra time and budget for site visits to allow for flight delays and changes due to weather conditions and or to make room for unexpected community events. Scheduling a second site visit to report on findings to the community is required to show respect and maintain the relationship (Chapter 3).

5.2 Conclusion

This thesis accomplished the main objectives of developing a conceptual model of slush-ice berm formation; documenting the specific traditional knowledge gathered; and describing the process of engaging Indigenous knowledge holders and local observers. A great amount of information has been gathered from working with indigenous knowledge holders and local observers in the area of natural resource management, but this is the first time their knowledge and observations have been discussed in the context of slush ice formation, leading to a formalized nomenclature of slush-ice berm types that lays the groundwork for a full development of a quantitative model that could eventually be applied in some sort of forecast process.

The project illustrates the advantage of working with Indigenous knowledge holders and local observers from Shishmaref, Shaktoolik and Gambell, and it benefited from their holistic understanding of slush-ice and slush-ice berm formation processes. Their unique observations shed light on the types of berm formation that protect coastal communities in Alaska from storm impacts in the fall, and also illuminated the effect that multiple factors – such as nearshore water depth, and atmospheric processes including snow, winds, temperature, and tides and current – play in the formation of slush ice and slush-ice berms.

This research underscores the fact that traditional knowledge is a science that can be interpreted and used to complement physical scientific studies. A critical point is that slush ice-related processes and features are complex phenomena driven by interplay between various components of the coastal morphology/air/ocean setting that cannot be captured using instruments alone, and that must rely on long-term human observations (traditional knowledge). Given this, the input of Indigenous and local observers is of the most value in advancing the knowledge of environmental conditions required for the formation of slush ice and slush-ice berms.

Given the difficulty of conducting instrument based scientific studies in arctic regions due to the lack of weather stations in remote communities, the difficulty of observing the cooling of ocean waters, the fact that the degree of cooling required is so small that it is close to levels of instrument error, and the danger that ice formed by cooling can damage measuring instruments, the engagement of local observers in scientific work becomes a crucial step in this process. It is expected that this type of research will contribute to the ability to forecast slush-ice berm formation, which is critical for residents of coastal communities, who may need to seek shelter and evacuate when flooding is imminent.

5.3 Future work

Future work in this topic could include an analysis of changes in the timing of in-situ slush-ice berm formation, which residents in Shaktoolik, Shishmaref and Gambell mentioned happens later and later in the year – in contrast to residents in Barrow and Kotzebue (AK), who see more slush forming early in the fall (WP, 2012) – and an analysis of changes in frequency and magnitude of the advective berms, which residents mentioned have never been of such magnitude.

In addition, there is the potential to continue working with Indigenous knowledge holders and local observers in identifying specific quantitative thresholds and ranges of air temperature, storm surge, and wind speed as well as research into interactions with fresh water and tides that support the formation of various types of slush-ice berms. Once these parameters are identified, the results could be incorporated into routines used by computer modellers to improve slush-ice berm forecasting. The work conducted in this project may also have potential benefit for engineering applications, considering that slush-ice berms appear earlier and form faster in shallow near-shore waters.

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