RISK AND UNCERTAINTY REGARDING INUIT TRANSPORTATION IN THE FACE OF CLIMATE CHANGE

by

Mitchell Brinton

A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Arts in Anthropology

Boise State University

May 2018

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the thesis submitted by

Mitchell Brinton

Thesis Title: Risk and Uncertainty Regarding Inuit Transportation in the Face of Climate Change

Date of Final Oral Examination: 7 March 2018

The following individuals read and discussed the thesis submitted by student Mitchell Brinton, and they evaluated the student's presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

John P. Ziker, Ph.D.	Chair, Supervisory Committee
Kathryn Demps, Ph.D.	Member, Supervisory Committee
Mark G. Plew, Ph.D.	Member, Supervisory Committee

The final reading approval of the thesis was granted by John P. Ziker, Ph.D., Chair of the Supervisory Committee. The thesis was approved by the Graduate College.

ACKNOWLEDGEMENTS

I of course could not have accomplished this mighty feat without the guidance of Dr. John Ziker who, even with his preposterously busy schedule, oft found time to aid me. Dr. Mark Plew, one of my committee members, deserves my recognition as well, as he was the one who sent me down the path of graduate school in the first place. The other member of my fine committee deserving thanks is Dr. Kathryn Demps. An admirable stalwart of the Anthropology department, she is no stranger to agent-based models and she helped ease the anxiety caused by developing this model, an endeavor with which I had no prior experience. There are others who are not of my committee that had great influence on my graduate career and this thesis. Dr. Kristin Snopkowski deserves accolades for her masterful instruction of statistics, her genuine concern for my well-being, and her unwavering positive attitude. The latter two may also be said of Dr. Pei-Lin Yu. Her get-it-done attitude coupled with her fun personality made the last two and a half years more bearable than they had any right to be.

Undoubtedly, there are other people and organizations whose mention is greatly deserved. I would very much like to thank the establishment of Papa Joe's for essentially being my office and moral support. I would also like to thank Dr. Stephen Crowley for piquing my interest in the use of agent-based models as well as his unyielding support in my success as a graduate student. Thank you to my friends Kat and Andres for getting me through the vicissitudes (look it up) of this trial through the endless provision of water and coffee and shared interest in Bomberman and Marvel movies, respectively.

ABSTRACT

The evaluation and minimization of risk and uncertainty is an integral part of human decision-making. There are many strategies humans employ to help manage risk and uncertainty. One kind of strategy that has been important for *Homo sapiens* involves technological innovation. For example, the ancestors of contemporary Inuit developed the dogsled which was likely critical to their expansion into, and survival in, the harsh environments of the North American and Greenlandic maritime Arctic. Much like how the automobile replaced the horse, however, snow machines have all but replaced the dog team as the main transportation technology employed by today's Inuit. Focusing on the Nunavut community of Igloolik, this thesis examines the costs and benefits of dogsleds and snowmobiles through an evolutionary, economic, and social lens. This thesis reports on the results from an agent-based model used to test conditions under which the Inuit of today may or may not continue to use snowmobiles in favor of dogsleds in an increasingly variable climate. Several variables including weather variability, wind speed, hazard susceptibility, hazard avoidance, technology speed, carry weight, and others are tested against harvest rates and likelihood of the need for search and rescue based on ethnographically documented base parameters. The model shows that in highly variable wind conditions, the use of a dogsled results in a higher rate of successful harvests than the use of a snowmobile. This effect occurs in the model because as wind variability increases so does the probability of a snowmobile needing search and rescue. This study is important in that it sheds light on how uncertainty and risk in the Arctic can affect

decisions about the acquisition of culturally significant country foods that require hunters to travel on the frozen sea ice.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SAR	Search and Rescue

CHAPTER ONE: INTRODUCTION

The Canadian Arctic is a unique ecosystem insomuch as terrestrial individuals that rely on it for food and other fitness-enhancing resources must deal with the cold and the shape-shifting frozen sea ice on which they often travel. The ancestors of today's Inuit successfully adapted to the harsh climate, one that has seen warming and cooling, for thousands of years (Smith 1991, Aporta 2004, Wenzel 2009). Contemporarily, however, the Arctic has seen radical changes within the last few decades. Between 1979 and 2006, for example, annual circumpolar sea ice extent shrank approximately 3.6% per decade, while sea ice extent in September shrank by 8.4% per decade (Laidler et al. 2011). Sea ice thickness thinned from 3.64 meters in 1980 to 1.89 meters in 2008 due in no small part to the almost 2°C change in air temperature over those years (Laidler et al. 2011, Clark et al. 2016a). Sea-ice extent is predicted to decrease at an additional rate of 10% per decade with a month or more decrease in ice cover and an ice-free Arctic Ocean in September by 2040 (Wassman et al. 2011, Clark and Ford 2017, Clark et al. 2016a). These changing climatic conditions are markedly affecting the Inuit's ability to travel. For many Arctic communities, sea ice is necessary for travel to and from hunting areas and other communities and these predicted changes will affect an Arctic forager's transportation options (Smith 1991). Even now, ice, and consequently travel, conditions have become increasingly hazardous as temperatures rise and wind, one of the factors most responsible for sea ice structure and safety, becomes more severe and less predictable. The Inuit of the Arctic attribute a lot of their travel hardships to more dynamic sea ice as well as wind and the hazards it produces (Gearheard 2013, Laidler et al. 2009, Weatherhead, Gearheard and Barry 2010, Prno et al. 2011, Gearheard et al. 2010, Inuksuk 2011).

The increasing unpredictability and fragility of the ice puts a strain on the widely used snowmobile. Though snowmobiles can cover greater distances in less time, they are also susceptible to hidden thin ice and other poor weather-generated ice hazards (Laidler et al. 2009). Prior to the adoption of the snowmobile, Arctic foragers utilized dog sleds. Though dog sleds cannot cover as much ground in the same amount of time, they weigh less and their weight is dispersed over a wider area. Dogs bred for traveling on the ice are also better at detecting possible hazards than snowmobiles (Laidler et al. 2009, Dinero 2013, Freeman 1984, Nelson 1966). Given the current and predicted Arctic climate change and the need for effective transportation to acquire culturally significant country foods (Cunsolo Willox et al. 2012), analyzing these two methods of travel in the face of ongoing climate change will increase our knowledge of decision-making about technologies' ability to buffer risk and uncertainty and can inform policies related to lessening the effects of climate change on current and future "climate refugees".

CHAPTER TWO: BACKGROUND

For the Inuit of the North American Arctic, the acquisition and consumption of country foods (caribou, fish, walrus, ringed seal, and sometimes beluga or bowhead whale), is important to physical, relational, and mental well-being (Cunsolo Willox et al. 2012, Cunsolo Willox et al. 2015, Ulturgasheva et al. 2014). The current changes to the ice that the Inuit rely on makes it more difficult to "travel to cabins and areas with historical, spiritual, and personal significance or access hunting grounds safely and reliably provide food for family and friends" (Cunsolo Willox et al. 2015). In order to provide for themselves, their family, or their social network with country foods essential to well-being, Inuit hunters must make difficult foraging and travel decisions based on risk and uncertainty.

Almost all human decision-making is affected by the unpredictability of future events. Most decisions made by humans involve some amount of risk *and* uncertainty where decision-makers in low risk situations can estimate the probabilities of different outcomes quite well (known unknowns) while decision-makers in uncertain situations cannot make these same estimations as outcomes are absolutely unknown (unknown unknowns) (Chibnik 2011). High risk, then, refers to instances where outcomes are known but it is rather difficult to predict their likelihood. It is important to note that one can measure risk but one cannot measure uncertainty. Decision-making regarding foraging and travel in the Arctic is as complex as the Arctic itself. Most, if not all, decisions revolving around the acquisition of country foods rely on the sea ice and the weather conditions that affect it.

Risk and Increasing Uncertainty on the Sea Ice

As mentioned in the previous section, the sea ice that the Inuit rely on for their livelihood is a unique landscape in that it is exceedingly dynamic. Ocean currents and wind constantly alter the sea ice in the winter when it is the safest (relatively) to engage in traditional activities via travel (Bravo 2009). Some of the most significant of these alterations in regards to transportation are polynyas (areas of thin sea ice or open water that remain open through the winter [Aporta 2011]), cyclical tidal cracks (literal cracks in the ice that open and re-freeze created from tidal cycles [Laidler et al. 2009]), changes in snow drifts (a change in wind direction causing the snow to face a different direction [Gearheard et al. 2010, Inuksuk 2011]), and detachment of ice at the floe edge (where the sea ice meets the sea). These hazards have always been a part of the sea ice landscape and, until recently, Inuit hunters could predict the probability of a successful acquisition of country foods quite well by checking reports or drawing from their body of ecological knowledge (Cunsolo Willox et al. 2012, Gearheard et al. 2010, Gearheard 2013). These alterations to the landscape are being reported by many Inuit as becoming more severe and less predictable, however, due to an increase in day-to-day, week-to-week, month-to-month, and year-to-year weather variability (Weatherhead et al. 2010, Inuksuk 2011, Gearheard et al. 2010, Pearce et al. 2011, Ford et al. 2008, Laidler et al. 2009). This change in weather persistence as Weatherhead and her colleagues (2010) call it, decreases an Inuit hunter's ability to predict the likelihood of a successful harvest, increasing uncertainty. However, even with increasing uncertainty, there are outcomes whose probabilities can be estimated. These outcomes involve the transportation technologies Inuit utilize.

Decisions, Decisions: Dogs vs Snowmobiles

The advent, or adoption, and utilization of transportation technologies can aid in risk management by increasing the probability of successful resource acquisition or decreasing the probability of injury. In the Canadian Arctic, there are two major technologies that the Inuit utilize for local movement: the dogsled and the snowmobile.

Before the introduction of the snow-machine (the terms snow-machine, ski-doo, and snowmobile are generally interchangeable) to the Canadian Archipelago in the 60's, dogsleds were the main transportation technology for the Inuit (Freeman 1984, Nelson 1966, Smith 1972). Lorne Smith (1972) sums up the transition perfectly in his article, "The Mechanical Dog Team: A Study of the Ski-Doo in the Canadian Arctic." He writes:

> The Ski-doo is the first relatively inexpensive, rapid vehicle suited for use in the Arctic to offer an alternative to dog power. As the automobile replaced the horse, the Ski-doo is replacing the dog in Eskimo settlements in the Canadian Arctic, and, as with the 'Horse versus Car' arguments, there are now 'Ski-doo versus Dog Team' arguments.

With environmental change in the Arctic, an analysis of the pros and cons of both snowmobiles and dogsleds is imperative for Inuit who rely on country food harvests to meet their somatic and cultural needs.

In terms of foraging efficiency it comes as no surprise that the snowmobile with its substantially greater speed (anywhere between 1 and 50 km/h [Mertens 2015, Smith 1972]), maneuverability, and load/pull capacity (100-600 kg [Mertens 2015, Smith 1972]) can bring in more country foods than the dogsled (average of 9 km/h and 100-250 kg depending on team size [Gerth et al. 2010, Stuck 2007]). Even the older 1960's version of the ski-doo could cover in two hours what would be a day's travel or more by dog team, allowing Inuit to reoccupy hunting areas that had been considered too distant from their newly formed permanent communities (Smith 1972, Freeman 1984). Forty or fifty years ago, one would be hard-pressed to not adopt the snow machine if the decision was based solely on foraging efficiency as "travelling by dog team is slow and often is back-breaking work. To kill enough seals to feed a dog team requires that a great deal of time and effort be spent hunting, often in the worst weather" (Smith 1972). Now that travel on the ice has become more hazardous the risk and uncertainty of injury or snowmobile loss is becoming more of a concern.

One major difference between the two technologies is that a snow-machine weighs more naturally and puts more pressure on the ice surface than a sled does (Mertens 2015). Compound this with the snowmobile's ability (and the user's tendency) to carry more weight and the contrast becomes more drastic. Snowmobiles fall through the ice never to be recovered again (Légaré 2007, Fleischer et al. 2014, Clark et al. 2016a, Clark et al. 2016b). For a (lone) forager to experience this would be catastrophic as it could lead to serious injury or death and a net hunting return of zero. Though falling through the ice does occur with dogsleds, there are several buffers that prevent or at least mitigate the effects of it. The weight distribution of a dog team is not as narrow as a snowmobile's as the musher and his gear/catch are separated from the dogs. Dogs in the Arctic are also known to be good at sensing danger and hazards and avoiding them (Aporta 2004, Dinero 2013, Freeman 1984, Nelson 1966). If the sled or dogs were to fall through the ice or become stuck, the dogs and the rider(s) can pull it out with relative ease (Freeman 1984, Smith 1972, Laidler et al. 2009). Lastly, if the rider were to fall in the ice, they would be able to stay warm by running alongside the dogsled, something that cannot be done with a snowmobile, even if it were recovered from falling in the ice (Nelson 1966). Lorne Smith (1972) summarizes these dissimilarities well by stating,

> Ski-doos obviously do not respond to stimuli on their own. Because they are mechanical and because they are relatively short, there are problems when travelling on thin ice or on sea ice in the spring, when melt water has formed holes and cracks in the surface. When dogs come to holes or cracks they will go around or swim. In the case of a wide crack the driver may throw them in the water to swim across. The komatik, because of its length, can then be pulled across (it is usually long enough to bridge the gap). When a ski-doo hits a wide crack it sinks. There are no dogs in front acting as path finders to warn of holes or cracks. Fortunately, the driver does not usually sink with the ski-doo since he is not enclosed.

These differences in susceptibility of falling through the ice are becoming meaningful as more potential hazards blanket the landscape.

As snowmobiles began replacing dogsleds in the 60's and 70's the debate raged on about how unreliable these machines could be (Ford et al. 2013). Many, if not most, search and rescue (SAR) incidents involving snowmobiles today are caused by mechanical failure, breakdown, or running out of gas and it is important to note that increasing temperatures will exacerbate this risk (Clark et al. 2016a, Clark et al. 2016b). When deciding to forage with a snowmobile, a hunter must take this risk into account as one can assume that any forager who requires rescue in this instance will be less likely to return with any foodstuffs. In contrast, referring to dogs, Nelson (1966) notes that:

> [Dogs] are slow, but they don't break, [they] have great stamina and endurance. They can pull heavy loads for long periods of time. If one dog dies or is crippled, the others keep pulling. If a team runs out of food, a hunter can re-supply on the trail… Conceivably, a hunter with a dog team could travel indefinitely, living off the land and feeding his dogs, whereas a hunter with a ski-doo is limited by the amount of fuel he can

> carry with him. Moreover, dogs can be eaten if necessary, but there is little nourishment in boiled ski-doo track.

Dog teams are not impervious, though; there are conditions under which the dogs can collectively become "sick" or unable to go on (temperatures around 0° Celsius or poor ice surface conditions [Gerth et al. 2010, Inuksuk 2011]), stranding the forager and his or her dog team. Inuit hunters that do use snowmobiles can also lessen the risk of breakdown while reducing the time required for maintenance by just purchasing a brand new snowmobile every year or two (Collings 2017). Though this does add to the financial cost of snowmobile use, it can save a lot of future heartache. With the Arctic climate becoming more hazardous, the likelihood for either of these technologies to "break down" and expose the forager to the harsh sea ice landscape increases as temperatures rise, and the consequences of being stranded for too long are more severe with greater storm frequency and overall climatic variability (Hovelsrud and Smit 2010).

Reducing travel time, according to Kelly (2007) should be the general goal of central-place foragers if the maximization of foraging efficiency is what they base their decisions. Snowmobiles have certainly done that for the Inuit. Nevertheless, there are some drawbacks associated with the greater speed of the snowmobile and advantages to the slow speed of the dogsled. An example of this is, "Snowmobile travel results in a much narrower perception of the landscape since the traveler focuses mostly on the trail. The lower pace of a dog sled allows better memorization of landmarks and a view of the surroundings that is 360 degrees wide" (Aporta 2004). This ability for dogsled operators to better study the landscape and to navigate more effectively is compounded by the dogs' innate ability to navigate as well. Richard Nelson (1966) noted that, "The best friends of the poor navigator or the man who becomes lost in a storm are his dogs. A lead dog is praised if it is able to find its way home well, and the older dogs are especially good at this… In most cases the dogs will seek out the dog trails that lead in the correct direction, but if necessary they can probably guide themselves without this aid." It goes without saying that a snowmobile cannot find its way home and a snowmobile operator must slow down or stop to get the same effect as the slower dog team, negating the snowmobile's speed advantage for a time. Another relevant facet to decreased speed and foraging efficiency is the sled dogs' ability to hunt and identify seal breathing holes or polar bears in real time while traveling or while stopped (Smith 1972, Freeman 1984). All of the aforementioned pros and cons of both technologies are relevant to a hunter making a risk assessment based on travel time, speed, distance, and overall harvest success. Of course, once the Inuit moved to more permanent settlements in the 50's and 60's and started participating in a wage economy, their transportation option decisions became more economic in nature, a topic that will be addressed in the discussion.

Study Site: Why Igloolik and Why Winter?

Igloolik (69°22′34″N 081°47′58″W) is a community in Nunavut approximately 320 km north of the Arctic Circle and approximately 70 kilometers north of Hall Beach, as the bird flies, in the Foxe Basin of the Canadian Archipelago (Laidler et al. 2009, Laidler et al. 2008). I chose Igloolik (ᐃᒡᓗᓕᒃ) for the intensity of research and number of academic articles specifically looking at Igloolik. It is also one of the four communities detailed in the SIKU Atlas (a website that, based on ethnographic interviews, GPS, and GIS, geographically pinpoints the floe edge of certain years, common camping sites, trails used for travel, and various hazards like cracks seen on the ice) developed by Laidler and her colleagues (2010). This coupled with the fact that Igloolik has its own video website and film production company (www.isuma.tv and Igloolik Isuma Productions Inc.) loaded with great ethnographic and visual resources of Inuit hunts and utilization of dogsleds and snowmobiles.

Since country foods make up the majority of the Inuit diet across the Arctic (Wenzel 1991, Laidler et al. 2009, Archer et al. 2017, Gearheard 2013), the people of the Canadian Arctic are harvesting year-round. It is during the winter months, though, when (relatively) safe long-distance travel on the ice by dogsled or snowmobile is possible as freeze-up has mostly completed. According to Clark et al. (2016b) it is also the time (November-March) when most SAR operations occur. I also chose winter to lessen temperature's affect as a variable and to reduce the complexity of the model and because it is when there is the greatest access to the most hunting areas traversable by either dogsled or snowmobile, whilst being hazardous enough to test this thesis' hypotheses.

Literature Review and Problem Statement

With the high prevalence of snowmobile related incidents and SAR operations (Légaré 2007, Fleischer et al. 2014, Clark et al. 2016a, Clark et al. 2016b), it is more crucial than ever to look at the trade-offs associated with transportation in the Canadian Arctic in the face of ongoing climate change. Evolutionarily speaking an actor should seek to maximize survivability and reproduction. Survivability in this context is engaging in behaviors that maximize personal safety and caloric return rates. Effective decision-making that involves a meticulous risk and uncertainty assessment can increase survivability. Arctic risk and uncertainty assessments, then, should be based on an actor's ability to safely and successfully harvest country foods. Thus, one trade-off relevant to travel in the Arctic is the amount of country food one can obtain for oneself, one's family, and one's social network, with another trade-off being personal safety while foraging on the frozen sea ice or harsh Arctic weather on land. These trade-offs have been discussed in depth in the previous sections in regards to the two major winter transportation options. What is missing is a synthesis of how these differences in the two technologies could affect an actor's ability to safely and successfully harvest country foods in the contemporary and predicted Canadian Arctic's rapidly changing weather and climate systems.

Most contemporary research concerning climate change in the Canadian Arctic briefly brushes upon snowmobiles versus dogsleds in terms of safety, but rarely goes into the specifics of how different weather conditions might influence successful harvests (or return rates) and safety. George Wenzel (1991) was close when he detailed the return rates of both transportation technologies, but failed to include how specific weather conditions and the hazards associated with them might affect cost-effectiveness. Regarding safety, Dylan Clark and colleagues (2016b) did a masterful job of linking specific weather conditions with travel safety (prevalence of SAR operations) in the Arctic but, due to the limitations of their data, could only pin mechanical failure or running out of gas as primary causes. Ethnographically, wind speed and direction are reported as having significant effects on travel safety (Weatherhead et al. 2010, Gearheard et al. 2010, Inuksuk 2011, Bravo 2009, Laidler et al. 2009). It is of interest to note that they found that the presence of a wind flag (wind speed > 30 km/h) had little to do with SAR prevalence (insignificant P-value). This is likely because they checked daily weather conditions just like an Inuit might before heading out. If wind conditions are too risky at the beginning of the decision-making process, travel is likely to be postponed and no SAR operations are possible (Laidler et al. 2009, Gearheard et al. 2010). Their wind data also did not take into account changes in wind speed that can occur within a day. In addition, due to the nature of their study, there was little to no mention of return rates.

With the importance that Inuit place on “going out on the land” and consuming country foods (Ulturgasheva et al. 2014, Cunsolo Willox et al. 2012, Gearheard 2013), looking at how climate change might affect local travel is vital. This study seeks to discover, through the use of an agent-based model, how an increase in weather variability (focusing on wind speed and direction) in the Arctic will affect the probabilities of a successful harvest considering the tradeoffs between the two major transportation options, and, more specifically, what it is about these technologies that might lead to an increase or decrease in this probability.

Hypotheses Tested

H1: In low-risk conditions where there is little to no weather variability, snowmobiles will out-produce dogsleds in terms of resource acquisition due to their increased speed and carry weight. The negative trade-offs (poorer navigation, greater susceptibility to hazards, inability to detect and avoid hazards) associated with the dangers of snowmobile travel will not have a significant enough effect on yield and successful harvest rate.

H2: In uncertain conditions where there is high weather variability, dogsleds will begin to produce more than snowmobiles in terms of resource acquisition regardless of snowmobiles’ greater speed and carry weight. The trade-offs associated with safety will have a significant negative effect on the yield and successful harvest rate of snowmobiles.

CHAPTER THREE: METHODS

Model Description

I used Netlogo (version 6.0.2) to develop an agent-based model. The model places artificial agents at the town center of Igloolik. From there the agents spread across the landscape in search of resources with which to return home. Agents interact with the landscape and make decisions based on a set of rules that are detailed in the coming sections. These rules, the dogsled and snowmobile agents, and the landscape work together to simulate different weather variability situations in which Inuit hunters might find themselves.

The Landscape

The model is a 193 x 189 (36,477 cells) sized grid where each cell represents approximately 500m^2 (calculated by seeing how many 1 cell moves it took to go the 70km between Igloolik and Hall Beach). I used a Google Maps picture of Igloolik and its surrounding area as the background. With the background image, each cell is assigned a specific color and from there a differentiation between the sea and the land can be made for Netlogo (patch colors of 97.9 [blue] are sea cells while patch colors of 39 and 39.5 [white] are land cells). I placed five floe edge locations into the agent-based model. The floe edge locations were taken from Laidler and colleagues (2010) work with the Inuit SIKU Atlas which compiled several ethnographic reports of ice characteristics and travel paths (Appendix B). Produced hazards are randomly strewn across the landscape based on set parameters and are colored red. I calibrated the model to last four days then stop as to give agents enough time to complete several trips to the flow edge. Appendix C is a screenshot of the model's interface.

Outcome Variables

The two major outcome variables are agent yield and successful harvests. Successful hunts of walrus at the floe edge yield the maximum carry weight of the agent, while successful seal hunts on the sea cells yield 1 unit (the usage of 1 unit and maximum carry weight is discussed in a later section). The model will also report how many successful harvests (a successful return of at least 1 unit of yield) have occurred over the course of four days.

Model Parameters

1) Agent Parameters— The agent parameters include:
   a) Dogsled and snowmobile susceptibility to hazards (If a hazard is encountered, the percent chance that an agent will require SAR).
   b) Snowmobile carry weight (how much more snowmobiles can carry and turn in than dogsleds [x1, x2, x3, x4], also affects speed of snowmobile when full; dogsled maximum carry weight is 2).
   c) Dogsled and snowmobile speed (range is 0 to 15km/h for dogsleds and 0 to 50 km/h for snowmobiles).
   d) Floe edge hunting success (percentage chance that maximum carry weight will be added to the agent when a floe edge space is reached).
   e) Dogsled and snowmobile seal hunting success (percentage chance that 1 unit will be added to the agent after each move on a sea ice cell).

f) Dogsled and snowmobile hazard avoidance (percentage chance that the agent will detect and avoid a hazard in front of them).

g) Dogsled and snowmobile navigation (likelihood that the agent stops for a turn; simulates getting lost and/or having to stop to gather one's bearings; heavily affected by wind direction change parameter and weather variability).

h) Possibility of mechanical breakdown (the likelihood that a snowmobile will require SAR due to a snowmobile's natural propensity to break down).

Landscape Parameters—Wind speed and wind direction are the two weather conditions used in this model as they are most relevant to winter climate change and are reported or predicted to worsen (a discussion on what conditions were removed and why is in a later section). Wind speed affects the concentration of hazards on the landscape and, if it is severe enough, affects the likelihood of agents requiring SAR. An increase in the wind speed value increases the concentration of hazards on the landscape. In the agent-based model, if an agent requires SAR they drop out of the model and they no longer add to yield or successful harvests. If the parameters wind speed or wind direction change are high enough there is also an increased likelihood of agents requiring SAR when they reach the floe edge (simulating the possibility of ice breaking off on the floe edge leaving foragers stranded on the floating ice). Wind direction also affects agents' ability to move on the landscape, simulating the possibility of getting lost. Wind speed was given more power in affecting hazard concentration on the ice than on land (wind can create thin ice or iceless patches). I developed a weather variability parameter that changes the likelihood that either wind speed or wind direction will change values for two simulated hours before returning to safe conditions. Hazards are redistributed among the landscape every two simulated hours as well.

<u>Model Walkthrough</u>

Once all parameters are set and the model begins running, agents set out from the town center of Igloolik. Their destination is always one of five randomly selected floe edge locations. Based on the weather variability parameter, hazards begin to randomly appear on the landscape at different concentrations. If an agent lands on a red hazard cell on their way to the floe edge (assuming they did not detect and avoid it), whatever was set as their "susceptibility" value will be the percent chance that they will require SAR and be removed from the model, no longer able to contribute to yield or successful harvests. Every time an agent lands on a blue sea ice cell, there is a percent chance, based on the "sealing success" value, that one unit of yield will be added. If an agent reaches their maximum carry weight from hunting seal before arriving at the floe edge, they will return to Igloolik.

The "floe edge hunting success" parameter dictates whether or not the maximum carry weight for either technology will be added once they reach the floe edge. There is an inherent chance that an agent will require SAR at the floe edge. This chance is increased depending on whether wind speed or wind direction values were increased to high enough levels by the weather variability parameter. Agents then turn around and return to Igloolik regardless of their floe edge success. Once any agent reaches Igloolik, all yield units and one successful harvest (so long as at least two units were returned) will be added to the counters of the respective technologies. On their way to the floe edge and back, depending on the agents' navigation value and weather variability's effect on the wind direction parameter, there is a chance that an agent will "get lost" requiring them to not move for a step. This process is repeated until 384 (or four simulated days) steps have been reached.

Model Caveats

I made several assumptions and variable exclusions while creating this model:

1. The model assumes that foragers would not decide to leave Igloolik and forage if weather conditions were not suitable at the onset of the decision-making process. At the beginning of each run, there are no hazards on the ice because wind speed is low and there is no wind direction change so the likelihood of getting lost or stranded on the floe edge is low.
2. Snowmobile and dogsled travel are not possible when there is little to no snow on the land and travelers would know this ahead of time and refrain from traveling. Thus, I eliminated snowfall on the land as a weather condition. I also did not implement ocean currents in the model, even though many Inuit report currents as having drastic effects on travel safety. The reason for their exclusion was because, even though they affect the landscape in major ways, they are cyclical and easily predictable (Inuksuk 2011). I took temperature out in the late stages of the model's creation to reduce the model's complexity and to focus more on wind speed and direction. By using facilities with more computing power, these three variables could be re-introduced into the model to increase realism.
3. Fuel (be it gasoline or food for the dogs) was not taken into account as long-distance travel (more than 160 Kilometers round-trip) would have increased the size of the model, decreasing the accuracy (zooming out the landscape would

make the cells/patches larger in regards to their actual area making a hazard such as a patch of thin ice several square kilometers in size). The model, then, assumes that foragers can complete a trip to any floe edge location and back on one tank of gas or with well-fed dogs.

4. Economically there are several factors that would have been relevant to Inuit travel in the Arctic (fuel, upkeep cost, snowmobile/sled purchases, etc) but, again, the addition of too many variables or reporters would require more time and computing power than is necessary.
5. A successful seal hunt was given the value of 1 unit and a successful walrus hunt at the floe edge gave the agent their maximum carry weight (if snowmobile carry weight is four, a successful walrus hunt will yield 8 units). This was done for simplicity's sake. Instead of reporting hundreds of thousands of calories I looked at the average weight dogsleds and snowmobiles could carry, implemented a slider to affect the ratio between the carry weights, and made it so the agents turn back when they are full and can only turn in what they have collected. Thus, the yield outcome variable essentially reports how many kilograms of seal or walrus meat each technology brings in. With this, the final report of dogsled and snowmobile yield is still accurate and easier to analyze.

Running the Model

It is important to note that, with BehaviorSpace (a tool in Netlogo), all parameters are tested against each other at least once (one can set how many times each combination is ran). For example, if one were to keep everything constant but give weather variability the values of 10, 20, 30, and 40, the program will produce four rows in an excel sheet. If one were to then include snowmobile susceptibility of 20 and 40, eight rows in the output would be produced. The number of rows exponentially increase with each variable added and every extra combination run doubles that value. The following parameters with one repetition garnered 8,000+ rows in the output. Adding any more values to the variables or any more combination runs would have increased the data points to extreme levels. Appendix A is a condensed output from the following run of the model.

Model Run 1: Technology Parameters' Effect on Harvest Rates

Reporters: Successful Snowmobile Harvests vs Successful Dogsled Harvests

Agent Count: 50 Snowmobiles and 50 Dogsleds

Each Combination Ran 1 Times

Rows in Output: 8748

Parameters:

Wind Speed	15 km/h	Weather Variability	0/20/40/60 %
Wind Direction Change	0	Snowmobile Avoidance	20/30/40%
Snowmobile Susceptibility	40/50/60%	Dogsled Susceptibility	10/20/30%
Snowmobile Speed	36 km/h	Snowmobile Navigation	60/70/80%
Snowmobile Carry Weight	2x/3x/4x	Breakdown Chance	.1%
Dogsled Sealing Success	5%	Dogsled Avoidance	60/70/80%
Dogsled Speed	9 km/h	Dogsled Navigation	80/90/100%
Snowmobile Sealing Success	2.5%		

With 8,748 data points, this run of the model demonstrates the effect weather variability has on each technology's trade-offs and how these trade-offs affect the number of successful harvests. In order to do this, I had to give each trade-off multiple values to see how a change in each value would influence successful harvest rates (to obtain a Pearson's r value). The multiple values that I gave to the trade-offs are not equal as I varied them around values that I estimated from ethnographic research. The results for this model run are in Table 1.

<u>Model Run 2: Weather Variability's Effect on Harvest Rates</u>

Reporters: Snowmobile Yield vs. Dogsled Yield and Successful Snowmobile Harvests vs Successful Dogsled Harvests

Agent Count: 10 Snowmobiles and 10 Dogsleds

Each Combination Ran 50 Times

Rows in Output: 550

Parameters:

Wind Speed	15 km/h	Weather Variability	0-100% at 10% Intervals
Wind Direction Change	0	Snowmobile Avoidance	30%
Snowmobile Susceptibility	50%	Dogsled Susceptibility	20%
Snowmobile Speed	36 km/h	Snowmobile Navigation	75%
Snowmobile Carry Weight	4x	Breakdown Chance	.1%
Dogsled Sealing Success	5%	Dogsled Avoidance	80%
Dogsled Speed	9 km/h	Dogsled Navigation	100%
Snowmobile Sealing Success	2.5%		

For the second model run, I only gave weather variability multiple values. Dogsled speed was set to 9 km/h adhering to Gerth et al. (2010)'s finding that the average speed of a dog team is 9 km/h. Though the max speed of a snowmobile can reach upwards of 50 km/h with no cargo (Mertens 2015), it is unrealistic for a snowmobile to maintain that speed for several hours, thus I chose a more modest 36 km/h (still four times faster than dogsleds). For the parameter, "Breakdown Chance" .1% might seem small but it is a .1% chance every time the snowmobile agent moves and an agent moves several hundred times per run. Keeping wind speed and wind direction change relatively low simulates that when the Inuit set out to engage in traditional activities the weather was decent enough. That is subject to change while they are out, however, with higher weather variability values. I estimated all other values based on ethnographic research.

CHAPTER FOUR: RESULTS

I used SPSS to analyze the results of the two runs. I varied the parameters around values that, to me, best reflected the various trade-offs associated with the two technologies. Dogsled users were generally (but not exclusively) better at navigating, avoiding hazards and were less susceptible to hazards when one was encountered. I also varied the carry weight parameter to determine how the reduction in speed with heavier loads might affect successful harvest rates for snowmobiles. This was done to test which parameter, when increased or decreased, had the greatest effect on successful harvests. The variables that I held constant were speed (though speed changes with how much weight is added to the agent), breakdown chance for snowmobiles, wind speed and direction, and seal harvest rates for both technologies. I then ran correlations to find the Pearson correlation value for the varied parameters. This run of the model shows that weather variability has relatively similar significant effects on both dogsleds and snowmobiles (Pearson Correlation of -.810 and -.822 respectively).

Table 1 shows how each parameter affects successful snowmobile harvests in various weather variability conditions. Across all variability conditions, carry weight (and its effect on speed on the return trip) has a significant moderate to strong negative effect on successful harvests. Not surprisingly, when conditions are not variable, higher snowmobile susceptibility and their inability to efficiently detect and avoid hazards has little effect on successful harvests. In higher weather variability, it is interesting that a snowmobile’s poor navigation and poor ability to detect and avoid hazards has a lesser effect on successful hazards than carry weight and snowmobile susceptibility. These results show that it is the snowmobile's greater susceptibility to hazards associated with its heavier, less dispersed weight, poor ability to get 'unstuck', and other factors related to the physical characteristics of the snowmobile, have the greatest negative effect on the need for SAR and subsequently successful harvests.

Table 1: Weather Variability's Effect on Snowmobile Parameters' Effect on Number of Successful Harvests

Weather Variability			Carry Weight	Snowmobile Susceptibility	Snowmobile Navigation	Snowmobile Avoidance
0	Successful Snowmobile Harvests	Pearson r	-.648	-.006	.601	-.008
		Sig.	.000	.770	.000	.714
		N	2187	2187	2187	2187
20	Successful Snowmobile Harvests	Pearson r	-.520	-.174	.352	.044
		Sig.	.000	.000	.000	.042
		N	2187	2187	2187	2187
40	Successful Snowmobile Harvests	Pearson r	-.441	-.304	.190	.096
		Sig.	.000	.000	.000	.000
		N	2187	2187	2187	2187
60	Successful Snowmobile Harvests	Pearson r	-.405	-.362	.129	.110
		Sig.	.000	.000	.000	.000
		N	2187	2187	2187	2187

The second model run (Figures 1-3) tested the hypotheses more thoroughly by making constant, rather than flexible, the relevant variables. I set each variable to better match the trade-offs discussed in previous sections (refer to second model run). I organized the data to show under what conditions one technology might outperform the other in regards to overall yield or successful harvests. To do this, I calculated the percent of snowmobile yield and successful harvests versus dogsleds for each case. All values above .5 indicate snowmobiles outperforming dogsleds in their respective reporters.

Figure 1 shows all data points organized by the recoded weather variability values. It also denotes the .5 thresholds for both yield and successful harvests.

Everything above the horizontal line in Figure 1 represents instances where snowmobiles had more successful harvests than dogsleds after four days and everything to the right of the vertical line represents instances where snowmobiles yielded more resources than dogsleds. Approximately 72% of cases lie below the horizontal line (for the majority of cases, snowmobiles had fewer successful harvests) with most of them grouped under moderate (80% under the line) and high variability (82.5%). 83% of cases lie to the right of the vertical line (for the majority of cases, snowmobiles out-produced dogsleds) with most of them grouped under low (95%) and no (100%) variability. Dogsleds out-produced snowmobiles 14% of the time under moderately variable conditions and 33.5% of the time in highly variable conditions.

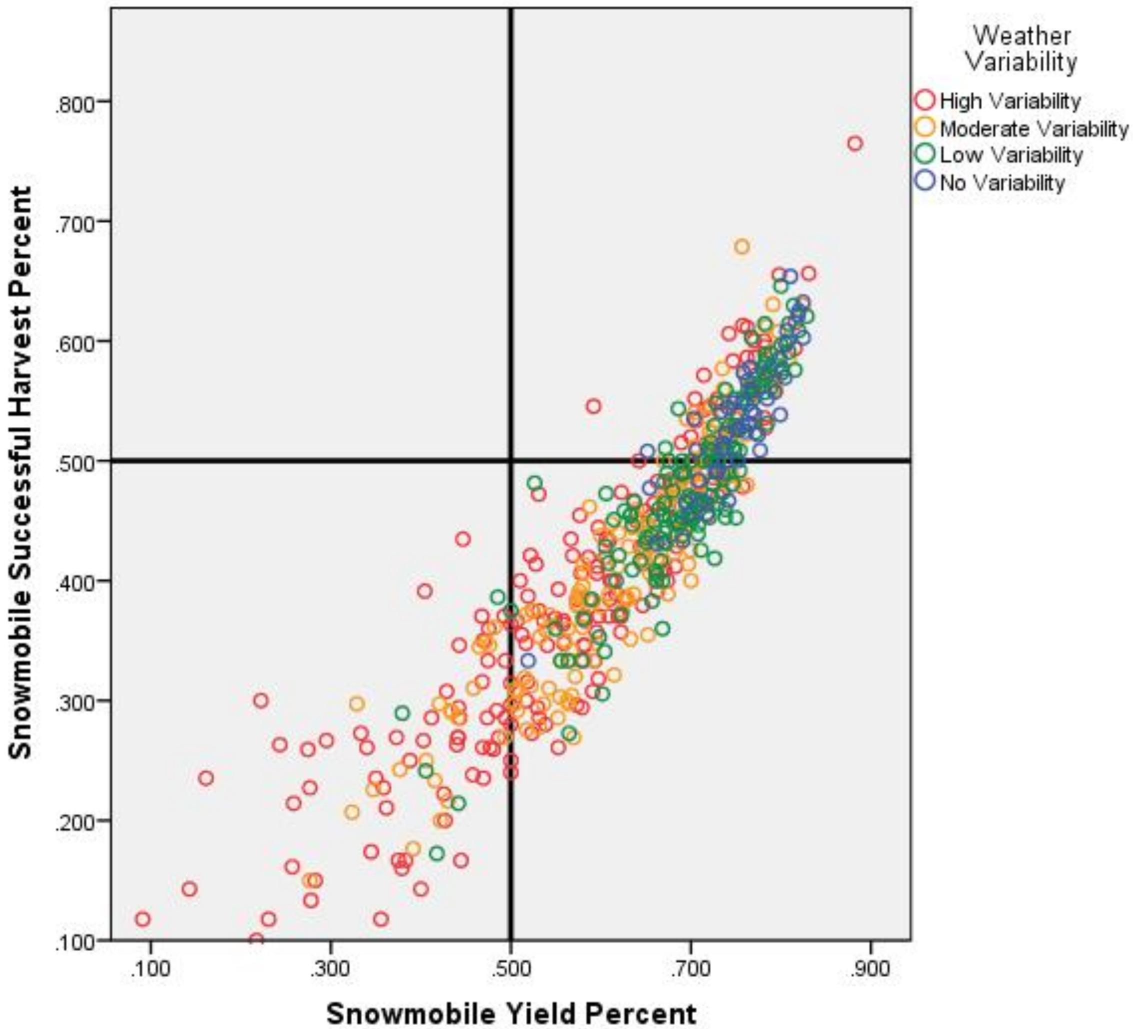


Figure 1: **Snowmobile Successful Harvests and Yield Percents**

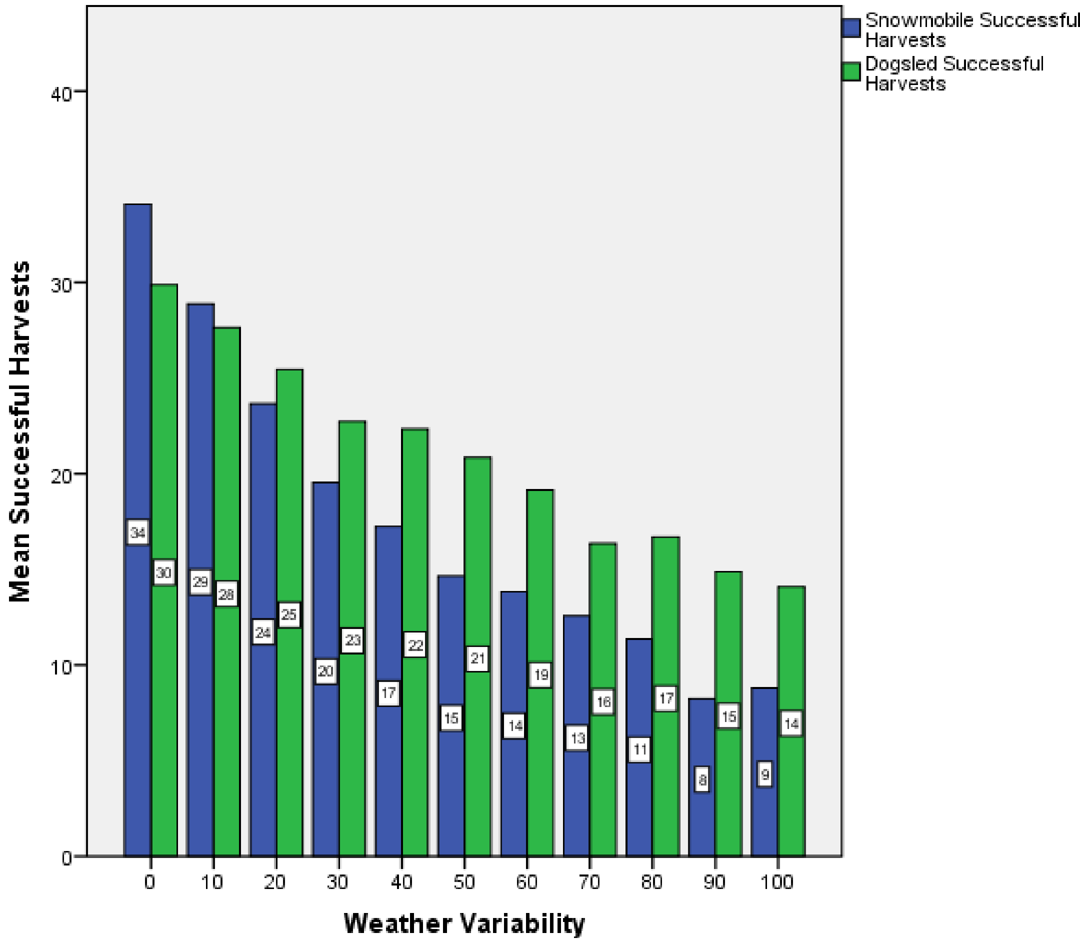


Figure 2: Weather Variability's Effect on Successful Harvests

Figures 2 and 3 break down the average successful harvests and average yield for both technologies under increasing weather variability. When weather conditions have a 20%+ of changing every two hours, dogsleds begin to have more successful harvests than snowmobiles and when weather variability is 80%+, the yields for dogsleds and snowmobiles are at their most equal (snowmobiles brought in on average 58.3% of both technologies' resources [Figure 3]). All differences between the two technologies at each level of weather variability are significant for both yield and successful harvests (p-value <.001).

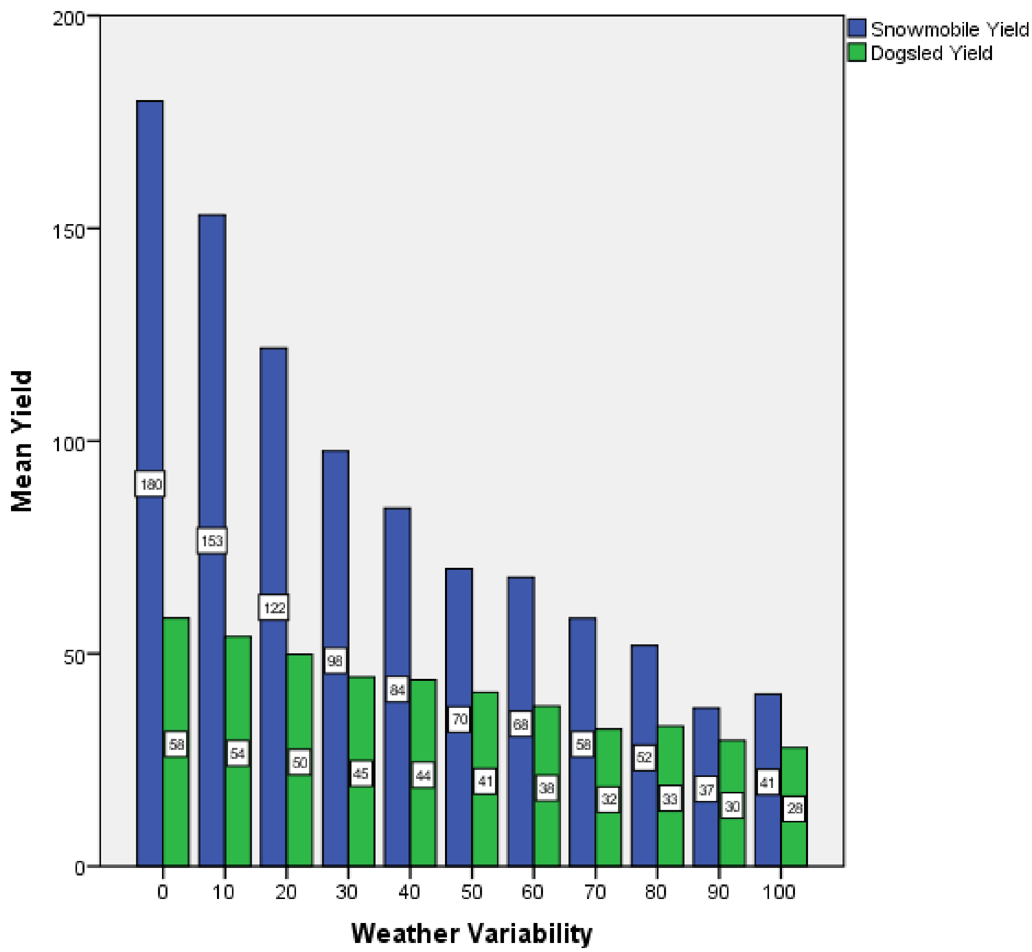


Figure 3: **Weather Variability's Effect on Both Technologies' Gross Yield**

Support for Hypotheses

<u>Hypothesis 1 was partially supported</u>

The model shows that snowmobiles in low-risk conditions (weather variability of 0-30) consistently out-produced dogsleds (Figures 1 and 3). Successful harvests decline rapidly for snowmobiles, however. Once there is a 20% or more chance of weather conditions changing every two hours, snowmobiles' successful harvest rate falls significantly below that of the dogsled (Figure 2). The results show that snowmobile susceptibility and poor ability to detect and avoid hazards do not have a significant effect on successful harvests when weather conditions are good and relatively stable. Carry weight and navigation still had significant effects on successful harvest rates under these conditions.

Hypothesis 2 was partially supported

Under no conditions in the model did dogsleds consistently average more resources than snowmobiles (Figure 3). The model shows that it is only when the likelihood of significant weather changes every two hours is above 80% that snowmobile and dogsled average output is closest to being equal (Figure 3). It is under these conditions that snowmobiles' greater susceptibility to hazards begins to have a strong negative effect on successful harvests. Though it has a significant effect (p-value $< .001$), a snowmobile operator's poor ability to detect and avoid hazards is a weak predictor (Pearson $r < .150$) of successful harvests when weather variability is higher.

CHAPTER FIVE: DISCUSSION

What the Model Can Tell Us

The first run of the model shows that dogsleds and snowmobiles are nearly equally affected by weather variability (Pearson r values of .810 and .822 respectively) when ethnographically relevant variables are taken into account. The model also demonstrates which negative aspects of snowmobiles have the greatest effect on successful harvest rates. As weather variability increases, so does the effect of a snowmobile's disadvantageous physical aspects relating to susceptibility when a hazard is encountered (hazard susceptibility parameter). This physical susceptibility is the strongest predictor on a snowmobile's likelihood for needing SAR and the decreased successful harvest rate that that entails. The operator of a snowmobile's relatively poor ability to detect and avoid hazards is not a strong predictor of successful harvests. This value might have changed if I increased the snowmobile's ability to detect and avoid hazards the slower it was moving; an improvement to the model that can be made. The influence of greater carry weight on successful harvests decreases as weather variability increases. This is likely the result of how the wind direction parameter causes snowmobiles to get lost. The significantly reduced speed of a snowmobile coming back from the floe edge with a hunk of walrus meat would make getting lost less dangerous as the slow speed would resemble that of a dogsled. If the predominant wind direction were to change on a whim, altering the snow drifts, slower speeds would allow for a snowmobile operator, like a dogsled operator, to get a better grasp of their surroundings, allowing them to identify possible landmarks or errors in the path they've taken. This might also explain why the effect navigation has on successful harvests also decreases as weather variability increases.

The second run of the model drew from ethnographic data to narrow the scope and better determine the effects weather variability (and therefore the likelihood of more hazards) might have on snowmobiles and dogsleds. Under these conditions, not surprisingly, snowmobiles with their added weight on the ice, propensity for breakdown, and other disadvantages, have greater need for SAR operations than do dogsleds, decreasing their successful harvest rate. Having said that, the agent-based model shows that the dogsled simply cannot consistently out-perform the snowmobile in regards to gross yield and successful harvests in low-risk conditions when weather variability is low and hazards are far and few in-between. In terms of risk, when weather variability is low, one could make a reasonably accurate estimation that a successful snowmobile trip has a higher probability of saving more time and yielding more resources than putting the dog team back together. One might also be able to estimate the likelihood of a successful harvest by weighing the probability of mechanical breakdown based on past events (maintenance efforts, purchase of a new snowmobile), or estimate the probability of getting lost (bringing a GPS, looking at wind reports), stuck (planning a route) or sunk (brushing up on different ice types and visual clues). The model shows that, it is when weather variability and the likelihood of requiring SAR for snowmobiles is high, that dogsledding is the safer, more reliable, and, at times, more lucrative choice (when weather variability is 70-100, dogsleds out-produced snowmobiles 33% of the time). If one were able to perfectly predict the percent chance of weather changing every two hours, the model shows that keeping a dog team handy in case of high variability would increase the probability of a successful harvest and a culturally significant meal at the table. This scenario is unrealistic as Inuit are having increasing trouble predicting the weather and it is difficult to predict the percent chance that the weather will change at a given moment. Weather conditions and variability are predicted to worsen, however. The agent-based model developed for this thesis and ethnographic research suggest that the use of snowmobiles in hazardous conditions has a negative impact on the probability of a successful, non-SAR needing, harvest of country foods. It may come to pass, then, that in the future a hunter would be able to predict, or rightfully assume, that good weather conditions (whose overall prevalence will decrease) have a low chance of holding up. Under these circumstances, uncertainty becomes risk. One could estimate the probability that the advantages dogsleds have over snowmobiles will lead to a greater number of successful harvests. Thus, it would behoove an Inuit hunter who relies on the frozen sea ice to acquire country foods to re-adopt the dogsled to increase the probability of successful harvests. Unfortunately, it is not that simple.

So Why Not Re-adopt the Dogsled?

The notion of a wide-scale, or even small-scale, re-introduction of dogsleds is more complicated than simply looking at physical and dietary risk and uncertainty. Time, effort, and money are also factors influencing the likelihood of a switch. Thus, an economic analysis is vital to answering this question. It would not be far-fetched to assume that dogsleds are economically more viable than snowmobiles. Snowmobiles, being from the South, must first be purchased and maintained by cash and the only way to obtain cash in the permanent Inuit settlements of the Canadian Arctic is to participate in various wage-earning activities. These activities include, mining, guiding tourists, working stores, selling country foods/goods, etc. (Prno et al. 2011, Smith 1991, Wenzel 1991, Wenzel 1995). Currently, being able to go out on the ice and engage in traditional activities relies heavily on the access to a snowmobile and Ford et al. (2013) emphasize that the effective use of snowmobiles as a hunting tool, "Is no longer determined just by a hunter's skill, knowledge, and social capital but also the ability to afford equipment and gasoline, tying hunters to volatile global markets." More specific to Igloolik Ford and Beaumier (2011) note that:

> High hunting costs were identified as constraining the availability of country foods. Modern hunting is capital intensive requiring expensive equipment including snowmobiles, boats with outboard engines, and rifles, and with increas- ing costs of gasoline and the cost of living in general, affording hunting is challenging for those on limited income. Even for households who have all the equipment, usage is often rationed due to the cost of gasoline. Hunting trips, for example, can cost hundreds of dollars without guarantee of catching any animals. In 2008, a return caribou hunting trip, for instance, would necessitate a minimum of 240 litres of gasoline at a total cost of $340.

Since prices are apt to change and for the purposes of this section regarding decisions and transportation technologies a detailed assessment of cost is not necessary. The aforementioned tethering of Inuit to global markets has affected access to snowmobiles and created a divide in some communities. For example, "In many instances, the persons best equipped for harvesting possess neither the time nor have the experience to use these items to best advantage. Conversely, the most experienced hunters are often cash poor" (Wenzel 1995). Those who can afford the expensive hunting equipment do not have time to use it because they are actively participating in the wage economy while those who do have the time and possible expertise to hunt effectively cannot afford the equipment on their own. This puts a damper on the economic feasibility of the snowmobile versus the dogsled as the only monetary cost in using a dogsled and dog team that is comparable to the snowmobile is food. The only thing that a hunter might (though not necessarily required to) spend cash on is low-quality dog food from the store or even high quality food from fellow hunters. One thing that the snowmobile has over the dogsled is that it one does not have to feed it when it is not in use, but when compared to the overall cost of the snowmobile, this advantage is negligible (Smith 1972).

This large economic disparity between the two technologies is softened a bit, though. In regards to the time and money divide George Wenzel (1991) found that, "Harvesting, even with the costs of periodic capitalization and annual operations and maintenance, proves to be a monetarily more economic alternative," to simply living off store food, a contemporary Inuit's only other option if their snowmobile breaks down or if they have no access to one. So, how then, can the Inuit mostly rely on country food when only the wageworkers can afford snowmobiles? Luckily, Inuit hunters have a way of bypassing their inaccessibility to snowmobiles. Inuit hunters rely heavily on their social networks when costs or risks are too high (Wenzel 1991, Wenzel 1995, Laidler et al. 2009, Ford et al. 2013, Archer et al. 2017, Hovelsrud and Smit 2010, Collings 2017). While visiting Ulukhaktok, Peter Collings (2017) found that:

> Hunters tend to solve the problems of subsistence hunting in a very specific way… Hunters seemed always to lack cash on hand, and they preferred to solve problems using their social networks. That is, food giving to collaterals and distant collaterals is part of a much more significant movement of goods, involving the free flow of snowmobiles and ATV parts, tools, sleds, labor, and other favors.

It's this free flow of snowmobiles that gives hunters who may have the time and expertise to hunt the ability to engage in more traditional activities and provide for themselves and their social network. In exchange for being allowed to borrow harvesting equipment, a portion of the harvest can be directed to the family member or other close tie who lent the equipment. The sharing of snowmobiles, then, increases the economic viability of the snowmobile. How much of a buffer can this sharing have on the ever-increasing prices of equipment and commodities, though?

Fuel, equipment, and commodity prices continue to rise in the secluded communities in the Canadian Arctic (Hovelsrud and Smit 2010, Ulturgasheva et al. 2014). Nowak (1975) argued that, "If this trend continues… foraging might become less mechanized in an attempt to reduce monetary costs; this would involve a return to earlier technologies, such as dog team travel in winter and kayak hunting in open water." It then seems that the switch to dogsleds, on top of the results from the model, is also more economically viable. Like anything involving humans, it is not that simple, though. Eric Alden Smith (1991), when talking about a hypothetical study not unlike this one, warned:

> If we assume further that the harvest rate would be the mean rate measured in this study, we obtain an estimated labor cost of provisioning a dog team of nearly 1500 hours. Although this is at best a rough estimate, it is so much larger than the 500 hour figure estimated for snowmobile labor investment that I think the burden of proof falls on those who would assert that the Inujjuamiut shift from dog teams to snowmachines is economically irrational.

Though Smith was arguing for the wide-spread shift from dogsleds to snowmobiles, his calculated labor costs of 1500 hours and 500 hours puts the "burden of proof" inversely on those who would suggest a switch to dogsleds being more economically rational. Ford et al. (2013) also speak to the time and effort cost of a dog team being a switch deterrent, "The reintroduction of dog teams would likely reduce vulnerabilities of ice use, but dog teams are unlikely to be widely adopted again due to the time and skill needed to raise and train hunting dogs." Even with the results of the agent-based model and the fact that dogsleds are less expensive than their counterpart, the decision to switch seems to rely more on time and skill. This, compounded with less inter-generational transfer of the traditional land skills necessary for safe and successful hunting (Laidler et al. 2009), makes the re-introduction of dogsleds on a major scale less likely contemporarily or in the future so long as snowmobiles have the ability to operate on the landscape. This is not to say that if prices climb high enough or if the climate becomes too severe that those who wish to continue in engaging in traditional activities will not make the switch.

An emotionless machine would likely continue the utilization of snowmobiles until the exact time where it is physically impossible or in the unlikely event where time and effort favors dogsleds somehow. One cannot disregard the great importance that Inuit place on “going out on the land” and consuming country food, however. Many Inuit, “Continue to rely closely on the land for hunting, trapping, foraging, firewood, leisure, socio-cultural connections, and physical, mental, emotional, and spiritual health and well-being” (Cunsolo Willox et al. 2012). The value that the Inuit place on their land might increase the pressure to switch to dogsleds if the dangers or cost of snowmobile usage worsen to the point where “going out on the land” is no longer safe or affordable.

The Future of the Arctic

The Arctic is already experiencing warmer weather, later ice formation, earlier ice break-up, increased weather variability, increased storm frequency, and other unfavorable weather conditions. The Arctic is also expected to become, “Much warmer, wetter, and cloudier, accompanied by a decrease in sea ice and atmospheric sea level pressure” (Vavrus et al. 2012). With warmer and wetter weather, though, comes certain boons. One thing that is especially relevant to those who rely on the sea ice is the predicted retreat of the floe edge (Laidler et al. 2009, Laidler et al. 2011). The floe edge, where Inuit do the majority of large sea-mammal hunting, will, over the next several decades, become closer in proximity to many Inuit communities. This will, in turn, decrease the travel time, cost, and energy required to hunt the larger marine mammals that call the floe edge their home. This shrinkage of the floe edge might cancel out some of the snowmobile's advantages as distance may not be as much of a factor in the future. It is also predicted that an overall increase in biomass will occur including an increased abundance and reproductive output of subarctic flora and fauna, marine and terrestrial (Callaghan et al. 2004, Wassmann et al. 2011). In making predictions about how the Inuit of today might adapt to these predicted changes, it would be wise to look back at how humans in the Arctic adapted to similar conditions.

The Arctic has seen several shifts in temperature over the last few thousand years. Archaeologically speaking, by 2000 B.C. humans inhabited the Canadian Arctic. Around this time, it was warmer than it was during the contact period and today and had vegetation that supported more substantial populations of large land mammals than nowadays (Peta et al. 2005). It would not be far-fetched, then, to assume the Arctic conditions of the past might reflect the changes the Arctic will soon go through. Unfortunately, the Inuit of today would be hard pressed to adapt to these conditions like their predecessors did. Archaeologists posit that during this warmer time, the human population was very dispersed, had low density, and high mobility (Smith 1991, Aporta 2004). High residential and logistic mobility allowed them to maximize their gains in terms of fitness-enhancing resources. Residential mobility is constrained for today's Inuit, however, as they are congregated in permanent settlements throughout the

Canadian Archipelago. They can no longer pick up and move to follow resources or avoid bad weather and with less ice allowing for speedy travel they, at least those in Igloolik, will be less able to hunt larger terrestrial mammals on the mainland around them via snowmobile or dogsled. One could make the argument that today’s Inuit could become seasonally mobile in terms of residence but this would take knowledge and know-how of traditional activities that the Inuit are losing rapidly (Laidler et al. 2009). Unless they constructed new settlements capable of housing thousands of members (which would cost time, effort, and money) in seasonally productive areas, increased residential mobility does not seem feasible. Rather, as the ice gives way to open water in the warmer months, the Inuit will likely increase their utilization of watercraft to aid in their harvest of large marine mammals. It is predicted and contemporarily seen that, with the increase in biomass, populations of large marine mammals (Gray whales, bowhead whales) will either increase in population, begin occupying the Arctic, or stay in the Arctic for longer periods (Moore and Huntington 2008). This will be a major boon for many Arctic communities who already have the expertise in hunting these mammals. Thus, depending on how one sees it, the future of the Arctic may not be as bleak as it seems as, “Circumpolar Indigenous people have a long history of adapting to change, including to past climatic variability and shifts in species abundance, by modifying seasonal hunting activities, pursuing alternative species, and alternating modes of transportation” (Cunsolo Willox et al. 2015). In order to fully exploit the new Arctic and continue to bring in important country foods, then, a change in technology, rather than mobility, might be more advantageous.

CHAPTER SIX: CONCLUSION

One of the biggest problems Inuit of today, and those in the future, will face is the inability to effectively predict the weather. These changes make the "unknown unknowns" of human decision-making more significant in regards to subsistence. With the importance the Inuit place on country foods and the country itself (Cunsolo Willox et al. 2012, Ulturgasheva et al. 2014, Wexler et al. 2013), it is imperative, then, to study how Inuit will continue to harvest country foods in the face of inclement climate change. This study looked at one of the integral parts of Inuit harvesting, how they get around. There are many trade-offs associated with the two main forms of Inuit transport and with the predicted changes in weather variability and the hazards stemming from it, these trade-offs become even more important for an Inuit decision-maker. In a perfect, non-hazardous, world, one can predict quite accurately that taking a snowmobile rather than a dog team on your next hunting trip will result in more cost-effective harvesting. It is when there is an increased probability of hazardous weather and ice conditions that the decision is not so cut and dry. This study shows that when various characteristics of both dogsleds and snowmobiles are taken into account, weather variability has a greater effect on snowmobiles than dogsleds. So much so, that in instances of high weather variability, the chances of a successful harvest plummets for snowmobiles and dogsleds have a chance of bringing in more country foods than snowmobiles.

This study shows that the re-adoption of the dogsled in Arctic communities who rely on the frozen sea ice might increase the likelihood of acquiring country foods in uncertain conditions. This is tricky, however, as, contemporarily, it is difficult to predict the level of unpredictability one will face (one cannot rightly say that today there will be a 70% chance that every two hours a change in weather will occur). There may come a time in the future that extremely unpredictable weather could become the norm, though (a 100% chance that there will be a 70% chance of change, for example). It is under this condition that one might make the decision to string up the dogs to improve the probability of a successful, non-SAR needing, harvest of culturally significant foods. Decisions in the wage-working communities of the Arctic are not solely based on successful harvests, however. One must take time (regarding employment or dogsled management), money, and effort into account. Regardless, this study demonstrates the complexity of Arctic foraging and the effects climate change will have on Inuit hunters in the future.

REFERENCES

Aporta, Claudio. 2004. “Routes, Trails and Tracks: Trail Breaking Among the Inuit of Igloolik.” Études Inuit Studies 28 (2): 9

Aporta, Claudio "The Sea, the Land, the Coast, and the Winds: Understanding Inuit Sea Ice Use in Context” in SIKU: Knowing Our Ice: Documenting Inuit Sea Ice Knowledge and Use, edited by Igor Krupnik, et al., Springer Netherlands, 2010.

Aporta, Claudio. 2011. “Shifting Perspectives on Shifting Ice: Documenting and Representing Inuit Use of the Sea Ice.” Canadian Geographer 55 (1): 6–19.

Archer, Lewis, James D. Ford, Tristan Pearce, Slawomir Kowal, William A. Gough, and Mishak Allurut. 2017. “Longitudinal Assessment of Climate Vulnerability: A Case Study from the Canadian Arctic.” Sustainability Science 12 (1). Springer Japan: 15–29.

Bravo, Michael, “Sea Ice Mapping,” in High places: Cultural Geographies of Mountains, Ice and Science, edited by Cosgrove, Denis E., and Veronica Della Dora. 2009. London: I.B. Tauris.

Callaghan, Terry V., Lars Olof Björn, Yuri Chernov, Terry Chapin, Torben R. Christensen, Brian Huntley, Rolf A. Ims, et al. 2004. "Biodiversity, Distributions and Adaptations of Arctic Species in the Context of Environmental Change". AMBIO: A Journal of the Human Environment. 33 (7): 404-417.

Chibnik, Michael. 2011. Anthropology, Economics, and Choice. Austin: University of Texas Press.

Clark, Dylan G., James D. Ford, Tristan Pearce, and Lea Berrang-Ford. 2016a. “Vulnerability to Unintentional Injuries Associated with Land-Use Activities and Search and Rescue in Nunavut, Canada.” Social Science and Medicine 169. Elsevier Ltd: 18–26.

Clark, D. G., J. D. Ford, L. Berrang-Ford, T. Pearce, S. Kowal, and W. A. Gough. 2016b. "The Role of Environmental Factors in Search and Rescue Incidents in Nunavut, Canada." Public Health 137. Elsevier Ltd: 44–49.

Clark, Dylan G., and James D. Ford. 2017. "Emergency Response in a Rapidly Changing Arctic." Cmaj 189 (4): E135–36. doi:10.1503/cmaj.161085.

Collings, Peter. 2017. "Economic Strategies, Community, and Food Networks in Ulukhaktok , Northwest Territories , Canada Author (S): PETER COLLINGS Source : Arctic , Vol . 64, No. 2 (JUNE 2011), Pp. 207-219 Published by: Arctic Institute of North America Stable URL: H" 64 (2): 207–19.

Cunsolo Willox, Ashlee, Sherilee L. Harper, James D. Ford, Karen Landman, et al. 2012. "From this place and of this place:" Climate change, sense of place, and health in Nunatsiavut, Canada". Social Science & Medicine. 75 (3).

Cunsolo Willox, Ashlee, Eleanor Stephenson, Jim Allen, François Bourque, Alexander Drossos, Sigmund Elgarøy, Michael J. Kral, et al. 2015. "Examining relationships between climate change and mental health in the Circumpolar North". Regional Environmental Change. 15 (1): 169-182.

Dinero, Steven C. 2013. "Indigenous Perspectives of Climate Change and Its Effects upon Subsistence Activities in the Arctic: The Case of the Nets'aii Gwich'in." GeoJournal 78 (1): 117–37.

Fleischer, N. L., P. Melstrom, E. Yard, M. Brubaker, and T. Thomas. 2014. "The Epidemiology of Falling-through-the-Ice in Alaska, 1990-2010." Journal of Public Health (Oxford, England) 36 (2): 235–42.

Ford, James D., Tristan Pearce, Justin Gilligan, Barry Smit, and Jill Oakes. 2008. "Climate Change and Hazards Associated with Ice Use in Northern Canada." Arctic, Antarctic, and Alpine Research 40 (4): 647–59.

Ford, James D., and Maude Beaumier. 2011. "Feeding the Family during Times of Stress: Experience and Determinants of Food Insecurity in an Inuit Community (Igloolik)." Geographical Journal 177 (1): 44–61.

Ford, James D., Graham McDowell, Jamal Shirley, Mike Pitre, Richard Siewierski, William Gough, Frank Duerden, Tristan Pearce, Peter Adams, and Sara Statham. 2013. "The Dynamic Multiscale Nature of Climate Change Vulnerability: An Inuit Harvesting Example." Annals of the Association of American Geographers 103 (5): 1193–1211.

Freeman, M. M. R. 1984. "Contemporary Inuit Exploitation of the Sea-Ice Environment." Proceedings of a Conference on Sikumiut: "the People Who Use the Sea Ice, no. January: 73–96.

Gearheard, Shari, Matthew Pocernich, Ronald Stewart, Joelie Sanguya, and Henry P. Huntington. 2010. "Linking Inuit knowledge and meteorological station observations to understand changing wind patterns at Clyde River, Nunavut".Climatic Change : An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change. 100 (2): 267-294.

Gearheard, Shari Fox. 2013. The meaning of ice: people and sea ice in three Arctic communities.

Gerth N., Starck J.M., Redman P., Speakman J., and Jackson S. 2010. "Energy metabolism of Inuit sled dogs". Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology. 180 (4): 577-589.

Hovelsrud, Grete K., and Barry Smit. 2010. "Community Adaptation and Vulnerability in Arctic Regions." Community Adaptation and Vulnerability in Arctic Regions, 1–353.

Inuksuk, Aipilik. 2011. "On the Nature of Sea Ice around Igloolik." Canadian Geographer 55 (1): 36–41.

Kelly, Robert L. 2007. The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways. New York: Percheron Press.

Légaré, G. 2007. Transportation Injuries and Safety. Nunavik Inuit Health Survey 2004, Qanuippitaa? How Are We?

Laidler, Gita J., Andrew Dialla, and Eric Joamie. 2008. “Human Geographies of Sea Ice: Freeze/thaw Processes around Igloolik, Nunavut, Canada.” Polar Record 44 (4): 335–61.

Laidler, Gita J., James D. Ford, William A. Gough, Theo Ikummaq, Alexandre S. Gagnon, Slawomir Kowal, Kevin Qrunnut, and Celina Irngaut. 2009. "Travelling and hunting in a changing Arctic: assessing Inuit vulnerability to sea ice change in Igloolik, Nunavut". Climatic Change : An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change. 94 (3-4): 363-397.

Laidler, Gita. J., Elee, P., Ikummaq, T., Joamie, E., and Aporta, C. 2010 ‘Mapping Inuit sea ice knowledge and use in Nunavut, Canada (Cape Dorset, Igloolik, Pangnirtung)’ in SIKU: Knowing Our Ice, ed. I. Krupnik, C. Aporta, S. Gearheard, G. J. Laidler, and L. K. Holm (New York, NY: Springer), 47–81

Laidler, Gita J., Tom Hirose, Mark Kapfer, Theo Ikummaq, Eric Joamie, and Pootoogoo Elee. 2011. “Evaluating the Floe Edge Service: How Well Can SAR Imagery Address Inuit Community Concerns around Sea Ice Change and Travel Safety?” Canadian Geographer 55 (1): 91–107.

Mertens, Karl. 2015. Mobility and economy of the Evenkis in eastern Siberia. http://scholarworks.boisestate.edu/cgi/viewcontent.cgi?article=2051&amp&context=td.

Moore SE, and HP Huntington. 2008. "Arctic marine mammals and climate change: impacts and resilience". Ecological Applications : a Publication of the Ecological Society of America. 18 (2): 157-165.

Nelson, Richard K. 1966. “Alaskan Eskimo Exploitation of the Sea Ice Environment.”

Nowak, Michael. 1975. "Subsistence Trends in a Modern Eskimo Community". ARCTIC. 28 (1): 21.

Pearce, T., Ford, J. D., Duerden, F., Smit, B., Andrachuk, M., Berrang-Ford, L., & Smith, T. 2011. Advancing adaptation planning for climate change in the Inuvialuit

Settlement Region (ISR): A review and critique. *Regional Environmental Change*, *11*(1), 1–17.

Peta J. Mudie, A. R. and E. L. (2005). Decadal-scale sea ice changes in the Canadian Arctic and their impacts on humans during the past 4,000 years. Environmental Archaeology, 9(November), 113–126. https://doi.org/10.1016/0305-4403(82)90036-X

Prno, Jason, Ben Bradshaw, Johanna Wandel, Tristan Pearce, Barry Smit, and Laura Tozer. 2011. "Community vulnerability to climate change in the context of other exposure-sensitivities in Kugluktuk, Nunavut". Polar Research. 30 (1): 7363.

Smith, Eric Alden. 1991. Inujjuamiut foraging strategies: evolutionary ecology of an arctic hunting economy. New York: A. de Gruyter.

Smith, Lorne. 1972. "The Mechanical Dog Team: A Study of the Skl-Doo in the Canadian Arctic Author (S): Lorne Smith Published by : University of Wisconsin Press

Stuck, Hudson. 2007. Ten Thousand Miles with a Dog Sled: a Narrative of Winter Travel in Interior Alaska. Project Gutenberg.

Ulturgasheva O, S Rasmus, L Wexler, K Nystad, and M Kral. 2014. "Arctic indigenous youth resilience and vulnerability: comparative analysis of adolescent experiences across five circumpolar communities". Transcultural Psychiatry. 51 (5): 735-56.

Vavrus, Stephen J., Marika M. Holland, Alexandra Jahn, David A. Bailey, and Benjamin A. Blazey. 2012. "Twenty-First-Century Arctic Climate Change in CCSM4". Journal of Climate. 25 (8): 2696-2710

Wassmann, Paul, Carlos M. Duarte, Susana Agusti, and Mikael K. Sejr. 2011. "Footprints of climate change in the Arctic marine ecosystem". Global Change Biology. 17 (2).

Weatherhead, E., S. Gearheard, and R.G. Barry. 2010. "Changes in weather persistence: Insight from Inuit knowledge". Global Environmental Change. 20 (3): 523-528.

Wenzel, George W. 1991. Animal rights, human rights: ecology, economy and ideology in the Canadian Arctic. Toronto: University of Toronto Press.

Wenzel, George W. 1995. "Ningiqtuq: Resource Sharing and Generalized Reciprocity in Clyde River, Nunavut". Arctic Anthropology. 32 (2): 43-60.

Wenzel, George W. 2009. “Canadian Inuit Subsistence and Ecological Instability - If the Climate Changes, Must the Inuit?” Polar Research 28 (1): 89–99.

Wexler, Lisa, Joshua Moses, Kim Hopper, Linda Joule, and Joseph Garoutte. 2013. "Central Role of Relatedness in Alaska Native Youth Resilience: Preliminary Themes from One Site of the Circumpolar Indigenous Pathways to Adulthood (CIPA) Study".American Journal of Community Psychology. 52 (3/4).

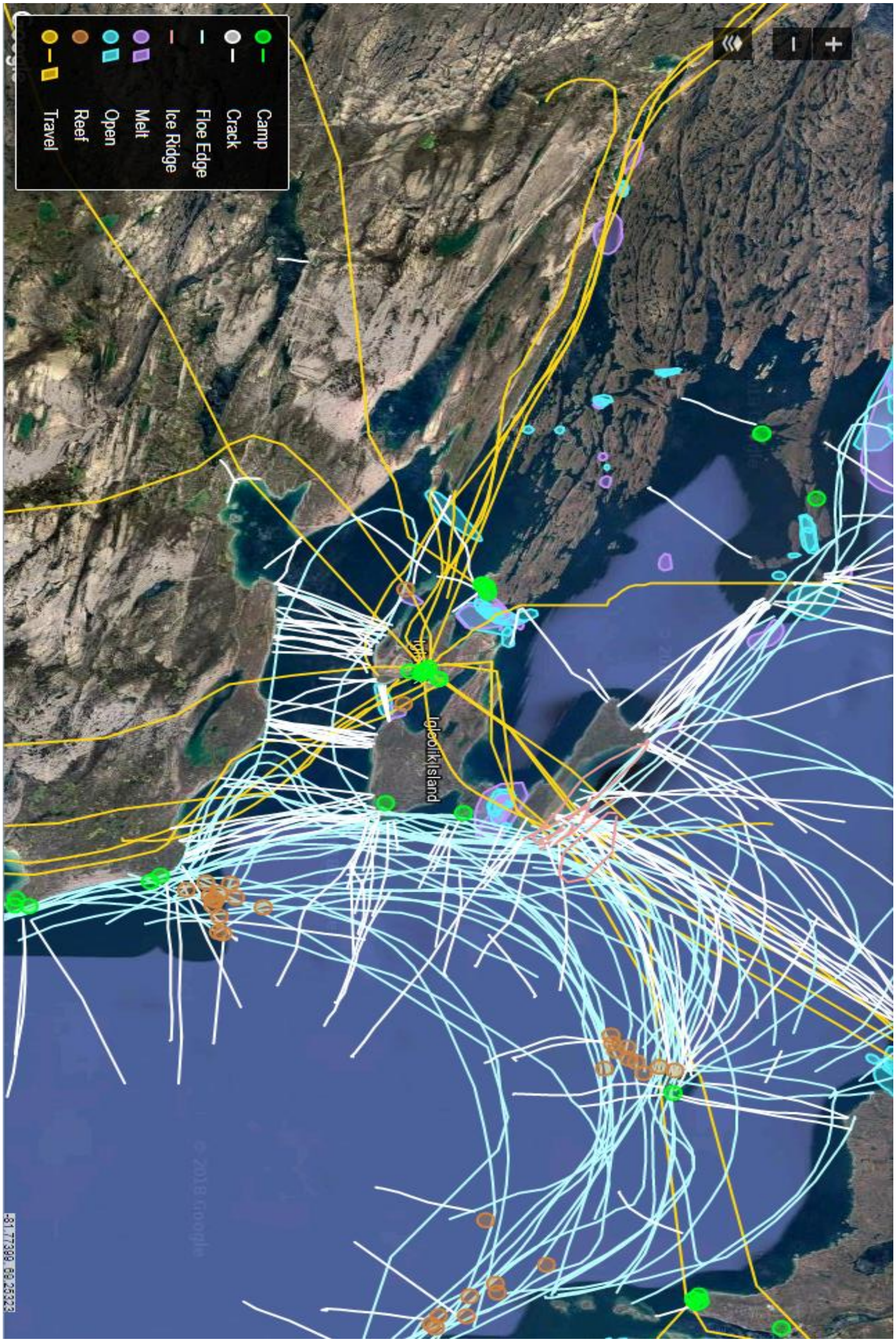
APPENDIX A

Condensed Behavior Space Output

Snowload	SnowmobileHazard	DogsledAvoidance	SnowNavigation	SnowmobileAvoidance	DogHazard	DogNavigation	Successful Snowmobile Harvests	Successful Dogsled Harvests
2	40	60	60	30	10	90	173	144
2	40	60	60	30	20	80	187	124
2	40	60	60	20	10	90	156	132
2	40	60	60	20	20	90	193	134
2	40	60	60	20	30	100	167	145
2	40	60	60	40	10	90	173	140
2	40	60	60	20	10	100	176	153
2	40	60	60	40	10	80	147	130
2	40	60	60	20	30	80	185	124
2	40	60	60	30	30	100	170	149
2	40	60	60	20	20	80	186	130
2	40	60	60	20	20	100	193	143
2	40	60	60	30	30	80	172	123
2	40	60	60	30	10	100	160	156
2	40	60	60	30	10	80	178	124
2	40	60	60	30	20	100	168	146
2	40	60	60	30	30	90	184	137
2	40	60	60	20	30	90	158	138
2	40	60	60	20	10	80	161	139
2	40	60	60	30	20	90	197	139
2	40	60	60	40	20	90	169	142
2	40	60	70	20	10	80	190	126
2	40	60	70	20	30	80	208	130
2	40	60	60	40	30	80	203	130
2	40	60	60	40	30	90	202	145
2	40	60	60	40	30	100	169	138
2	40	60	70	20	10	90	211	140
2	40	60	60	40	20	100	177	137
2	40	60	70	20	10	100	207	145
2	40	60	60	40	20	80	187	128
2	40	60	60	40	10	100	171	142
2	40	60	70	20	20	90	215	141
2	40	60	70	20	20	100	211	159
2	40	60	70	20	20	80	223	118
2	40	60	70	20	30	90	199	141
2	40	60	70	20	30	100	228	159
2	40	60	70	30	10	100	188	144
2	40	60	70	30	10	80	196	126
2	40	60	70	30	10	90	169	130
2	40	60	70	30	20	80	204	129
2	40	60	70	30	20	90	185	141
2	40	60	70	30	20	100	205	152
2	40	60	70	30	30	100	218	153
2	40	60	70	40	30	80	226	124
2	40	60	70	40	20	90	215	140
2	40	60	70	30	30	80	207	134
2	40	60	70	40	30	90	200	143
2	40	60	70	40	20	80	197	132
2	40	60	70	30	30	90	213	144

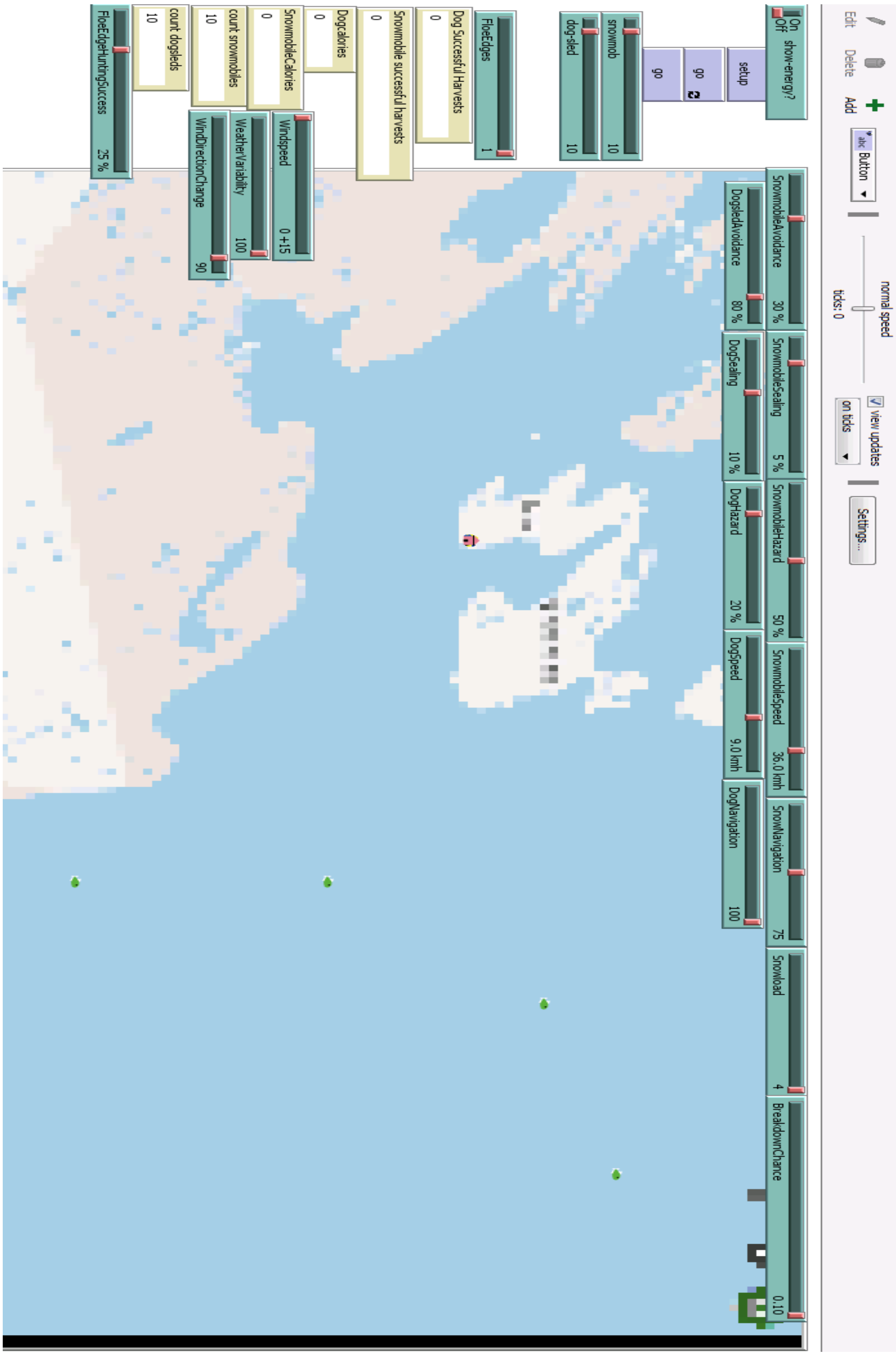
APPENDIX B

Siku Atlas Map of Igloolik


Camp
Crack
Floe Edge
Ice Ridge
Melt
Open
Reef
Travel
Igloolik Island
© 2018 Google

APPENDIX C

Snapshot of Agent Based Model in Netlogo


Edit
Delete
Add
Button
normal speed
ticks: 0
view updates
on ticks
Settings...
On
Off
show-energy?
setup
go
go
snowmob
10
dog-sled
10
FloeEdges
1
Dog Successful Harvests
0
Snowmobile successful harvests
0
Dogcalories
0
SnowmobileCalories
0
count snowmobiles
10
count dogsleds
10
FloeEdgeHuntingSuccess
25 %
Windspeed
0 +15
WeatherVariability
100
WindDirectionChange
90
SnowmobileAvoidance
30 %
DogsledAvoidance
80 %
SnowmobileSealing
5 %
DogSealing
10 %
SnowmobileHazard
50 %
DogHazard
20 %
SnowmobileSpeed
36.0 kmh
DogSpeed
9.0 kmh
SnowNavigation
75
DogNavigation
100
Snowload
4
BreakdownChance
0.10