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Marsh Creek 3D

PLAN OF OPERATIONS
WINTER SEISMIC SURVEY

Submitted by:

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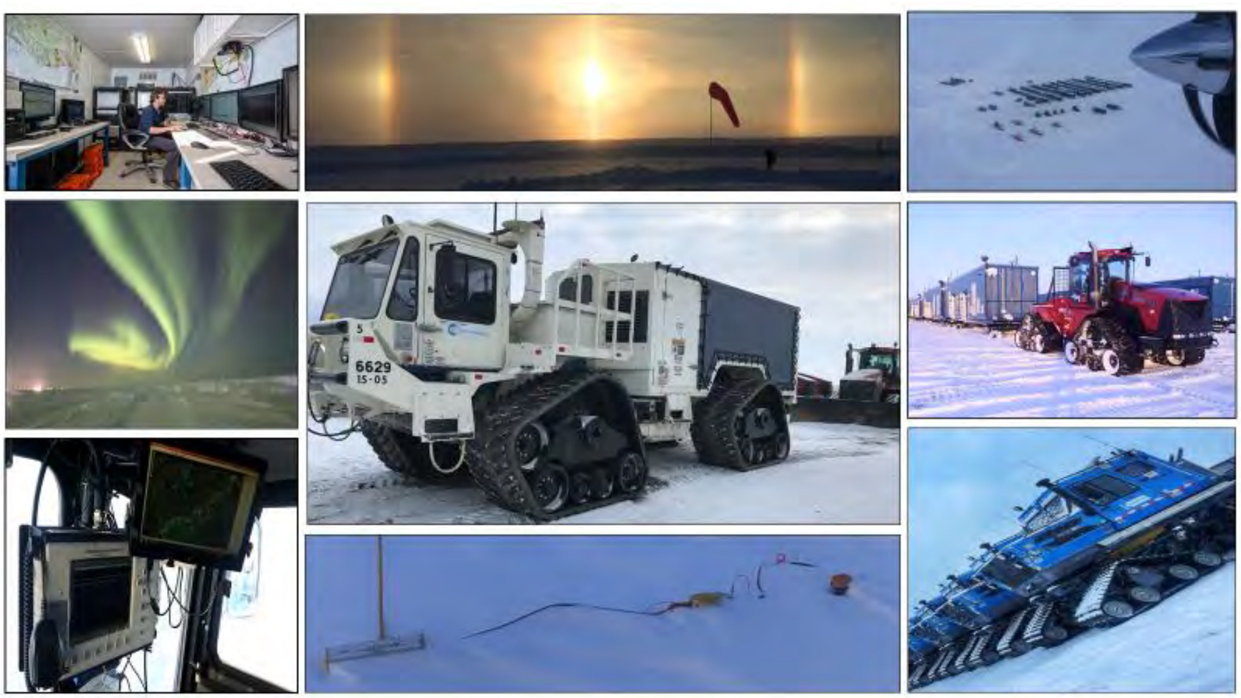

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Marsh Creek Plan of Operations

Winter Plan of Operations 2018 Project Description

1.0 Introduction

SAExploration, Inc (SAE), along with our partners, Arctic Slope Regional Corporation (ASRC) and Kaktovik Iñupiat Corporation (KIC), is pleased to submit their plan of operations for the Marsh Creek 3D Program. Together ASRC, KIC, and SAE, through its joint venture with the Kuukpik Corporation (Kuukpik-SAE), are in the process of forming a joint venture, Iñupiat Geophysical Partnership, LLC. SAE is requesting permits on behalf of its partners to conduct a seismic survey within the 1002 Area of the Arctic National Wildlife Refuge (ANWR) beginning during the winter season of 2018-2019 initially. SAE will be the operator conducting seismic operations during open tundra travel winter season within this boundary with an estimated start date of December 10th, 2018 with ice checking and continuing until the close of tundra or the sea ice deteriorates. Land ownership within this boundary area is primarily federal lands that fall within the Arctic National Wildlife Refuge 1002 area, Native Corporation land owned by ASRC and KIC, and private lands all within the North Slope Borough.

2.0 Scope

SAE is proposing to acquire seismic data from within ANWR with the opening of the coastal plain area (1002) for oil exploration. SAE would like to be the entity that initiates the exploration phase of the 1002 Area, this area represents the interests of the people of the local communities. SAE will use the best available technology, to acquire better quality and higher resolution seismic data, using new recording methodology to image potential targets for future lease sales. SAE would support two (2) crews each winter season for two (2) winter seasons to complete the acquisition of the seismic program. This plan of operations will cover the winter seasons of 2018-2019 and 2019-2020, starting approximately December 1st each winter season and ending on May 31st, or tundra closure.

3.0 Location

The survey permit area encompasses approximately 2602 sq. miles. The project area will include parts, or all the following townships:

<u>All of:</u>
U003N034E, U003N035E, U003N036E, U004N031E, U004N032E, U004N033E
U004N034E, U004N035E, U004N036E, U004N037E, U005N024E, U005N025E
U005N026E, U005N027E, U005N028E, U005N029E, U005N030E, U005N031E
U005N032E, U005N033E, U005N034E, U005N035E, U005N036E, U005N037E
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U006N030E, U006N031E, U006N032E, U006N033E, U006N034E, U006N035E

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Part of:

U009N024E, U009N025E, U009N026E, U009N032E, U009N033E, U009N034E U009N035E, U009N036E, U008N024E, U008N027E, U008N028E, U008N030E U008N031E, U008N032E, U008N037E, U008N038E, U007N023E, U007N028E U007N029E, U007N030E, U007N038E, U007N039E, U006N023E, U006N039E U006N040E, U005N023E, U005N038E, U005N039E, U005N040E, U004N038E U004N039E, U003N037E, U003N038E

The program areas are defined by the enclosed boundary map in Appendix A.

4.0 Environmental Management

This partnership is dedicated to minimizing the effect of our operations on the environment. We are unified in a commitment to environmental excellence and continuous improvement. We will constantly assess our impact on the environment, and will apply what we have learned over the past several years to each new project.

“Environmental management is not just the job of a few specialists - it is a crucial and integral part of our day-to-day business and an environmental culture for our seismic projects.” Our experience on the tundra and sea ice has enabled us to manage and develop equipment and procedure to minimize environmental impact caused by seismic operations. This type of health, safety and environment (HSE) management has enable us to successfully implement many environmental improvements a few are listed below:

- Reduce the number of equipment on the tundra, through new technology, thereby has reduced the total environmental impact of the crew.
- The use of articulating, rubber tracked, low ground pressure vehicles has minimized the compaction of the tundra and risk of damage when vehicles are turning.
- Reduced vehicle size
- Many modifications of seismic equipment have minimized the risk of hydrocarbon spills to the tundra.
    - Containments systems
    - High resolution rear mounted vehicle monitoring cameras, aids in spill detection.
    - Daily and weekly maintenance of equipment.
    - Daily equipment inspections.
    - Hourly equipment walk-arounds.
    - The use of biodegradable, environmentally sensitive products is number one priority when operating in delicate regions such as the NPRA and ANWR. This includes lubricants, hydraulic fluids, greases and glycol that

have readily biodegradable based oils that are virtually non-toxic, still delivering maximum protection to our equipment aiding in preventing breakdowns.

5.0 Cultural Interface

SAE will coordinate its seismic activities with the local communities and villages to mitigate and to prevent potential conflicts when operating in close proximity of subsistence users. Prior to the commencement of the 2018-2019 and 2019-20 winter seasons, representatives will hold a meeting with the village of Kaktovik to discuss the planned activities. These discussions will include text and visual documentation of the crew's activities, as well as the project boundaries. It is anticipated that as a result of these meetings various protocols and procedures can be developed and implemented which will allow both subsistence and exploration activities to co-exist with respect to this project. Any subsistence hunting and fishing that will be in the area of operations can be documented at this time with the help of community members. All meetings will be documented and kept on file as a resource during and after activities. We are dedicated to enhance, sustain and develop locally based economic and employment opportunities for Borough businesses and residents.

6.0 Oversight Panel

An oversight panel for subsistence and the native community of Kaktovik will be developed to address subsistence issues and will report back to the communities near the project area and the agencies overseeing the project. This oversight panel will have the charter for the following:

- Meet with the Kaktovik Native Community prior to the season start to discuss the concerns.
- Document past subsistence activities in the area.
- Work with a biologist hired by SAE on any wildlife or environmental issues.
- Conduct scouting with a local subsistence representative from the community.
- Staff a subsistence observer on each crew-each shift to scout with the survey team and consult on any unknown subsistence or cultural sites.
- Address any key issues with communities.
    - "An issue is a significant opportunity, problem, factor or trend or a challenge to our mission, direction, way of doing business, or culture".

7.0 Crew Integrity

SAE's commitment at all levels to continue "Raising the Bar" for HSE awareness is paying off. Our health and safety goal is to achieve a zero-accident rating consistently. Over the past six seasons and more than 4,769,424 man hours we have not recorded a lost time accident. We attribute a portion of this success to the following critique:

7.1 Our Hiring Process:

- We work to attract and hire the best in the industry to operate the crew.
- A comprehensive pre-employment screening for new hires.
- Prospective employees are administered a drug and alcohol screening test.
- Prospective employees must complete a Physical exam and Functional Capacity Exam.
- Prospective employees complete an eight-hour Health, Safety and Environmental orientation and task specific training as well as a competency assessment while on the crew.

7.2 Our Training Process:

- The operations are controlled with high quality, experienced arctic personnel.
- Provide unique employment opportunities for its employees.
- Engages its employees in operations outside the seismic sector.
- Holds an Annual HSE Seminar for the full crew.
- Comprehensive online SAE training and testing.
- Hold daily orientation and safety briefings (for each shift) accounting for: hazards which could be encountered, other conflicting operations, daily conditions, and review of the day before and the day ahead.
- Tailgate meetings are held to review procedures in areas of known hazard or where operational requirements have changed from those expected.
- Annual training for employees, including:
    - Remote medicine training
    - Arctic survival training
    - first aid/CPR
    - Hazard recognition, rating and mitigation seminars
    - NSTC refreshers
    - Hazwoper training
    - Hazcom awareness training
    - Behavior based safety awareness training
    - Wildlife interaction training
    - Permit stipulation reviews

8.0 Permit Requirements

Provided below is a list of permits, approvals, authorizations and supporting documents required for the operations described in this Plan. Land ownership for this program includes Federal, Native Corporation (ASRC and Kaktovik Iñupiat Corporation) and private holdings all within the North Slope Borough.

Agency	Authorization
Federal Government	
Bureau of Land Management	Geophysical Exploration Permit
US Fish and Wildlife Service	Incidental Harassment Authorization (IHA), Polar Bear
North Slope Borough	
Planning Department	Land Management Development Permit for seismic: Landing Strips: Mobilization Route
IHLC Department	Form 600
TLUI Department	Administrative Approval form 400
ICAS Department	Coordination
State of Alaska	
Alaska Department of Natural Resources, State Historic Preservation Office	Letter of Concurrence
Department of Natural Resources, Division of Mining Land and Water	Temporary Water Use Permit (if necessary) Tundra Travel Permit
Alaska Department of Environmental Conservation	Kitchen Potable Water Permits Discharge Permits
State of Alaska Fish and Game	Fish Habitat Permit Water Withdrawal Permit (if necessary)
Other Approvals	
Lease Holders	Letter of Non-Objection
Kaktovik Inupiat Corporation	Letter of Non-Objection
Arctic Slope Regional Corporation (ASRC)	Letter of Non-Objection
Native Allotments	“No go buffers” placed around lands.

9.0 Mobilization and Access

SAE will stage equipment from existing facilities in Deadhorse. Camp and equipment will be trucked via road infrastructure to a point of access to the tundra or sea ice (See Appendix C). The crews will mobilize to existing gravel pads which will allow access to the tundra and provide a resupply area for the crews. All mobile equipment will have a navigation system installed for logistics and hazard Identification. Tracked and wheeled tundra vehicles will be used to transport the sled camp along the tundra. The camp will remain close to the survey activities and will move every 2-5 days depending on the survey progress and snow cover. When the survey is completed each season, the camp and equipment will travel along the tundra or sea ice to gravel pad for offloading and then trucked back to our Deadhorse pad location. Snow packed trails will be made throughout the project area, these trails will be used for the purpose of less environmental impact and crew travel /re-supply. The location of these trails will depend on snow coverage and terrain conditions. SAE will attempt to coordinate with companies to use any existing or planned trails.

10.0 Survey and Ice check

Surveyors will establish survey controls by setting up a base station; controls will be set with a satellite navigation system transported by tracked vehicles. One of the highest risk potentials for arctic operations is properly verifying the integrity of the ice. This will be done by "ice checking units" consisting of a Tucker vehicle capable of supporting 24 hour operations. Snow machines may also be used for survey and ice check operations. The survey units will be equipped with ground penetrating radar systems (GPR), which are extremely accurate on fresh water. In addition, each ice check unit is equipped with battery operated ice auger which is used to verify the calibration of the GPR, measure ice depths on sea ice, or verify if depths where the GPR units cannot reach. Freeboard testing (ice stabilization) is also be conducted when working on floating ice to insure the ice has the strength to safely hold the equipment. Preliminary trails or snail trails will be established for every foot that the vibrators must travel on the sea ice, lakes or rivers, which will minimize the potential for breaking through the ice. Survey will also map each hazard that is discovered and placed into Tiger-Nav which is a navigation system that allows each vehicle to display the program area, hazards and avoidance areas.

In low snow years, snow surveys will be conducted to substantiate depths and will be recorded for equipment movement efforts

11.0 River Crossings

There may be areas where we encounter floating ice which may not safely support the weight of some equipment. In these cases, SAE will permit this activity with State of Alaska Department of Fish & Game, to apply water to increase the thickness of the ice to establish temporary river crossings. There also may be areas on rivers, streams and lakes that need to be protected with snow for traversing from tundra to ice for crossing. SAE will make snow ramps in these areas and establish that the ice is grounded or the ice is of sufficient ice depth to cross. This will eliminate any impact to river banks and or tundra.

12.0 Willow Protocol

SAE is committed to operate in a manner that all its operations or activities do not damage or affect the social, cultural or community in the areas where we work. If it is determined that willows are in the area, SAE has developed a willow protocol that ensures willow areas are mapped and defined by size. Willow areas will first be identified via aerial photos and possibly snow machines, the areas will then be placed on maps. It is the responsibility of the survey manager to ensure that willow areas are recorded on the hazard maps and appropriate markings are in place. During the ground truthing of willows, Subsistence Representatives will be responsible for assisting in identifying sensitive willow areas and defining size. Survey will mark trials to be follow by the crews if it is determined that the area is accessible.

13.0 Recording Operations

The method of acquisition is Random Source Driven Acquisition (RSD) combined with a Compressive Sensing design. Seismic operations will be conducted utilizing rubber tracked/buggy vibrators and wireless, autonomous recording channels (nodes). Vibrators will typically operate within a distinct area proximal to each other. Vibrator source points will be located along source lines every 41.25 feet. Geophone receiver lines will run perpendicular to source lines, and both source and receiver lines are spaced approximately 660 feet apart. Geophones will be located along source lines every 165 feet. Up to 20 receiver lines could be placed on the ground at one time. Wireless nodes and geophones will be laid out by crews on foot and through the use of rubber tracked tundra travel approved vehicles. Each station will be placed individually and will be surveyed by GPS upon deployment. Upon retrieval, all GPS data is then entered into a database.

Using the RSD methodology, multiple vibrators can collect data at the same time. This methodology means that only a single vibrator is required to travel down any source line, thereby reducing risk compaction or damage to the tundra. Vibrators will only operate on snow covered tundra or grounded sea ice.

Recording Operations continue for 24 hours per work day and are based on two 12 hour shifts. Communications with the crews while out in the field will be via VHF radio systems and wireless data transfer radios.

14.0 Camp Facilities

Each camp can accommodate up to 150 - 160 persons. Equipment included at camp stations will include long haul fuel tractors, remote fuelers, water maker, incinerator, resupply and survival sleigh, tractors, loaders and tuckers.

Sanitary conditions in the kitchen and diner and washrooms will be maintained in full compliance with governmental regulations.

Grey water will be filtered to meet the discharge requirements of the Alaska Department of Environmental Conservation (ADEC) Alaska Pollutant Discharge Elimination System (APDES) permit prior to discharge. SAE holds a current APDES discharge permit for this purpose.

Due to the size of the project, SAE may use 2 camps and 2 crews at different locations within the project area for logistical purposes. The mobilization of the camp or camps will be from the existing gravel roads, starting off a gravel pad. A pre-determined route will be used to move equipment to the project location. Camp trails during project will be scouted out in advance by project manager to avoid hazards and measure snow depth. To mitigate any tundra damage the sleigh camp could be moved up to 2 miles every few days, this will depend on the weather, snow covering and the advancement of the project.

The SAE HSE advisor and the local hire subsistence representative will revisit every camp site, after camp has moved on, to review the area and sign-off that no damage occurred.

During the active work season, crews will travel to the camp area by personnel carrier tundra travel. If existing airstrips are within the project area those area may be utilized to allow personnel, food and fuel to be delivered to the work area.

15.0 Water Withdrawal

Potable water will be produced at camp with a skid-mounted snow melter. Water is produced by melting snow or if it is a low snow year this can be supplemented by withdrawing water from lakes, it is then processed through our ADEC approved water system. SAE will identify lakes and will be permitted if used. If lakes are used, SAE has fish and game approved water withdrawal pumps that will be utilized during this process. If there is not an adequate source of snow, water may need to be transported to each camp from an approved source.

16.0 Temporary Snow Airstrips

The project will need airstrips to transport crews on crew change days. Having temporary airstrips will save several hours of tundra travel. SAE will create a flat area on predetermined grounded, frozen lakes, or tundra to serve as landing strip to receive the aircraft for crew changes. An advance scouting trip will be identifying grounded lakes and or tundra locations that can be used for this purpose. The landing strip will only be on areas that have adequate space for safely landing aircraft. On lakes, a rubber tracked Steiger with a blade will clear the snow down to ice approximately 75 feet wide and 2300 to 3500 feet long for the aircraft to land. Black bags filled with snow will be placed along the side of the berm to delineate the edge of landing strip along with lighting.

After crew has mobilized and initial scouting has been done lakes which may support this operation will be documented for possible airstrip locations. The GPS location of the landing strip will be documented.

The strips will be used for landing and will not be maintained unless the same location is needed again. After use of the strip is no longer necessary, the crews will inspect the location and record that area that was used by GPS location to be included in the final reporting. An example of airstrip is listed in Appendix E.

17.0 Fuel Supply and Storage

SAE will be using long haul sleigh tanks for fueling. All fuel will be ultra-low sulfur for vehicles and equipment. Fuel will be delivered using over land Rolligon or rubber tracked carriers. In the event the supply is disrupted by weather or other unforeseen events fuel may have to be delivered by aircraft, SAE will use temporary airstrips for these occasions. An advance scouting trip will assist SAE in identifying existing airstrips if any that can be used for this purpose. Off-loading fuel from aircraft will be done in accordance with SAE's fueling procedure. Fueling storages and fueling activity will be located at least 100 feet from any water body. All equipment fuel locations will be tracked and recorded. SAE fueling procedures include spill management practices such as drip plan placement under any vehicle parked and placement of vinyl liners with foam dikes under all valves or connections to diesel fuel tanks. All fuel tanks are double-wall tank construction. Fuel dye is added to all fuel as part of spill detection. All spills, no matter what the size are tracked and cleaned up by SAE and used for spill prevention operations. We also hold a Spill Prevention Countermeasure Control (SPCC) plan for our fueling and fuel storage operations associated with seismic operations. This SPCC plan is site specific and will be amended for each new project. All reportable spills will be communicated through the proper agencies and reporting requirements.

18.0 Waste Management

Food waste generated by the field operations will be stored in vehicles until the end of the shift. The garbage will then be consolidated at camp in wildlife resistance containers for further disposal. All food waste generated in camp will also be collected and stored in the same consolidation area. A skid-mounted incinerator will be used for daily garbage waste. This equipment falls within the regulatory requirements of 40 CFR 60. This cyclonator will use on an average 1 to 2 gallons of fuel per hour while in use. The use of electricity is for the motor to the unit that maintains the air to fuel mixture. SAE will collect data to provide the required records on a calendar basis of description and weight of camp wastes burned.

Any wastes generated by seismic operations will be properly stored and disposed of in accordance with applicable permit stipulations and SAE controls. Food waste is continually incinerated to avoid attracting wildlife. Gray water generated from the mobile camp will be discharged according general permit AKG332000 and 18 AAC 83.210 and NPDES discharge limits. Toilets are "PACTO" type to eliminate "black water". Ash from the incinerator will be back-hauled to the North Slope Borough disposal facility in Deadhorse. The sleigh camp will move approximately every two to five days depending on weather conditions. An inspection by the HSE Advisor will be done after camp has left to ensure that the area is clean of all debris.

19.0 Wildlife

Wildlife that may be in the area during the winter season are owls, ravens, arctic fox, wolverine, musk ox, and, possibly, over-wintering caribou, ringed seals, and polar bears. Grizzly bears also inhabit the general area in the project, but are likely to be inactive during the winter season. Polar Bears may be seen along the coastal areas and out on the sea ice. Although encounters with Polar Bears or Grizzly bears are unlikely, SAE and its contractors will exercise caution during the project. Should a Grizzly Bear or Polar Bear be encountered, SAE would follow the procedures as outlined in our comprehensive Wildlife Interaction Plan that is approved by the ADF&G and USFWS. Food and food waste will be kept inside vehicles while out in field. All Polar Bear sightings will be reported to the USFWS as per the authorization from USFWS. Any type of bear dens, suspected or confirmed will be reported to the USFWS or ADF&G agency personnel.

SAE will work with agencies to avoid and minimize interactions with wildlife; this includes abiding by relevant regulations and obtaining required authorizations. Our Wildlife Interaction Plan is listed in Appendix F.

20.0 Historic and Cultural Resources

SAE and its partners have commissioned a Cultural Resources Study to identify the historic and cultural resources in the program area. The Cultural Resources Study will inform SAE's activities. Cultural resources known and new that fall within the mapped area will have avoidance buffers placed around them. If required, an Archeological study will be permitted through the appropriate agencies and conducted approximately August 2018. Any known existing studies will be reviewed. SAE will not be accessing any native allotments without permission of the owners. A licensed archeologist will work with the NSB, State of Alaska and the Refuge manager to review existing records. The studies will include the use of the Alaska Heritage Resource Survey (AHRS) database, maintained by the Alaska Department of Natural Resources (ADNR) and the Traditional Land Use Inventory (TLUI) database, maintained by the NSB.

Previously recorded and any new AHRS sites will not be affected by any of the proposed seismic activities. All areas will have 500-foot buffers placed around them as a non-activity zone. These buffers will be placed in our Tiger Nav system and placed on maps to ensure no vehicles enter avoidance areas.

21.0 Communication & Supervision

The following personnel at SAE can be contacted for information during the permitting survey program are:

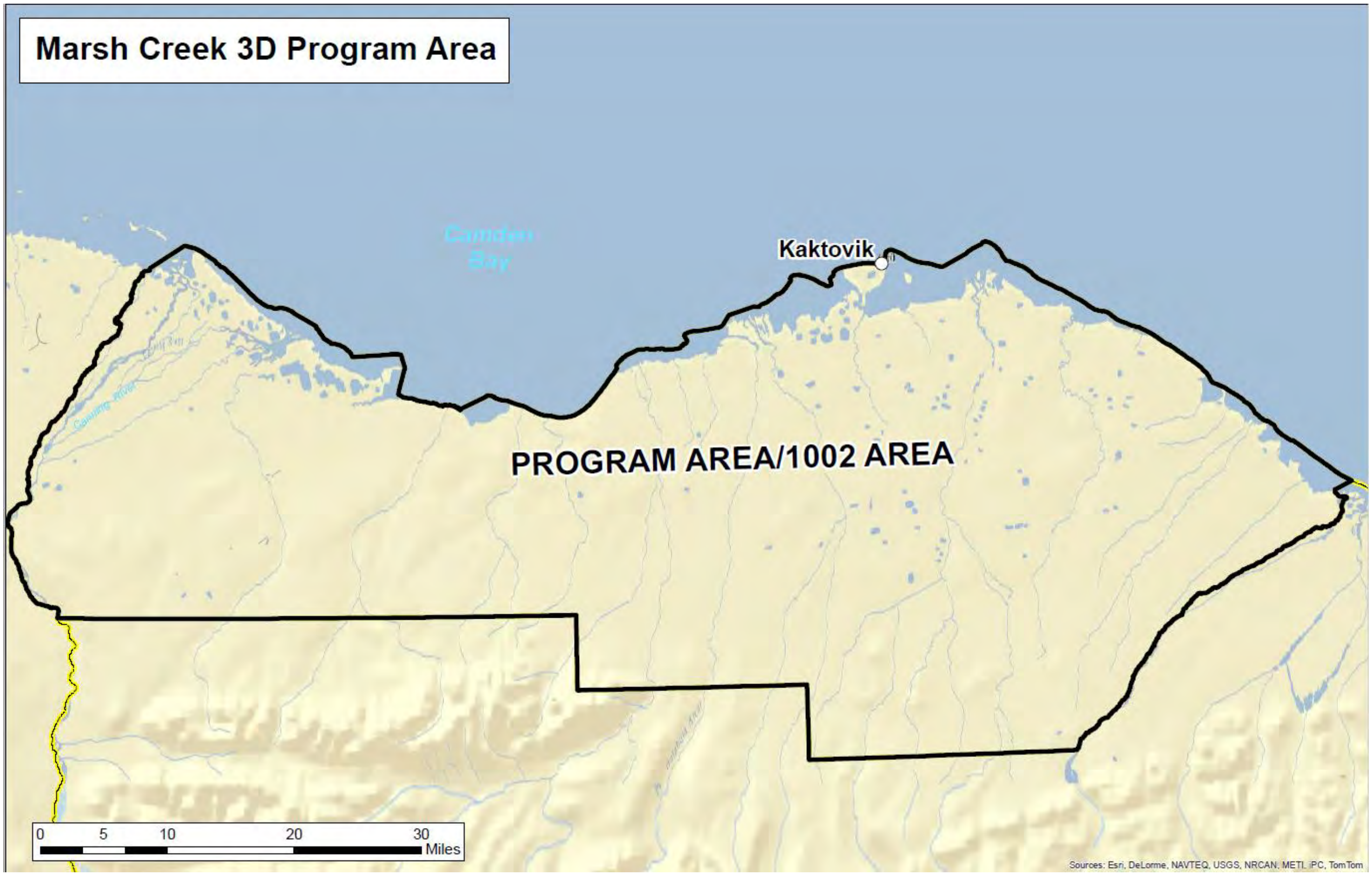
Ted Smith Operations Supervisor 907-522-4499 907-301-5434 cell
Suzan Simonds Permits and Regulatory Manager 907-522-4499 907-331-8140 cell
Rick Trupp General Manager of Alaska 907-522-4499
Oversight Panel Suzan Simonds 907-522-4499 907-331-8140

22.0 Appendices

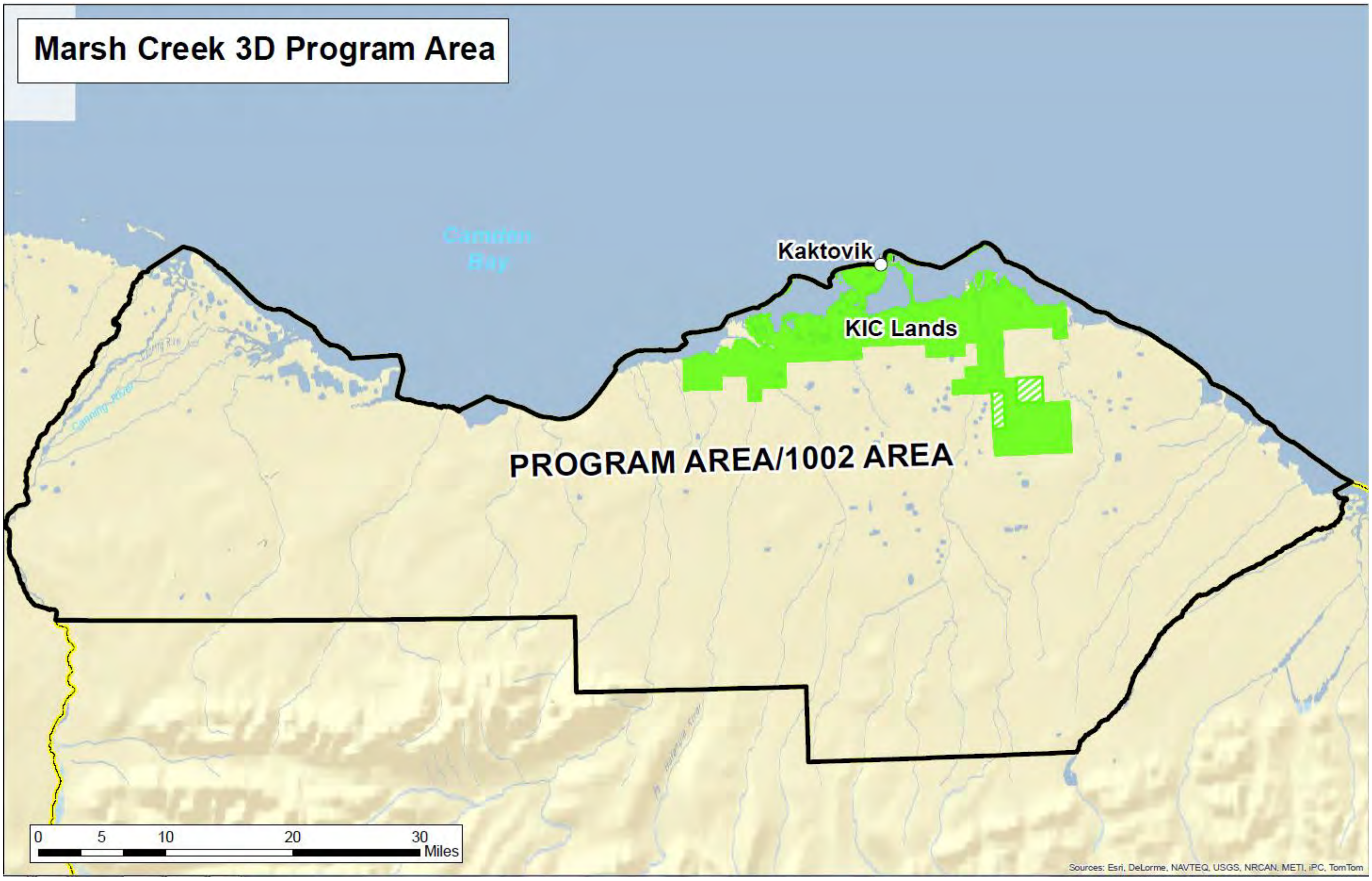
Appendix A -	Project Area Maps
Appendix B -	Equipment List
Appendix C -	Example Map of Mobilization Route
Appendix D-	Equipment Pictures
Appendix E-	Example of Temporary Airstrip
Appendix F-	Wild Life Interaction Plan

Appendix A: Project Area Maps

Project Area



Project Area with Land Status



Appendix B: Equipment List Per Crew

Equipment list per crew	Qty	Model or Similar
Crew Transportation		
Tucker Snow Cat	12	1644
Tucker Ice Cat	8	1644
Tucker Personnel Carrier	3	1600
GPS Base Station	3	Hagglund
		Trailer
Vibe Tender	2	Tucker Trailer
Mechanic Field Shop	1	Tucker Trailer
Node Charging Shack	3	Tucker Trailer
Recorder	1	Tucker Trailer
Taco	6	Trailer
Survival Trailer	2	Tucker Trailer
GSX Nodes	TBD	GSX-1
Batteries	TBD	BX10
Sensor	TBD	Arctic Base
AHV-IV Vibrators	12	Commander (PLS-364)
Crew Camp/Support Equipment		
Sleigh Camp	1	150 Man
Fuel Tanks/Fuel Stations	7	3,000 / 4000 Gallon
Long Haul Fueler	4	4,000 Gallon
Rolligons	1	
Case/Steiger Tractors	9	535
CAT Dozer	2	D7G
CAT loader	1	977H

Appendix C: Example of Mobilization Route

Appendix D: Equipment Pictures

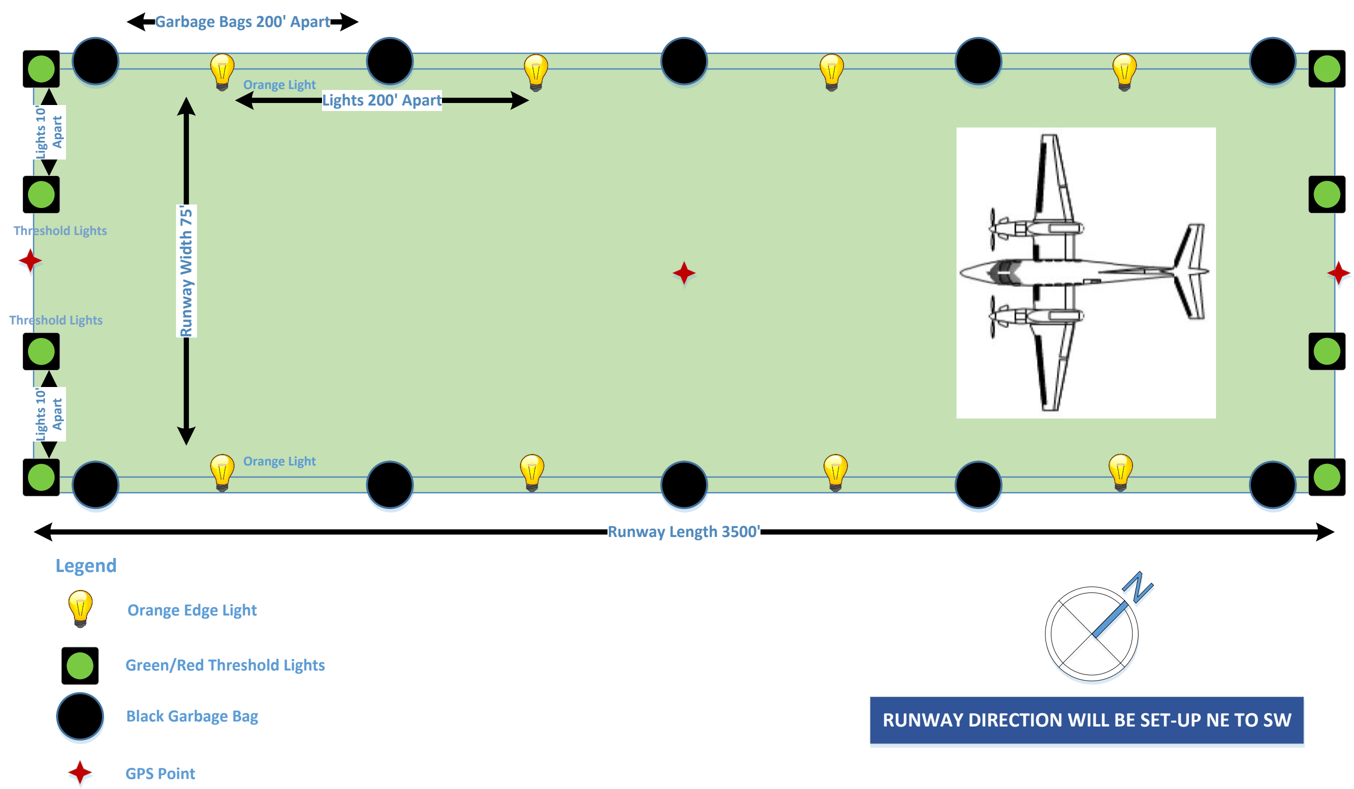
NODES
Cable-Free/Radio-Free Autonomous Data Recording
Seismic Recorder (GSX)

Tucker

Approximately 90,000 pounds with Tracks, 60,000 with tires
AHV4 Commander Vibrator (Source Equipment)

Vibe rectangular baseplate

Appendix E: Example of Temporary Airstrip



Wildlife Interaction Plan

Purpose: To provide guidelines for assuring the prompt reporting, investigation, and documentation of Polar Bears, sightings or incidents involving animals that are protected by the Marine Mammal Protection Act of 1972. This plan also covers reporting of Brown Bears, or any other wildlife that seismic crews may come in contact with during operations. This plan is intended to meet the requirement of a site specific Polar Bear awareness and interaction plan as required by 50 Code of Federal Regulations (CFR) 18.124(c)(3) and to meet the requirements for a Letter of Authorization (LOA) for the non-lethal, incidental and Non-intentional take of Polar Bear. Any permit stipulations that may be requested by permitting agencies will be added to this document as necessary.

Polar Bears: The United States Fish and Wildlife Service estimates that approximately 1,500 Polar Bears occur in the southern Beaufort Sea (SBS). Worldwide there are approximately 20,000 to 25,000 Polar Bears. During the summer months, Polar Bears typically remain on the southern edge of the sea ice. However, they are also known to swim long distances, haul out onto ice flows and barrier islands and can occasionally be found on the coast. It is expected that Polar Bears will be encountered on ice, in the water and on barrier islands,

Responsibility: The Project Manager have overall responsibility. They are responsible for coordination and implementation of all surveillance or monitoring personnel who deal with wildlife/human encounters, sightings and reporting on the North Slope.

Procedure:

Crews will be trained to maintain a constant level of awareness for the potential conflict with Polar Bears. In areas where high potential of conflict exists, SAE will evaluate and if required, place a dedicated watch for Polar Bears in the area of operations. This is not to say that a continuous watch is not always in effect but rather that the crew will have a dedicated person or persons for oversight in areas of known activity. A Polar Bear education program will be given to all workers at a pre-job conference or on-site prior to the start of operations or at commencement of employment on the North Slope. Polar Bear awareness refresher briefings will be held as part of regular safety briefings. A dedicated Health, Safety and Environment (HSE) Advisor will be based with the survey crew for the duration of the seismic program, and workers will be instructed to notify the Project Manager, or HSE Advisor immediately whenever a bear is detected. All personnel will be aware of the restrictions regarding "taking” of Polar Bears as described by the Marine Mammals Protection Act. When a bear is in the immediate area of the crew location, workers will stay inside vehicles or aircraft and away from the bear. Approaching a bear for taking pictures or any other reason is strictly forbidden. USFWS will be called immediately.

Land based activities:

1. A polar bear den detection survey shall be conducted prior to activities occurring in polar bear denning habitat during the maternal denning period (November to mid-April). All personnel must use caution when operating near polar bear denning habitat during the denning period.

2. When a Polar Bear is detected near any part of the operation, any employee (permanent, temporary, or contract) or visitor shall immediately notify the Project Manager, or HSE Advisor. They shall then notify the Permits Manager.

3. The priority is the protection of human life. The second priority is to avoid any situation in which a bear will be harmed.

4. In a camp situation, the lead person with crew shall radio Project Manager/Administrative Office. The Administrative Office will sound the "air horn" with 5 short blasts and make a radio announcement on all crew channels of the sighting. At the sound of the air horn, EVERYONE is to go to the nearest vessel, helicopter, or vehicle and remain inside with doors and windows secured until the ALL CLEAR is given over the radio. The all clear signal is a long blast on the "air horn".

5. In the field, drivers of each vehicle will advise the personnel they are responsible for and have them get inside the vehicles and wait until further notice.

6. If the bear takes refuge near or in a vehicle and does not appear likely to move, crew HSE will be notified depending on the location of operation. No action will be taken unless authorized by the USFWS or their designated agents.

7. When a sighting is made by a standalone vehicle, such as the survey crew, they must not approach the bear further. The crew will notify the Project Manager, HSE Advisor radio to alert them. The crew must avoid the bear and if necessary cease operations until the bear has left the area.

8. Personnel must remain at least a one-half mile distance in all directions for brown bears and 1-mile distance in all directions from any known polar bear. The radio announcement must indicate whether this will be necessary or not. An all-clear signal will be sounded when the area is determined to be safe.

9. SAE must observe a 1.6 km (1 mi) operational exclusion zone around all known polar bear dens during the denning season (November-April, or until the female and cubs leave the areas). Should previously unknown occupied dens be discovered within 1.6 km (1 mi) of activities, work must cease and the Service contacted for guidance.

10. After any individual sighting or interaction with Polar Bears during operations

on the North Slope, a Polar Bear Sighting Report shall be completed by the HSE Advisor. The SAE Permits Manager will forward this report to the Office of Marine Mammals Management, Christopher Putnam 786-3810 by phone and or 786-3816 by fax, within 24 hours.

Aircraft:

1. Aircraft will not operate within 0.5 miles of Polar Bears.
2. Aircraft will avoid flying over ideal Polar Bear habitat including but not limited to sea ice and barrier islands.
3. When marine mammals are encountered, aircraft will not operate below 1,500ft unless the aircraft is engaged in marine mammal monitoring, approaching, landing, taking off, or as conditions allow.
4. Plan all aircraft routes to minimize any potential conflict with active or anticipated polar bear subsistence hunting activity as determined through community consultations.

Subsistence Hunting:

1. SAE will employ a subsistence advisor to reduce impacts on Polar Bear subsistence hunting.
2. Vessels and aircraft will avoid areas in which subsistence hunting is being conducted.

Reporting:

Polar Bears: When a Polar Bear is observed or crew member they shall immediately notify the HSE and Permits Manager who will be responsible for filling out the Polar Bear report form. Reports of sightings will be sent to the USFWS on a regular basis through the Permits Manager.

Reports will be sent to:

Christopher Putnam
USFWS-Marine Mammals Section
1011 East Tudor Road
Anchorage, AK 99503
Telephone: 907-786-3800
Fax: 907-786-3816

Brown Bears : (Ursus americanus) are the most abundant and widely distributed of the three species of North American bears.

Responsibility: The Project Manager and wilderness guides have overall responsibility. They are responsible for coordination and implementation of all surveillance who deal with wildlife/human encounters, sightings and reporting.

Procedure:

Crews will be trained to maintain a constant level of awareness for the potential conflict with bears. In areas where high potential of conflict exists, SAE will evaluate and if required, place a dedicated wilderness guides in the area of operations. This is not to say that a continuous watch is not always in effect but rather that the crew will have a dedicated wildlife guide for oversight in areas of known activity. Bear education program will be given to all workers at a pre-job conference or on-site prior to the start of operations or at commencement of employment. Bear awareness refresher briefings will be held as part of regular safety briefings. A dedicated Health, Safety and Environmental (HSE) Advisor will be based with the survey crew for the duration of the seismic program, and workers/wilderness guides will be instructed to notify the Project Manager or HSE Advisor whenever a bear is sited by use of a hazard card. When a bear is in the immediate area of the crew location, workers will stay inside vehicles or aircraft and away from the bear. Approaching a bear for taking pictures or any other reason is strictly forbidden.

1 When a bear is detected near any part of the operation, any employee (permanent, temporary, or contract) or visitor shall immediately notify the Project Manager or HSE Advisor.

2 The first priority is the protection of human life. The second priority is to avoid any situation in which a bear will be harmed.

3. In a camp situation, the lead person with crew shall radio Project Manager/Administrative Office. The Administrative Office will sound the “air horn” with 5 short blasts and make a radio announcement on all crew channels of the sighting. At the sound of the air horn, EVERYONE is to go to the nearest vessel, helicopter, or vehicle and remain inside with doors and windows secured until the ALL CLEAR is given over the radio. The all clear signal is a long blast on the “air horn”.

4. In the field, drivers of each vehicle will advise the personnel they are responsible for and have them get inside the vehicles and wait until further notice. If no vehicles are near, the wilderness guide shall lead crew away from bear.

5. If the bear takes refuge near or in a vehicle and does not appear likely to move, crew HSE will be notified depending on the location of operation. No action will be taken unless authorized by the AKFG or their designated agents.

6. The crew must avoid the bear and if necessary cease operations until the bear has left the area. The bear’s safe distance from the crew will determine by the

wilderness guide. The distance should be far enough as not to affect the bears behavior. The radio announcement must indicate whether this will be necessary or not. An all-clear signal will be sounded when the area is determined to be safe.

7. Personnel must report any active bear dens. These dens will be mapped and sent to AKFG. After any individual interaction with bears during operations, the Bear Sighting Report shall be completed by the HSE Advisor or the wilderness guide. The SAE Permits Manager will forward this report to the agencies which are listed in the permit stipulations of all permits within 24 hours.

Caribou / Foxes / Wolverines or Other wildlife:

Responsibility: The Project Manager and wilderness guides have overall responsibility. They are responsible for coordination and implementation of all surveillance who deal with wildlife/human encounters, sightings and reporting.

Procedure:

1 Avoid any interaction with wildlife.

2 Do not take any actions that would cause the animals to change course or behavior unless approved by Alaska Fish and Game

3 After any individual interaction with Caribou or other types of wildlife during operations, the Wildlife Sighting Report shall be completed by the HSE Advisor or the wilderness guide. The SAE Permits Manager will forward this report to the agencies which are listed in the permit stipulations of all permits.

4 If foxes or other wildlife take up shelter within camp area, notify the permits manager.

5 Feeding of animals is strictly prohibited.

6 There is no hunting or fishing allowed on project.

U.S. Fish And Wildlife Service
Marine Mammals Management
POLAR BEAR SIGHTING REPORT

Company: ________________________ **LOA #:** __________________________
Date: ____________________________ **Observer Name:** ____________________
Time: __________________ **am / pm / 24** **Phone/Email:** _____________________

Location: ____
____

Latitude: __________________ **Longitude:** ___________________ **Datum:** __________

Weather Conditions: Fog____ Snow____ Rain____ Clear____ Temperature____ °F / °C

Wind Speed____ mph / kts Wind Direction (from) ____ N NE E SE S SW W NW

Visibility: Poor____ Fair____ Good____ Excellent____

Total Number of Bears: _______ (total number of bears & how many of each type)

	adult	sub-adult	2 year-old	yearling	cub of year
Male	____	____	____	____	____
Female	____	____	____	____	____
Unknown	____	____	____	____	____

Closest Distance of Bear(s): from personnel_________ facility/vessel_________ m / yd / ft

Bear Behavior (Initial Contact): curious ignore aggressive walk run swim hunt feed rest other
____

Bear Behavior (After Contact): curious ignore aggressive walk run swim hunt feed rest other
____

Description of Encounter: ____
____
____
____

Duration of Encounter: _____________ **Possible Attractants Present:** Y / N

Describe Attractants: ____

Deterrents Used & Distance: If Yes, submit report within 48 hours of incident

Vehicle	Y / N ____	m / yd / ft	______	Spotlight/Headlight	Y / N ____	m / yd / ft	____
Horn/Siren/Noise	Y / N ____	m / yd / ft	______	Other (describe)	Y / N ____	m / yd / ft	____
Crackershell	Y / N ____	m / yd / ft	______	______________________			
Rubber Bullet	Y / N ____	m / yd / ft	______	______________________			
Bean Bag	Y / N ____	m / yd / ft	______	______________________			

Report Sent To: FW7_MMM_REPORTS@FWS.GOV Date: ____________ Time: _________

For further information contact USFWS Marine Mammal Office: 907-786-3800 or 1-800-362-5148

Jack Winters
Habitat Biologist
Division of Habitat
Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701
907-459-7285

Date:_________
Time:_________

Bear Interaction Report

Location:____
____

Observer name: ____

Weather conditions: Fog ___ Snow ___ Rain ___ Clear ___ Wind Speed ___
Wind Direction ____ Approx. Temp ___

Total number of bears: ___ Sow/cubs __/__ Adult ___ Subadult ___

Estimated distance of bear from personnel/facility: _____/_____

Possible attractants present: _____________________________

Bear behavior: Curious ___ Aggressive ___ Predatory ___ Other ___

Description of encounter:____
____
____

Injuries sustained: Personnel ____________________________

Bear ____________________________

Deterrents used/distance: Vehicle ___ Noise-maker ___ Firearms ___
Other ___

Duration of encounter: ______

Agency Contacts: _____________________Time:_____Date:______

ADF&G__________________Time:_____Date:______

SAE____________________Time:_____Date:______

SAE Representative:______________________________________Date:_________

Jack Winters
Habitat Biologist
Division of Habitat
Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701
907-459-7285

Date:_________
Time:_________

Wildlife Sighting Report

Location:____
____

Observer name: ____

Weather conditions: Fog ____ Snow ___ Rain ___ Clear ___ Wind Speed ___
Wind Direction _____ Approx. Temp ___

Total number of animals: ___ Type __/__ Adult ___ Subadult ___

Estimated distance from personnel/facility: _____/_____

Possible attractants present: _________________________

Animal behavior: Curious ___ Aggressive ___ Predatory ___ Other ___

Description of encounter:____
____
____

Injuries sustained: Personnel ________________________

Animal ________________________

Deterrents used/distance: Vehicle ___ Noise-maker ___ Firearms ___
__________ Other ___
Duration of encounter: ______
Agency Contacts: ___________________Time:_____Date:______
ADF&G_________________Time:_____Date:______
SAE_________________Time:_____Date:______

SAE Representative:_________________________________Date:_________

Field Operating Procedure
Polar Bear Protocol

Purpose: To provide guidelines for assuring the prompt reporting, investigation, and documentation of Polar Bear sightings or incidents involving animals that is protected by the Marine Mammal Protection Act of 1972.

Scope: This procedure applies to all sightings or interaction with Polar Bears occurring during operations on the North Slope.

Responsibility: The Project Manager and HSE Advisor have overall responsibility. They are responsible for coordination and implementation of all surveillance or monitoring personnel who deal with wildlife/human encounters or sightings on the North Slope.

Procedure:

1. A polar bear den detection survey shall be conducted prior to activities occurring in polar bear denning habitat during the maternal denning period (November to mid-April). All personnel must use caution when operating near polar bear denning habitat during the denning period.

2. When a Polar Bear is detected near any part of the operation, any employee (permanent, temporary, or contract) or visitor shall immediately notify the Project Manager or HSE Advisor.

3. The first priority is the protection of human life. The second priority is to avoid any situation in which a bear will be harmed.

4. The Administrative Office will sound the “air horn” with 5 short blasts and make a radio announcement on all crew channels of the sighting. At the sound of the “air horn, EVERYONE in camp is to go to the nearest trailer or vehicle and remain inside with doors and windows secured until the ALL CLEAR is given over the radio. The all clear signal is a long blast on the “air horn”.

5. In the field, drivers of each vehicle will advise the personnel they are responsible for and have them get inside the vehicles and wait until further notice.

6. If the bear takes refuge near, in, or under a trailer or vehicle and does not appear likely to move, crew HSE security will be notified depending on the location of operation. No action will be taken unless authorized by the USFWS or their designated agents. The District Manager and North Slope Security must be contacted at this time.

7. Areas which have been identified as possible denning sites will be avoided per the permit stipulations. (Typically, prior to mobilization, Polar Bear den locations are received and entered into our hazard mapping system.) Survey crew, trained in Polar

Bear awareness, will be responsible as the lead vehicles in the field to scout for possible additional locations and bring to the crew's attention at the daily safety meetings those locations. Possible locations will be staked in the field and entered on the hazard maps for the crew per permit stipulations. If a den is encountered protocols from USFW will be followed. Operations will then be evaluated and modifications to the operation will be implemented that will allow the avoidance of the denning site and the continuation of exploration activity.

8. When a sighting is made by a stand-alone vehicle, such as the survey crew, they must not approach the bear further. The crew will notify the Project Manager or HSE Advisor via radio to alert them. The crew must avoid the bear and if necessary cease operations until the bear has left the area. The bear's distance from camp will determine whether step 3(b) is required. All personnel must remain at least a one mile distance in all directions from any known bear dens. The radio announcement must indicate whether this will be necessary or not. An all-clear signal will be sounded when the area is determined to be safe.

9. After any individual sighting or interaction with Polar Bears during operations on the North Slope, a Polar Bear Sighting Report shall be completed by the HSE Advisor. The SAE Permits Manager will forward this report to the Office of Marine Mammals Management as listed in the plan of operations.

10. A skid-mounted incinerator will be used for solid waste incineration. All garbage that contains any food will be bagged, stored inside the facilities and incinerated on site two times per day. The resulting ash will be back hauled to the North Slope Borough disposal facility during the winter season.

11. Winter crews will be trained to maintain a constant level of awareness for the potential conflict with Polar Bears. In areas where high potential of conflict exists, SAE will evaluate and if required, place a dedicated watch for Polar Bears in the area of operations. This is not to say that a continuous watch is not always in effect but rather that the crew will have a dedicated person or persons for oversight in areas of known denning or activity. A Polar Bear education program will be given to all workers on-site prior to the start of operations or at commencement of employment on the North Slope. Polar Bear awareness refresher briefings will be held as part of regular safety briefings. A dedicated Health, Safety and Environmental (HSE) Advisor will be based at the camp for the duration of the winter seismic program, and workers will be instructed to notify the Project Manager or HSE Advisor immediately whenever a bear is detected. All personnel will be aware of the restrictions regarding "taking" of Polar Bears as described by the Marine Mammals Protection Act. Approaching a bear for taking pictures or any other reason is strictly forbidden.

12. Plan all aircraft routes to minimize any potential conflict with active or anticipated polar bear subsistence hunting activity as determined through community consultations.

Permits Manager will send reports to:

Christopher Putnam
USFWS-Marine Mammals Section
1011 East Tudor Road
Anchorage, AK 99503
Telephone: 907-786-3800
Fax: 907-786-3816

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Seismic Application and updated Agenda - Friday May 4

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:15 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Wixon, Donna** <dwixon@blm.gov>
Date: Thu, May 3, 2018 at 5:26 PM
Subject: Seismic Application and updated Agenda - Friday May 4
To: Lonnie Bryant <lbryant@blm.gov>, Sarah LaMarr <slamarr@blm.gov>, Sarah Conn <sarah_conn@fws.gov>, Joanna Fox <joanna_fox@fws.gov>, Robert Brumbaugh <rbrumbau@blm.gov>, John Trawicki <john_trawicki@fws.gov>, Christopher Latty <christopher_latty@fws.gov>, Hollis Twitchell <hollis_twitchell@fws.gov>, Stephanie Brady <stephanie_brady@fws.gov>, Joshua Rose <joshua_rose@fws.gov>, Roger Kaye <roger_kaye@fws.gov>, Serena Sweet <ssweet@blm.gov>, Ted Swem <ted_swem@fws.gov>, Greta Burkart <greta_burkart@fws.gov>, Joseph Keeney <jkeeney@blm.gov>, Murphy, Ted <t75murph@blm.gov>, Steve Berendzen <steve_berendzen@fws.gov>, kdebenham <kdebenham@blm.gov>, Terra Meares <tmeares@blm.gov>, Stacey <sfritz@blm.gov>, Stephen Arthur <stephen_arthur@fws.gov>, Shelly Jacobson <njones@blm.gov>, Wendy Loya <Wendy_loya@fws.gov>, Richard Kemnitz <rkemnitz@blm.gov>, Debbie <dnigro@blm.gov>, Matthew Whitman <mwhitman@blm.gov>, Timothy Vosburgh <tvosburgh@blm.gov>, Lynnda Kahn <lynnda_kahn@fws.gov>, Mary Colligan <mary_colligan@fws.gov>

Hello All,

I am attaching the seismic application that we just received and an updated agenda.

See you tomorrow.
Thank-you,
Donna

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

2 attachments

Final Agenda Coastal Plain Seismic Meeting.docx
14K

Marsh Creek Plan of Operations_V8.1_F.pdf
1547K

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Information Request - DD Friday May 11

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:15 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Wixon, Donna** <dwixon@blm.gov>
Date: Mon, May 7, 2018 at 10:38 AM
Subject: Information Request - DD Friday May 11
To: Alfredo Soto <alfredo_soto@fws.gov>, Mitch Ellis <Mitch_ellis@fws.gov>, Bud Cribley <bud_cribley@fws.gov>, Christopher Latty <christopher_latty@fws.gov>, Cindy Hamfler <chamfler@blm.gov>, Debbie <dnigro@blm.gov>, Greta Burkart <greta_burkart@fws.gov>, Joanna Fox <joanna_fox@fws.gov>, John Trawicki <john_trawicki@fws.gov>, Joseph Keeney <jkeeney@blm.gov>, Joshua Rose <joshua_rose@fws.gov>, kdebenham <kdebenham@blm.gov>, Lonnie Bryant <lbryant@blm.gov>, Lynnda Kahn <lynnda_kahn@fws.gov>, Matthew Whitman <mwhitman@blm.gov>, me <dwixon@blm.gov>, Randy Goodwin <rgoodwin@blm.gov>, Richard Kemnitz <rkemnitz@blm.gov>, Robert Brumbaugh <rbrumbau@blm.gov>, Roger Kaye <roger_kaye@fws.gov>, Sarah Conn <sarah_conn@fws.gov>, Sarah LaMarr <slamarr@blm.gov>, Serena Sweet <ssweet@blm.gov>, Shelly Jacobson <njones@blm.gov>, Stacey <sfritz@blm.gov>, Stephanie Brady <stephanie_brady@fws.gov>, Stephen Arthur <stephen_arthur@fws.gov>, Steve Berendzen <steve_berendzen@fws.gov>, Ted Murphy <t75murph@blm.gov>, Ted Swem <ted_swem@fws.gov>, Terra Meares <tmeares@blm.gov>, Wendy Loya <Wendy_loya@fws.gov>, Timothy Vosburgh <tvosburgh@blm.gov>

Hello All,

Thank-you for participating in the Seismic Application Meeting last Friday. Attached is a copy of the sign in sheet. There were a few people that missed the sign in sheet so I added some names. If you notice I missed anyone please let me know.

As we pointed out Friday, the application is missing information that is needed to evaluate the proposed action. Please send me any questions you have about the proposed action so that I may compile them and ask the company to supply answers.

I would like all of the questions by the end of the day Friday May 11.

Thank-you,
Donna

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

BLM USFWS Seismic Discussion Sign In Sheet 5.4.18.pdf
136K

BLM/USFWS Seismic EA Initial Meeting
May 4, 2018
Fairbanks, Alaska

Name	Title	Agency/Office	Phone #	Resource
Rob Brumbaugh	O&G Section Chief	BLM	271-4429	Oil & Gas
Ted Murphy	BLM AK Associate State Dir.	BLM	271-5076	
Donna Wixon	NRS	BLM	474-2301	permiting + compliance
Randy Goodwin	VRM/Sound Program Lead	BLM	474-2369	VRM/Sound
Roger Kaye	Wilderness Coordinator	FWS	456-0405	
Debbie Nigro	wildlife biologist	BLM	474-2324	birds
Ted Swem	biologist	FWS	456-0441	end. spp.
Melody Debenham	Physical Scientist	BLM	474-2307	hazardous materials
Matthew Whitman	Fish Bio	BLM	474-2249	Fish
Sarah Conn	Field Supervisor Fairbanks Field Office	FWS	456-0499	Paper

Name	Title	Agency/Office	Phone #	Resource
Terra Meares	Physical Science Technician	BLM Arctic District office	919-800-7824	Legacy Wells
Lonnie Bryant	Realty Specialist	Blm ADO	(907)474-2306	
Richard Kemnitz	Hydrologist	BLM	474-2225	water
Sarah LaMarr	Assist. Manager	BLM-Arctic	474-2334	Manager
Cindy Hamfler	GIS	BLM	474 2213	GIS
Stacey Fritz	Anthropologist/Subsistence Spec.	BLM Arctic	474-2309	Anth/Subsist.
Alfredo Soto	Wildlife Refuge Specialist	USFWS-Arctic NWR	456-0303	
Steve Berendzen	Refuge Manager-Arctic NWR	" "	456-0253	
Greta Burkart	Aquatic Ecologist	USFW	456-0519	
Christopher Latty	Avian Biologist	USFW	347-4300	
Stephen Arthur	Sup. Wildlife Biologist	USFW	455-1830	
Joshua Rose	hydrologist	USFW	456-0409	

Name	Title	Agency/Office	Phone #	Resource
Joanna Fox	Deputy Manager / ~~Arctic NWR~~	Arctic NWR	907-456-0549	
Shelly Jones	Acting DM	BLM Arctic Dist	907-474-2310	
Joe Keeney	Archaeologist	BLM Arctic DO	474-2312	Archeology
Lynnda Kahn	Fish & Wildlife Biologist	USFWS Kenai Refuge	907-260-2818	Fish/wildlife
Bud Cribley	Senior Advisor for Energy with USFWS	USFWS	202-208-4331	
Serena Sweet	Planning & Environmental Coordinator	BLM	907-271-4543	Planning
Wendy Loya	Coordinator - Office Science Applications	USFWS	907-786-3532	
Stephanie Brady	Branch Chief, Conservation Planning & Policy	USFWS	907-306-7448	
John Trawicki	Chief Hydrologist Water Resources Branch	USFWS	907-786-3474	Hydrology
Mitch Ellis	Chief of Refuges, Alaska Region	USFWS	907-786-3998	

phone

PO Box 69 Barrow, Alaska 99723

P 907-852-0320 | F 907-852-0322

NSB 18-466 SAExploration (SAE LLC) - Kuukpik Corporation.pdf
2394K

North Slope Borough

PLANNING AND COMMUNITY SERVICES DEPARTMENT

P.O. Box 69
Barrow, AK 99723
☏ (907) 852-0320
Fax: (907) 852-0322
Email: gordon.brower@north-slope.org

Gordon R. Brower, Director

DRAFT DEVELOPMENT PERMIT - REQUEST FOR COMMENTS

COMMENTS DUE BY: JUNE 3, 2018

This is a Draft Development Permit only for the purposes of review and gathering comments during the comment period prescribed by NSBMC 19. It contains conditions proposed for inclusion in a final permit, if a decision is made to issue a final permit. This draft permit should not be taken to mean that the proposed project is, or will, be approved. Only upon issuance of a final permit will the proposed project be approved to commence.

May 14, 2018

SAExploration, Inc (SAE LLC) - Kuukpik Corporation
Kuukpik-SAE LLC
C/O Sue Simonds, Permits and Regulatory Manager
8240 Sandlewood Place, Suite 102
Anchorage, Alaska 99507
E-mail: ssimonds@saexploration.com

RE: NSB 18-466, Draft Development Permit, **STAINES 3D**, Various Locations, Umiat Meridian, Point Thomson Unit, Conservation and Resource Development Districts.

Dear Ms. Simonds:

We are in the process of reviewing your request to conduct seismic activities for the winter seasons of 2018/2019. The seismic survey will cover 511 square miles. SAE will start the seismic operations during open tundra travel winter season with an estimated start date of December 2018 with ice checking and continuing until the close of tundra travel or the sea ice deteriorates.

SAE will stage equipment from existing facilities in Deadhorse. Camp and equipment will be trucked via road infrastructure to a point of access to the tundra or sea ice (See Appendix C). The crews will mobilize to existing gravel pads which will allow access to the tundra and provide a resupply area for the crews. All mobile equipment will have a navigation system installed for logistics and hazard Identification. (Tiger Nav) Tracked tundra vehicles will be used to transport the sled camp along the tundra. The camp will remain close to the survey activities and will move every 2-5 days depending on the survey progress and snow cover. When the survey is completed each season, the camp and equipment will travel along the tundra or sea ice to gravel pad for offloading and then trucked back to our Deadhorse pad location. Snow packed trails will be made throughout the project area, these trails will be used for the purpose of less environmental impact and crew travel /re-supply. The location of these trails will depend on snow coverage and terrain conditions. SAE will attempt to coordinate with companies to use any existing or planned trails.

Surveyors will establish survey controls by setting up a base station; controls will be set with a satellite navigation system transported by tracked vehicles. One of the highest risk potentials for arctic operations is properly verifying the integrity of the ice. This will be done by "ice checking units" consisting of a Tucker vehicle capable of supporting 24 hour operations. Snow machines may also be used for survey and ice check operations. The survey units will be equipped with ground penetrating radar systems (GPR), which are extremely accurate on fresh water lakes and streams. In addition, each ice check unit is equipped with battery operated ice auger which is used to verify the calibration of the GPR, measure ice depths on sea ice, or verify if depths where the GPR units cannot reach. Where river channels exist, unusual surface fracturing is evident or drillings shows substandard ice the standard grid is tightened up to insure a safe path for the equipment to follow. Freeboard testing (ice stabilization) is also conducted when working on floating ice to insure the ice has the strength to safely hold the equipment. Preliminary trails or snail trails will be established for every foot that the vibrators must travel on the sea ice, lakes or rivers, which will minimize the potential for breaking through the ice. Survey will also map each hazard that is discovered and placed into Tiger-Nav which is a navigation system that allows each vehicle to display the program area and hazard within the area.Hazards and information that are typically displayed in addition to the standard program area are:

- Areas of thin Ice.
- Historic areas.
- Subsistence use areas.
- Areas where vegetation requires avoidance.
- Native allotments.
- Safe routes of travel.
- Low snow areas.

In low snow years, snow surveys will be conducted to substantiate depths and will be recorded for equipment movement efforts.

Seismic operations will be conducted utilizing 12-15 (rubber tracked/buggy) vibrators and approximately 20,000 wireless, autonomous recording channels. The method of acquisition is Random Source Driven Acquisition (RSD) combined with a Compressive Sensing design. Generally, receiver (geophone) lines run perpendicular to source lines and will be typically spaced a minimum of 660ft apart. Source and Receiver point distance along lines are randomized and will be positioned between 41.25 ft. and 200ft from an adjacent source or receiver point on a given line.

Each Receiver point is consisting of wireless nodes and single geophone. Receivers are transported to each location and from location to location with the use of a low ground pressure Tucker Sno-Cat or snow machine. Each Tucker is manned by three personnel and can carry up to 220 receiver points.There could be up to 48 receiver lines placed on the ground at a time with approximately 32 lines being active at any given time. Although there may be only 32 lines required to be recorded for any given source point all wireless nodes on the ground are recording 24 hours per day.

The energy source is Vibrosies. Each source point is occupied by a single vibrator which generated frequencies during a "sweep" of approximately 1.5 to 96Hz. The duration of each sweep is anticipated to be 16 to 24 seconds per source point. Using the SDS methodology multiple vibrators can collect data at the same time provided the vibrators are separated by approximately 1320 feet. This methodology means that only a single vibrator is required to travel down any source line, thereby reducing risk compaction or damage to the tundra. Vibrators will only operate on snow covered tundra or grounded sea ice. The duration and decibel level of the source levels are so low that hearing protection is not required for seismic crew members.

Recording Operations continue for 24 hours per work day and are based on two 12 hour shifts. Communications with the crews, while out in the field will be via VHF radio systems and wireless data transfer radios.

Each camp can accommodate up to 150 persons. The camp will consist of sled-mounted units including a kitchen and diner, sleeping areas, washrooms, laundry, offices, shops, medical clinic, storage, generator rooms, and storage compartments. The mobilization of the camp will be from the existing gravel roads, starting off a gravel pad. A pre-determined route will be used to move equipment to the project location. Camp trails during project will be scouted out in advance by project manager to avoid hazards. To mitigate any tundra damage the sleigh camp could be moved up to 2 miles every few days, this will depend on the weather, snow covering and the advancement of the project.

The SAE Health, Safety and Environment (HSE) advisor and the local hire subsistence representative will revisit every camp site, after camp has moved on, to review the area and sign-off that no damage occurred. Equipment included at camp stations will include long haul fuel tractors, remote fuelers, water maker, incinerator, resupply and survival sleigh, tractors, loaders and tuckers. Sanitary conditions in the kitchen and diner and washrooms will be maintained in full compliance with governmental regulations.

Grey water will be filtered and treated to meet the discharge requirements of the Alaska Pollution Discharge Elimination System (APDES). AKG332029 authorizations for discharge is already in place. During the active work season, crews will travel to the camp area by personnel carrier tundra travel. If existing airstrips are within the project area those area shall be utilized to allow personnel, food and fuel to be delivered to the work area. The camp operates with a Vsat communications system allowing for both phone and internet access.

SAE will coordinate its seismic activities with communities and villages in the area to mitigate and prevent potential conflicts when operating near of areas of subsistence use. Prior to the commencement of the 2018-2019 winter season, representatives will hold a meeting with the village associations to discuss the planned activities. These discussions will include text and visual documentation of the crew's activities, as well as the project boundaries. It is anticipated that as a result of these meetings various protocols and procedures can be developed and implemented which will allow both subsistence and exploration activities to co-exist with respect to this project. Any subsistence hunting and fishing that will be in the area of operations can be documented at this time with the help of community members. All meetings will be documented and kept on file as a resource during and after activities.

SAE is dedicated to minimizing the effect of their operations on the environment. SAE is committed to environmental excellence and continuous improvement. SAE will constantly assess their impact on the environment, and will apply what they have learned over the years to each new project.

SAE's experience on the tundra and sea ice has enabled them to manage and develop equipment and procedure to minimize environmental impact caused by seismic operations. This type of HSE management has enable them to successfully implement many environmental improvements, a few are listed below:

- Reduce the number of equipment on the tundra, through new technology, thereby has reduced the total environmental impact of the crew.

- The use of articulating, rubber tracked, low ground pressure vehicles has minimized the compaction of the tundra and risk of damage when vehicles are turning.
- Reduced vehicle size
- Many modifications of seismic equipment have minimized the risk of hydrocarbon spills to the tundra.
    - Containments systems.
    - High resolution rear mounted vehicle monitoring cameras, aids in spill detection.
    - Daily and weekly maintenance of equipment.
    - Daily equipment inspections.
    - Hourly equipment walk arounds. See attached Plan of Operations and figures for additional details.

Purpose of Development

To acquire better quality, higher resolution seismic data. The project will use new recording technology to locate potential targets for existing production and future lease sales.

This project is scheduled to commence on November 10, 2018, with a completion date of May 15, 2019.

We have preliminarily determined that your proposed development is consistent with Title 19 provided that you comply with the following conditions:

Our review of your application dated May 10, 2018, is being conducted in accordance with NSBMC, Title 19. The purpose of our review is to ensure that your project achieves the goals and objectives, and implements the policies, of the Borough Comprehensive Plan; to ensure that the future growth and development of the Borough is in accord with the values of its residents; to identify and secure, for present and future residents, the beneficial impacts of development; to identify and avoid, mitigate, or prohibit the negative impacts of development; and to ensure that future development is of the proper type, design and location, and is served by a proper range of public services and facilities.

PROJECT ADVISORY

- This permit is for the seismic operations only; all other projects associated with this permit such as temporary airstrips, ice pad(s)/road(s) and/or tundra travel route(s) must be permitted separately.

- SAE shall get Non-Objection letter from all land owners and provide a copy to the NSB Planning Department.

ECONOMIC STIPULATIONS

1. The applicant is advised that the Borough strongly encourages those seeking to do business on the North Slope to conduct their operations in a manner, which enhances locally-based economic and employment opportunities for Borough businesses and residents. In order to ensure that these goals have been considered in the design and administration of project operations the applicant shall submit an economic opportunity plan to the Land Management Administrator that outlines, in detail, how the policies outlined below and codified at NSBMC 19.70.030 have been addressed.

2. Developers are encouraged to conduct operations to the extent practical and feasible:

A. Using suppliers or subcontractors from within the Borough for work, which can be accomplished competitively by local private businesses, regional or village corporations.

B. Employing local Borough residents, unless residents of the local villages express no interest in the work.

C. Utilizing flexible employment procedures, which allow the pursuit of subsistence opportunities by Borough resident employees.

D. Incorporating job-training programs targeting Borough residents.

3. The applicant shall present the economic opportunity plan to the Land Management Administrator for consideration prior to commencement of operations.

WILDLIFE STIPULATION

The Permittee shall prepare and implement a Polar, Grizzly & Brown Bear Interaction Plan to minimize conflicts between bears and humans, including measures to: (a) minimize attraction of bears to the commercial recreation use areas; (b) organize layout of commercial recreation use areas to minimize human/bear interactions; (c) warn personnel of bears near or in the commercial recreation use areas and the proper procedures to take; (d) if authorized, deter bears from the commercial recreation use areas; (e) provide contingencies in the event that bears do not leave the site or cannot be deterred by authorized personnel; (f) discuss proper storage and disposal of materials that may be toxic to bears; and (g) provide a systematic record of bears on the site and in the immediate area. The Polar, Grizzly & Brown Bear Interaction Plan must be submitted to the NSB Planning and Community Services Department before the start of any field activities.

TUNDRA STIPULATIONS

1. Vehicles shall be operated in a manner such that the vegetative mat of the tundra is not disturbed and blading or removal of tundra or vegetative cover is prohibited unless specifically approved by the Land Management Administrator or his/her designee. Snow ramps, snow/ice bridges or cribbing shall be used to cross frozen water bodies to preclude cutting, eroding or degrading of their banks. Snow ramps and snow/ice bridges shall be substantially free of soil and debris and of sufficient thickness to support vehicles. Snow/ice bridges must be removed or breached, and cribbing removed after final use or prior to breakup, whichever occurs first. Frozen water courses shall be crossed at shallow riffle areas, if such areas exist. Where such areas do not exist, an environmentally preferred location will be identified. Vehicles shall not be abandoned. NSBMC 19.60.040 O., NSBMC 19.70.050 L. 3.

2. Existing roads and trails shall be used wherever possible. Trail widths shall be kept to the minimum necessary. Trail surface may be cleared of timber, brush, stumps and snags NSBMC 19.70.050 L. 2. and 3.

3. Movement of equipment through willow (Salix) stands shall be avoided where possible NSBMC 19.70.050. K. 2.

4. Trails and campsites must be kept clean. All solid waste including incinerator residue shall be backhauled to an authorized solid waste disposal facility NSBMC 19.70.050 I. 4. and 5.
5. All hazardous material containers and fuel drums shall be marked with the contractor's initials and dated.

6. Fuel storage facilities shall not be placed within 100 feet of water bodies. NSBMC 19.70.050 I. 11.

7. Only those vehicles approved for summer/winter travel use by the State of Alaska Department of Natural Resources, Division of Mining, Land and Water Management are permitted.

8. Vehicle maintenance, campsites, and storage or stockpiling of material on the surface ice of lakes, ponds or rivers or on sea ice within the borough is prohibited with the following exceptions: a) the use of light plants and water pumps (including refueling) on the surface ice of lakes and ponds may be allowed with consent from the North Slope Borough, b) storage or stockpiling of material on the surface ice of lakes and ponds that do not contain fish may be allowed with consent from the North Slope Borough; c) storage or stockpiling of material on grounded ice in fish bearing waters may be allowed with consent from the North Slope Borough.

9. Winter on-tundra travel may begin when six inches (6") of snow cover and twelve inches (12") of frost depth conditions exist for the activities intended as determined by an authorized field representative of the Land Management Administrator. Certain on-tundra activities may begin sooner than others depending on the impact or magnitude of the operations NSBMC 19.70.050 L. 3.

10. Crossings of rivers and streams is to be restricted to only those areas where the ice is frozen solidly to the river/stream bed to avoid impacts to potential fish over wintering areas NSBMC 19.70.050 K. 2.

11. After April 15, 2019, on-tundra travel shall be subject to termination within 72 hours of notification by the Land Management Administrator or his/her designee for protection of surface vegetation. NSBMC 19.70.050 L. 3.

12. ***A completion report shall be submitted within thirty (30) days upon termination of permit activities. This report shall contain the following information:***

    - Actual routes of travel, and, if utilized, the location of all camps depicted on a Shape File/USGS topo map.

    - A list of vehicles used for any off-road travel, which may have taken place.

    - Statement of clean-up activities.

    - Methods of disposal of garbage, and other camp debris.

    - A report covering any known incidents of tundra damage and follow-up corrective actions that may have taken place while operating under this permit.

    - Any tundra damages that have occurred shall be reported to the Permitting Division, Attn: Herbert Ipalook Jr., or Tony Cabinboy, Field Inspectors at (907) 480-2028 or Brower Frantz, Leroy Oenga Jr. and/or James Ahmaogak, Field Inspectors at (907) 852-0440.

    - Report any tundra damage within 24 hours and consult with NSB Permitting staff with any questionable activity unsure of.

SPILL RESPONSE TACTICS

1. Place drip pans under vehicles parked over 5 minutes.

2. Placement of adequate surface liners is required under all valves or connections to diesel fuel tanks.

3. Impermeable lining and diking is required for fuel storage facilities with a capacity greater than 660 gallons.

Pink dye is added to all diesel fuel prior to transporting to the field crews to aid in spill detection.
All spills will be reported and cleaned up by SAE.

SPILL RESPONSE REQUIREMENTS

SAE shall have an approved spill response and contingency plan. The approved Plan shall be attached to this file for reference. NSBMC 19.70 .050 I (11)

OIL SPILL PREVENTION AND RESPONSE STIPULATIONS FOR FUEL STORAGE

1. The permittee is reminded to conform to the provisions of NSBMC Chapter 19.70 for industrial development. The proper design, installation and operation of fuel storage, transfer and loading facilities are a condition of this permit. NSBMC 19.70.

2. Impermeable lining and diking is required for fuel storage facilities with a capacity greater than 660 gallons. The facility must be designed to hold 110% of the contents of the largest tank in the containment area, plus additional capacity to account for annual average precipitation. An engineer must certify that the lining and diking system meets these standards.

3. An oil spill prevention and response plan must be in place, including sufficient trained personnel and oil spill response equipment to respond to the worst-case discharge at this facility, prior to operating this facility.

GENERAL STIPULATIONS

1. The permittee is reminded to conform to the provisions of NSBMC Chapters 9.08, 9.12 and 9.16 regarding solid and sanitary waste collection/disposal and potable water. The proper and lawful disposal of waste in an environmentally sound manner is a condition of this permit. If the permittee does not anticipate using facilities operated or approved by NSB, the Alaska Department of Environmental Conservation at (907) 269-7500 shall be contacted for an approved sanitary and solid waste disposal plan as well as a plan for potable water for temporary and permanent facilities described in this permit. A copy of the approved plans shall be submitted to the North Slope Borough Permitting and Zoning Division to become a part of this permit file. NSBMC 19.70.050(I)(4)&(5)

2. Should any cultural, archeological or paleontological resource materials (including, but not limited to artifacts, house mounds, grave sites, ice cellars, and fossilized animal remains) be discovered in the course of activities conducted under this permit, the site shall not be disturbed and the North Slope Borough Inupiat History, Language and Culture Commission shall be promptly notified at (907) 852-0422. NSBMC 19.70.050(E) through (G)

3. All oil and other hazardous material spills over 55 gallons shall be reported immediately to the NSB by telephoning (907) 852-0440. The follow-up written report will be faxed to the NSB Permitting and Zoning Division fax (907) 852-0321 or email to: brower.frantz@north-slope.org; leroy.oenga@north-slope.org; james.ahmaogak@north-slope.org; herbert.ipalook@north-slope.org; and/or tony.cabinboy@north-slope.org. A report of all spills shall be submitted to our office on a weekly basis. A sufficient amount of absorbent materials shall be on hand at all times in the event of any fuel, oil, or chemical spills. Spills shall be cleaned up as soon as possible. NSBMC 19.50.030(I)

4. The Land Management Administrator may require that his/her authorized representative be on-site during any operations conducted under this permit. NSBMC 19.30.100

5. Within the constraints of federal, state and local law, the permittee and its agents are encouraged, through a voluntary affirmative action program, to hire and train residents of the North Slope Borough. In order to comply with this stipulation the permittee and its agents shall contact the Mayor or City Manager and the village corporation of any village most affected by this permit. In this case contact the village of Kaktovik at (907) 640-6313 and Kaktovik Inupiat Corporation at (907) 640-6120 to determine if there are qualified people available or people who could be employed for on-the-job training. NSBMC 19.70.030

6. The permittee shall comply with all local, state and federal laws and permits applicable to this project. NSBMC 19.30.100

7. This permit is valid for the duration of the existence of the development and the developer's compliance with the terms and conditions herein. This permit automatically expires within twelve months of approval if no actual development has commenced. Failure to comply with the conditions of this permit could result in immediate revocation of this permit. NSBMC 19.30.070

8. The permittee shall inform and ensure compliance with these stipulations by its agents and employees. This permit shall be posted in a conspicuous place for these individuals to see. NSBMC 19.30.100

You are encouraged to contact this office if you wish to discuss the applicability of the above conditions to this approval. By copy of this letter, we are soliciting comments from the below-listed individuals and their respective agencies regarding the adequacy of the above stipulations to meet the purpose of our review.

Comments on the adequacy of these stipulations should be sent to Waska A. Williams, Jr., Land Management Specialist at the address above or by email at: waska.williams@north-slope.org or by telephone at (907) 852-0320 ext. 5418

Sincerely,

Gordon R. Brower,
Land Management Administrator

cc: NSB Planning Commission
Selene Tirre, Assessing Division, NSB
Jeanne.proulx@alaska.gov
Donna Wixon, USDI/BLM
Jeanne Frazier, Adele Lee, AkDNR/DO&G, Anchorage

Lee McKinley, ADF&G JPO Liaison, Anchorage
Audra Brase, ADF&G Regional Supervisor/Division of Habitat, Fairbanks
Jeanne Hanson, USDI/NMFS, Anchorage
Josephina Delgado-Plikat, DCOM, Juneau
Tonya Bear, AkDEC, Fairbanks
Dog.permitting@alaska.gov
Reese.Thieme@alaska.gov
Katie Farley, State Pipeline Coordinators Office/ JPO, SOA
Realty Director, Inupiat Community of the Arctic Slope
AKFF 018780A
Rex Rock Sr., President, Arctic Slope Regional Corporation
Nora Jane Burns, Marianne Rexford, Kaktovik Village Deputy Assistant, NSB
Nora Jane Burns, Mayor, City of Kaktovik
Matthew Rexford, President, Kaktovik Inupiat Corporation
Brower Frantz, Leroy Oenga Jr., James Ahmaogak Field Inspectors, Barrow
Tony Cabinboy, Herbert Ipalook Jr., Field Inspectors, Nuiqsut
Wayne Cary, Assistant Attorney, NSB
Charmaine Hingada, Jonathan Aiken Jr., CPD/GIS, NSB
Files

N18-466/GRB/md/pl LMR Manager/ww

North Slope Borough

Department of Planning and Community Services

Land Management Regulations (LMR) Permit Application

Permit Number: 18-4666

Applicant: Kuupik-SAE LLC

Address: 8240 Sandlewood Place suite 102

Contact Person: Sue Simonds

Email: ssimonds@saexploration.com

Location (TRS): T: See Map R: Sec:

Zoning District: Developmental

Proposed Start Date: 10/10/2018

Proposed Development: 3D seismic project

Permit Type: Developmental

Date: 4/23/2018

State ID:

Phone: 907-522-4499

Project Name: STAINES 3D

Field Name & Pad: N/A

Completion Date: 5/15/2019

Purpose of Development: To acquire better quality, higher resolution seismic data. The project will use new recording technology to locate potential targets for existing production and future lease sales.

☐ Fill/Dredge	Material: N/A		Acres:	N/A
☐ Oil & Gas Wells	Number of New Surface Holes: N/A			
☐ Temp. Water Use	Sources:	N/A	Access:	N/A
	Purpose:	N/A	Maximum Amount:	N/A
☑ Off Road Travel	Period:	10-10-2018/tundra closing	Equipment:	Off Road Vehicles
	Site Access:	From gravel pad		
☑ Fuel Storage	Type:	Long Haul Fuelers (4)	Amount:	20,000 gallons
	Handling:	double walled tanks on ski's		
☐ Hazardous Material Storage	Type:	N/A	Amount:	N/A
	Handling:	N/A		
☑ Solid Waste	Treatment:	Pacto style		
☐ Mining	Habitat:	N/A		
☐ Air Emissions	Type:	N/A	Amount:	N/A
☑ Noise/Vibrations	Type:	AHV4 Commander Vibrator	Amount:	12 vibes
☐ Sensitive Habitat	Floodplain:	N/A/ winter project	Shoreline:	N/A/ winter project
☐ Transportation	Type:	N/A		

☐ Marine Tanker Facility	☑ Seismic Work	☐ Utility Development	☐ Recreational Development
☐ Causeway Construction	☐ Offshore Drilling	☐ Residential Development	☐ CD-ROM Included
☐ Airport or Helicopter Pad	☐ Oil Transportation System	☐ Snow Removal	☐ Maps Included

ATTACH TO THIS APPLICATION THE FOLLOWING:

- GENERAL VICINITY MAP
- SPECIFIC LOCATION MAP, INCLUDING NEARBY EXISTING DEVELOPMENT AND NATURAL FEATURES
- SITE SPECIFIC FOOTPRINT (IN ESRI SHAPE FILE FORMAT) ON A CD-ROM.
- A DIGITAL GIS SHAPE FILE OR GEODATABASE OF THE PERMIT AREA WITH NO ATTRIBUTES.
- THE PROJECTIONS SHOULD BE NAD 1927 ALASKA ALBERS OR GEOGRAPHIC.
- DESIGNN PLANS (PLOT PLAN), ELEVATIONS, CROSS SECTIONS, PROFILES, AS APPROPRIATE.
- SUPPLEMENTAL INFORMATION, AERIAL PHOTOGRAPHS, STUDIES, ETC. (AS NEEDED).

SEND TO:
NORTH SLOPE BOROUGH, LAND MANAGEMENT ADMINISTRATOR
P.O. BOX 69
BARROW, ak 99723
PHONE: (907) 852-0320 TOLL FREE (IN-STATE): (800) 476-6066 EXT. 320

I HEREBY CERTIFY THAT THE FOREGOING IS TRUE AND CORRECT TO THE BEST OF MY KNOWLEDGE.
ALL APPLICATION MATERIAL IS CONSIDERED PART OF THE PERMIT.

[signature] 4/23/2018

Authorized Signature **Date**

Suzan Simonds Permits and Regulatory

Name **Title**

FEE PAID			
	☐	SPECIAL PLANNING COMMISSION MEETING	$12,000
	☑	DEVELOPMENT PERMIT	$2,000, plus $500/well
	☐	ADMINISTRATIVE APPROVALS	$1,500
	☐	CONDITIONAL DEVEOPMENT PERMITS	$3,000
		AMOUNT PAID	

DECISION

☐ **ADMINISTRATIVELY APPROVED**
This is a minor alteration to a previously approved development permit for commercial recreation

☐ **REZONING APPROVED**
This proposed development substantially complies with the Master Plan, and a use permit is issued, conditioned on compliance with all relevant Master Plan Conditions, lease stipulations, and provisions of the state and federal law and permit served thereunder.

☐ **DEVELOPMENT PERMIT APPROVED**
The proposed development meets all applicable mandatory policies, represents the developer's best efforts to implement all relevant best efforts and minimization policies, and as long as conditions set forth in the accompanying letter are complied with, will represent a net public benefit (See accompanying letter.)

☐ **CONDITIONAL DEVELOPMENT PERMIT APPROVED**
This is a use of land that is listed as a conditional development for this zoning district or has been elevated by the NSB Land Management Administrator to the Planning Commission

☐ **PERMIT DENIED**
(See accompanying letter)

NSB Land Management Administrator **Date**

If you wish to appeal this decision, you must submit written notice to the Commission Clerk of the Planning Commission (PO Box 69, Barrow, Alaska, 99723) within 30 days of the issuance of this decision, stating the policy or policies in question and the reason you believe the decision is incorrect. NSMBC §19.30.130.

4-23-2018

Gordon Brower
North Slope Borough
P.O. Box 69
Barrow, AK 99723

NORTH SLOPE BOROUGH

MAY 10 2018

PLANNING DEPARTMENT
PERMITTING DIVISION

Re: Staines 3D

Dear Gordon:

SAExploration, Inc (SAE) along with their joint venture partner, Kuukpik Corporation (Kuukpik SAE, LLC) would like to submit their permit application for the seismic project called Staines 3D. Kuukpik-SAE is requesting a permit to conduct seismic activities for the winter seasons of 2018\2019. This seismic survey will cover approximately 511 square miles and will start approximately December 10, 2018 or tundra opening. In support of the permit application, I have enclosed a map of the project area, plan of operations and a check for $2000.00. Your review and approval of the application is greatly appreciated

Please contact me at 907-331-8140 or 907-522-4499, ssimonds@saexploration.com if you have questions or need additional information.

Sincerely,

Suzan Simonds
Permits and Regulatory Manager
SAExploration Inc

SAExploration
8240 Sandlewood Pl. Suite 102
Anchorage, Alaska 99507
907-522-4499 fax 907-522-4498

Staines 3D Plan of Operations

Winter Plan of Operations 2018/2019 Project Description

1.0 Introduction

SAExploration, Inc (SAE), and its joint venture with the Kuukpik Corporation (Kuukpik-SAE), is pleased to submit their plan of operations for the Staines 3D Program. Kuukpik-SAE is requesting permits to conduct a seismic survey beginning during the winter season of 2018-2019. SAE will start the seismic operations during open tundra travel winter season with an estimated start date of December 2018 with ice checking and continuing until the close of tundra or the sea ice deteriorates. Land ownership within this project area is the State of Alaska and all within the North Slope Borough.

2.0 Scope

SAE is proposing to acquire seismic data using the best available technology, to acquire better quality and higher resolution seismic data. This plan of operations will cover the winter season of 2018-2019, starting approximately December 10st and ending on May 31st, or tundra closure.

3.0 Location

The survey permit area encompasses approximately 511 sq. miles. The project area will include parts, or all the following townships:

Townships and Ranges		
All of	Part of	
U007N022E	U005N022E	U008N024E
U006N022E	U005N023E	U009N021E
U008N022E	U006N021E	U009N024E
U008N023E	U006N023E	U009N025E
U009N022E	U007N021E	U010N021E
U009N023E	U007N023E	U010N024E
U010N022E	U007N024E	U010N025E
U010N023E	U008N021E	U011N021E
	U011N023E	U011N022E

The program area proposed will be acquired using the following parameters or similar depending on final plot.

Typical Parameters			
Receivers		Sources	
Line Interval:	1320'	Line Interval:	660'
Station Interval:	165'	Station Interval:	41.25'
Number of Lines	426	Number of Lines	280
Recording Parameters		Type	Vibroseis
Patch	20 lines		
	160 stations		

4.0 Environmental Management

SAE is dedicated to minimizing the effect of our operations on the environment. We are committed to environmental excellence and continuous improvement. We will constantly assess our impact on the environment, and will apply what we have learned over the years to each new project.

Our experience on the tundra and sea ice has enabled us to manage and develop equipment and procedure to minimize environmental impact caused by seismic operations. This type of health, safety and environment (HSE) management has enable us to successfully implement many environmental improvements a few are listed below:

- Reduce the number of equipment on the tundra, through new technology, thereby has reduced the total environmental impact of the crew.
- The use of articulating, rubber tracked, low ground pressure vehicles has minimized the compaction of the tundra and risk of damage when vehicles are turning.
- Reduced vehicle size
- Many modifications of seismic equipment have minimized the risk of hydrocarbon spills to the tundra.
    - Containments systems
    - High resolution rear mounted vehicle monitoring cameras, aids in spill detection.
    - Daily and weekly maintenance of equipment.
    - Daily equipment inspections.
    - Hourly equipment walk arounds.

5.0 Cultural Interface

SAE will coordinate its seismic activities with communities and villages in the area to mitigate and prevent potential conflicts when operating near of areas of subsistence use. Prior to the commencement of the 2018-2019 winter season, representatives will hold a meeting with the village associations to discuss the planned activities. These discussions will include text and visual documentation of the crew's activities, as well as the project boundaries. It is anticipated that as a result of these meetings various protocols and procedures can be developed and implemented which will allow both subsistence and exploration activities to co-exist with respect to this project. Any subsistence hunting and fishing that will be in the area of operations can be documented at this time with the help of community members. All meetings will be documented and kept on file as a resource during and after activities.

6.0 Crew Integrity Culture

SAE's commitment at all levels to continue "Raising the Bar" for HSE awareness is paying off. Our health and safety goal is to achieve a zero-accident rating consistently. We attribute a portion of this success to the following critique:

6.1 Our Hiring Process:

- We work to attract and hire the best in the industry to operate the crew.
- A comprehensive pre-employment screening for new hires.
- Prospective employees are administered a drug and alcohol screening test.
- Prospective employees must complete a Physical exam and Functional Capacity Exam.
- Prospective employees complete an eight-hour Health, Safety and Environmental orientation and task specific training as well as a competency assessment while on the crew.

6.2 Our Training Process:

- The operations are controlled with high quality, experienced arctic personnel.
- Provide unique employment opportunities for its employees.
- Engages its employees in operations outside the seismic sector.
- Holds an Annual HSE Seminar for the full crew.
- Comprehensive online SAE training and testing.
- Holds daily orientation and safety briefings (for each shift) accounting for: what hazards will be encountered, other conflicting operations, daily conditions, review of the day before and the day ahead as well as:
- Tailgate meetings are held to review procedures in areas of known hazard or where operational requirements have changed from those expected.
- Annual training for employees.

6.3 Employee Recognition of Achievement Program

It is the objective of SAE to complete our seismic prospects in a manner that simultaneously achieves complete safe HSE operating practices for the seismic crew, and satisfies the data requirements of the client. In order to reach this goal, we will fulfill our corporate obligation of providing the maximum support necessary to allow the crew members to complete this project with an expected result of a "zero" frequency rate of HSE incidents or accidents. In recognition of these achievements, SAE rewards the seismic crew during certain programs for their efforts with discretionary bonuses or gifts for HSE performance and positive environmental awareness and reporting.

7.0 Permit Requirements

Provided below is a list of permits, approvals, authorizations for the operations described in this Plan. Land ownership for this program includes state lands within the North Slope Borough.

PERMITS AND APPROVALS	
Federal Government	
U.S. Fish and Wildlife Service	Letter of Authorization (LOA), Polar Bear Incidental Take – USF&WS
North Slope Borough	
NBS IHLC TLUI ICAS	Land Management Development Permit Form 600 Administrative Approval form 400 Coordination
Alaska State Government	
Department of Natural Resources, Division of Oil and Gas	Geophysical Exploration Permit
Department of Natural Resources, Division of Mining Land and Water	Temporary Water Use Permit (if required)
Department of Natural Resources, Division of Mining Land and Water	Tundra Travel Permit
Department of Fish and Game	Fish Habitat Permit (Title 16)
Department of State Historic	Letter of Concurrence
Other Approvals	
Lease LNO's	

8.0 Mobilization and Access

SAE will stage equipment from existing facilities in Deadhorse. Camp and equipment will be trucked via road infrastructure to a point of access to the tundra or sea ice (See Appendix C). The crews will mobilize to existing gravel pads which will allow access to the tundra and provide a resupply area for the crews. All mobile equipment will have a navigation system installed for logistics and hazard Identification. (Tiger Nav) Tracked tundra vehicles will be used to transport the sled camp along the tundra. The camp will remain close to the survey activities and will move every 2-5 days depending on the survey progress and snow cover. When the survey is completed each season, the camp and equipment will travel along the tundra or sea ice to gravel pad for offloading and then trucked back to our Deadhorse pad location. Snow packed trails will be made throughout the project area, these trails will be used for the purpose of less environmental impact and crew travel /re-supply. The location of these trails will depend on snow coverage and terrain conditions. SAE will attempt to coordinate with companies to use any existing or planned trails.

9.0 Survey and Ice check

Surveyors will establish survey controls by setting up a base station; controls will be set with a satellite navigation system transported by tracked vehicles. One of the highest risk potentials for arctic operations is properly verifying the integrity of the ice. This will be done by "ice checking units" consisting of a Tucker vehicle capable of supporting 24 hour operations. Snow machines may also be used for survey and ice check operations. The survey units will be equipped with ground penetrating radar systems (GPR), which are extremely accurate on fresh water. In addition, each ice check unit is equipped with battery operated ice auger which is used to verify the calibration of the GPR, measure ice depths on sea ice, or verify if depths where the GPR units cannot reach. Where river channels exist, unusual surface fracturing is evident or drillings shows substandard ice the standard grid is tightened up to insure a safe path for the equipment to follow. Freeboard testing (ice stabilization) is also be conducted when working on floating ice to insure the ice has the strength to safely hold the equipment. Preliminary trails or snail trails will be established for every foot that the vibrators must travel on the sea ice, lakes or rivers, which will minimize the potential for breaking through the ice. Survey will also map each hazard that is discovered and placed into Tiger-Nav which is a navigation system that allows each vehicle to display the program area and hazard within the area Hazards and information that are typically displayed in addition to the standard program area are:

- Areas of thin Ice
- Historic areas
- Subsistence use areas
- Areas where vegetation requires avoidance
- Native allotments

- Safe routes of travel
- Low snow areas

In low snow years, snow surveys will be conducted to substantiate depths and will be recorded for equipment movement efforts

10.0 River Crossings

There may be areas where we encounter floating ice which may not safely support the weight of some equipment. In these cases, SAE will permit this activity with State of Alaska Department of Fish & Game, to apply water to increase the thickness of the ice to establish temporary river crossings. There also may be areas on rivers, streams and lakes that need to be protected with snow for traversing from tundra to ice for crossing. SAE will make snow ramps in these areas and establish that the ice is grounded or the ice is of sufficient ice depth to cross. This will eliminate any impact to river banks and or tundra.

11.0 Willow Protocol

SAE is committed to operate in a manner that all its operations or activities do not damage or affect the social, cultural or community in the areas where we work. If it is determined that willows are in the area, SAE has developed a willow protocol that ensures willow areas are mapped and defined by size. Willow areas will first be identified via aerial photos and possibly snow machines, the areas will then be placed on maps. It is the responsibility of the survey manager to ensure that willow areas are recorded on the hazard maps and appropriate markings are in place. During the ground truthing of willows, Subsistence Representatives will be responsible for assisting in identifying sensitive willow areas and defining size. Survey will mark trials to be follow by the crews if it is determined that the area is accessible. In areas where willow can not be traversed with vehicles larger vehicles the crews will utilize snow machines or foot traffic to access the receiver points

12.0 Recording Operations

Seismic operations will be conducted utilizing 12-15 (rubber tracked/buggy) vibrators and approximately 20,000 wireless, autonomous recording channels. The method of acquisition is Random Source Driven Acquisition (RSD) combined with a Compressive Sensing design. Generally, receiver (geophone) lines run perpendicular to source lines and will be typically spaced a minimum of 660ft apart. Source and Receiver point distance along lines are randomized and will be positioned between 41.25 ft. and 200ft from an adjacent source or receiver point on a given line.

Each Receiver point is consisting of wireless nodes and single geophone. Receivers are transported to each location and from location to location with the use of a low ground pressure Tucker Sno-Cat or snow machine. Each Tucker is manned by three personnel and can carry up to 220 receiver points There could be up to 48 receiver lines placed on the ground at a time with approximately 32 lines being active at any given time. Although there may be only 32 lines required to be recorded for any given source point all wireless nodes on the ground are recording 24 hours per day

The energy source is Vibrosies. Each source point is occupied by a single vibrator which generated frequencies during a "sweep" of approximately 1.5 to 96Hz. The duration of each sweep is anticipated to be 16 to 24 seconds per source point. Using the SDS methodology multiple vibrator can collect data at the same time provided the vibrators are separated by approximately 1320 feet. This methodology means that only a single vibrator is required to travel down any source line, thereby reducing risk compaction or damage to the tundra. Vibrators will only operate on snow covered tundra or grounded sea ice. The duration and decibel level of the source levels are so low that hearing protection is not required for seismic crew members.

Recording Operations continue for 24 hours per work day and are based on two 12 hour shifts. Communications with the crews, while out in the field will be via VHF radio systems and wireless data transfer radios.

13.0 Camp Facilities

Each camp can accommodate up to 150 persons. The camp will consist of sled-mounted units including a kitchen and diner, sleeping areas, washrooms, laundry, offices, shops, medical clinic, storage, generator rooms, and storage compartments. The mobilization of the camp will be from the existing gravel roads, starting off a gravel pad. A pre-determined route will be used to move equipment to the project location. Camp trails during project will be scouted out in advance by project manager to avoid hazards. To mitigate any tundra damage the sleigh camp could be moved up to 2 miles every few days, this will depend on the weather, snow covering and the advancement of the project.

The SAE HSE advisor and the local hire subsistence representative will revisit every camp site, after camp has moved on, to review the area and sign-off that no damage occurred. Equipment included at camp stations will include long haul fuel tractors, remote fuelers, water maker, incinerator, resupply and survival sleigh, tractors, loaders and tuckers. Sanitary conditions in the kitchen and diner and washrooms will be maintained in full compliance with governmental regulations.

Grey water will be filtered and treated to meet the discharge requirements of the Alaska Pollution Discharge Elimination System (APDES). AKG332029 authorizations for discharge is already in place. During the active work season, crews will travel to the camp area by personnel carrier tundra travel. If existing airstrips are within the project area those area may be utilized to allow personnel, food and fuel to be delivered to the work area.

The camp operates with a Vsat communications system allowing for both phone and internet access.

14.0 Water Withdrawal

Potable water will be produced at camp with a skid-mounted snow melter. Water is produced by melting snow or if it is a low snow year this can be supplemented by withdrawing water from lakes or other areas of with fresh water, it is then processed through our Department of Environmental Conservation (DEC) approved water system, which consists of filtration and chlorination that is regulated by the DEC. SAE will identify lakes during the scouting process and will be permitted if used. If lakes are used, they will be identified in final reporting. If there is not an adequate source of snow that can be extracted in the camp site(s) any shortfall of water required may need to be transported to each camp. Each crew requires approximately 3500 gallons of water per day.

15.0 Temporary Snow Airstrips

The project will need airstrips to transport crews on crew change days. Having temporary airstrips will save several hours of tundra travel. SAE will create a flat area on predetermined grounded, frozen lakes, or tundra to serve as landing strip to receive the aircraft for crew changes. An advance scouting trip will be identifying grounded lakes and or tundra locations that can be used for this purpose. The landing strip will only be on areas that have adequate space for safely landing aircraft. A rubber tracked Stieger with a blade will clear the snow down to ice approximately 75 feet wide and 2300 to 3500 feet long for the aircraft to land. Black bags filled with snow will be placed along the side of the berm to delineate the edge of landing strip along with lighting.

After crew has mobilized and initial scouting has been done lakes which may support this operation will be documented for possible airstrip locations. The GPS location of the landing strip will be on daily reports.

The strips will be used for landing and will not be maintained unless the same location is needed again. After use of the strip is no longer necessary, the crews will inspect the location and record that area that was used by GPS location to be included in the final reporting. An example of airstrip is listed in Appendix F.

16.0 Fuel Supply and Storage

SAE will be using long haul sleigh tanks for fueling. A total of 6-7,000 gallons of fuel will be our average daily consumption per crew. All fuel will be ultra-low sulfur for vehicles and equipment. Fuel will be delivered using over land Rolligon or rubber tracked carriers. In the event the supply is disrupted by whether or other unforeseen events fuel may have to be delivered by aircraft, SAE will use temporary airstrips for these occasions. Scouting trips will assist SAE in identifying existing airstrips if any that can be used for this purpose. Off-loading fuel from aircraft, will be done in accordance with SAE's fueling procedure. Fueling storages and fueling activity will be located at least 100 feet from any water body. SAE fueling procedures include spill management practices such as drip plan placement under any vehicle parked; and placement of vinyl liners with foam dikes under all valves or connections to diesel fuel tanks. All fuel tanks are double- wall tank construction. Fuel dye is added to all fuel as part of spill detection. All spills, no matter what the size are tracked and cleaned up by SAE and used for spill prevention operations. We also hold a Spill Prevention Countermeasure Control (SPCC) plan for our fueling and fuel storage operations associated with seismic operations. This SPCC plan is site specific and will be amended for each new project. All reportable spills will be communicated through the proper agencies and land owners.

17.0 Waste Management

Food waste generated by the field operations will be stored in vehicles until the end of the shift. The garbage will then be consolidated at camp in wildlife resistance containers for further disposal. All food waste generated in camp will also be collected and stored in the same consolidation area. A skid-mounted incinerator will be used for daily garbage waste. This equipment falls within the regulatory requirements of 40 CFR 60. This double chamber cyclonator series cy2000 will use on an average 1 to 2 gallons of fuel per hour while in use. The use of electricity is for the motor to the unit that maintains the air to fuel mixture. SAE will collect data to provide the required records on a calendar basis of description and weight of camp wastes burned.
Any wastes generated by seismic operations will be properly stored and disposed of in accordance with applicable permit stipulations and SAE controls. Food waste is continually incinerated to avoid attracting wildlife. Gray water generated from the mobile camp will be discharged according general permit AKG332000 and 18 AAC 83.210 and NPDES discharge limits. SAE sleigh camp is permitted by the State of Alaska DEC and The Fire Marshal. Toilets are "PACTO" type to eliminate "black water". Ash from the incinerator will be back-hauled to the North Slope Borough disposal facility in Deadhorse. The sleigh camp will move approximately every two to five days depending on weather conditions. An inspection by the HSE Advisor will be done after camp has left to ensure that the area is clean of all debris.

18.0 Wildlife

Wildlife that may be in the area during the winter season are owls, ravens, arctic fox, wolverine, musk ox, and possibly, over-wintering caribou. Grizzly bears also inhabit the general area in the project, but are likely to be inactive during the winter season. Polar Bears may be seen along the coastal areas and out on the sea ice. Although encounters with Polar Bears or Grizzly bears are unlikely, SAE and its contractors will exercise caution during the project. Should a Grizzly Bear or Polar Bear be encountered, SAE would follow the procedures as outlined in our comprehensive Wildlife Interaction Plan that is approved by the ADF&G and USFWS. Any sightings will be reported immediately to project manager and crew HSE advisor. Bear sightings will be reported within 24 hours to proper agencies. In the event of a problem bear or if an actual bear/human encounter occurs the individuals listed below should be contacted immediately. Crew personnel will be instructed not to feed wildlife of any type per regulations 5 AAC 81.218 or in any other way attempt to attract them. SAE and its contractors will exercise caution while working and always watching for bear signs. Food and food waste will be kept inside vehicles while out in field. All Polar Bear sightings will be reported to the USFWS within 24 hours of the sighting. Any type of bear dens, suspected or confirmed will be reported within 24 hours unless otherwise instructed by USFWS or ADF&G agency personnel.

SAE will work with agencies to avoid and minimize interactions with wildlife; this includes abiding by relevant regulations and obtaining required authorizations. Our Wildlife Interaction Plan is listed in Appendix G.

19.0 Historic and Cultural Resources

An archeological study was permitted through the NSB and the State of Alaska in 2015 the study was completed by a licensed archeologist. Dr. Rick Reanier. A small portion of the project towards the south end will have an additional study area completed this summer. The project was conducted in August of 2015. All land ownership is the State of Alaska. SAE will not be accessing any native allotments without permission of the owners. SAE will submit a clearance request to the NSB, the State of Alaska and the Traditional Land Use Inventory (TLUI) database, maintained by the NSB. Previously recorded and any new AHRS sites will not be affected by any of the proposed seismic activities. All areas will have 500-foot buffers placed around them as a non-activity zone. Any native allotments will be avoided and will also have a 500-foot buffer placed around them. These buffers will be placed in our Tiger Nav system and placed on maps to ensure no vehicles enter avoidance areas.

20.0 Communication & Supervision

The following personnel at SAE can be contacted for information during the permitting survey program are:

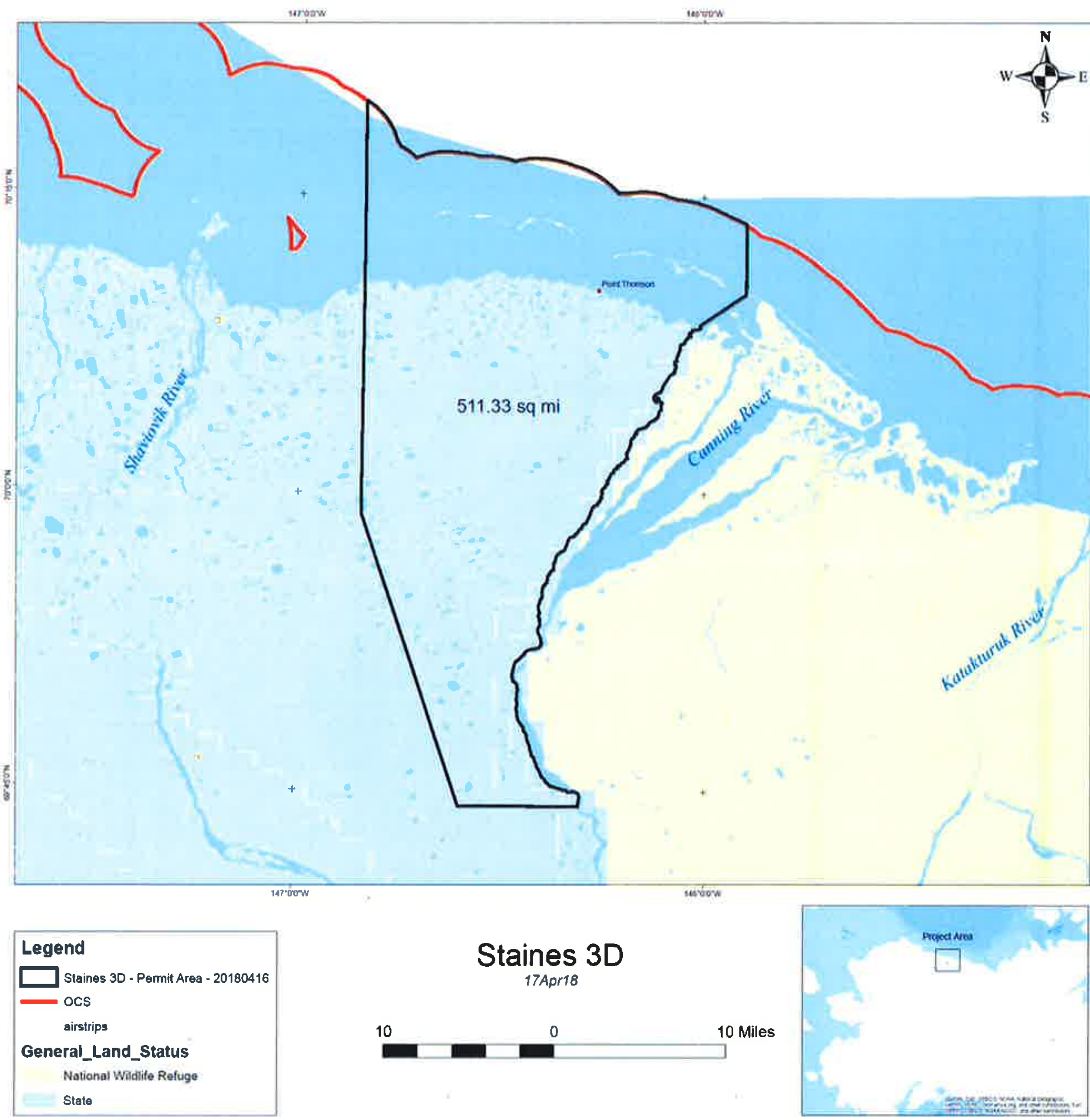
Ted Smith Operations Supervisor 907-522-4499 907-301-5434 cell
Suzan Simonds Permits and Regulatory Manager 907-522-4499 907-331-8140 cell
Rick Trupp General Manager of Alaska 907-522-4499

21.0 Appendices

Appendix A -	Project Area Maps
Appendix B -	Equipment List
Appendix C -	Example Map of Mobilization Route
Appendix D-	Best Practices for Ice Travel
Appendix E-	Equipment Pictures
Appendix F-	Example of Temporary Airstrip
Appendix G-	Wild Life Interaction Plan

Appendix A: Project Area Maps

Project Area



Appendix B: Equipment List Per Crew

TUCKER UNIT #	TYPE	COMMENTS	Phase	ASSET #
T-1	SAE PERSONAL CARRIER	AMBULANCE / MEDIC	Camp transit	14-01
T-3	SAE PM TUCKER	ICE CHECK	Pre Pack	14-03
T-4	SAE ICE CHECK	ICE CHECK	Pre Pack	14-04
T-5	SAE ICE CHECK	PM	Ice Check	14-05
T-6	SAE NODE TUCKER	CLIENT	Ice Check	14-06
T-7	SAE NODE TUCKER	Layout	Camp transit	14-07
T-10	SAE NODE TUCKER	Line Viewer	Camp transit	14-10
T-11	SAE NODE TUCKER	Line Viewer	Camp transit	14-11
T-12	SAE NODE TUCKER	VIBE TECH / SHIFT MAINT	Vibe Transit	14-12
T-13	SAE NODE TUCKER	LAYOUT	Camp transit	14-13
T-14	SAE VIBE TECH	VIBE TECH	Vibe Transit	14-14
T-17	SAE NODE TUCKER	LAYOUT	Camp transit	14-17
T-18	SAE NODE TUCKER	LAYOUT	Camp transit	15-18
T-19	SAE NODE TUCKER	VIBE TECH	Vibe Transit	15-19
T-20	SAE NODE TUCKER	Layout Spare	Camp transit	15-20
T-21	SAE NODE TUCKER	RCM	Camp transit	15-21
T-22	SAE NODE TUCKER	CLIENT	Camp transit	15-22
T-23	SAE NODE TUCKER	Layout	Camp transit	15-23
T-24	SAE NODE TUCKER	Layout	Camp transit	15-24
T-25	SAE NODE TUCKER	Layout	Camp transit	15-25
T-26	SAE NODE TUCKER	Layout	Camp transit	15-26
T-27	SAE NODE TUCKER	ICE CHECK	Camp transit	15-27
T-28	SAE PERSONAL CARRIER	Vibe Crew	Vibe Transit	15-28
T-29	SAE PERSONAL CARRIER	Vibe Crew	Vibe Transit	15-29
T-30	SAE PERSONAL CARRIER	Line Crew / Air Strip ?	Camp transit	15-30

TRACTOR	TYPE	COMMENTS		ASSET #
C-12	SAE PLOW/WINCH	VIBE WINCHER	Vibe Transit	14-19
C-20	SAE PLOW/WINCH	VIBE WINCHER	Vibe Transit	14-20
C-21	SAE PLOW/WINCH	LONG HAUL	Ice Check	14-21
C-23	SAE PLOW/WINCH	LONG HAUL	Ice Check	14-23
C-24	SAE LOADER / WINCH	LONG HAUL	Camp transit	14-24
C-31	SAE WINCH	VIBE TECH	Camp transit	15-31
C-32	SAE WINCH	VIBE TECH	Camp transit	15-32
C-33	SAE PLOW/WINCH	CAMP SUPPORT/AIRSTRIPS	Ice Check	15-33
C-34	SAE WINCH	REMOTE FUEL	Camp transit	15-34
C-35	SAE WINCH	REMOTE FUEL	Camp transit	15-35
C-36	SAE WINCH	LINE CREW / TACO	Camp transit	15-36
C-37	SAE WINCH	LONG HAUL	Camp transit	15-37

GPS BASE	TYPE	COMMENTS		
GPS-BS #4	SAE Tucker Tracks	SURVEY / ICE CHECK	Ice Check	15-42
GPS BS #5	SAE Tucker Tracks	SURVEY / ICE CHECK	Ice Check	15-43
GPS BS #6	SAE Tucker Tracks [illegible]	SURVEY / ICE CHECK	Ice Check	14-44

DOZERS	TYPE	COMMENTS		ASSET #
D7G	D7G DOZER	SAE / RAMPS	Ice Check	15-89
D7G	D7G DOZER	SAE / RAMPS	Camp transit	15-99
D7G	D7G DOZER	SAE / RAMPS	Camp transit	??
277K	277K LOADER	WATERMAKER	Camp transit	15-101

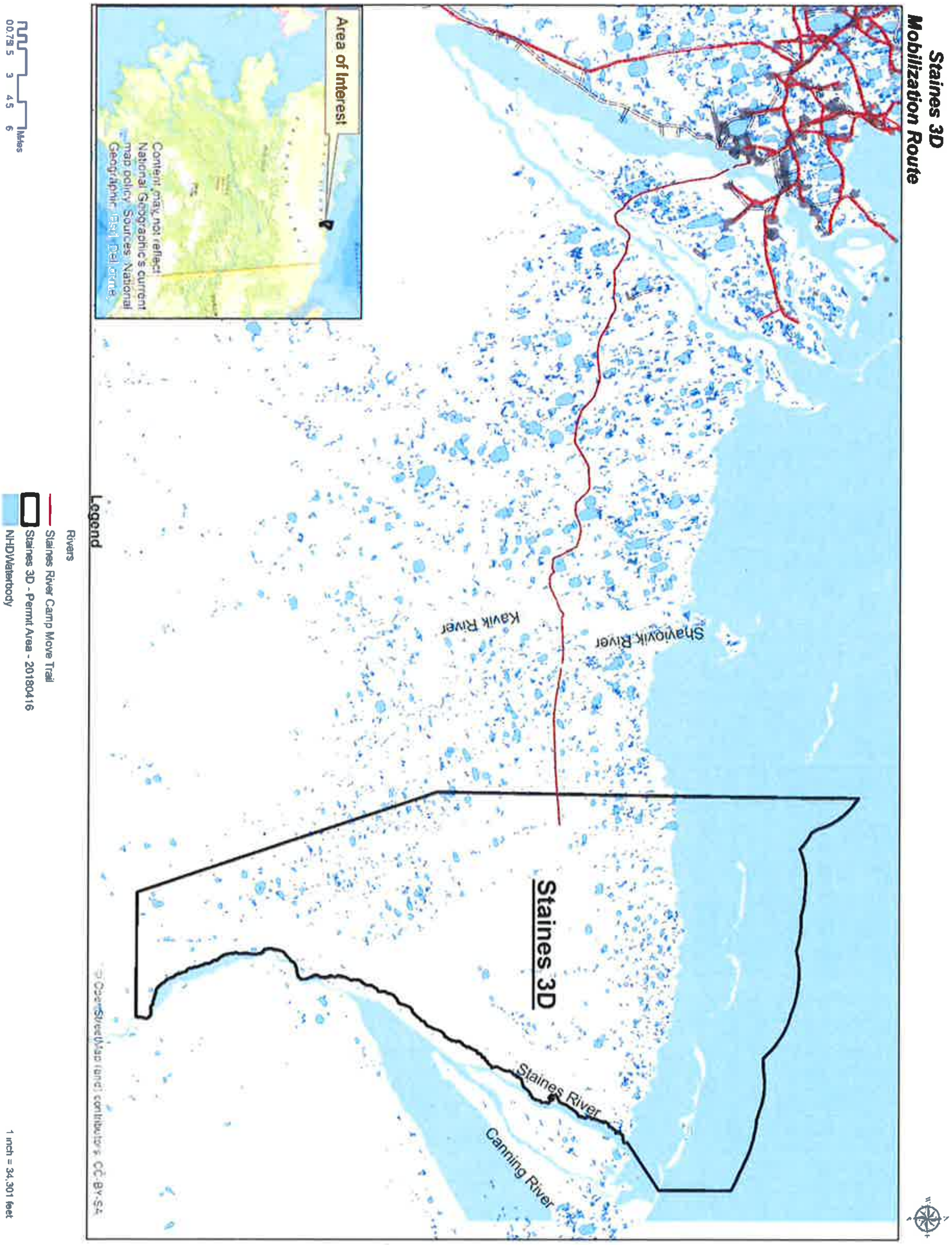
AHV4 COMMANDER VIB	TYPE	COMMENTS	Phase	ASSET #
V-#1	Track	SAE	Vibe Transit	15-01
V-#2	Track	SAE	Vibe Transit	15-02
V-#3	Track	SAE	Vibe Transit	15-03
V-#4	Track	SAE	Vibe Transit	15-04
V-#5	Track	SAE	Vibe Transit	15-05
V-#6	Track	SAE	Vibe Transit	15-06
V-#7	Track	SAE	Vibe Transit	15-07
V-#8	Track	SAE	Vibe Transit	15-08
V-#9	Track	SAE	Vibe Transit	15-09
V-#10	Track	SAE	Vibe Transit	15-10
V-#11	Track	SAE	Vibe Transit	15-11
V-#12	Track	SAE	Vibe Transit	15-12
V-#13	Track	SAE	Vibe Transit	14-30
V-#14	Track	SAE	Vibe Transit	14-33

TUCKER TRAILERS	TYPE	COMMENTS		ASSET #
VT TUCKER TRAILER	VIBE TENDER	VIBRATORS RM	Vibe Transit	15-13
VT TUCKER TRAILER	VIBE TENDER	VIBRATORS RM	Vibe Transit	14-38
FS TUCKER TRAILER	FIELD SHOP	FIELD EQUIPMENT RM	Ice Check	15-14
NR TACO SLEIGH	NODE REAPER	LINE CREW	Camp transit	15-15
NR TACO SLEIGH	NODE REAPER	LINE CREW	Camp transit	15-16
NR TACO SLEIGH	NODE REAPER	LINE CREW	Camp transit	14-40
REC TUCKER TRAILER	OBSERVER	LINE CREW	Camp transit	15-39
SUR TUCKER TRAILER	SURVIVAL	AIR STRIP / LUGGAGE	Camp transit	15-40
SUR TUCKER TRAILER	SURVIVAL	SUPPLY	Camp transit	14-49
SW TUCKER TRAILER	POTABLE WATER	FOR LONG HAUL FUEL CAMP	Camp transit	15-38

TACO SLEIGHS	TYPE	COMMENTS		ASSET #
TACO #1 1501	LINE EQUIPMENT	LINE CREW	Camp transit	DDE-1501
TACO #2 1502	LINE EQUIPMENT	LINE CREW	Camp transit	DDE-1502
TACO #3 1503	LINE EQUIPMENT	LINE CREW	Camp transit	DDE-1503
TACO #4 1504	LINE EQUIPMENT	LINE CREW	Camp transit	DDE-1504
TACO #5 1505	LINE EQUIPMENT	LINE CREW	Camp transit	SAE-#1
TACO #6 1506	CAMP SUPPLIES	LINE CREW	Camp transit	SAE-#2
TUCKER TRAILER TACO	METALS / OILS / MISC	MECHANICS	Camp transit	

FUEL TANKS	TYPE	COMMENTS		ASSET #
CAMP FUELER	SKIS	120V & 12V PUMP 3000GAL	Ice Check	15-50
CAMP FUELER	SKIS	NO PUMP-STORAGE 3000 GAL	Ice Check	15-49
CAMP FUELER	SKIS / LONG HAUL CAMP	120V & 12V PUMP 3000GAL	Camp transit	14-51
REMOTE FUELER	TRACKS	120V & 12V PUMP 4000 GAL	Camp transit	15-45
REMOTE FUELER	TRACKS	120V & 12V PUMP 4000 GAL	Camp transit	15-46
LONG HAUL FUELER	TRACKS	120V & 12V PUMP 4000 GAL	Camp transit	15-47
LONG HAUL FUELER	TRACKS	120V & 12V PUMP 4000 GAL	Camp transit	15-48
LONG HAUL FUELER	TRACKS	120V & 12V PUMP 4000 GAL	Camp transit	14-53
LONG HAUL FUELER	TRACKS	120V & 12V PUMP 4000 GAL	Camp transit	14-54
STORAGE FUEL	TRACKS	NO PUMP-STORAGE 4000 GAL	Camp transit	14-55
STORAGE FUEL	TRACKS	NO PUMP-STORAGE 4000 GAL	Camp transit	14-56
	TOTAL CAPACITY	41,000 GALLONS		

Appendix C: Example of Mobilization Route



Appendix D: Best Practices for Ice Travel

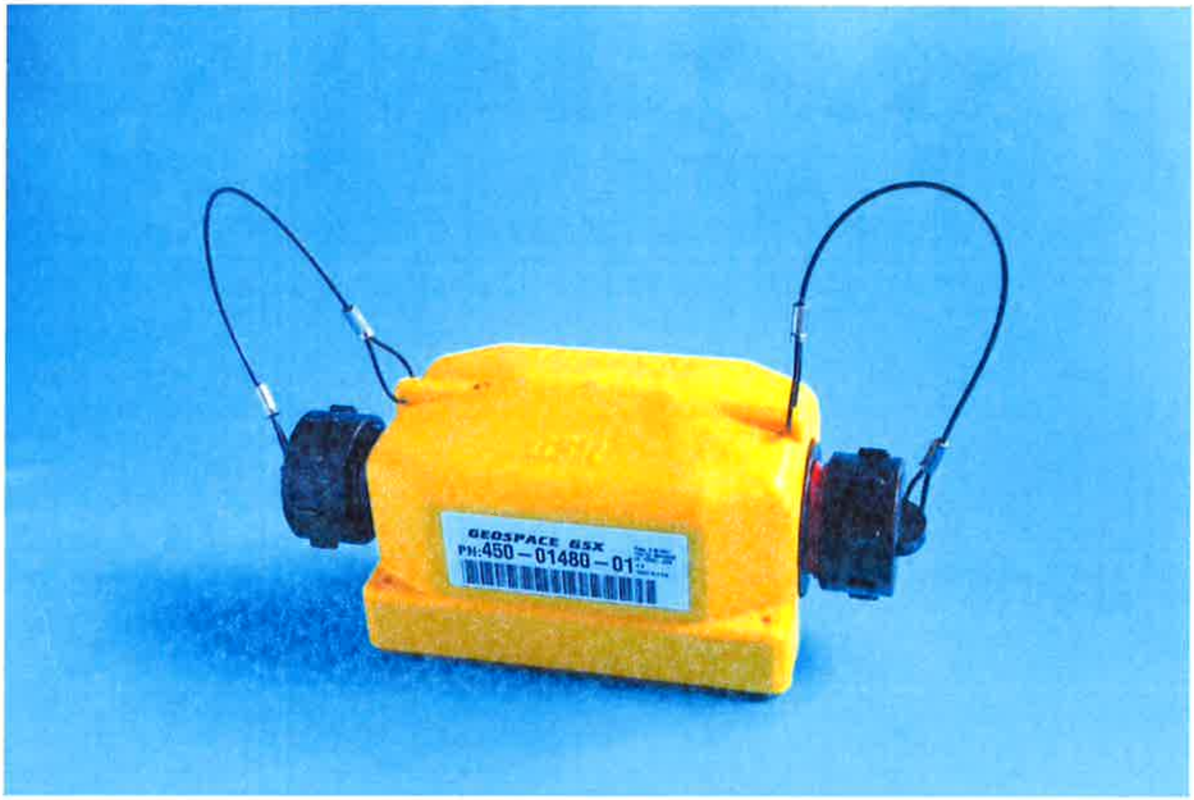
Approximate Equipment Weight and Ice Requirements

BEST PRACTICES ICE REQUIREMENTS								
Equipment	**Contact Area Tractor**	**Contact Area Trailer**	**Tractor displacement**	**TARE**	**PAYLOAD**	**GVW**	**Fresh Ice**	**Sea Ice**
				(lbs)	**(lbs)**	**(lbs)**	**(Inches)**	**(Inches)**
Tucker Vehicles								
Tucker 1643	8320		1.38	9,200	2,300	11,500	18	23
Tucker 1644 line truck loaded	8320		1.68	11,700	2,300	14,000	20	25
Trailers-4 track.								
Tucker Trailer - Vibe Tender		6677	5.24	13,000	22,000	35,000	28	34
VIBE TENDER & STEIGER	8640	6677	10.42	68,000	22,000	90,000	47	51
Tucker Trailer - Batt Shack		6677	4.49	13,000	17,000	30,000	28	34
BATTERY SHACK & STEIGEF	8640	6677	9.84	68,000	17,000	85,000	45	50
Tucker Trailer - Recorder		6677	4.04	13,000	14,000	27,000	28	34
RECORDER & STEIGER	8640	6677	9.49	68,000	14,000	82,000	43	48
Dozers and Loaders								
D7G	6677		8.39			56,000	37	47
977 Loader	5008		11.18			56,000	39	47
Vibrators								
AHV IV ATI Tracks (on plate)	12380		7.67			95,000	54	66
AHV IV ATI Tracks (traveling)	12380		7.67			95,000	46	52
AHV IV Wheels (on plate)	7692		9.49			73,000	48	54
AHV IV Wheels (traveling)	7692		9.49			73,000	42	48
Steigers (single)								
Steiger with winch	8640		6.37			55,000	35	41
Steiger with blade/loader	8640		7.06			61,000	36	42
Steigers & Trailers-4 track								
Steiger with Tucker Trailer	8640	6677	9.95	68,000	18,000	86,000	45	50
Steiger with Challenger Trailer	8640	6677	15.19	82,000	49,280	131,280	60	64

For cold ice <15° F.

No dynamic loading; speed <10 mph.

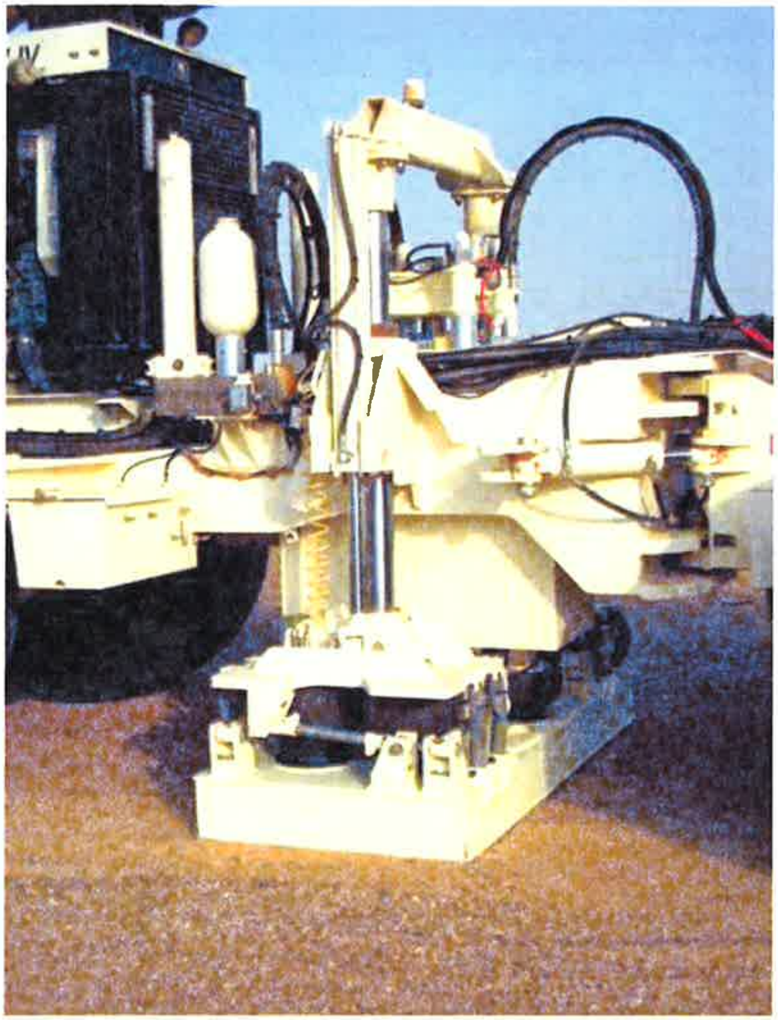
Appendix E: Equipment Pictures



NODES
Cable-Free/Radio-Free Autonomous Data Recording
Seismic Recorder (GSX)

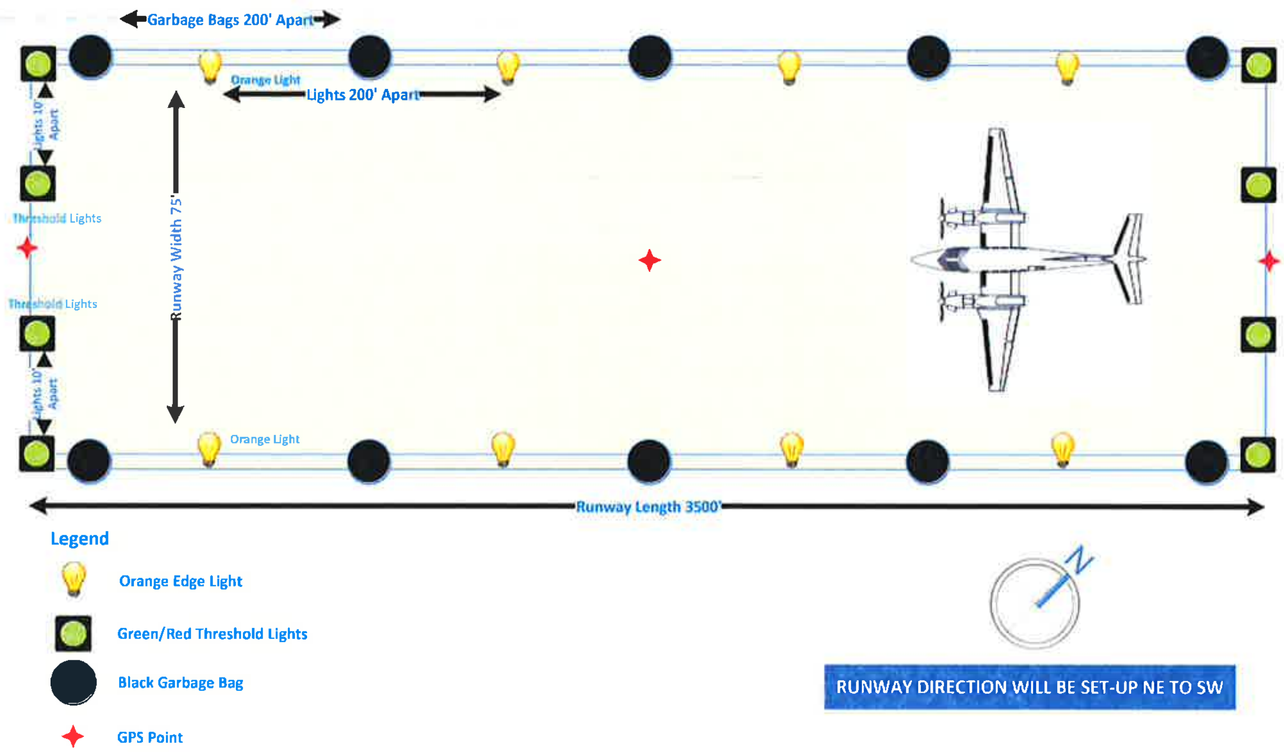
Tucker

Approximately 90,000 pounds with Tracks, 60,000 with tires
AHV4 Commander Vibrator (Source Equipment)



Vibe rectangular baseplate

Appendix F: Example of Temporary Airstrip



Appendix G: Wildlife Interaction Plan

Wildlife Interaction Plan

Wildlife Interaction Plan / Procedure

Purpose: To provide guidelines for assuring the prompt reporting, investigation, and documentation of Polar Bears, sightings or incidents involving animals that are protected by the Marine Mammal Protection Act of 1972. This plan also covers reporting of Brown Bears, or any other wildlife that seismic crews may come in contact with during operations. This plan is intended to meet the requirement of a site specific Polar Bear awareness and interaction plan as required by 50 Code of Federal Regulations (CFR) 18.124(c)(3) and to meet the requirements for a Letter of Authorization (LOA) for the non-lethal, incidental and Non-intentional take of Polar Bear. Any permit stipulations that may be requested by permitting agencies will be added to this document as necessary.

Polar Bears: The United States Fish and Wildlife Service estimates that approximately 1,500 Polar Bears occur in the southern Beaufort Sea (SBS). Worldwide there are approximately 20,000 to 25,000 Polar Bears. During the summer months, Polar Bears typically remain on the southern edge of the sea ice. However, they are also known to swim long distances, haul out onto ice flows and barrier islands and can occasionally be found on the coast. It is expected that Polar Bears will be encountered on ice, in the water and on barrier islands,

Responsibility: The Project Manager have overall responsibility. They are responsible for coordination and implementation of all surveillance or monitoring personnel who deal with wildlife/human encounters, sightings and reporting on the North Slope.

Procedure:

Crews will be trained to maintain a constant level of awareness for the potential conflict with Polar Bears. In areas where high potential of conflict exists, SAE will evaluate and if required, place a dedicated watch for Polar Bears in the area of operations. This is not to say that a continuous watch is not always in effect but rather that the crew will have a dedicated person or persons for oversight in areas of known activity. A Polar Bear education program will be given to all workers at a pre-job conference or on-site prior to the start of operations or at commencement of employment on the North Slope. Polar Bear awareness refresher briefings will be held as part of regular safety briefings. A dedicated Health, Safety and Environment (HSE) Advisor will be based with the survey crew for the duration of the seismic program, and workers will be instructed to notify the Project Manager, or HSE Advisor immediately whenever a bear is detected. All personnel will be aware of the restrictions regarding "taking" of Polar Bears as described by the Marine Mammals Protection Act. When a bear is in the immediate area of the crew location, workers will stay inside vehicles or aircraft and away from the bear. Approaching a bear for taking pictures or any other reason is strictly forbidden. USFWS will be called immediately.

Land based activities:

1. When a Polar Bear is detected near any part of the operation, any employee (permanent, temporary, or contract) or visitor shall immediately notify the Project Manager, or HSE Advisor. They shall then notify the Permits Manager.

2. The priority is the protection of human life. The second priority is to avoid any situation in which a bear will be harmed.

3. In a camp situation, the lead person with crew shall radio Project Manager/Administrative Office. The Administrative Office will sound the "air horn" with 5 short blasts and make a radio announcement on all crew channels of the sighting. At the sound of the air horn, EVERYONE is to go to the nearest vessel, helicopter, or vehicle and remain inside with doors and windows secured until the ALL CLEAR is given over the radio. The all clear signal is a long blast on the "air horn".

4. In the field, drivers of each vehicle will advise the personnel they are responsible for and have them get inside the vehicles and wait until further notice.

5. If the bear takes refuge near or in a vehicle and does not appear likely to move, crew HSE will be notified depending on the location of operation. No action will be taken unless authorized by the USFWS or their designated agents.

6. When a sighting is made by a standalone vehicle, such as the survey crew, they must not approach the bear further. The crew will notify the Project Manager, HSE Advisor radio to alert them. The crew must avoid the bear and if necessary cease operations until the bear has left the area.

7. Personnel must remain at least a one-half mile distance in all directions from any known bear. The radio announcement must indicate whether this will be necessary or not. An all-clear signal will be sounded when the area is determined to be safe.

8. After any individual sighting or interaction with Polar Bears during operations on the North Slope, a Polar Bear Sighting Report shall be completed by the HSE Advisor. The SAE Permits Manager will forward this report to the Office of Marine Mammals Management, Christopher Putnam 786-3810 by phone and or 786-3816 by fax, within 24 hours.

Aircraft:

1. Aircraft will not operate within 0.5 miles of Polar Bears.

2. Aircraft will avoid flying over ideal Polar Bear habitat including but not limited to sea ice and barrier islands.

3. When marine mammals are encountered, aircraft will not operate below 1,500ft unless the aircraft is engaged in marine mammal monitoring, approaching, landing, taking off, or as conditions allow.

Subsistence Hunting:

1. SAE will employ a subsistence advisor to reduce impacts on Polar Bear subsistence hunting.

2. Vessels and aircraft will avoid areas in which subsistence hunting is being conducted.

Reporting:

Polar Bears: When a Polar Bear is observed or crew member they shall immediately notify the HSE and Permits Manager who will be responsible for filling out the Polar Bear report form. Reports of sightings will be sent to the USFWS on a regular basis through the Permits Manager.

Reports will be sent to:

Christopher Putnam
USFWS-Marine Mammals Section
1011 East Tudor Road
Anchorage, AK 99503
Telephone: 907-786-3800
Fax: 907-786-3816

Brown Bears : (Ursus americanus) are the most abundant and widely distributed of the three species of North American bears.

Responsibility: The Project Manager and wilderness guides have overall responsibility. They are responsible for coordination and implementation of all surveillance who deal with wildlife/human encounters, sightings and reporting.

Procedure:

Crews will be trained to maintain a constant level of awareness for the potential conflict with bears. In areas where high potential of conflict exists, SAE will evaluate and if required, place a dedicated wilderness guides in the area of operations. This is not to say that a continuous watch is not always in effect but rather that the crew will have a dedicated wildlife guide for oversight in areas of known activity. Bear education program will be given to all workers at a pre-job conference or on-site prior to the start of operations or at commencement of employment. Bear awareness refresher briefings will be held as part of regular safety briefings. A dedicated Health, Safety and Environmental (HSE) Advisor will be based with the survey crew for the duration of the seismic program, and workers/wilderness guides will be instructed to notify the Project Manager or HSE Advisor whenever a bear is sited by use of a hazard card. When a bear is in the immediate area of the crew location, workers will stay inside vehicles or aircraft and away from the bear. Approaching a bear for taking pictures or any other reason is strictly forbidden.

1 When a bear is detected near any part of the operation, any employee (permanent, temporary, or contract) or visitor shall immediately notify the Project Manager or HSE Advisor.

2 The first priority is the protection of human life. The second priority is to avoid any situation in which a bear will be harmed.

3. In a camp situation, the lead person with crew shall radio Project Manager/Administrative Office. The Administrative Office will sound the "air horn" with 5 short blasts and make a radio announcement on all crew channels of the sighting. At the sound of the air horn, EVERYONE is to go to the nearest vessel, helicopter, or vehicle and remain inside with doors and windows secured until the ALL CLEAR is given over the radio. The all clear signal is a long blast on the "air horn".

4. In the field, drivers of each vehicle will advise the personnel they are responsible for and have them get inside the vehicles and wait until further notice. If no vehicles are near, the wilderness guide shall lead crew away from bear.

5. If the bear takes refuge near or in a vehicle and does not appear likely to move, crew HSE will be notified depending on the location of operation. No action will be taken unless authorized by the AKFG or their designated agents.

6. The crew must avoid the bear and if necessary cease operations until the bear has left the area. The bear's safe distance from the crew will determine by the wilderness guide. The distance should be far enough as not to affect the bears behavior. The radio announcement must indicate whether this will be necessary or not. An all-clear signal will be sounded when the area is determined to be safe.

7. Personnel must report any active bear dens. These dens will be mapped and sent to AKFG. After any individual interaction with bears during operations, the Bear Sighting Report shall be completed by the HSE Advisor or the wilderness guide. The SAE Permits Manager will forward this report to the agencies which are listed in the permit stipulations of all permits within 24 hours.

Caribou / Foxes / Wolverines or Other wildlife:

Responsibility: The Project Manager and wilderness guides have overall responsibility. They are responsible for coordination and implementation of all surveillance who deal with wildlife/human encounters, sightings and reporting.

Procedure:

1 Avoid any interaction with wildlife.

2 Do not take any actions that would cause the animals to change course or behavior unless approved by Alaska Fish and Game

3 After any individual interaction with Caribou or other types of wildlife during operations, the Wildlife Sighting Report shall be completed by the HSE Advisor or the wilderness guide. The SAE Permits Manager will forward this report to the agencies which are listed in the permit stipulations of all permits.

4 If foxes or other wildlife take up shelter within camp area, notify the permits manager.

5 Feeding of animals is strictly prohibited.

6 There is no hunting or fishing allowed on project.

Field Operating Procedure
Polar Bear Protocol

Purpose: To provide guidelines for assuring the prompt reporting, investigation, and documentation of Polar Bear sightings or incidents involving animals that is protected by the Marine Mammal Protection Act of 1972.

Scope: This procedure applies to all sightings or interaction with Polar Bears occurring during operations on the North Slope.

Responsibility: The Project Manager and HSE Advisor have overall responsibility. They are responsible for coordination and implementation of all surveillance or monitoring personnel who deal with wildlife/human encounters or sightings on the North Slope.

Procedure:

1. When a Polar Bear is detected near any part of the operation, any employee (permanent, temporary, or contract) or visitor shall immediately notify the Project Manager or HSE Advisor.

2. The first priority is the protection of human life. The second priority is to avoid any situation in which a bear will be harmed.

3. The Administrative Office will sound the "air horn" with 5 short blasts and make a radio announcement on all crew channels of the sighting. At the sound of the "air horn, EVERYONE in camp is to go to the nearest trailer or vehicle and remain inside with doors and windows secured until the ALL CLEAR is given over the radio. The all clear signal is a long blast on the "air horn".

4. In the field, drivers of each vehicle will advise the personnel they are responsible for and have them get inside the vehicles and wait until further notice.

5. If the bear takes refuge near, in, or under a trailer or vehicle and does not appear likely to move, crew HSE security will be notified depending on the location of operation. No action will be taken unless authorized by the USFWS or their designated agents. The District Manager and North Slope Security must be contacted at this time.

6. Areas which have been identified as possible denning sites will be avoided per the permit stipulations. (Typically, prior to mobilization, Polar Bear den locations are received and entered into our hazard mapping system.) Survey crew, trained in Polar Bear awareness, will be responsible as the lead vehicles in the field to scout for possible additional locations and bring to the crew's attention at the daily safety

meetings those locations. Possible locations will be staked in the field and entered on the hazard maps for the crew per permit stipulations. If a den is encountered protocols from USFW will be followed. Operations will then be evaluated and modifications to the operation will be implemented that will allow the avoidance of the denning site and the continuation of exploration activity.

7. When a sighting is made by a stand-alone vehicle, such as the survey crew, they must not approach the bear further. The crew will notify the Project Manager or HSE Advisor via radio to alert them. The crew must avoid the bear and if necessary cease operations until the bear has left the area. The bear's distance from camp will determine whether step 3(b) is required. All personnel must remain at least a one mile distance in all directions from any known bear dens. The radio announcement must indicate whether this will be necessary or not. An all-clear signal will be sounded when the area is determined to be safe.

8. After any individual sighting or interaction with Polar Bears during operations on the North Slope, a Polar Bear Sighting Report shall be completed by the HSE Advisor. The SAE Permits Manager will forward this report to the Office of Marine Mammals Management as listed in the plan of operations.

9. A skid-mounted incinerator will be used for solid waste incineration. All garbage that contains any food will be bagged, stored inside the facilities and incinerated on site two times per day. The resulting ash will be back hauled to the North Slope Borough disposal facility during the winter season.

10. Winter crews will be trained to maintain a constant level of awareness for the potential conflict with Polar Bears. In areas where high potential of conflict exists, SAE will evaluate and if required, place a dedicated watch for Polar Bears in the area of operations. This is not to say that a continuous watch is not always in effect but rather that the crew will have a dedicated person or persons for oversight in areas of known denning or activity. A Polar Bear education program will be given to all workers on-site prior to the start of operations or at commencement of employment on the North Slope. Polar Bear awareness refresher briefings will be held as part of regular safety briefings. A dedicated Health, Safety and Environmental (HSE) Advisor will be based at the camp for the duration of the winter seismic program, and workers will be instructed to notify the Project Manager or HSE Advisor immediately whenever a bear is detected. All personnel will be aware of the restrictions regarding "taking" of Polar Bears as described by the Marine Mammals Protection Act. Approaching a bear for taking pictures or any other reason is strictly forbidden.

Permits Manager will send reports to:

Christopher Putnam
USFWS-Marine Mammals Section
1011 East Tudor Road
Anchorage, AK 99503

Telephone: 907-786-3800
Fax: 907-786-3816

Staines 3D

PLAN OF OPERATIONS
WINTER SEISMIC SURVEY

Submitted by:

SAExploration, Inc.
8240 Sandlewood Pl. Suite 102
Anchorage, AK 99507

Table of Contents

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:16 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Jones, Nichelle (Shelly)** <njones@blm.gov>
Date: Wed, May 23, 2018 at 10:12 AM
Subject: Fwd: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation
To: Donna Wixon <dwixon@blm.gov>, LaMarr, Sarah <slamarr@blm.gov>, Debora Nigro <dnigro@blm.gov>, Timothy Vosburgh <tvosburgh@blm.gov>, Matt Whitman <mwhitman@blm.gov>, Steve Berendzen <steve_berendzen@fws.gov>, Fox, Joanna <joanna_fox@fws.gov>, Guyer, Scott <sguyer@blm.gov>, Eric Geisler <egeisler@blm.gov>, Richard Kemnitz <rkemnitz@blm.gov>, Longan, Sara <slongan@blm.gov>

Hello All: I thought you might be interested in the attachment Melissa Head attached to this email. I would like to set up some time to discuss with you how much more of this type of monitoring we might want to do as part of the seismic permit we are working on.

It sounds like part (maybe most) of the 1002 area will fall in the coastal plain region and DNR tundra opening minimums would require 6" of snow. Other areas further south might use 9". As I understand it, the idea is that there should be enough snow to protect the vegetation. We should consider tweaking these minimum requirements based on our own analysis of the vegetation and types of tundra in this area.

The benefit of additional snow and soil temperature monitoring from the applicant's stand point is they might be able to show conditions meet the minimum standards earlier than the data coming in from the DNR monitoring. I am not sure how many monitoring stations inform the tundra opening decisions for DNR or where they are located. I know Melissa has that information and told me the increased monitoring by the applicants does often allow increased number of tundra travel opportunities. If we do not think the current amount of monitoring forms a good basis for representing the average conditions across this area, we may want to increase the monitoring for our own risk management concerns as well.

The dynamic between freeze down, snow cover, ground pressure of the vehicles, type of tundra vegetation, the amount of moisture and the type of permafrost soils cuts across many of the critical NEPA elements. It would be helpful if these could be considered collectively by an arctic engineering specialist. I would like work more collaboratively with DNR to stay informed on the snow and freeze conditions throughout the season, so I can start to fine tune my understanding of the relationship between the environmental conditions we are tracking and the residual impacts we are documenting from our permits.

-Shelly

Shelly Jones
Acting Manager
Arctic District Office
222 University Avenue
Fairbanks, AK 99709

(907) 474-2310 (w)
(907) 460-0086 (c)

---------- Forwarded message ----------
From: **Head, Melissa M (DNR)** <melissa.head@alaska.gov>
Date: Mon, May 21, 2018 at 4:34 PM
Subject: RE: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation
To: "Jones, Nichelle (Shelly)" <njones@blm.gov>

Hi Shelly,

Here is our snow sampling protocol for your reference.

Contacts for you-

Henry Brooks (DNR/DMLW Water Section for Temporary Water Use Authorizations): henry.brooks@alaska.gov

Jack Winters (ADFG/Habitat Division for Fish Habitat Permits for water withdrawals): jack.winters@alaska.gov

Tiffany Carey (ConocoPhillips for advancements in seismic technology): tiffany.c.carey@conocophillips.com

- She was the seismic manager for the 3D Bear program and GMT2 seismic. You may already have her contact info.
- Tiffany gave us a great presentation about how their new seismic technology reduces overall travel needs and how she is managing seismic operations. She is very enthusiastic about her job and is very good at explaining their process.
- I would expect all seismic companies to be following a similar process to reduce impacts.

It was good talking to you this afternoon. Please don't hesitate to get in touch. I'm happy to help in any way that I can.

Kind Regards,

Melissa

Melissa Head

Manager, Northern Oil & Gas Team

DNR/DMLW

907-451-2719

Kind Regards,

From: Jones, Nichelle (Shelly) [mailto:njones@blm.gov]
Sent: Monday, May 21, 2018 4:10 PM
To: Head, Melissa M (DNR) <melissa.head@alaska.gov>
Subject: Fwd: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation

Shelly Jones

Acting Manager

Arctic District Office

222 University Avenue

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Annamae J. Leavitt, Senior Office Specialist

North Slope Borough | Planning & Community Services

PO Box 69 Barrow, Alaska 99723

P 907-852-0320 | F 907-852-0322

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BISON CONNECT

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:16 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Sara Longan** <slongan@blm.gov>
Date: Wed, May 23, 2018 at 1:56 PM
Subject: Re: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation
To: Jones, Nichelle (Shelly) <njones@blm.gov>
Cc: Donna Wixon <dwixon@blm.gov>, LaMarr, Sarah <slamarr@blm.gov>, Debora Nigro <dnigro@blm.gov>, Timothy Vosburgh <tvosburgh@blm.gov>, Matt Whitman <mwhitman@blm.gov>, Steve Berendzen <steve_berendzen@fws.gov>, Fox, Joanna <joanna_fox@fws.gov>, Guyer, Scott <sguyer@blm.gov>, Eric Geisler <egeisler@blm.gov>, Richard Kemnitz <rkemnitz@blm.gov>

Thank you, Shelley.
I am happy to stay a part of this effort and conversation. Exxon conducted monitoring and thermistor use along their routes for PT, including exploration. It provided important data and was helpful as they managed their own use, also for DNR as it relates to opening/closure.
It would be a good conversation, I think, for BLM to have with an applicant and operator for work in the 1002.
Where additional monitoring might be helpful, NSSI could help leverage and coordinate future work.
Thanks,
Sara

On May 23, 2018, at 10:12 AM, Jones, Nichelle (Shelly) <njones@blm.gov> wrote:

> Hello All: I thought you might be interested in the attachment Melissa Head attached to this email. I would like to set up some time to discuss with you how much more of this type of monitoring we might want to do as part of the seismic permit we are working on.
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> It sounds like part (maybe most) of the 1002 area will fall in the coastal plain region and DNR tundra opening minimums would require 6" of snow. Other areas further south might use 9". As I understand it, the idea is that there should be enough snow to protect the vegetation. We should consider tweaking these minimum requirements based on our own analysis of the vegetation and types of tundra in this area.
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> Shelly Jones
> Acting Manager
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Kind Regards,

Melissa

Melissa Head

Manager, Northern Oil & Gas Team

DNR/DMLW

907-451-2719

Kind Regards,

From: Jones, Nichelle (Shelly) [mailto:njones@blm.gov]
Sent: Monday, May 21, 2018 4:10 PM
To: Head, Melissa M (DNR) <melissa.head@alaska.gov>
Subject: Fwd: [EXTERNAL] NSB 18-466 SAExploration, Inc. (SAE LLC) - Kuukpik Corporation

Shelly Jones

Acting Manager

Arctic District Office

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Annamae J. Leavitt, Senior Office Specialist

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<SnowSampling_2014-10-31.pdf>

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: [EXTERNAL] Fwd: Water in ANWR

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:17 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Christopher Arp** <cdarp@alaska.edu>
Date: Sun, May 27, 2018 at 9:52 AM
Subject: [EXTERNAL] Fwd: Water in ANWR
To: Matthew Whitman <MWhitman@blm.gov>, Richard Kemnitz <RKemnitz@blm.gov>

Here's write up I sent to one of Murkowski's aids as requested by Schnabel. Tried to keep it pretty simple. Would be interested to know what you guys thought of this. - Chris

----

Christopher D. Arp
Associate Research Professor
Water and Environmental Research Center
Institute of Northern Engineering
University of Alaska Fairbanks
346 Engineering Learning and Innovation Facility
P.O. Box 755910
Fairbanks, AK 99775-5910
Phone: 907-474-2783
Email: cdarp@alaska.edu
http://ine.uaf.edu/werc/people/faculty/chris-arp/
https://scholar.google.com/citations?user=y1AFG-QAAAAJ&hl=en

---------- Forwarded message ----------
From: **Christopher Arp** <cdarp@alaska.edu>
Date: Wed, Feb 28, 2018 at 4:42 PM
Subject: Re: Water in ANWR
To: William Schnabel <weschnabel@alaska.edu>
Cc: annie_hoefler@energy.senate.gov

Hi Annie,

Glad to hear that you, Bill, and Senator Murkowski were able to discuss this issue. I put together a short write up of what I see as the issue of water supply in ANWR and how we might help address it through UAF's research capacity and collaborations with USGS, BLM, and USFWS.

Let me know if you have any questions or would like to discuss further.

Best regards,
Chris

Christopher D. Arp
Associate Research Professor
Water and Environmental Research Center
Institute of Northern Engineering
University of Alaska Fairbanks
346 ELIF (Engineering Learning and Innovation Facility)
P.O. Box 755910
Fairbanks, AK 99775-5910
Phone: 907-474-2783
Email: cdarp@alaska.edu
http://ine.uaf.edu/werc/people/chris-arp/
https://scholar.google.com/citations?user=y1AFG-QAAAAJ&hl=en

On Wed, Feb 28, 2018 at 10:04 AM, William Schnabel <weschnabel@alaska.edu> wrote:

> Chris and Annie,
>
> Chris - we had a great conversation today with Senator Murkowski and several of her staff members. The Senator was quite intrigued with the ANWR cartoon you put together, and we talked for quite awhile about it. Staff member Annie Hoefler was also quite interested, and I

mentioned that I would put you in touch with each other to follow up on the issue. Annie will serve as point person on this particular issue.

Annie - Chris Arp is an Associate Professor in the Water and Environmental Research Center, and has worked on North Slope water resource issues for years. He would be a great source of information for the ANWR-water issue, and he works frequently with USGS, USF&WS, etc so is also familiar with what they've been up to.

Chris - I gave Annie and the Senator a quick verbal overview of the ANWR surface water situation. Will you follow up this email and send to Annie a one or two page description of the challenges associated with finding water for ice roads in ANWR? Do you have a good recommendation for how we should approach the problem? How can and should we be collaborating with agencies such as USGS to take a broad approach? In what ways can we use work that we have already been doing to enhance our efforts?

Annie - great to meet you. Thanks for expressing interest in this topic. I hope we'll get a chance to catch up soon.

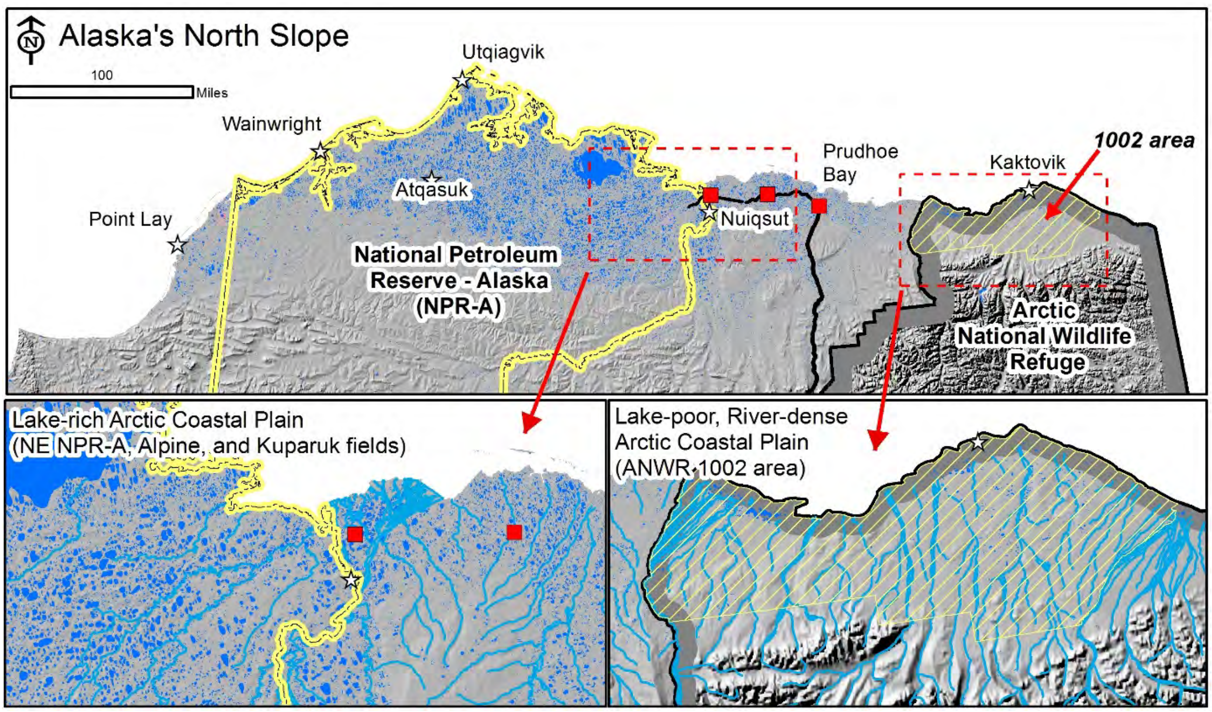
-Bill Schnabel

ANWR_watersupply_issue_20180228.docx
633K

Winter Water Supply for Ice Road Construction to Support Oil Exploration in the Arctic National Wildlife Refuge: Challenges and Ways Forward

Ice Roads and Winter Water Supply New exploration into places like the National Petroleum Reserve – Alaska (NPR-A) happens exclusively during the winter via ice roads, leaving a transient footprint compared to the smaller network of permanent roads for drilling pads and pipeline access. Temporary winter ice roads are designed to protect the tundra and underlying permafrost, while allowing exploration for new oil and gas reserves in more remote areas. Water for ice road construction in Alaska comes primarily from freshwater lakes (Jones et al. 2009), which are highly abundant throughout much of the Arctic Coastal Plain covering over 20% of the land surface (Arp and Jones 2009). This high density of lakes is advantageous for ice road construction because relatively small amounts of water can be accessed as temporary networks are expanded each winter. Lake water withdrawal for ice roads is managed with the goal of protecting overwintering fish habitat for subsistence use and ecological integrity (Jones et al. 2009). Yet recent winter warming would suggest that more winter water will be available for future ice road construction (Arp et al. 2012).

Water Supply Challenges in ANWR Compared to Prudhoe Bay, Kuparuk, and the NPR-A, ANWR's coastal plain is incredibly narrow and lacks the surface water storage in lakes. Satellite based radar analysis of ANWR's coastal plain shows very low lake densities and also much shallower lakes that freeze solid by late winter (White et al. 2008). At least seven major rivers fed by mountain and foothills runoff cut through the ANWR's 1002 area and extraction of water from alluvial aquifers or floodplain gravel pits would be the most likely sources of winter water for ice road construction.



Alternative Water Sources and Considerations One potentially positive outcome of the changing arctic climate is that late summer and early winter river discharge appear to be increasing in many areas of the Alaskan coastal plain (Stuefer et al. 2017). This suggests that potential water supply from rivers and associated groundwater may be more abundant than previous surveys would suggest. Still an important consideration will be how much water can be expected to be available in a given winter and how is this distributed relative to ice road construction routes. Pumping water from alluvial aquifers will require not only understanding water availability, but also how these systems are linked to instream overwintering fish habitat. Digging gravel pits in floodplain may also have advantages because they can recharge by snowmelt and be extracted using the same technologies as lakes, but again environmental impacts may be prohibitive. Both pumping alluvial aquifers and excavating gravel pits would also be limited by river density, potentially making small stream systems more advantageous because of their higher density and because these are less likely to support overwintering fish habitat. Knowing how reliable these alternative water sources are in ANWR's 1002 area is the first step in this process.

Data and Information Needs River gauging programs are challenging because of remote roadless conditions and short seasons when measurement are traditionally made. The USGS and USFWS have variously gauged several larger rivers in ANWR over the years with the Hulahula River being the only currently active gauge. Longer-term river flow records have been developed for several smaller rivers along the Dalton Highway by hydrologist Dr. Douglas Kane at the University of Alaska Fairbanks starting in the 1980s. This program is well known for detailed measurements of river breakup to inform mitigation of flooding (Kane et al. 2003), but like USGS and USFWS programs has had little focus on late summer and early winter flows. Analysis of existing UAF, USGS, and BLM gauging data suggest this late season river discharges are increasing (Stuefer et al. 2017), but more focus is needed on this period to increase certainty and develop models applicable to ANWR water supply predictions. Taking advantage of existing long-term hydrology and climate monitoring programs in the Kuparuk River Basin coupled with USGS climate monitoring programs in ANWR likely provides the best path forward in bridging this gap towards informing the water supply challenges for new oil exploration in ANWR. Mapping winter water supply using radar from satellites, similar to use in winter lake inventories (White et al. 2008), but with higher resolution products such as TerraSAR-X for resolving river and stream conditions (Jones et al. 2013) would provide complementary data.

References

Arp, C. D., B. M. Jones, et al. (2012). "Shifting balance of lake ice regimes on the Arctic Coastal Plain of northern Alaska " Geophysical Research Letters 39(L16503):1-5.

Arp, C. D. and B. M. Jones (2009). Geography of Alaska Lake Districts: Identification, description, and analysis of lake-rich regions of a diverse and dynamic state. Scientific Investigations Report, U.S. Geological Survey: 40.

Jones, B. M., C. D. Arp, et al. (2009). "Arctic lake physical processes and regimes with implications for winter water availability and management in the National Petroleum Reserve Alaska." Environmental Management 43: 1071-1084.

Jones, B. M., A. Gusmeroli, et al. (2013). "Classification of freshwater ice conditions on the Alaskan Arctic Coastal Plain using ground penetrating radar and TerraSAR-X satellite data." International Journal of Remote Sensing 34(23): 8267-8279.

Kane, D. L., J. P. McNamara, et al. (2003). "An extreme rainfall/runoff event in Arctic Alaska." Journal of Hydrometerology 4(6): 1220-1228.

Stuefer, S. L., C. Arp, et al. (2017). "Recent Extreme Runoff Observations From Coastal Arctic Watersheds in Alaska." Water Resources Research 53.

White, D. M., P. Prokein, et al. (2008). "Use of synthetic aperture radar for selecting Alaskan lakes for winter water use." Journal of the American Water Resources Association 44(2): 276-284.

Prepared by: Christopher D. Arp
Water and Environmental Research Center
University of Alaska Fairbanks
Phone: (907) 474-2783, Email: cdarp@alaska.edu

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: communication

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:29 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Whitman, Matt** <mwhitman@blm.gov>
Date: Tue, Jun 12, 2018 at 1:50 PM
Subject: communication
To: <john_trawicki@fws.gov>, <randy_j_brown@fws.gov>

John/Randy - I know this sounds weird, but this is due to very specific directions we were given here at BLM just yesterday.....

For now, if you want to communicate with me about the Arctic Refuge seismic EA or the EIS you have to route through our district manager Shelly Jones (njones@blm.gov 474-2310). And I guess, similarly, I'm supposed to go through her to coordinate with guys, as well.

This all seems highly ineffective for working together, among other things, but I don't make the rules (& not sure who does). Good luck.

Thanks,
Matthew

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: communication

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:17 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Brown, Randy** <randy_j_brown@fws.gov>
Date: Tue, Jun 12, 2018 at 2:19 PM
Subject: Re: communication
To: Whitman, Matt <mwhitman@blm.gov>
Cc: John Trawicki <john_trawicki@fws.gov>

Thanks for the notice on this Matt,
I'll comply.
Randy

On Tue, Jun 12, 2018 at 1:50 PM, Whitman, Matt <mwhitman@blm.gov> wrote:

> John/Randy - I know this sounds weird, but this is due to very specific directions we were given here at BLM just yesterday.....
>
> For now, if you want to communicate with me about the Arctic Refuge seismic EA or the EIS you have to route through our district manager Shelly Jones (njones@blm.gov 474-2310). And I guess, similarly, I'm supposed to go through her to coordinate with guys, as well.
>
> This all seems highly ineffective for working together, among other things, but I don't make the rules (& not sure who does). Good luck.
>
> Thanks,
> Matthew

--
Randy J. Brown
Fishery Biologist
U.S. Fish and Wildlife Service
101 12th Ave., Room 110
Fairbanks, Alaska 99701

Phone: (907) 456-0295
E-mail: <randy_j_brown@fws.gov>

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: communication

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:17 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Whitman, Matt** <mwhitman@blm.gov>
Date: Mon, Oct 15, 2018 at 7:17 AM
Subject: Fwd: communication
To: <blm_ak_coastal_plain_seismic_ea@blm.gov>

---------- Forwarded message ---------
From: **Brown, Randy** <randy_j_brown@fws.gov>
Date: Tue, Jun 12, 2018 at 2:19 PM
Subject: Re: communication
To: Whitman, Matt <mwhitman@blm.gov>
Cc: John Trawicki <john_trawicki@fws.gov>

Thanks for the notice on this Matt,
I'll comply.
Randy

On Tue, Jun 12, 2018 at 1:50 PM, Whitman, Matt <mwhitman@blm.gov> wrote:

> John/Randy - I know this sounds weird, but this is due to very specific directions we were given here at BLM just yesterday.....
>
> For now, if you want to communicate with me about the Arctic Refuge seismic EA or the EIS you have to route through our district manager Shelly Jones (njones@blm.gov 474-2310). And I guess, similarly, I'm supposed to go through her to coordinate with guys, as well.
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> This all seems highly ineffective for working together, among other things, but I don't make the rules (& not sure who does). Good luck.
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> Thanks,
> Matthew

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Randy J. Brown
Fishery Biologist
U.S. Fish and Wildlife Service
101 12th Ave., Room 110
Fairbanks, Alaska 99701

Phone: (907) 456-0295
E-mail: <randy_j_brown@fws.gov>

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: communication

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:17 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Trawicki, John** <john_trawicki@fws.gov>
Date: Tue, Jun 12, 2018 at 1:56 PM
Subject: Re: communication
To: Whitman, Matt <mwhitman@blm.gov>, Nichelle (Shelly) Jones <njones@blm.gov>
Cc: Brown, Randy <randy_j_brown@fws.gov>, Wendy Loya <wendy_loya@fws.gov>

Mathew-

Thanks for the heads -

I concur, but will work with the rule.

john t

On Tue, Jun 12, 2018 at 1:50 PM, Whitman, Matt <mwhitman@blm.gov> wrote:

> John/Randy - I know this sounds weird, but this is due to very specific directions we were given here at BLM just yesterday.....
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>
> Thanks,
> Matthew

--
John Trawicki
Water Resources Branch Chief
National Wildlife Refuge System, Alaska
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
Work: (907) 786-3474
Mobile: (907) 360-1656

"The single biggest problem with communication is the illusion that it has taken place"
George Bernard Shaw

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Cooperating agencies and tribes on the Seismic EA

1 message

Wixon, Donna <dwixon@blm.gov> Sun, Oct 28, 2018 at 8:33 PM
To: BLM_AK Coastal_Plain_Seismic_EA <blm_ak_coastal_plain_seismic_ea@blm.gov>

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

---------- Forwarded message ---------
From: **Wixon, Donna** <dwixon@blm.gov>
Date: Fri, Jun 29, 2018 at 1:41 PM
Subject: Re: Cooperating agencies and tribes on the Seismic EA
To: Edmonds, Joseph <jwedmonds@blm.gov>

Hi Joe,

Currently the only cooperating agency is USFWS, and there are no cooperating tribes.

Donna

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

On Fri, Jun 29, 2018 at 1:19 PM, Edmonds, Joseph <jwedmonds@blm.gov> wrote:

> Donna,
>
> Would you be able to tell me how many cooperating agencies and cooperating tribes we have on the Coastal Plain Seismic EA?
>
> Thank you for your time!
>
> Joe Edmonds
> Planning and Environmental Coordinator
> Master of Science, Environmental Policy
> Diversity Change Agent
> Bureau of Land Management
> Alaska State Office
> 222 West 7th Avenue, #13
> Anchorage, AK 99513
> Office #: 907-271-3244
> Cell #: 907-290-0115
> jwedmonds@blm.gov

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Cooperating agencies and tribes on the Seismic EA

1 message

Wixon, Donna <dwixon@blm.gov> Sun, Oct 28, 2018 at 8:33 PM
To: BLM_AK Coastal_Plain_Seismic_EA <blm_ak_coastal_plain_seismic_ea@blm.gov>

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

---------- Forwarded message ---------
From: **Edmonds, Joseph** <jwedmonds@blm.gov>
Date: Fri, Jun 29, 2018 at 1:42 PM
Subject: Re: Cooperating agencies and tribes on the Seismic EA
To: Wixon, Donna <dwixon@blm.gov>

Thank you Donna!

Joe Edmonds
Planning and Environmental Coordinator
Master of Science, Environmental Policy
Diversity Change Agent
Bureau of Land Management
Alaska State Office
222 West 7th Avenue, #13
Anchorage, AK 99513
Office #: 907-271-3244
Cell #: 907-290-0115
jwedmonds@blm.gov

On Fri, Jun 29, 2018 at 1:41 PM, Wixon, Donna <dwixon@blm.gov> wrote:

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>
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>
> Donna
>
> Donna L Wixon
> Natural Resource Specialist
> BLM Arctic District Office
> 222 University Ave
> Fairbanks, Alaska 99709
> 907-474-2301 Office
> 907-474-2386 Fax
> dwixon@blm.gov
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> On Fri, Jun 29, 2018 at 1:19 PM, Edmonds, Joseph <jwedmonds@blm.gov> wrote:
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>> Office #: 907-271-3244
>> Cell #: 907-290-0115
>> jwedmonds@blm.gov

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Updated Seismic Timeline and Example Issue Statements

1 message

Whitman, Matt <mwhitman@blm.gov> Mon, Oct 15, 2018 at 7:18 AM
To: blm_ak_coastal_plain_seismic_ea@blm.gov

---------- Forwarded message ---------
From: **Wixon, Donna** <dwixon@blm.gov>
Date: Fri, Jun 29, 2018 at 9:32 AM
Subject: Fwd: Updated Seismic Timeline and Example Issue Statements
To: Debbie <dnigro@blm.gov>, Joseph Keeney <jkeeney@blm.gov>, kdebenham <kdebenham@blm.gov>, Lonnie Bryant <lbryant@blm.gov>, Matthew Whitman <mwhitman@blm.gov>, me <dwixon@blm.gov>, Richard Kemnitz <rkemnitz@blm.gov>, roy nageak <rnageak@blm.gov>, Sarah LaMarr <slamarr@blm.gov>, Shelly Jacobson <njones@blm.gov>, Stacey <sfritz@blm.gov>, Terra Meares <tmeares@blm.gov>, Timothy Vosburgh <tvosburgh@blm.gov>

Good Morning,

FYI, Proposed updated Seismic EA Schedule.

Donna

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

---------- Forwarded message ----------
From: **Sarah LaMarr** <slamarr@blm.gov>
Date: Wed, Jun 27, 2018 at 4:34 PM
Subject: Updated Seismic Timeline and Example Issue Statements
To: Wendy Loya <wendy_loya@fws.gov>
Cc: "Wixon, Donna" <dwixon@blm.gov>

Hi Wendy - attached is the latest version of the schedule. Like we discussed on Tuesday, here are some example issue statements. The issue statements will narrow and drive what is discussed in the EA so folks need to be clear and concise.

Example Issue Statements: Frame Issues as a Ques on

1. How would disturbance from seismic explora on impact denning polar bears?
2. What would be the effects of seismic ac vi es on overwintering fish?
3. How would seismic equipment impact stream banks?
4. How would water withdrawal from lakes (or streams?) impact aqua c habitat and overwintering fish?
5. What would be the impacts of overland travel from seismic explora on vehicles on vegeta on?
6. What would be the impacts from seismic ac vi es to subsistence users and wildlife species important for subsistence use?

Thanks, sarah

Sarah La Marr
Bureau of Land Management
Arctic District Office
Fairbanks, Alaska
907-474-2334 (desk)
907-888-3407 (cell)
slamarr@blm.gov

Timeline June 26 2018.docx
20K

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Updated Seismic Timeline and Example Issue Statements

1 message

Nigro, Debora <dnigro@blm.gov> Tue, Sep 25, 2018 at 2:21 PM
To: BLM_AK Coastal_Plain_Seismic_EA <blm_ak_coastal_plain_seismic_ea@blm.gov>

---------- Forwarded message ---------
From: **Wixon, Donna** <dwixon@blm.gov>
Date: Fri, Jun 29, 2018 at 9:32 AM
Subject: Fwd: Updated Seismic Timeline and Example Issue Statements
To: Debbie <dnigro@blm.gov>, Joseph Keeney <jkeeney@blm.gov>, kdebenham <kdebenham@blm.gov>, Lonnie Bryant <lbryant@blm.gov>, Matthew Whitman <mwhitman@blm.gov>, me <dwixon@blm.gov>, Richard Kemnitz <rkemnitz@blm.gov>, roy nageak <rnageak@blm.gov>, Sarah LaMarr <slamarr@blm.gov>, Shelly Jacobson <njones@blm.gov>, Stacey <sfritz@blm.gov>, Terra Meares <tmeares@blm.gov>, Timothy Vosburgh <tvosburgh@blm.gov>

Good Morning,

FYI, Proposed updated Seismic EA Schedule.

Donna

Donna L Wixon
Natural Resource Specialist
BLM Arctic District Office
222 University Ave
Fairbanks, Alaska 99709
907-474-2301 Office
907-474-2386 Fax
dwixon@blm.gov

---------- Forwarded message ----------
From: **Sarah LaMarr** <slamarr@blm.gov>
Date: Wed, Jun 27, 2018 at 4:34 PM
Subject: Updated Seismic Timeline and Example Issue Statements
To: Wendy Loya <wendy_loya@fws.gov>
Cc: "Wixon, Donna" <dwixon@blm.gov>

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1. How would disturbance from seismic explora on impact denning polar bears?
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Thanks, sarah

Sarah La Marr
Bureau of Land Management
Arctic District Office
Fairbanks, Alaska
907-474-2334 (desk)
907-888-3407 (cell)
slamarr@blm.gov

--
Debbie Nigro
Bureau of Land Management
222 University Ave.
Fairbanks, AK 99709
907-474-2324

dnigro@blm.gov

Timeline June 26 2018.docx
20K

DRAFT
June 27, 2018

Projected Timeline

May 11- Due date for application questions from FWS and BLM to IDT Lead
May 22 – IDT Lead compiles application questions and sends letter to applicant
May 23 – Project Initiation Letter sent to IDT
May 22-June 26 – Draft Affected Environment (FWS and Key BLM IDT members) (Refer to Table 1)
June 22 – Deadline for applicant response to questions
June 22- July 5 - Finalize Proposed Action and post to BLM ePlanning website (IDT Lead)
July - November –Assuming an application is received shortly, MMPA Incidental Take Regulations development (published in Federal Register in November and final rule in January)
July 6 - IDT Lead sends letter to applicant regarding schedule
July 6 – IDT Lead sends Proposed Action to team to draft Issue Statements
July 10 – November 9 –ESA Formal Section 7 Consultation for both BLM and FWS evaluating and authorizing the seismic permit and MMPA Incidental Take Regulations
July 13 – Deadline for Issue Statements from ID, draft Best Management Practices and draft Alternatives to IDT Lead.
July 17 – In person IDT meeting to identify draft Best Management Practices and Alternatives. Additional BMPs may be identified during the environmental impacts analysis.
July 19 – IDT Lead sends Alternatives including draft Best Management Practices to Managers for review
July 19– IDT Lead sends list of projects to include in cumulative effects analysis to IDT for review
July 24 – Manager Alternative Briefing and Identify Preferred Alternative (IDT Lead, Managers and key IDT members)
July 25 – August 1 – IDT finalizes Best Management Practices and completes Environmental Impacts including Cumulative Effects analysis (BLM and Key FWS IDT members) (Refer to Table 1)
August 3 – Post draft EA for 30 day comment period.
August 6-August 9 – Public Meetings and Government to Government
September 3– All Public Comments Received
September 12 – IDT Responds to Comments
November 9 – Biological Opinion concluding section 7 consultation issued to BLM and FWS Marine Mammals Management Office.
November 12 – Sign FONSI and Decision (BLM District Manager)
November 16 – Incidental Take Regulations published in Federal Register
January 2019 – Final Incidental Take Regulations Rule

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: Timely article

1 message

Heath, Nolan <nheath@blm.gov> Wed, Oct 3, 2018 at 3:49 PM
To: BLM_AK Coastal_Plain_Seismic_EA <blm_ak_coastal_plain_seismic_ea@blm.gov>

---------- Forwarded message ---------
From: **Jones, Nichelle (Shelly)** <njones@blm.gov>
Date: Tue, Sep 4, 2018 at 8:00 AM
Subject: Fwd: Timely article
To: Murphy, Ted <t75murph@blm.gov>, Nolan Heath <nheath@blm.gov>, Robert Brumbaugh <rbrumbau@blm.gov>, Serena Sweet <ssweet@blm.gov>, Hayes, Miriam (Nicole) <mnhayes@blm.gov>, Guyer, Scott <sguyer@blm.gov>, Eric Geisler <egeisler@blm.gov>, Kenneth Peck <kpeck@blm.gov>, Casey Burns <ctburns@blm.gov>

Shelly Jones
Acting Manager
Arctic District Office
222 University Avenue
Fairbanks, AK 99709

(907) 474-2310 (w)
(907) 460-0086 (c)

---------- Forwarded message ----------
From: **Nigro, Debora** <dnigro@blm.gov>
Date: Tue, Sep 4, 2018 at 7:51 AM
Subject: Timely article
To: "Krystal (Melody) Debenham" <kdebenham@blm.gov>, Roy Nageak <rnageak@blm.gov>, Cindy L Hamfler <chamfler@blm.gov>, Donna L Wixon <dwixon@blm.gov>, Joseph Keeney <jkeeney@blm.gov>, Lonnie Bryant <lbryant@blm.gov>, Matt Whitman <mwhitman@blm.gov>, Sarah LaMarr <slamarr@blm.gov>, Shelly Jacobson <njones@blm.gov>, Stacey A Fritz <sfritz@blm.gov>, Terra Meares <tmeares@blm.gov>, Timothy Vosburgh <tvosburgh@blm.gov>

Landscape change in ANWR.

--
Debbie Nigro
Bureau of Land Management
222 University Ave.
Fairbanks, AK 99709
907-474-2324
dnigro@blm.gov

Landscape change ANWR using aerial imagery.pdf
15723K

remote sensing

MDPI

Article

Landscape Change Detected over a Half Century in the Arctic National Wildlife Refuge Using High-Resolution Aerial Imagery

Janet C. Jorgenson [1,*], M. Torre Jorgenson [2], Megan L. Boldenow [3] and Kathleen M. Orndahl [4]

1 U. S. Fish & Wildlife Service, Fairbanks, AK 99701, USA
2 Alaska Ecoscience, Fairbanks, AK 99709, USA; ecoscience@alaska.net
3 Department of Biology and Wildlife, University of Alaska, Fairbanks, AK 99775, USA; mboldenow@gmail.com
4 School of Informatics, Computing & Cyber Systems, Northern Arizona University, Flagstaff, AZ 86011, USA; kmo265@nau.edu
* Correspondence: janet_jorgenson@fws.gov; Tel.: 1-907-456-0250

Received: 2 June 2018; Accepted: 27 July 2018; Published: 18 August 2018

Abstract: Rapid warming has occurred over the past 50 years in Arctic Alaska, where temperature strongly affects ecological patterns and processes. To document landscape change over a half century in the Arctic National Wildlife Refuge, Alaska, we visually interpreted geomorphic and vegetation changes on time series of coregistered high-resolution imagery. We used aerial photographs for two time periods, 1947–1955 and 1978–1988, and Quick Bird and IKONOS satellite images for a third period, 2000–2007. The stratified random sample had five sites in each of seven ecoregions, with a systematic grid of 100 points per site. At each point in each time period, we recorded vegetation type, microtopography, and surface water. Change types were then assigned based on differences detected between the images. Overall, 23% of the points underwent some type of change over the ~50-year study period. Weighted by area of each ecoregion, we estimated that 18% of the Refuge had changed. The most common changes were wildfire and postfire succession, shrub and tree increase in the absence of fire, river erosion and deposition, and ice-wedge degradation. Ice-wedge degradation occurred mainly in the Tundra Biome, shrub increase and river changes in the Mountain Biome, and fire and postfire succession in the Boreal Biome. Changes in the Tundra Biome tended to be related to landscape wetting, mainly from increased wet troughs caused by ice-wedge degradation. The Boreal Biome tended to have changes associated with landscape drying, including recent wildfire, lake area decrease, and land surface drying. The second time interval, after ~1982, coincided with accelerated climate warming and had slightly greater rates of change.

Keywords: Alaska; Arctic; tundra; boreal; climate change; shrub increase; aerial photography; remote sensing; vegetation; permafrost; thermokarst; fire

1. Introduction

The Arctic National Wildlife Refuge (hereafter, Refuge) in northeastern Alaska spans from the Beaufort Sea coast and coastal plain tundra across the high Brooks Range to the boreal forest. It covers 80,324 km^2 and is the largest protected conservation area in the United States. The Refuge encompasses a wide temperature range and a diversity of ecosystems and, thus, is a natural laboratory for evaluating climate change impacts. Because the Refuge is very remote, with no roads and few airstrips, we used high-resolution imagery to remotely sense geomorphic and vegetative changes over a ~50-year period.

The arctic climate has warmed rapidly during the past 50 years, with annual average temperatures increasing nearly twice as fast as the world average [1]. The rate of warming in Alaska rose sharply beginning in 1977, concurrent with large-scale atmosphere and ocean regime shifts, such as the Pacific Decadal Oscillation [2–4], and warming has continued since then [5,6].

Most evidence for landscape change in the Arctic comes from remote sensing, mainly automated processing of satellite images at 30-m (LANDSAT) to 1-km resolution (AVHRR), because of the vast remote areas [7,8]. The normalized difference vegetation index (NDVI), an index of quantity of green vegetation derived from satellite data, has increased Arctic-wide since the 1970s, with the greatest increases in northern Alaska [9–11]. The increase has generally been attributed to broad-scale increases in shrubs [12–15]. There can be considerable spatial heterogeneity, however, depending on remote sensing technique and scale. Bhatt et al. [16] used AVHRR to reveal that trends in the summer warmth index (sum of degree months above freezing) from 1982 to 2011 varied by region, with summer warmth index increasing over time in northern Alaska. Pattison et al. [17] found little change in NDVI from 1984 to 2009 in the northern portion of the Refuge, corresponding with little change in ground monitoring plots. Using high-resolution Landsat data (1985–2007) to detect NDVI trends in the foothills of northern Alaska, Raynolds et al. [18] found both significant increases and decreases across the heterogeneous terrain.

Ground-based data documenting change in Alaska and the Arctic have been accumulating rapidly. Elmendorf et al. [19] synthesized vegetation changes over time in plots across the Arctic and found a widespread trend of increasing shrub abundance. Plots from that synthesis that were from the Refuge showed patchy change but no trend, with only one of 27 plots showing shrub increase and three with augmented ice-wedge degradation between 1984 and 2009 [20]. Other studies documented increasing ice-wedge degradation [21] and wildfire [22,23] in Alaska in recent decades.

More work is needed at high-resolution scales to relate results from large-scale remote sensing studies to small-scale field studies. For example, there is a mismatch between the many remote sensing studies that indicate a wide-spread shrub invasion of Arctic tundra and local field-based observations suggesting that the changes are less dramatic, more complex, and heterogeneous. Manual photointerpretation of high-resolution (<4 m) images provides that high-resolution scale but is limited to smaller areas due to cost, time, and data-processing load. Yet manual image interpretation of high-resolution imagery has many advantages. It can detect both geomorphic changes (e.g., ice-wedge degradation, channel migration) and vegetation structural changes (e.g., tree and tall shrub changes evident from shadows), it allows for comparison among vastly different image types (e.g., black and white and color-infrared (CIR) aerial photos, satellite imagery), and its ability to detect change is improved by the expertise and experience of the photointerpreter. A disadvantage is that consistency between observers, or for one observer working on different landscape types, is not assured.

Interpretation of repeat aerial photography and satellite imagery has long been used to quantify landscape and vegetation changes that have occurred since the 1950s. Surface waterbody decreases in subarctic Alaska have been documented by manual image interpretation [24] and in western Alaska by automated classification of imagery [25]. For changes not involving waterbodies, such as the following examples, change detection has usually been done by manual interpretation of images. Increases in shrub cover have been observed at some northern Alaska tundra sites between the 1950s and present [26–28]. Photointerpretation of time-series imagery also has been used to quantify recent increases in thermokarst associated with collapse-scar fens [29], ice-wedge degradation [21,30], and thaw slumps [31]. These studies often focused on small rapidly changing areas, so are of limited use for assessing changes over larger regions. We addressed this limitation by using a random-systematic sampling design to estimate changes across the entire Refuge and its diverse ecosystems.

Our objectives were to: (1) document geomorphic and vegetative changes across the entire Arctic National Wildlife Refuge since the 1950s; (2) quantify the amount of change in seven ecoregions of the Refuge; and (3) compare rates of change between early and recent intervals of the study (before and after ~1982). We used visual interpretation to document landscape change at points located on multiple time series of coregistered aerial images, which consisted of panchromatic aerial photographs from 1947 to 1955, CIR aerial photographs from 1978 to 1988, and high-resolution, multispectral satellite images (Quick Bird, IKONOS) from 2000 to 2007. We undertook this study with a view to validating global change models and predicting future changes based on climate modelling.

2. Materials and Methods

2.1. Study Area

The Refuge spans from the Beaufort Sea coast in the north, across the Brooks Range to the boreal forest and tributaries of the Yukon River in the south. Our study area thus extended across Tundra, Mountain, and Boreal Biomes. Table 1 summarizes geographic and temperature data. The mean annual temperature is below freezing and all parts of the Refuge are underlain by continuous permafrost except for larger river valleys in the far south. Surficial permafrost features such as ice-wedge polygons, beaded streams, peat ridges, and frost boils are common throughout. Vegetation types are summarized in Table A1. There is increasing continental and diminishing maritime influence with distance from the coast. While long-term climate records do not exist for the Refuge, mean annual temperatures have risen 2.0 °C since the 1950s at Barrow, on the Arctic coast, and 2.3 °C at Bettles, in the boreal forest [32]. The greatest warming has occurred during winter and spring. Higher temperatures are causing earlier spring snow melt, reduced sea ice, glacier retreat, insect outbreaks, and permafrost warming [6].

Table 1. Geographic and temperature information for ecoregions of the Arctic Refuge. Size, elevation, and slope are derived from Refuge GIS data and 2005 digital elevation model. Average temperatures (°C) are based on data from nearby weather stations, 1961–1990, and a model that included topographic data (PRISM). Percent burned is from the Alaska Fire Service database.

Biomes & Ecoregions (North to South)	% of Refuge	Area (km^2)	% Burned (1950–2010)	Mean Annual Temp. (°C)	January Temp. (°C)	July Temp (°C)	Mean Elevation (m)	Mean Slope (°)
Tundra Biome:								
Beaufort Sea Coast	1	850	0	−11	−26	6	3	1
Beaufort Coastal Plain	5	3788	0	−11	−26	6	59	1
Brooks Foothills	8	6278	0	−10	−26	9	317	3
Mountain Biome:								
Brooks Range North	31	24,731	0	−8	−25	9	1106	22
Brooks Range South	21	16,488	0	−8	−26	10	1170	18
Boreal Biome:								
Interior Uplands	27	22,064	12	−6	−24	14	633	5
Interior Lowlands	8	6126	58	−5	−26	15	350	3
Whole Refuge	100	80,325	8	−8	−25	11	813	13

The Tundra Biome extends from the Brooks Range in the south to the Arctic Ocean in the north and includes the northern foothills of the Brooks Range, the coastal plain, and the coast of the Arctic Ocean. It has an arctic climate with a short (June to August) growing season and low precipitation. The coastal plain is comprised mainly of undulating moist tundra with vast floodplains and small areas of thaw lake plains. The foothills have rolling hills and plateaus, with better defined drainages. Vegetation is composed mainly of hardy dwarf shrubs, sedges, and mosses. Habitats can be grouped into four broad categories: coastal lagoons, wet sedge tundra and lakes, river floodplains, and upland moist sedge-shrub tundra areas [33].

The Mountain and Boreal Biomes have a continental subarctic climate. Annual precipitation and snow depths exceed those of the Tundra Biome and higher evapotranspiration and warmer summers create drier habitats. The Mountain Biome includes the rugged topography of the Brooks Range. The four highest peaks and the largest glaciers in the range are in the Refuge. Valleys are wide, steep sided, and flat floored, cut by glaciers and then filled with alluvium. Barren rock and sparse, dry alpine tundra predominate. Valleys contain moist sedge-shrub tundra and white spruce woodlands extend up the south-flowing rivers on favorable sites. The Boreal Biome occurs south of the Brooks Range. White and black spruce forests and woodlands predominate in the lowlands, whereas the uplands are rounded ridges with woodlands or open moist sedge-shrub tundra. Frequent, large wildfires shape the vegetation in this biome.

2.2. Sampling Design

Site selection involved regional stratification, image review to identify random sites with time series of suitable imagery, and establishment of sampling grids for photointerpretation. We used a stratified-random sampling design to select five random sites in each of seven ecoregions for a total of 35 study sites (Figure 1).

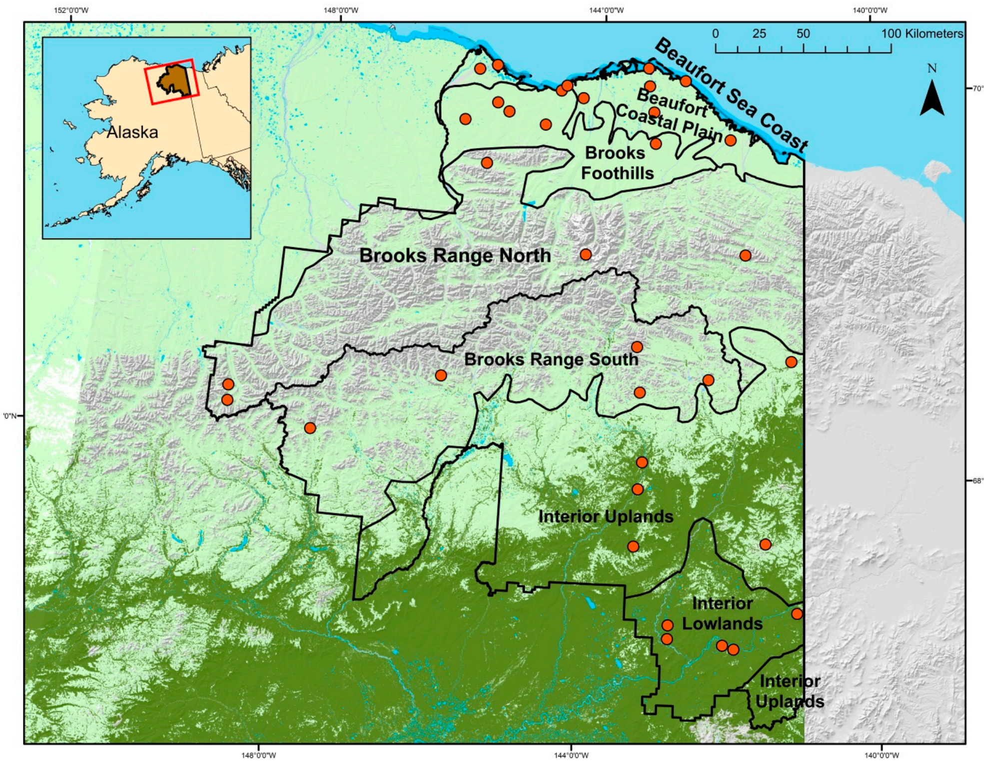

Figure 1. Map of ecoregions of the Arctic National Wildlife Refuge based on Nowacki et al. (2001), with five sites in each ecoregion randomly chosen from area of overlap between acceptable images in all three time periods of the study (red dots).

We defined ecoregions according to Ecoregions of Alaska [34], with minor modifications (Figure 1, Table 1). We separated out a Beaufort Sea Coast ecoregion, defining this as a 300-m wide band stretching the length of the coast, widened as necessary to encompass salt marshes. We also divided the Brooks Range ecoregion into two units north and south of the continental divide. We combined the Davidson Mountains and Ogilvie Mountains ecoregions into a single Interior Uplands ecoregion because they had similar topography and snow-free satellite imagery was not available for the Ogilvie Mountains (1% of Refuge).

To establish the sampling grids, we first generated a set of random locations in each ecoregion. We then went sequentially through the list to identify locations with acceptable images for all three periods (Figure A1). We required all imagery to have greened-up vegetation (generally mid-June to August) and little or no snow cover, clouds, or haze.

2.3. Image Acquisition and Manipulation

Image preparation included image acquisition, enhancement and georeferencing. We acquired and compiled imagery for three sampling periods. Image sources and resolution are listed in Table 2 and extent of available imagery is shown in Figure A1. For the first time period, we used 1947–1950 military aerial photographs, available for 21 of 35 sites, including all sites in the northern four ecoregions and two of five in the southern Brooks Range ecoregion. We used 1955 US Geological Survey aerial photographs for the remaining 14 sites. For the second time period, 1978–1988, we had excellent CIR aerial photograph coverage of the northern part of the Refuge, including a grid of flight lines that spanned most of the Coast, Coastal Plain, and Arctic Foothills ecoregions, repeated in 1984, 1985, and 1988. In addition, we had complete coverage of 1981 true color photographs. For the southern part of the Refuge in this time period, we used CIR aerial photographs from the Alaska High Altitude Project (AHAP). For the third time period, 2000–2007, we acquired map layers showing all Quickbird and IKONOS satellite imagery archived and available for purchase in 2008. We chose the "standard" imagery option, which was geographically referenced and terrain corrected. We recently acquired Worldview satellite images from 2011 to 2014 for some of our grids and used them as additional verification of changes. However, our data and results are from 2000 to 2007 imagery. For the aerial photography, we acquired high-resolution scans of all images for each grid (1200–1800 dpi). The images were either scanned from transparencies (preferred) or prints depending on availability. An example of overlapping images for a site is provided in Figure 2.

Table 2. Aerial photographs and satellite imagery used to detect change in the Arctic National Wildlife Refuge, with source, dates, and resolution.

Image Type	Source	Dates	Color	Scale	Resolution (m)
Aerial Photography	U. S. Air Force	1947	B & W	1:40,000, 1:30,000, 1:12,000	0.3–1.0
Aerial Photography	Naval Arctic Research Laboratory	1948–1950	B & W	1:20,000	0.4–0.6
Aerial Photography	U. S. Geological Survey	1955	B & W	1:50,000	1.0
Aerial Photography	Alaska High-Altitude Photography Program	1978–1982	Color Infrared	1:60,000	1.0
Aerial Photography	U. S. Fish & Wildlife Service	1981	True Color	1:18,000	0.3
Aerial Photography	U. S. Fish & Wildlife Service	1984, 1985, 1988	Color Infrared	1:6,000	0.1
Quickbird Satellite Imagery	Digital Globe	2002–2007	Color (pan-sharpened) & B&W (pan)		0.6 (pan), 2.4 (color)
IKONOS Satellite Imagery	Digital Globe	2000–2006	Color (pan-sharpened) & B&W (pan)		0.8 (pan), 4 (color)
Worldview Satellite Imagery	Digital Globe	2010–2015	True Color (pan-sharpened)		0.3

We produced a time series of spatially aligned images for each 100-point study grid. Image processing was done with ERDAS Imagine software. We pan-sharpened the satellite image by merging the panchromatic and multispectral bands. A portion of each aerial photograph (~2.6 km^2 needed to cover the study grid) was then georeferenced to the satellite image using 15–40 ground control points that were developed from distinct features visible on the images. Stable features were easy to find on most landscape types and included individual trees and shrubs, junctions between ice-wedge polygon troughs, other permafrost features, bird mounds, and boulders. Georeferencing was often difficult on steep mountain slopes with scree and dwarf shrub vegetation, which tended to have fewer distinct and constant points across all images. On steep slopes, we resorted to rectifying different slopes separately or stretching the photo with temporary ground control points as we worked across different parts of the photo.

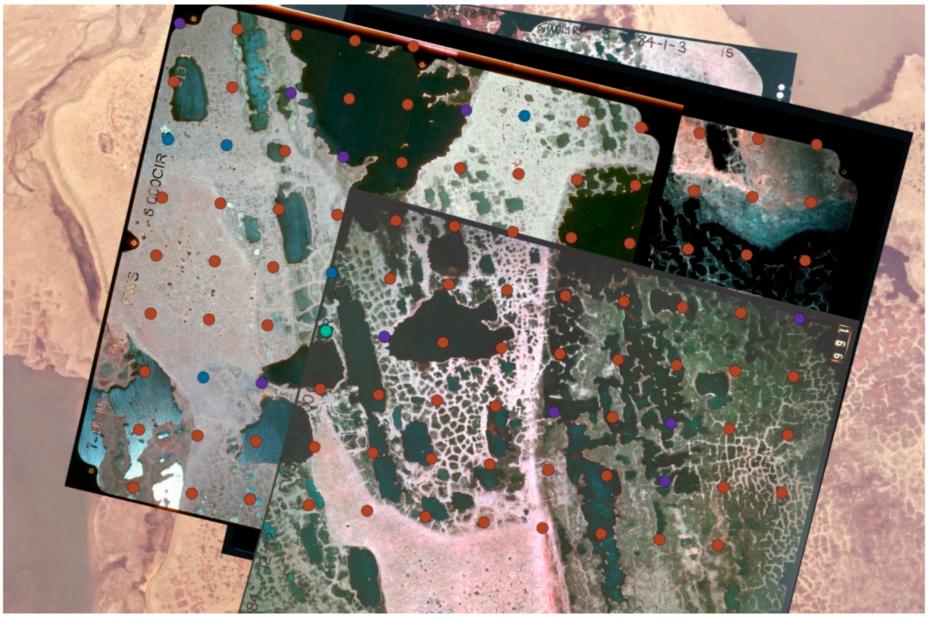

Figure 2. Example of a 100-point grid used for interpreting landscape change. Background is a 1981 aerial photograph, overlain with overlapping color-infrared (CIR) aerial photographs from 1984, 1985, and 1988. 1950 and 2003 images not shown. Site is on a thaw lake plain with polygonised microtopography in drained lake basins. Dots are grid points, 10-m-radius circles on the ground, color coded by type of change detected. Blue = ice-wedge degradation; purple = lake area increase; green = lake area decrease; brown = no change. Points are 160 m apart on the ground.

2.4. Image Interpretation

The stratified random sample had 5 sites in each of 7 ecoregions, with a systematic grid of 100 points per site. A grid approach was used instead of delineating polygons on each image because it was quicker. Image interpretation was done in ArcMap, with a separate file kept for detailed notes. At each point, a 10-m-radius circle was displayed on screen and the area inside the circle was visually evaluated on images. Satellite images were displayed in false-CIR and also in panchromatic for comparing to the 1950s-era black and white photographs.

We assigned landscape change types to each point based on differences detected within the circle between images from the three time periods. Change types were assigned for the early interval (~1952 to ~1982), recent interval (~1982 to ~2004), and overall. Vegetative and nonvegetative change types we detected are listed on Table A2. Differences were most often detected by a change in pattern or texture. We evaluated whether apparent changes were likely due to differences in image quality, including resolution, color scheme, or sun angle between years. Where image quality could not be confidently dismissed as the reason behind apparent change at a point, we did not record that point as changed. In practice, the only vegetative changes identified consistently were changes in density or size of trees, tall shrubs, and low shrubs, since dwarf shrubs and graminoid vegetation often lacked texture and potential changes between time periods could not always be identified. We overlaid historical fire perimeters mapped by the Alaska Fire Service on the images, but we found photointerpreted fire occurrence to be more reliable because burns were patchy within the perimeters and not all were mapped. We assigned the ice-wedge degradation change type in areas of polygonal microtopography but only at points where the width or depth of ice-wedge troughs changed between images. This was most often detected by changes in areal extent of water in troughs. Changes seen on the images but not at points were recorded in a separate file as incidental observations.

For each point in each time period, we recorded a number of variables. A vegetation type was assigned plus secondary vegetation types and water if they covered more than 10% of the circle.

Vegetation types were based on the Alaska Vegetation Classification [35] and are summarized in Table A1. To facilitate interpretation, the spectral and pattern characteristics of CIR images were described for each vegetation type, based on extensive previous work with aerial photographs. We also recorded presence or absence of ice-wedge polygon microtopography, polygon morphology (distinguishing high-, flat-, and low-centered polygons), and type of surface water (e.g., lake, river). To estimate the amount of water on the landscape, we recorded presence or absence of surface water at the center of each circle.

Vegetation data and photographs taken on the ground within 10–15 km of most grids in the Tundra Biome and in the lowlands of the Boreal Biome were available from previous projects. These reference data aided in interpretation of vegetation types on imagery. We did not visit grids on the ground but were able to fly over 22 of the 35 grids to make observations and take photographs that aided in interpretation. The main benefit was to verify photointerpreted burned areas by the presence of dead snags, which were often not distinguishable on imagery.

2.5. Environmental Variables

We compiled ancillary data on a suite of environmental variables, including climate, topography, geology, and fires. Data included mean annual and monthly temperatures for 1961–1990 from CRU6-9 (interpolated from climate station data, PRISM). Topographic variables were from the 2005 National Elevation Dataset. Geomorphic variables included general geologic unit, bedrock geology, geomorphology, and physiography derived from Jorgenson and Grunblatt [36]. We coded major rivers at each study site as glacially fed or nonglacial.

2.6. Data Analysis

Analysis involved data aggregation and summarizing of point data to produce descriptive statistics for regional and temporal comparisons. To simplify the analyses and increase sample sizes, we did several levels of aggregation including: (1) summarizing the frequency of each data category for each grid so that the grid (100 points) was considered the sample unit; (2) aggregating 29 image-interpreted change types into 19 broader categories (Table A2); (3) aggregating the seven ecoregions into three biomes (Table 1), and (4) simplifying time periods (e.g., 1947–1955) by assigning them the mean year of the period (e.g., ~1952). We lumped some change types into generally wetting change vs. generally drying change categories to enable assessment of broad hydrologic changes (Table A2). We also examined some environmental attributes to allow comparison of changes associated with specific factors, including (1) two types of substrate (alluvial and nonalluvial), (2) active floodplains of glacial vs. nonglacial rivers, and (3) four types of ice-wedge polygons.

To analyze changes, we calculated the mean frequency and confidence intervals for each change type and vegetation type within each ecoregion (original stratification). We them calculated the weighted mean for each biome (Tundra, Mountain, and Boreal) and the overall Refuge based on area of each ecoregion. For example, the Beaufort Sea Coast ecoregion was very small but had as many grids as the larger ecoregions, and data from this ecoregion were therefore given less weight. We calculated confidence intervals using a studentized bootstrap method with 10,000 replicates. For change types that were "opposites" (e.g., tree increase versus decrease) we also compared positive and negative changes to determine the net effect on a Refuge-wide scale. For comparing amount of change between the early and recent time intervals, which were of unequal duration, we calculated the annual rate of change (% of points changed/years in interval) for each grid in each time interval. Analyses were conducted in R (R Development Core Team, 2017).

3. Results

Analysis of time series of georeferenced aerial photos and satellite images at 35 sites in the Arctic National Wildlife Refuge revealed 29 types of landscape change over a 50-year period, which we simplified into 19 classes for analysis (Table A2). Below, we present the extent of change caused by the diverse geomorphic and ecological factors, first for the whole Refuge and then for the three major biomes of the Refuge, Tundra, Mountains, and Boreal. We highlight a few changes in particular biomes. We then compare rates of change between the early and recent intervals of the study. We also examine change types according to vegetation types and compare differences in change types associated with differing microtopography (polygonised vs. nonpolygonized) and substrate (alluvial vs. nonalluvial).

3.1. Change Types

Of all 3500 points we evaluated, 23% changed during the last half-century. Weighted by areal extent of each ecoregion, we estimated 18% of the Refuge changed (Table 3). The most common changes detected were wildfire and postfire succession (occurring on 6% of the Refuge), shrub increase (4%) or tree increase (2%) in the absence of fire, river erosion (3%) or deposition (2%), and thermokarst (soil ice-wedge degradation, 2%).

Change types varied by biome (Table 3, Figure 3). In the Tundra Biome, 19% of the area changed, mainly due to ice-wedge degradation (12%), river erosion or deposition (4%), and coastal changes (3%). In the Boreal Biome, 28% of the area changed, mainly due to fire and postfire vegetation succession (18%), tree and shrub increase in the absence of fire (7%), and landscape drying (2%). In the Mountain Biome, 10% changed, mainly due to river erosion and deposition (6%) overlapping with shrub increase in absence of fire (6%).

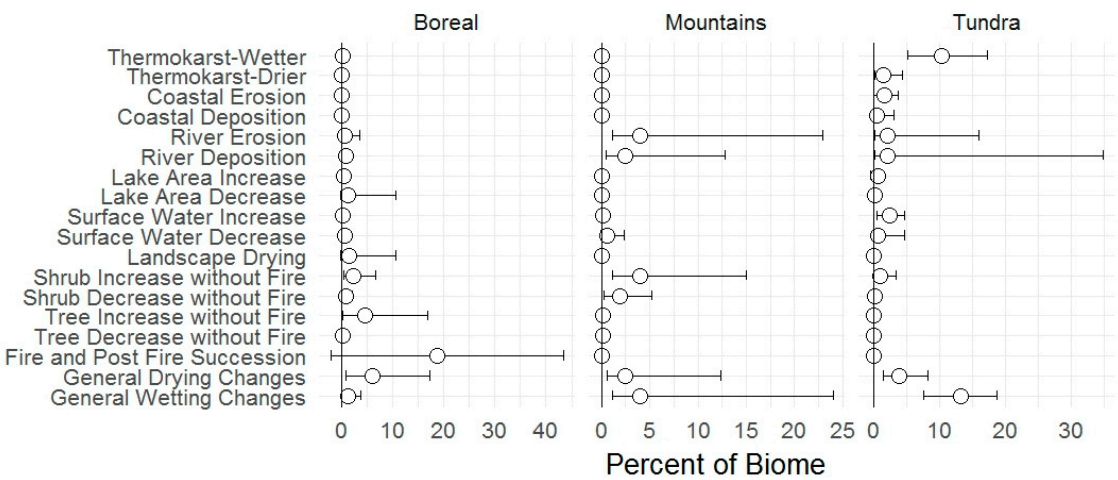

Figure 3. Percent of each biome with each major landscape change type, with means and 95% confidence intervals. Change types are defined in Table A2.

Because many types of change have opposing effects, we examined net change to evaluate the overall direction of landscape transitions over the study period (Figure 4). Based on weighted averages for the entire Refuge, tree and shrub increases were more common than decreases. This was mainly because fire was more prevalent before the study period began and gains associated with postfire successional recovery exceeded losses caused by fire. We estimate we could detect postfire vegetation succession after fires that had occurred up to ~50 years prior to our earliest imagery. Even in areas not affected by fire, we found small net increases in trees and shrubs indicating modest forest and shrubland expansion. Lakes and other surface water showed small net decreases, indicating more waterbodies shrank or were lost to drainage or water balance changes than increased in size. Ice-wedge degradation caused more ground wetting than drying and both coastal and river erosion caused more loss of land than was gained by deposition.

Table 3. Landscape changes detected on ~50-year time series of aerial images (between 1947 and 2007) in the Arctic National Wildlife Refuge, summarized by three biomes and seven ecological regions. Values are percentage of points that were affected (e.g., 45% of the Interior Lowlands points burned). Percentages for 7 ecological regions are based on 500 points per region. Percents for biomes and whole Arctic Refuge are weighted means, weighted by relative area of each ecoregion within its biome. Change types are described in Table A2.

Landscape Change	BIOMES										Whole Refuge
	Boreal			Mountains			North Slope Tundra				
	Interior Lowlands	Interior Uplands	Whole Biome	South Side	North Side	Whole Biome	Brooks Foothills	Coastal Plain	Coastal Marine	Whole Biome	
Fire & post-fire succession	45	11	18	0	0	0	0	0	0	0	6
Thermokarst wetting	1	0	<1	0	0	0	10	12	7	10	1
Thermokarst drying	<1	0	0	0	0	0	1	2	2	2	<1
Vegetation change without fire:											
Tree increase	4	5	5	<1	0	<1	0	0	0	0	2
Tree decrease	0	<1	<1	<1	0	<1	0	0	0	0	<1
Shrub increase	5	1	2	4	6	6	1	1	0	1	4
Shrub decrease	0	1	1	2	2	2	<1	0	0	<1	<1
River erosion	<1	1	1	4	4	4	1	4	1	2	3
River deposition	0	1	1	3	2	2	1	5	<1	2	2
Lake decrease	4	<1	1	0	0	0	0	<1	1	<1	<1
Lake increase	1	<1	<1	0	0	0	0	2	0	1	<1
Coastal erosion	0	0	0	0	0	0	0	0	18	2	<1
Coastal deposition	0	0	0	0	0	0	0	0	5	1	<1
Coastal storm surges & dunes	0	0	0	0	0	0	0	0	2	<1	<1
Landscape drying	2	1	2	0	0	0	0	0	0	0	<1
Glacial retreat	0	0	0	0	1	<1	0	0	0	0	<1
Scree slides	0	0	0	<1	<1	<1	0	0	0	0	<1
% with change of any type	58	20	28	9	11	10	14	24	36	19	18

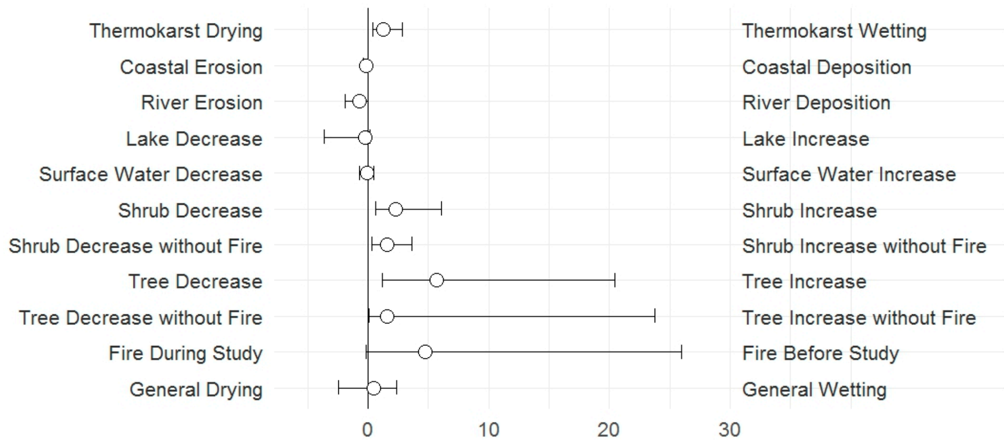

Figure 4. The net result of analyzing increase vs. decrease for opposing pairs of landscape change types. Values are mean percent, depicted as circles, with 95% confidence intervals given by error bars. Net increases are shown to the right of the zero line (y-axis), while net decreases fall to the left. Values shown indicate net change across the whole Refuge.

Rates of change were generally similar between the early and recent intervals (i.e., the first ~ 30 years compared to the last ~20 years) of the study. For some change types, there appeared to be a slight increase during the recent interval (Figure 5). These included ice-wedge degradation, tree and shrub increase in the absence of fire, general wetting, and general drying. However, the differences in net changes between intervals were small relative to the large variability encountered across the Refuge over the ~50-year study period.

Representative examples of imagery showing the changes associated with fire, increases in trees and shrubs, and ice-wedge degradation are shown in Figures 6–9. Other changes are illustrated in Figures A2–A5.

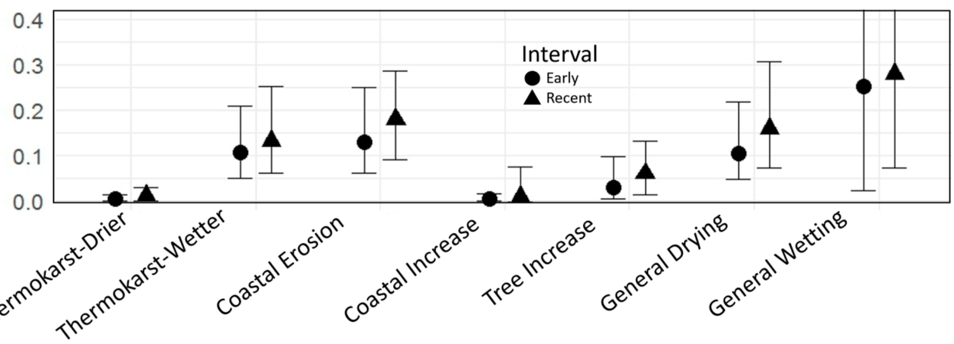

Figure 5. Annual rates of landscape change in the early study interval (1947–1955 to 1978–1988; circles) vs. the more recent interval (1978–1988 to 2000–2007; triangles), depicted for change types with differences between intervals. The y-axis is a mean annual rate of change (all < 1%/year), with 95% confidence intervals given by error bars.

3.2. Vegetation Types

Forest covered 19% of the Refuge, tall shrubs 5%, low or dwarf shrubs 28%, graminoid tundra 22%, and 26% of the Refuge had little or no vegetation (Table 4). Distributions of vegetation types were very different among the three biomes. Forest predominated in the Boreal Biome (52%), low and dwarf shrubs in the Mountain Biome (40%), and graminoids in the Tundra Biome (77%).

When examining types of change by vegetation type, we found forests had a high frequency of points that changed (39%), primarily due to wildfire and postfire vegetation succession. Tall shrubs showed the most change (44%) due to both wildfire and to riparian shrubs adjusting to river channel migration. Graminoid-dominated types changed less (16%), with ice-wedge degradation as the main cause.

3.3. Changes Associated with Alluvial and Polygonal Terrain

Alluvial terrain is dynamic due to channel migration, and polygonal terrain has abundant wedge ice that is sensitive to thermokarst associated with climate warming. We therefore compared changes occurring on alluvial vs. nonalluvial terrain and between high-, low, and flat-centered polygons to better understand potential drivers of change.

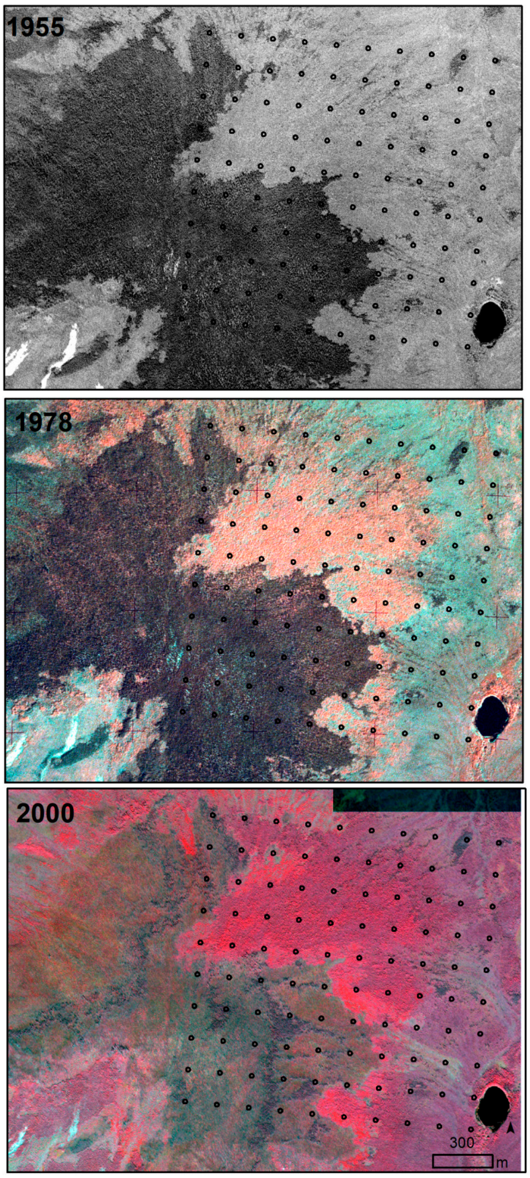

Figure 6. Time series showing a grid of 100 points with wildfire and postfire succession in the Boreal Biome. This forested site burned in 1950, leaving a patch of spruce forest (black in the 1955 and 1978 images). In 1986 most of the remaining forest disappeared in another fire that reached the site from the west and did not burn the dense young deciduous trees and shrubs to the east of the forest patch. Also visible are active layer detachment slides just SW of the grid (white streaks), probably caused by the 1950 fire. 2000 satellite image ©2018 DigitalGlobe, a Maxar company.

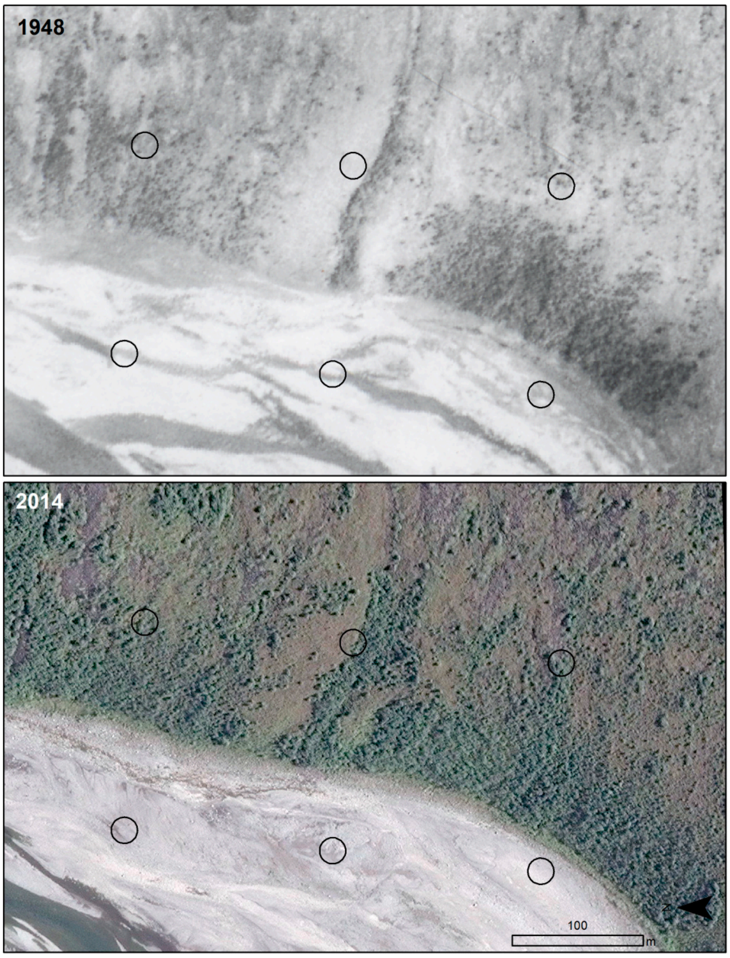

Figure 7. Images showing increase in alder shrub cover between 1948 and 2014 on a steep slope above a river in the northern Brooks Range, 30 km south of the north-most alder found to-date in the Arctic National Wildlife Refuge. 2014 satellite image ©2018 DigitalGlobe, a Maxar company.

River floodplains cover vast areas of the Refuge and have a gravelly, well-drained substrate that contrasts with the deeper organic soils found outside of floodplains. Of all study points, 23% were located on alluvial substrates, including active river floodplains, abandoned floodplains, and alluvial fans. Alluvial and nonalluvial substrates had a similar overall amount of change, but the vegetation and types of change were different. Alluvial substrates had more shrub-dominated area and less graminoid-dominated area. In particular, they lacked tussock tundra and had more tall shrubs.

On alluvium, the main changes over time were river erosion, deposition, and shrub increase or decrease. On nonalluvial substrates, the main changes were wildfire, tree increase, and ice-wedge degradation. The proportion of each grid that was alluvial varied greatly between grids, contributing greatly to the variability in our change-type data. Shrub changes were common on alluvial substrates, particularly shrub increase on alluvial fans in the mountains, and rare on nonalluvial (in absence of fire). Polygonization of the ground, requisite for the ice-wedge degradation change type, was almost absent on alluvium.

Because ice-wedge degradation was the major change type in the Tundra Biome and was only detected at points with visible polygonal surface patterns, we examined polygonized ground characteristics in more detail. Polygonized ground, indicative of a network of buried vertical ice wedges, varied among biomes. In the Tundra Biome, 67% of points had visible polygonal patterns, which were more common on flat ground than on slopes. Of these polygonised points, 64% were flat-centered, 17% low-centered, 9% high-centered, and 10% mixed. Most polygonized points were quite stable over time (Figure A2), with only 17% showing a change in ice-wedge degradation during the study period. In the other biomes, we found polygonized ground only in flat valley bottoms that were not on floodplains. Within the Interior Lowlands, 9% of points were polygonized but only a few had visible ice-wedge degradation, always after fire.

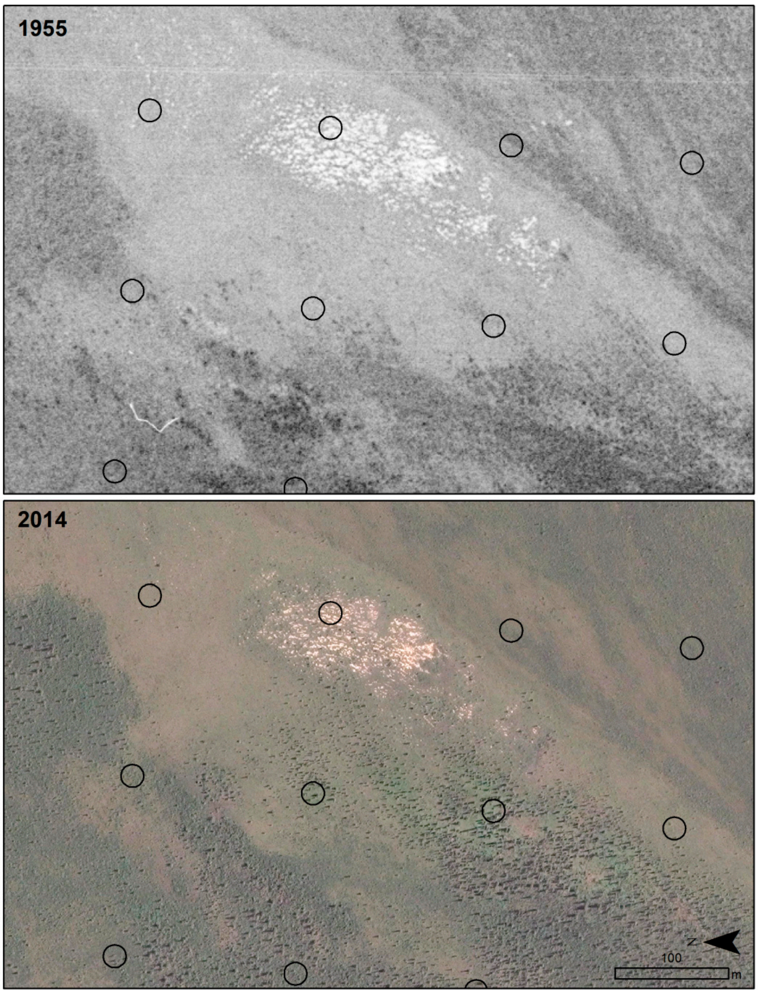

Figure 8. Images showing increase in tree cover at an upland site in the boreal forest between 1955 and 2014. 2014 satellite image ©2018 DigitalGlobe, a Maxar company.

The amount of polygonized ground differed by vegetation type. In the Tundra Biome, dwarf shrub tundra, moist sedge-Dryas tundra, and aquatic graminoid had the greatest proportion of polygonized points. In those types, plus moist sedge-willow and wet graminoid tundra, polygonized ground occurred at two-thirds or more of the points. For tussock tundra and saltmarsh vegetation, polygonized ground was observed at about half of the points. In the Boreal Biome, 27% of low shrub tundra points were polygonized. All other vegetation types had few or no polygonized points.

Ice-wedge degradation differed by polygon morphology and was more prevalent on points with flat-centered (22%) or mixed (high-, flat-, and low-centered; 23%) polygons than on points containing only low-centered (13%) or only high-centered (5%) polygons. Flat-centered polygon points initially had little vertical relief compared to points with low- or high-centered polygons; but at some of these points, ice-wedge troughs deepened over time, forming pools at trough intersections. This was most noticeable on points with moist sedge-Dryas tundra (Figure 9), likely due to soil properties associated with that vegetation type. (Specifically, high ground- ice contents, and deep summer thaw associated with frost boils that have bare mineral soil without an insulating organic layer.) Points with mixed polygons were probably unstable because of the ongoing ice-wedge degradation that had caused their mixed morphology. Points with low-centered polygons (most common in salt marshes and drained lake basins on thaw lake plains) were surprisingly stable over the half-century study period. Points with high-centered polygons were uncommon and also quite stable. High-centered polygons appeared to generally be the "changed" feature that remained following degradation. These points often had shrubby vegetation, which may have shaded the soil and minimized further thaw.

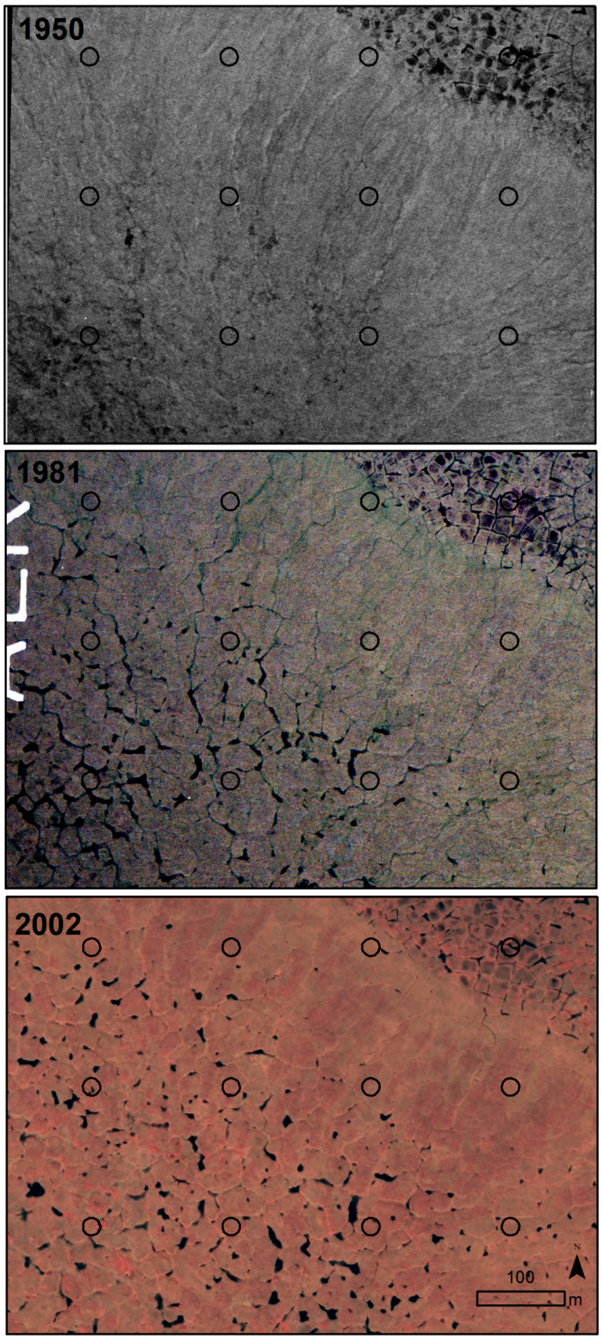

Figure 9. Time series of images showing ice-wedge degradation, evidenced by enlarged troughs and increased surface water on flat-centered polygons in a tundra basin and on an adjacent gentle slope. Note the lesser change visible in the wet, low-centered polygons (upper right). 27% of points at site had a change in ice-wedge degradation over the study period. 2002 satellite image ©2018 DigitalGlobe, a Maxar company.

Table 4. Distribution of vegetation types in the Arctic National Wildlife Refuge and in each of the three biomes, most common type of change detected in each vegetation type, and percent of points with each change type. Vegetation types are described in Table A1.

Vegetation Types	% of Whole Arctic Refuge	% of Tundra Biome	% of Mountain Biome	% of Boreal Biome	Most Common Change Detected in This Vegetation Type	% with Any Change
FOREST	19	0	2	52	Fire & post-fire succession	39
Spruce Forest	9	0	2	21	Fire & post-fire succession	31
Mixed Forest	8	0	0	25	Fire & post-fire succession	39
Broadleaf Forest	2	0	0	6	Fire & post-fire succession	77
TALL SHRUB	5	0	5	9	Shrub increase, with or without fire	44
Tall Riparian Shrub	2	0	3	1	River erosion & shrub increase (without fire)	53
Tall Non-riparian Shrub	3	0	2	8	Fire & post-fire succession	38
LOW OR DWARF SHRUB	28	12	40	21	Fire & post-fire succession	19
Low Riparian Shrub	3	1	4	1	River erosion	32
Low Non-riparian Shrub	14	10	15	20	Fire & post-fire succession	26
Dwarf Shrub	11	1	21	<1	Shrub increase (without fire)	7
GRAMINOID	22	77	9	15	Thermokarst-wetting	16
Tussock Tundra	6	19	4	4	Thermokarst-wetting	5
Moist Sedge-Dryas Tundra	6	25	2	3	Thermokarst-wetting	24
Moist Sedge-Willow Tundra	4	15	2	3	Thermokarst-wetting	14
Wet Graminoid Tundra	5	15	1	7	Thermokarst-wetting	16
Salt marsh and Aquatic	<1	3	0	<1	Thermokarst-wetting & coastal erosion	27
OTHER	26	11	43	3	River erosion & deposition	20
Sparsely Vegetated	6	1	11	<1	Shrub increase (without fire)	15
Non-vegetated	17	4	31	3	River erosion	19
Water	3	6	1	1	River deposition	21

4. Discussion

The Arctic National Wildlife Refuge has heterogenous landscapes with diverse ecosystems that are subject to a wide variety of geomorphic and vegetation processes that drive change. During the ~50-year study period, 18% of the Refuge underwent some type of landscape change, primarily due to wildfire, postfire succession, changes in shrub and tree cover, river dynamics, and ice-wedge degradation. This is similar to the amount of change detected in the Arctic Network of National Parks, located to the west of the Refuge, where a similar methodology found 24% of 206 systematically distributed plots showed change between 1975–1985 and 2008–2010 [27]. Our finding also compare to an Alaska-wide analysis, in which Pastick et al. [37] found 14% of the landscape had undergone change from 1984 to 2015, based on an analysis of spectral trends in Landsat imagery.

Below, we discuss some of the dominant changes affecting the landscape, compare and contrast the major drivers of change across the Refuge, evaluate rates of change during early and recent time intervals, and discuss the limitations of our remote sensing approach.

4.1. Change Types

We documented 19 broad categories of change associated with geomorphic and ecological processes. The major change types that emerged as most prevalent on the Refuge landscape included fire, river channel dynamics, tree or shrub increase, ice-wedge degradation, changes to the coastline, and hydrologic changes that included lake expansion and drainage, discussed in more detail below.

Wildfire caused the most change in our study Refuge-wide (6%) and was an important driver of change in the Boreal Biome (18%). Wildfire is a natural part of the boreal forest ecosystem (Figure A6). While fire frequency has increased in recent decades in Alaska [38], in the Refuge a huge area that burned in 1950 has been unequaled by any subsequent year. Therefore, large areas have been recovering from that fire, and our study found more tree increase than decrease after wildfire. Fire occurred only at our forested grids. Fires are known to occur in the tundra of northern Alaska but are uncommon [39]. The recent large fire near the Anaktuvuk River, visible on Figure A6, indicates that fire activity within the Tundra Biome could increase with climate warming, which could exacerbate thermokarst [40,41]. Severe fires accelerate thermokarst by removing the insulating soil organic layer, allowing summer heat to penetrate and thaw the permafrost [42]. We found some evidence that this process has occurred within the Refuge, as we noted several active-layer detachment slides that began within five years after fires (Figures 6 and A5).

Channel dynamics of active river floodplains can result in rapid changes. Half of our grids included points on active floodplains and we found river erosion and deposition were important drivers of change, affecting 5% of the Refuge. Differences between erosion and deposition can be linked to the rapid melting of glaciers in the Brooks Range [43]. The glacially fed river floodplains had twice the frequency of changed points as the nonglacial river floodplains (63% vs. 30% of active floodplain area), including more erosion, deposition, and shrub increase or decrease. The ratio of river erosion to deposition was skewed slightly towards erosion on the glacial rivers, and towards deposition on the nonglacial.

Shrub expansion onto tundra is widespread in the Arctic, with large ramifications for ecological processes and climate feedbacks [44]. In the Refuge, shrub cover increase in the absence of fire occurred almost entirely in the Mountain and Boreal Biomes, on alluvial substrates (e.g., active or abandoned floodplains, banks along floodplains, or alluvial fans). This change type affected 4% of the Refuge. In comparison, Swanson [45] photointerpreted tall shrub presence and density at 471 plots (mostly Mountain Biome) in the Arctic Network of National Parks and found that 8% had dense canopies of tall shrubs (often on floodplains), associated with higher summer temperatures, deep summer thaw, and well-drained soils. Tape et al. [46] also observed widespread shrub expansion on floodplains or nearby slopes. The scarceness of shrub increase we detected in the Tundra Biome and on nonalluvial surfaces throughout the Refuge appeared to be linked to soil conditions, and perhaps also to seasonality. Peak solar radiation at these latitudes occurs in late June, at which time soils may be thawed in Brooks Range valleys, especially on well-drained alluvial substrates, allowing plants to begin growth. The Tundra Biome, narrower within the Arctic Refuge than elsewhere in Arctic Alaska, is more affected by colder temperatures nearer to the Arctic Ocean. This causes soils to remain frozen near the ground surface at summer solstice, retarding the ability of shrubs to take full advantage of that period of maximum solar radiation.

Tree increase unrelated to fire was found almost entirely in the Boreal Biome (5%). One Boreal grid showed altitudinal tree line advance, where spruce trees had advanced out of gullies and onto high tundra between the earliest and latest time series images (Figure 8). Overflights of this grid together with a hand-drawn map showing tree extent in 1911 [47] indicate that the advance was not due to vegetation recovery following wildfire. At another grid on an inactive floodplain trees had become denser in wetlands, perhaps attributable to reduced flooding. The overall increase in tree cover was greater in the recent interval than in the early one. Little tree increase occurred at other grids (without wildfire). A review of worldwide tree line studies found that only 52% of sites showed tree line advance [48].

Ice-wedge degradation (a thermokarst process) is affecting ecosystems throughout the Arctic [21,49]. It affected 2% of the entire Refuge and was the dominant change detected in the Tundra Biome (12%). In comparison, ice-wedge degradation was observed at a few of 206 photointerpreted plots in the Arctic Network of National Parks [50]. Within small, targeted areas in northern Alaska, the extent of ice-wedge degradation increased from 0.5% to 4.4% (1945–2001) near Fish Creek [21] and increased from 0.9% to 7.5% (1949–2012) near Prudhoe Bay [30]. Farquharson et al. [51] found thermokarst troughs and pits covered 7% of 12 small mapped areas across northern Alaska. For central and northern Alaska, Jorgenson et al. [52] found thermokarst features occurred on 8% of sample points on airphotos from 2005 and 2006, with the frequency of occurrence much higher in the continuous permafrost zone in arctic Alaska (13.5%) compared to the discontinuous zone in boreal Alaska (5%). Ice-wedge degradation usually causes radical redistribution of water, resulting in newly wetting or drying conditions [53]. The only type of thermokarst recorded in our study was ice-wedge degradation, which overall caused much more wetting (1.5%) than drying (0.2%). Other types of thermokarst may be common in the Refuge, going undetected in our study due to small areal extent. For example, several small active-layer-detachment slides (ALDs) were incidentally observed to have occurred at one forested site after a wildfire, although not at a point (Figure 6). Many slides up to 90-m long have also occurred in severely burned forest 2 km NW of another study site (Figure A5). In comparison, 848 ALDs and 276 retrogressive thaw slumps were mapped within the 2.7 million hectare Noatak National Preserve [54].

On the Beaufort Sea coast, there were changes associated with coastal erosion, deposition, and salt water intrusion during storm surges. Deposition occurred at the mouths of rivers, and elsewhere the shore eroded gradually, seldom more than 1 m/year. Jorgenson and Brown [55] compiled mean annual erosion rates (1950s to 1980s) for sections of Refuge's coastline, and found coastline changes that ranged from erosion at ~1 m/year to accretion at ~12 m/year. Rates depended on the coastline type and soil texture. A long-term monitoring site in the Refuge had a mean annual erosion rate of 0.5 m/year between 1949 and 2001 [56]. In comparison, Jones et al. [57] documented a maximum erosion rate of 18.3 m/year at a point north of Teshepuk Lake, in low-lying thaw lake terrain that is rare within the Refuge.

Hydrologic changes included changes in lake area, river channel migration, irregular surface water changes on vegetated ground, water redistribution associated with ice-wedge degradation, and surface drying on inactive floodplains. Changes in the Tundra Biome tended to be related to landscape wetting (mainly ice-wedge degradation and surface water increase), while changes in the Boreal Biome tended to involve landscape drying (including reduced area of lakes and recent wildfire). Lake area tended to increase in the Tundra Biome and decrease in the Boreal Biome, where we found the process of lake drying on inactive floodplains left concentric rings of shrub and graminoid vegetation in former lake beds. Our results are consistent with those of Riordan et al. [24], who examined surface water, lakes, and ponds at 11 regions of Alaska, using images from the 1950s to 2002. They found a decrease in the area of closed-basin ponds in all locations except the Arctic coastal plain. In the adjacent Yukon Flats National Wildlife Refuge, historic aerial imagery indicates that lake drying and vegetation invasion have occurred in the Boreal Biome since about the 1980s [58]. Necsoiu et al. [59] mapped waterbodies on a time series of high-resolution imagery for the Kobuk Valley and found total surface area decreased by only 0.4% during 1951–1978, but then decreased by 5.5% during 1978–2005. In contrast, Plug et al. [60] used a time series of Landsat imagery (1978–2001) to show that lakes mostly increased during 1978–1992 and decreased during 1992–2001. Our limited sampling did not detect the decline in river icings documented by Pavelskiy et al. [61].

4.2. Vegetation Types

Although only 18% of the Refuge changed during the study period, some vegetation types had much higher amounts of change. Tall shrub and broadleaf forest together covered just 7% of the Refuge, but when present, changed greatly (38% and 77% of points, respectively). These types were usually associated with early to mid-succession stages after fire or on dynamic river floodplains. In contrast, only 7% of points changed in dwarf shrub vegetation. It was the most common vegetation type in the Mountain Biome, covering high-elevation, dry, rocky slopes that were not prone to any of the change types we detected. Only 5% of tussock tundra points changed, the least of all tundra types, likely because it occurred mainly on slopes in the Arctic Foothills, where water was less likely to impound and cause ice-wedge degradation than on the flatter Coastal Plain.

4.3. Rates of Change

We found little evidence for increasing rates of change over the course of our study, even though the recent interval of the study coincided with a period of increased climate warming in northern Alaska. An apparent slight increase in rates of change for ice-wedge degradation, surface water increase, and tree increase in absence of fire suggested a response to a warming climate, but the variability in change observed among grids was too high to detect a difference (Figure 5). The small differences in rates of change were unexpected, given that there was a large jump in air temperatures after a large Pacific Decadal Oscillation (PDO) shift in 1977 [4].

4.4. Limitations and Applications of Remotely Sensed Change

There were some limitations on our ability to detect change related to image quality and high spatial variability. We chose to manually interpret the changes we could see on images, using visual cues, such as pattern, texture, brightness, and juxtaposition, as well as ecological knowledge of the interpreters. When imagery was high quality, this worked very well and proceeded rapidly. The aerial photographs varied in quality and resolution, however. In the Mountain Biome, some of the oldest photographs in the southern Brooks Range were of poor quality. In addition, the aerial photographs were difficult to rectify on mountain slopes due to steepness and to lack of reliable ground reference points on slopes that had only scree and dwarf shrub vegetation. We believe we are correct in concluding that there was little change in the Mountain Biome other than on river floodplains, despite the image limitations. Images for the Boreal Biome were generally acceptable and changes in forested types were easy to detect. Imagery was excellent for the Tundra Biome but we likely could not detect subtle vegetation changes since most plants are <0.3 m tall and are hard to differentiate on imagery, partly due to lack of shadows. We could not reliably detect increases in dwarf shrubs, but if taller shrubs (e.g., alder) were to invade the tundra, they would be easy to detect. A vegetation type was assigned for each time period, but in practice, types could not be photointerpreted on the 1950s images without referring to the later images, so we did not analyze changes in vegetation type over the study period. Stereoscopy could have improved interpretation but was not used.

The combination of high variability in landscape characteristics (e.g., the diverse vegetation types and substrates) and high variability in drivers of change across the Refuge landscape, combined with a small sample size (35 sites spread across three biomes), limited our ability to detect significant differences in the data. In particular, large differences in the abundance of highly dynamic alluvial terrain, polygonized ground that is subject to ice-wedge degradation, and fires that are highly variable in space and time lead to high variability in both vegetation and change types. Due to high between-site variability and low number of sites, confidence intervals overlapped for most of the comparisons we made. As high-resolution satellite imagery becomes more available, cost decreases, and methods are developed to efficiently automate the image rectification process, larger sample sizes will be feasible. Similar studies to ours could have larger sample sizes with little increase in interpretation effort by having more sites and fewer points per site. Yet, the high variability among sites related to different vegetation types being affected by different change drivers in different regions at different times will remain a large obstacle in assessing whether changes are significant.

The 15 grids in the Tundra Biome had the best-quality aerial photographs, so we are most confident of our results for that biome. The photographs from the first time period (~1952) were of better resolution and higher quality than those available for the rest of the Refuge. For the second time period (~1982), most Tundra grids had excellent aerial photographs from four years: 1981, 1984, 1985, and 1988. We used the 1985 photograph to record data for that time period. However, we eventually georeferenced and examined the other photos at most grids to aid in interpretation. This was useful for detecting ice-wedge degradation because it gave us a range of different water levels to determine what normal seasonal variability was (Figure A2). We found observed widths and extent of ice-wedge polygon troughs remained fairly constant for the 1981–1988 period despite expected rising and falling water levels over the summer season, allowing more confidence in our interpretation of ice-wedge degradation. We believe this is because actively subsiding troughs are steep sided, minimizing changes to the aerial extent of water as water rises and lowers in the troughs. We were conservative about assigning ice-wedge degradation change. For example, if a point had similar patterns of surface water in ~2004 to any one of the 1980s years, we did not interpret it as changed, even if the area of surface water was different than in 1985.

These empirical data can be applied to modelling efforts to improve prediction of future change by providing realistic input variables to models. The dataset developed by this study has been used for projecting future changes across a broader region of northern Alaska using state-transition modeling [62] and for landscape change analysis using satellite remote sensing and decision-tree modeling [37]. We found that environmental variables were very useful in explaining variations in change types across the region and can be incorporated into other studies. Sormunen et al. [63] showed that including local environmental conditions, such as topography and soils information, in models of subarctic vegetation change greatly improved the predictive accuracy and changed the model outputs by constraining possible vegetation shifts using more realistic data. They found that climate-only models overestimated the amount of vegetation change. Results including environmental data fine-tuned the predictions and could also predict potential refugia in future climates. Our findings of the large differences between change types on alluvial vs. nonalluvial substrates, such as shrub changes on alluvial and ice-wedge degradation on nonalluvial terrain, can be used to improve modelling of future landscape changes with climate change.

5. Conclusions

Manual interpretation of time series of historical aerial photographs and satellite images in the Arctic National Wildlife Refuge of Alaska showed that 18% of the Refuge had detectable landscape changes over a half-century. Wildfire was the most common change agent, resulting in extensive post-fire successional vegetation changes in forested parts of the Refuge. Other common changes were tree or shrub increase without fire, river erosion and deposition, and ice-wedge degradation. The change types varied greatly among biomes, with ice-wedge degradation occurring mainly in the Tundra Biome, shrub increase and river changes in the Mountain Biome, and fire and postfire succession in the Boreal Biome. When change types were examined as generally wetting change vs. generally drying change, the Tundra Biome tended to be affected by landscape wetting (mainly ice-wedge degradation), while the Boreal biome tended to be affected by landscape drying (including fire, reduced area of lakes, and land surface drying). The recent interval of our study period (1980s to 2000s) coincided with a documented shift towards a warmer climate; this interval had slightly more change in several categories, including ice-wedge degradation, lake changes, and tree and shrub increase. However, differences in the amount of change were not statistically significant, given the high variability of changes across the heterogeneous landscapes.

Our unbiased stratified random sampling design allowed extrapolation of the results to the whole Refuge, which is not possible with the more common approach of focusing studies in areas with known, dramatic changes. Results of this study can be incorporated into models to predict changes and outcomes for future climate-warming scenarios in the Arctic. This study can be repeated in the future to continue tracking changes occurring across this diverse landscape during a time of rapid climate warming. Much of the Arctic is remote and roadless, so monitoring landscapes using high-resolution imagery can be the most cost effective approach. It will become even more feasible in the future, as increasing availability of multispectral, high-resolution satellite imagery will provide more and shorter time intervals that will improve monitoring and detection of trends.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

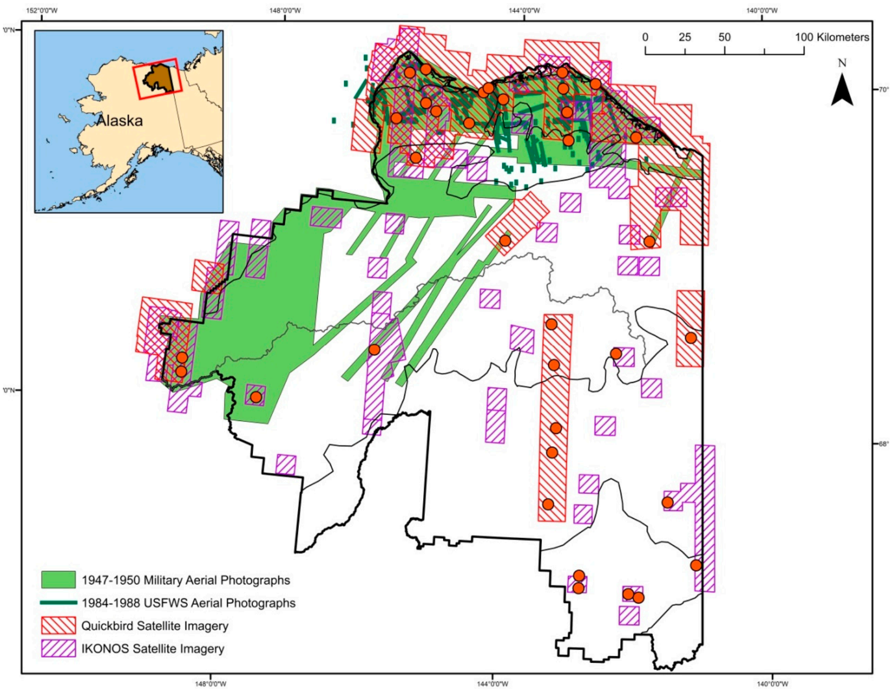

Figure A1. Map of available imagery for landscape change detection project. For 1947–1950 photos, green shows general area of coverage but not individual flight lines; gaps occurred between lines.

Table A1. Vegetation types of the Arctic Refuge based on the Alaska Vegetation Classification [35].

Vegetation Type	Description
1 FOREST	Trees >10% cover. Includes all trees even if temporarily low stature due to intermediate succession after fire or flooding. Includes open and closed canopy forest and woodlands. Understory has abundant shrubs, forbs, mosses and lichens.
1.1 Spruce Forest	>60% of tree cover is needleleaf trees, mainly *Picea glauca* and also *Picea mariana* in most southern areas
1.2 Mixed Forest	40–60% each of spruce and broadleaf trees
1.3 Broadleaf Forest	>60% of tree cover is broadleaf. Poplar (*Populus balsamifera*) mainly on floodplains, aspen (*Populus tremuloides*) and paper birch (*Betula neoalaskana*) mainly after fire.
2 TALL SHRUB	Shrubs >1.5 m tall cover >25% of area. Includes open and closed canopies. Willows, mainly *Salix alaxensis*, and alder (*Alnus viridis*).
2.1 Tall Riparian Shrub	Tall shrubs on river floodplains, banks of floodplains and narrow drainages.
2.2 Tall Non-riparian Shrub	Non-floodplain, common in early and intermediate stages of post-fire succession
3 LOW OR DWARF SHRUB	Shrubs <1.5 m tall cover >25% of area.
3.1 Low Riparian Shrub	Shrubs 20–150 cm tall on river floodplains, banks of floodplains and narrow drainages. Mainly willows, e.g., *Salix pulchra*, *S. richardsonii*.
3.2 Low Non-riparian Shrub	Shrubs 20–150 cm tall not on floodplains. Mainly the same willows above plus shrub birch (*Betula glandulosa, B. nana*) and other willows, e.g., *S. glauca*.
3.3 Dwarf Shrub	Shrubs <20 cm tall. Mainly mountain avens (*Dryas* species, mainly *D. integrifolia*), dwarf willows (e.g., *Salix reticulata*), blueberry (*Vaccinium uliginosum*), cranberry (*V. vitis-ideae*), Labrador tea (*Ledum groenlandicum*, *L. decumbens*). On mountain slopes, late snow-melt areas, high-centered polygons and infrequently flooded river terraces. Many additional species in alpine areas.
4 GRAMINOID	Graminoids predominate. The first 3 below also have high cover of mosses and dwarf and low shrubs.
4.1 Tussock Tundra	Dominated by the tussock-forming sedge *Eriophorum vaginatum*. Includes shrubby tussock tundra, which may have >25% low shrub cover.
4.2 Moist Sedge-Dryas Tundra	Dominated by sedges, usually *Carex bigelowii*, and the dwarf shrub *Dryas integrifolia*
4.3 Moist Sedge-Willow Tundra	Dominated by sedges, usually *Carex aquatilis* and *Eriophorum angustifolium*, and willows, usually *Salix pulchra*.
4.4 Wet Graminoid Tundra	Sedges, usually *Carex aquatilis* and *Eriophorum angustifolium*. Soil saturated throughout the growing season, so little willow or moss cover, except aquatic mosses. Some grass-dominated near the coast, e.g., *Dupontia fisherii*.
4.5 Aquatic graminoid	Sedges and grasses in persistent standing water, mainly in shallow lakes
4.6 Salt marsh	Coastal marshes with salt-tolerant species, mainly *Carex subspathacea*, *Puccinellia* spp. and *Dupontia fisherii*
5 OTHER	Little cover of live plants, mainly on steep mountain slopes and active floodplains
5.1 Sparsely Vegetated	10–30% cover of vegetation
5.2 Non-vegetated	0–10% vegetation
5.3 Water	<10% vegetation

Table A2. Twenty-nine types of landscape change detected on time series of aerial images in the Arctic Refuge with descriptions, 19 broad change types, and the number of points in each type.

Interpreted Change Type	Broad Change Type	Definition of Interpreted Type	# Points
1 Fire:		Any change due to wildfire, even if the fire occurred before the study period	
1.1 Fire & post-fire succession	Fire & post-fire succession	Burned by wildfire, causing vegetation changes	273
1.2 Fire, post-fire & thermokarst	Fire & post-fire succession	Burned, causing vegetation changes and ice wedge melting	5
2 Ice-wedge degradation (Thermokarst):		Included only points with a change from one time period to the next, not all points with polygonal microtopography. Recorded for saltmarsh vs. other.	
2.1 Thermokarst-wetter	Thermokarst-wetter	Thermokarst with wetting effects within the circle. Increase in depth, width, or extent of ice-wedge polygon troughs, often with increase in water in troughs.	130
2.2 Thermokarst-drier	Thermokarst-drier	Thermokarst with drying effects within the circle. Drying of troughs above ice wedges due to increased drainage of the general area as troughs enlarged, became more connected and allowed drainage. Or, graminoid cover increasing in troughs, accumulating dead leaves and causing less area and depth of surface water. Or, drying of polygon centers.	22
3 River changes:			
3.1 River bank erosion	River erosion	Erosion into bank or uplands	11
3.2 River erosion	River erosion	More river water in circle than in previous time period. River channel moving around on active floodplain, not into uplands.	62
3.3 River deposition	River deposition	Less river water in circle than in previous time period. River channel moving around on active floodplain.	61
4 Lake changes:		Recorded only if change in surface water detected within the 20-meter circle, not at points in centers of lakes	
4.1 Lake drying	Lake decrease	Lake became smaller and shallower. Water in circle disappeared.	20
4.2 Lake drained	Lake decrease	Lake evidently drained all at once	5
4.3 Lake accretion	Lake decrease	Sediment accreted along edge of lake, so less open water in circle	1
4.4 Lake erosion	Lake increase	Lake eroded bank inside the circle, so more open water in circle	9
4.5 Lake increase	Lake increase	Lake became larger. In circle, water covered previous land.	5
5 Vegetation changes:		Recorded separately for post-fire changes vs. non-fire-related	
5.1 Shrub decrease	Shrub decrease	Decreased cover of shrubs	26
5.2 Shrub increase	Shrub increase	Increased cover of shrubs	83
5.3 Tree decrease	Tree decrease	Decreased cover of trees	2
5.4 Tree increase	Tree increase	Increased cover of trees	47

Table A2. *Cont.*

Interpreted Change Type	Broad Change Type	Definition of Interpreted Type	# Points
6 Coastal changes:			
6.1 Barrier erosion	Coastal erosion	Decreased area of off-shore barrier island in circle	4
6.2 Coastal erosion	Coastal erosion	Erosion not including delta mud flat changes	43
6.3 Salt marsh flooded	Coastal erosion	Within a salt marsh, increase in area of water and decrease in land in the circle	2
6.4 Delta erosion	Coastal erosion	Decreased area of delta mud flats in circle (and increased area of sea)	20
6.5 Barrier deposition	Coastal deposition	Increased area of barrier island in circle	5
6.6 Coastal deposition	Coastal deposition	Deposition not including delta mud flats	2
6.7 Delta deposition	Coastal deposition	Increased area of delta mud flats in circle	10
6.8 Deposition in creek	Coastal deposition	Storm surge pushed beach gravels & logs into mouth of creek, forming pond	1
6.9 Drift line move	Coastal - other	Driftwood line moved further inland over time, reaching to or beyond the point, indicating salt water intrusion	4
6.10 Salt killed tundra	Coastal - other	Dead tundra vegetation, killed by salt water intrusion	1
6.11 Sand deposition	Coastal - other	Sand deposition onto tundra from beach during storm surge	1
6.12 Sand dune change	Coastal - other	Movement of sand dunes caused change in vegetation and sand cover	5
7 Surface water change:			
7.1 Surface water increase	Surface water increase	Surface water, recorded at center of circle, absent in first year and present in last year	45
7.2 Surface water decrease	Surface water decrease	Surface water, recorded at center of circle, present in first year and absent in last year	22
8 Other:			
8.1 Land surface drying	Land surface drying	Drying of land surface, usually on abandoned floodplains near drying lake basins	16
8.2 Scree fan increase	Scree fan increase	Scree at base of steep slope spread out over previously vegetated area	2
8.3 Glacial retreat	Glacial retreat	Points on glacier in first 2 time periods and on bedrock outcrops protruding through the thinning glacier in last time period	3
9. General drying or wetting:		Composite categories derived from some of the change types recorded	
9.1 General drying changes	General drying changes	Sum of points with drying changes: Less water at surface due to river deposition, lake or surface water decrease, thermokarst with drying, land surface drying or wildfire during the study period	182
9.2 General wetting changes	General wetting changes	Sum of points with wetting changes: More water at surface due to river erosion, lake or surface water increase, or thermokarst with wetting	236

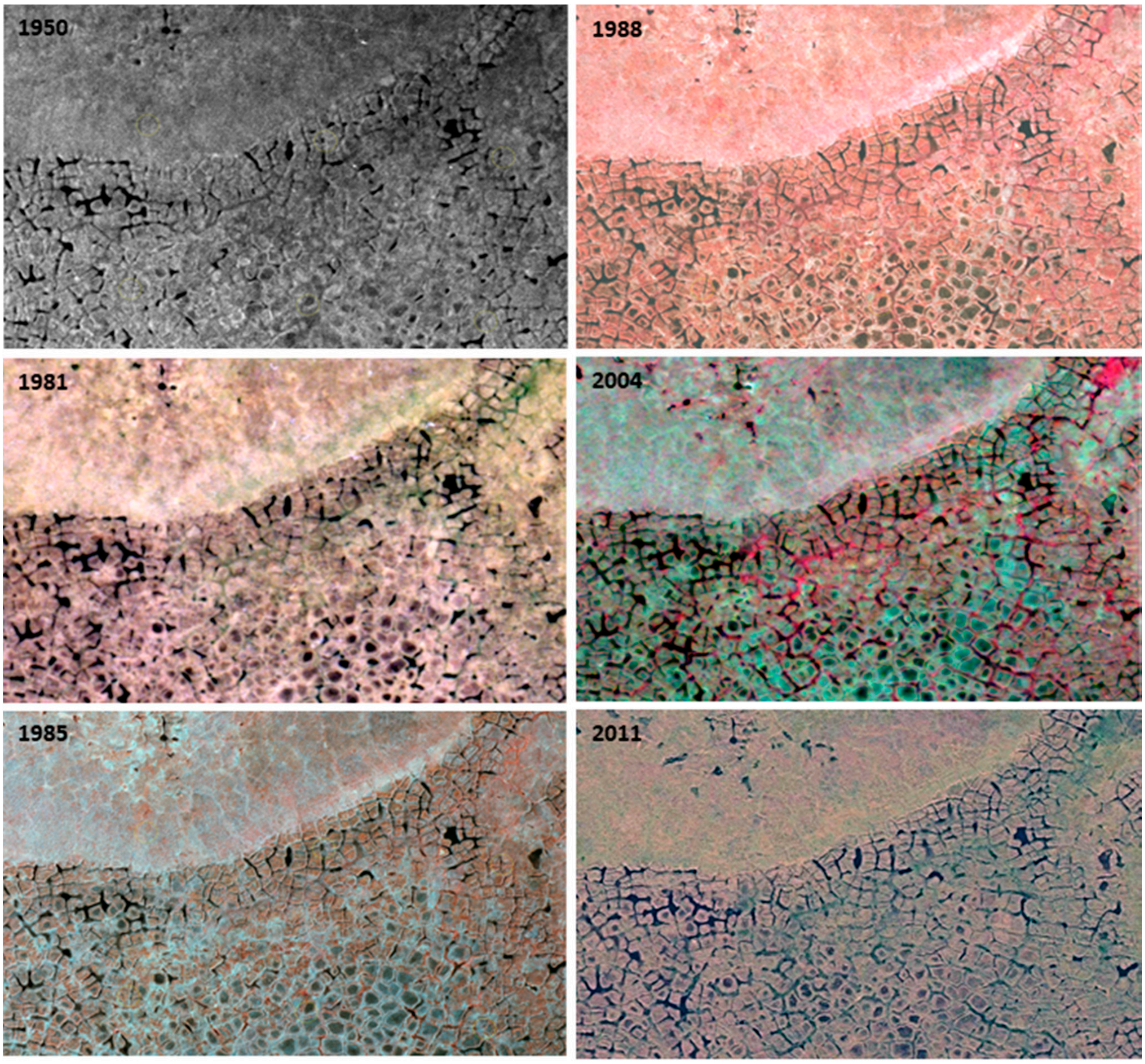

Figure A2. Time series of six images over a 61-year period on coastal plain tundra with flat-centered polygon morphology. Some change occurred, but there was overall surprising stability. 2004 and 2011 are satellite images ©2018 DigitalGlobe, a Maxar company.

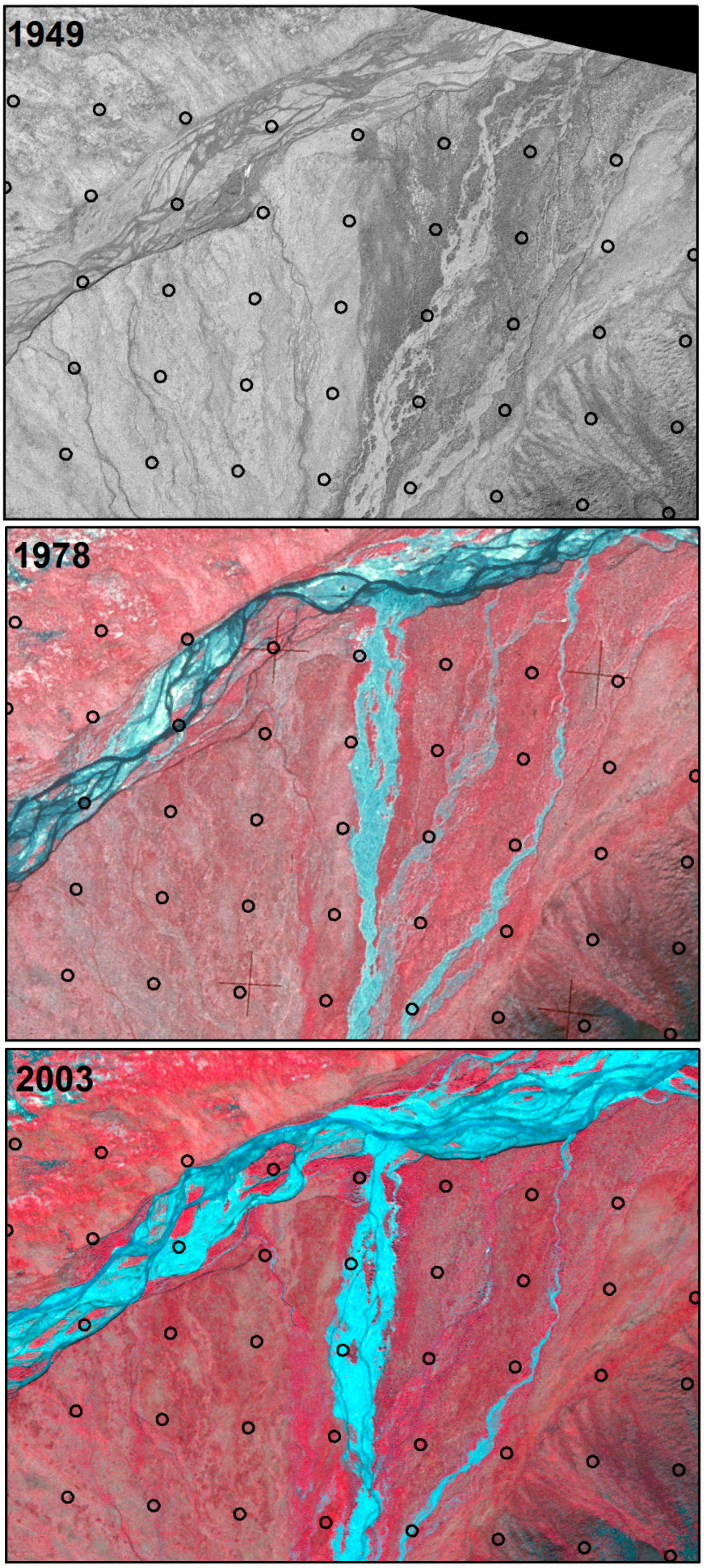

Figure A3. Time series of an alluvial fan in the northern Brooks Range, showing rerouting of creek on the fan and shrub changes along the creek as well as some shrub increase on the inactive parts of the fan. 2003 satellite image ©2018 DigitalGlobe, a Maxar company.

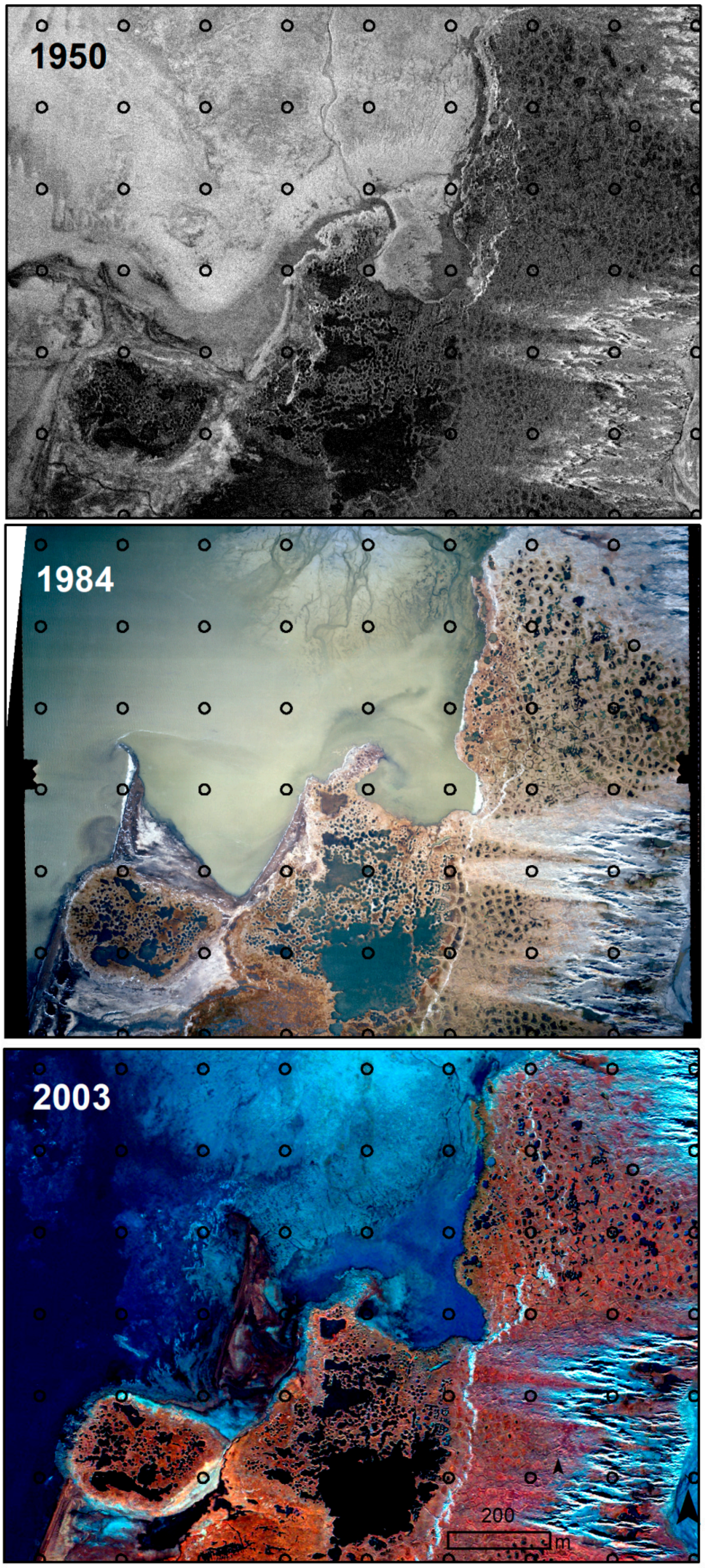

Figure A4. Time series of images at a coastal site showing salt marshes, long-shore sediment transport, moving drift wood lines from storm surges (right of center), and dunes (at right). 2003 satellite image ©2018 DigitalGlobe, a Maxar company.

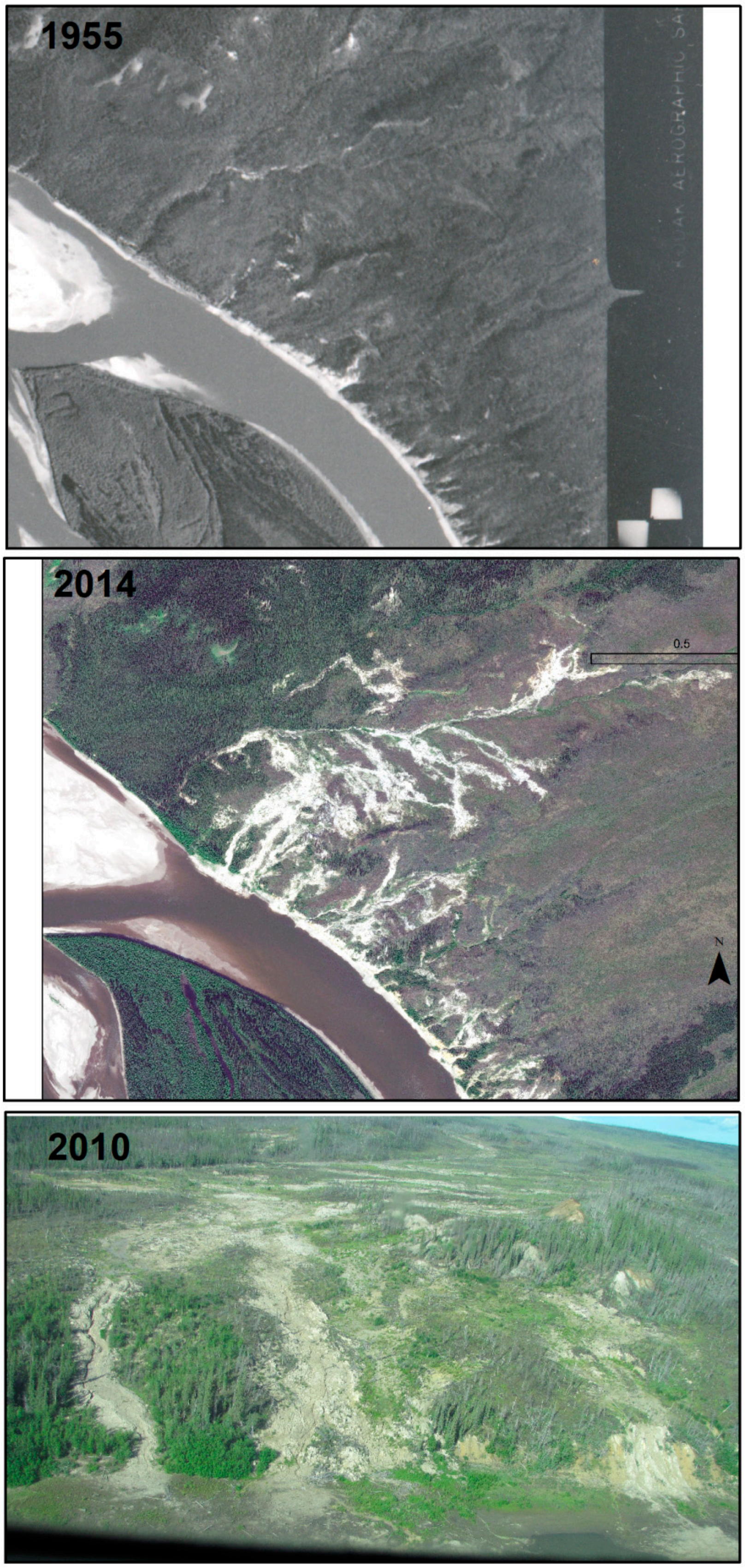

Figure A5. Active-layer detachment slides in spruce forest along the Porcupine River that burned in 2005. 2014 satellite image ©2018 DigitalGlobe, a Maxar company.

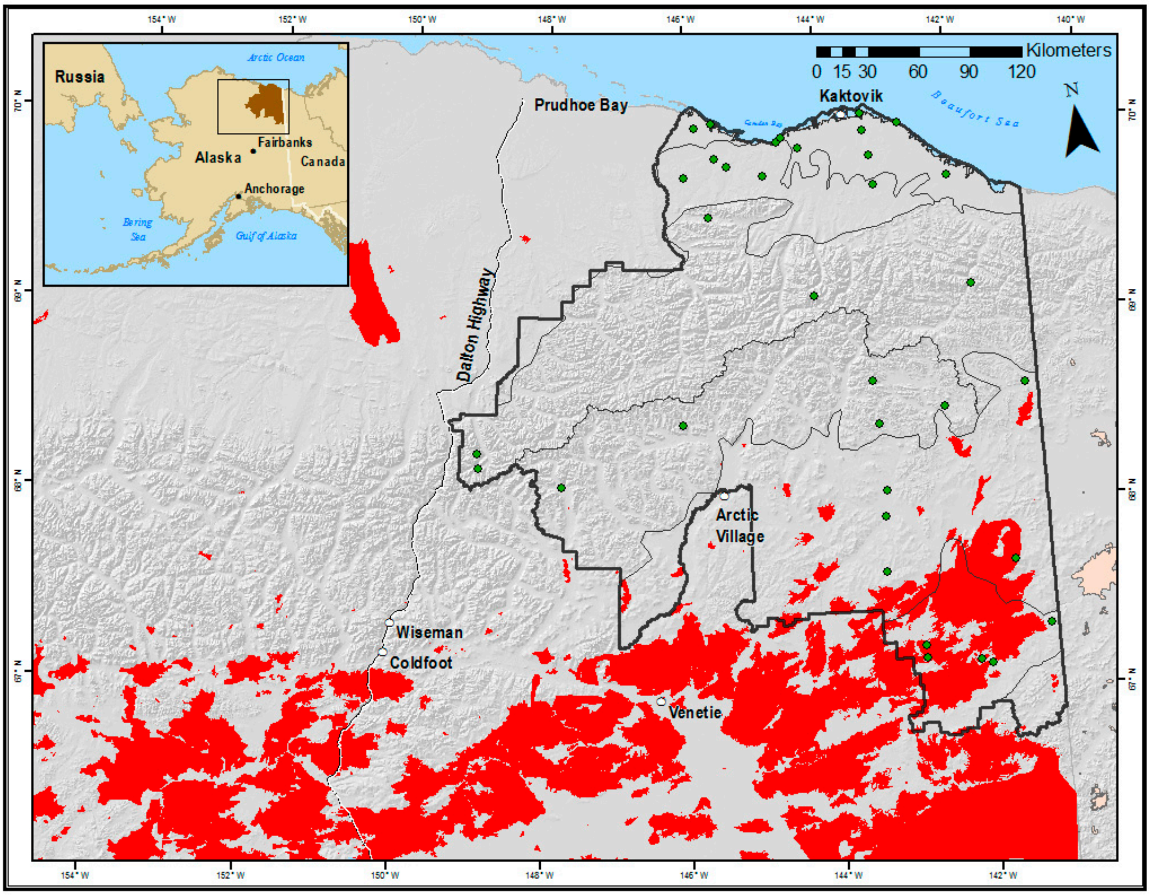

Figure A6. Map of recorded wildfires during 1950–2010 (in red) in the Arctic National Wildlife Refuge (black outline) and environs (Alaska Fire Service database). Green dots are study sites.

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Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: [EXTERNAL] DNR/DMLW North Slope Management

1 message

Heath, Nolan <nheath@blm.gov> Wed, Oct 3, 2018 at 3:38 PM
To: BLM_AK Coastal_Plain_Seismic_EA <blm_ak_coastal_plain_seismic_ea@blm.gov>

---------- Forwarded message ---------
From: **Jones, Nichelle (Shelly)** <njones@blm.gov>
Date: Thu, Sep 6, 2018 at 9:01 AM
Subject: Fwd: [EXTERNAL] DNR/DMLW North Slope Management
To: Eric Geisler <egeisler@blm.gov>, Murphy, Ted <t75murph@blm.gov>, Nolan Heath <nheath@blm.gov>, LaMarr, Sarah <slamarr@blm.gov>, Donna Wixon <dwixon@blm.gov>, Robert Brumbaugh <rbrumbau@blm.gov>, Serena Sweet <ssweet@blm.gov>

Shelly Jones
Acting Manager
Arctic District Office
222 University Avenue
Fairbanks, AK 99709

(907) 474-2310 (w)
(907) 460-0086 (c)

---------- Forwarded message ----------
From: **Head, Melissa M (DNR)** <melissa.head@alaska.gov>
Date: Thu, May 31, 2018 at 10:43 AM
Subject: [EXTERNAL] DNR/DMLW North Slope Management
To: "Leonard, Paul" <paul_leonard@fws.gov>, "Jones, Nichelle (Shelly)" <njones@blm.gov>

Paul and Shelly,

I came across this document that I put together a while back for our Commissioner regarding DNR management of off-road travel (winter and summer) and ice road construction. I thought it may be useful to you.

Kind Regards,

Melissa

Melissa Head

Manager, Northern Oil & Gas Team

DNR/DMLW

907-451-2719

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27K

Coastal_Plain_Seismic_EA, BLM_AK <blm_ak_coastal_plain_seismic_ea@blm.gov>

Fwd: [EXTERNAL] North Slope Snow 2018

1 message

Heath, Nolan <nheath@blm.gov> Wed, Oct 3, 2018 at 3:39 PM
To: BLM_AK Coastal_Plain_Seismic_EA <blm_ak_coastal_plain_seismic_ea@blm.gov>

---------- Forwarded message ---------
From: **Loya, Wendy** <wendy_loya@fws.gov>
Date: Thu, Sep 6, 2018 at 8:25 AM
Subject: Fwd: [EXTERNAL] North Slope Snow 2018
To: Nolan Heath <nheath@blm.gov>

Per our conversation today, here is the white paper synthesizing snow science for the north slope and Arctic Refuge.

Wendy
Dr. Wendy M. Loya, Coordinator
Office of Science Applications -Arctic Program
US Fish and Wildlife Service
Anchorage, Alaska
907.786.3532 (office)
907.227.2942 (mobile)

---------- Forwarded message ---------
From: **Matthew Sturm** <msturm1@alaska.edu>
Date: Mon, Aug 20, 2018 at 7:48 PM
Subject: [EXTERNAL] North Slope Snow 2018
To: Fisher, Daniel - NRCS, Anchorage, AK <daniel.fisher@ak.usda.gov>, Sousanes, Pamela <pam_sousanes@nps.gov>, Head, Melissa M (DNR) <melissa.head@alaska.gov>, Greta Burkart <greta_burkart@fws.gov>, Steve Berendzen <steve_berendzen@fws.gov>, Wendy Loya <wendy_loya@fws.gov>, Paul Leonard <paul_leonard@fws.gov>, Craig George <Craig.George@north-slope.org>, Kyle Joly <kyle_joly@nps.gov>, Matt Macander <mmacander@abrinc.com>, Sveta Stuefer <sveta.stuefer@alaska.edu>, Scott.Goetz@nau.edu <Scott.Goetz@nau.edu>, Larsen_Chris <chris.larsen@gi.alaska.edu>, Skip Walker <dawalker@alaska.edu>, Tako Raynolds <martharaynolds@gmail.com>, Christopher A. Hiemstra <Christopher.A.Hiemstra@usace.army.mil>, Entin <jared.k.entin@nasa.gov>, anne.nolin@gmail.com <anne.nolin@gmail.com>, Griffith, Peter C. (GSFC-618.0)[SIGMA SPACE CORPORATION] <peter.c.griffith@nasa.gov>

Dear Friends and Colleagues:

Several snow-focused groups were active this winter on the N. Slope and northern Brooks Range. It seemed worthwhile to pull the snow data together across the group and put it in one place, and it may prove of interest to you. It seems particularly relevant with impending opening of the Arctic Refuge.

Feel free to share this.

Matthew

--
Dr. Matthew Sturm
Geophysical Institute
University of Alaska-Fairbanks
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msturm1@alaska.edu

SnowReportMarch2018_Aug20sm.pdf
2344K

A Report on the Snow Conditions of the North Slope and Brooks Range of Alaska during the Winter of 2018

Geophysical Institute-UAF Occasional Report-82018

August 20, 2018

Funding for this report was supplied by NASA, the National Science Foundation and the Geophysical Institute, with logistical support from the U.S. Fish and Wildlife Service.

A Report on the Snow Conditions of the North Slope and Brooks Range of Alaska during the Winter of 2018

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Mr. Frank Urban, USGS Denver (furban@usgs.gov)
Dr. Jeff Welker, Dept. of Biological Sciences, University of Alaska Anchorage (jmwelker@alaska.edu)
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Communications regarding this report should be directed to Dr. Matthew Sturm

Introduction

The Brooks Range and North Slope stretch from the Canadian border to the west coast of Arctic Alaska, encompassing an area of over 250,000 km^2. This region is blanketed with snow from late-September through June, more than 9 months each year. This snow cover is the source of much of the run-off from the area, plays a key role in the thermal state of the underlying permafrost, and determines icing conditions on rivers and lakes. It is also a critical element in the habitat of the animals and birds of the region, affecting how they forage, den, travel and migrate. A fundamental character of this snow cover is that it is heterogeneous; deep drifts often exist adjacent to areas where the tundra is virtually bare of snow all winter.

Despite the widespread and obvious importance of snow, relatively few snow measurements are available from the region. The limited data reflects that the region is sparsely inhabited and mostly roadless. Much of the data that is available come from autonomous weather stations, chiefly RAWS (Remote Automatic Weather Stations: https://raws.dri.edu/akF.html) installations operated by the Desert Research Institute for the National Park Service (NPS), SNOTEL sites operated by the National Resource Conservation Service (NRCS: NRCS website), and a series of stations installed by the USGS primarily for studies related to permafrost and climate change (GTN-P; https://pubs.usgs.gov/ds/812/introduction.html). Just two manned NOAA Weather Service (NWS) stations are found in the region (Barrow (*Utqiagvik*) and Kotzebue), so with these two few exceptions, normal snow data are collected by electronic instruments. Over much of the region and most of the time, the actual snow conditions are not observed by humans. One consequence of this is that there is no easy way to ascertain whether the instrument measurements are reporting good data. Moreover, virtually all of the values of snow depth and snow water equivalent (SWE) collected autonomously from these networks are “spot” values, typically reflecting conditions from an area less than 1 m^2 in size adjacent to the tower. There is no easy way to know if just a few meters away, the conditions are quite different.

More specifically, the RAWS and GTN-P sites report snow depth using sonic sounders that sample about 0.25-m^2, not a very big sample. The NRCS report depth in the same way, but also record snow water equivalent (SWE) using totaling precipitation gauges. Crtical snow properties like hardness, layering, density, and suitability for over-snow travel, all of which contribute to the overall impact of the snow in the region on animals, plants, and human activity, are not measured anywhere in the region by humans, nor have they been measured in the past.

Consequently, for this vast region, we have almost no baseline or historical record against which we can examine current conditions and detect trends due to a changing climate.

With that knowledge gap in mind, an unusual situation occurred in late-winter and spring of 2018: four grant-funded research groups made extensive snow measurements across the region in March, April and early-May, a period during which there was little additional snowfall. When these data were combined, it presented an opportunity to examine the snow cover over a wide area independent of the existing instrument network. Here we present these data (which include over 39,000 individual depth measurements), explore what they tell us about the regional snow cover, and compare the data to the values recorded by the autonomous instruments. As it turns out, the winter of 2017-2018 produced one of the deepest and long-lasting snow covers in the past 30 years, making the result particularly interesting.

Field Area

Figure 1 shows the region over which the snow measurements were made. Much of the field work originated from Toolik Lake Field Station, hence the high density of measurements near there. The measurements were made between March 4th and May 2nd, 2018, during which time there was little new snowfall and not much wind. We think it is therefore reasonable to view the data set as simultaneous; i.e., essentially as if it were taken at single time. We refer to this as the late-winter snow pack of 2018. Unfortunately, no measurements were made in the far western end of the study area, so snow conditions there remain an unknown.

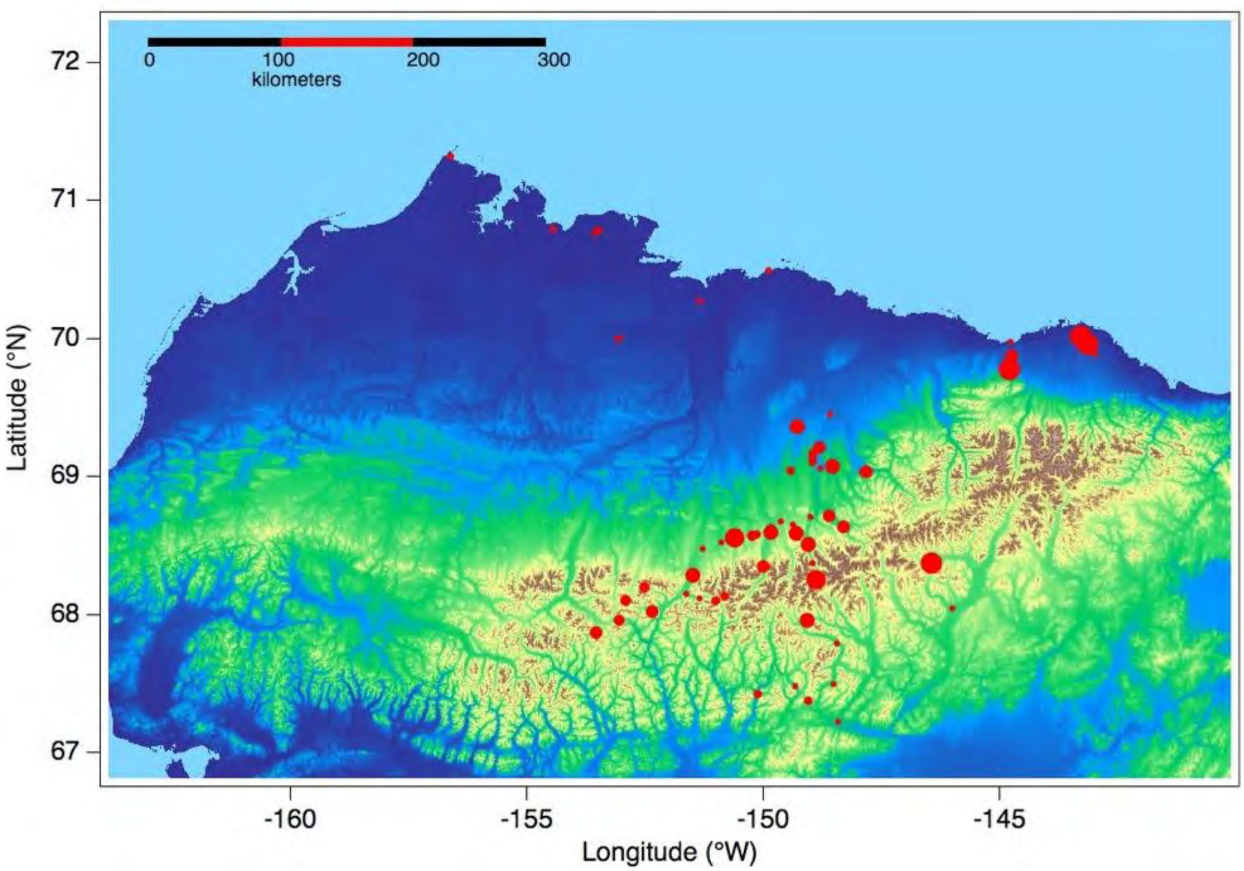

Figure 1: The study area. Measurement locations are shown by the red circles, with the relative number of measurements (mostly depth) suggested by the circle size (ranging from 10 to several thousand values). The results come from four research groups (see author list).

The data shown in Figure 1 have been derived from four separate research groups (see author list) and in many cases consisted of depth measurements only. However, a more comprehensive set of measurements were made during an 800-km snowmobile traverse from Toolik Lake to the west and return (stations shown in Fig. 2). At stations along this traverse measurements included depth probing along transect lines, density measurements, stratigraphic and texture measurements, coring for snow water equivalent, and wind drift mapping. These more comprehensive data are used below to explore the snow density, hardness and other attributes.

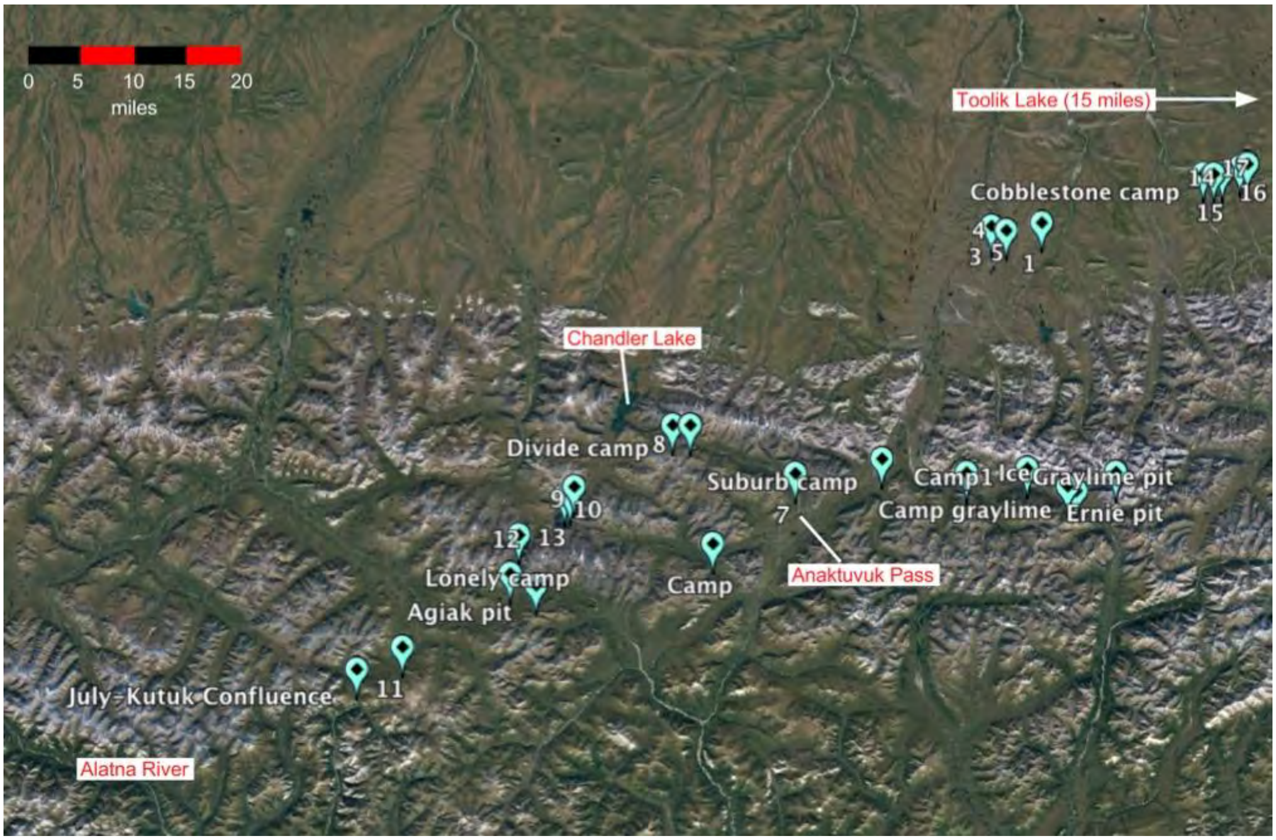

Figure 2: Location of more detailed snow measurements.

Methods: "Neutral" areas were sought when selecting measurement stations, *i.e.*, areas where neither wind scour nor deposition had occurred. These areas are typically flat, have vegetation characteristic of the surrounding locality, and show little sign of wind action. Faced with the huge and extremely diverse snow landscape that makes up the study area (Figs. 1, 2 and 3), we believe picking such stations is the only practical way to capture the large-scale trends in the snow cover. The measurement locations shown in Figure 2 were generally about a day's snowmobile travel apart (20 to 50 km) and were quasi-random in their location in that we had not selected the locations in advance. They were selected in the field by noting that we had traversed far enough, then looking around for flat, non-wind affected areas. The spacing of the measurements in Figure 1 is greater and more random, reflecting the various research objectives of the four groups.

Figure 3: The view to the NE at the headwaters of the N. Fork, Koyukuk River showing deep snow among the willows, scoured snow in the middle ground on ridges, and drifted snow in gullies. Choosing a neutral area here was challenging, but ultimately possible (e.g."Ernie Pit" on Figure 2).

Depth measurements were generally made using a GPS-enabled automatic snow depth probe (Magnaprobe, U.S. Patent 5,864,059), with depth and location measured along one or several legs radiating from a central location. The legs varied from about 100 to over 500-m in length. Allowing for the potential to over-probe (the probe penetrating soft ground beneath the snow), we estimate depth values were accurate to better than +5 cm. Typically at least 100 depths were collected along a line at 1.5 to 3.0 m spacing.

SWE measurements were made using a Federal Sampler. This is the standard coring tool used by the NRCS throughout its western U.S. network. The aluminum cylindrical sampler has a cross-sectional area of 11.46 cm^2 and a serrated steel cutter edge. The accuracy of SWE measurements taken this way has been investigated and varies widely with snow quality and operator skill. With care, bulk snow density and SWE values accurate to ±15% can be achieved, though we have found the device has a low bias. Typically, we collected 10 cores at each location (see also *Snow Pits*), two near the snow pit, and an additional 8 cores on a line running north from the pit, the cores done in pairs with each pair about 20 m north of the previous core. Core samples were bagged and weighed immediately after collection using a digital balance accurate to 0.01 g.

Snow pit measurements were done using the following protocol: at each location (Fig. 4) a snow trench was dug that was about 2.5 meters wide. From the wall of the trench we recorded the snow layering, the layer density (in duplicate or triplicate), the hardness, grain characteristics, and the thickness of each layer. Two Federal cores bracketing the pit were collected so that they that could be compared directly to the integrated bulk density computed from layer densities. Two orthogonal snow depth probe lines radiated from the pit outward. Photographs of the pit and the surrounding landscape (4 cardinal directions) were general taken for reference.

Snow Isotopes measurements were made on snow samples collected from the snow pits. We measured $\delta^{18}O$, $\delta^{2}H$ and *d-excess* values as surrogates for moisture sources in order to deduce the storm tracks that deposited the snow. Samples were taken from the top and the bottom of the pits, and we primarily compared results from samples taken north of the Brooks Range with those taken from the south. A long-term record of isotope geochemistry in Alaska and across the US provides the basis for some of our interpretation and the use of this approach.

Winter Wind Directions were inferred from surrounding drift features. We created sketch maps in the field of general wind/snow transport directions. These were inferred from a) cornices, b) scour zones, c) crag and tail feathers, and d) wind waves, dunes and barchans. In making these maps, we focused on the larger features that had been created over much of the winter, rather than in the most recent wind/snow events.

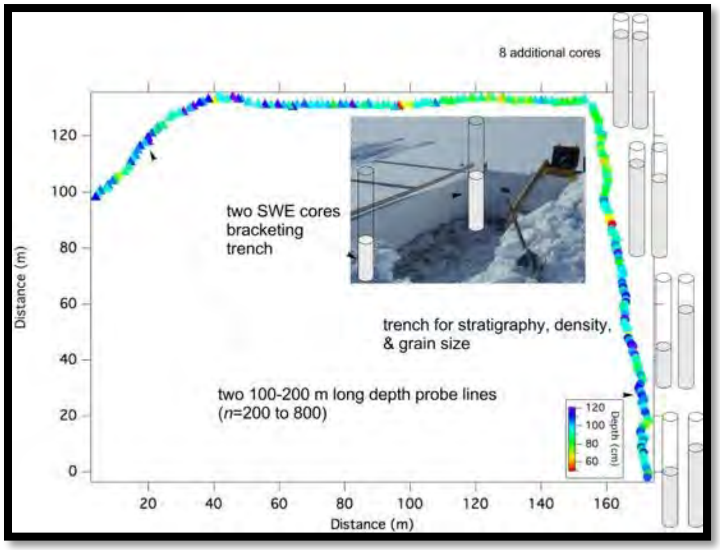

Figure 4: A general layout of snow pit, core locations, and depth probe lines.

Aerial Snow Mapping: We used structure from motion (SfM) mapping techniques to produce snow depth maps over three areas, each about 4 by 16 km in extent. These maps have a ground resolution of 1-m, and can resolve snow depth to ±0.1m. The technique we used is highly accurate, and is described in detail in a publication by M. Nolan, C. Larsen and M. Sturm (Nolan, M., Larsen, C. F., & Sturm, M. (2015). *Mapping snow-depth from manned-aircraft on landscape scales at centimeter resolution using Structure-from-Motion photogrammetry*. ***Cryosphere Discussions***, ***9***(1)). The areas mapped consisted of (1) a N-S swath near Happy Valley, Alaska, (2) a swath from Toolik Lake Field Station east, and (3) a swath from the Sadlerochit Mountains north to the Arctic Coast at Camden Bay.

Results

The mean snow depth based on the average value at each station (Table I; note that *n* is highly variable by station) was 53.5 cm (*n*=39,972), and the mean value weighted by the number of observations (*n*) was just slightly lower (53.4 cm). The mean standard deviation was 15.4 cm. Depths near the coast were consistently lower than those taken in the Brooks Range (Fig. 5) (both north and south of the crest), as would be expected from prior work, but the full spread in values was not large when considering the range that can be found in seasonal snow covers worldwide. A few of the stations measured and reported in Table I were scoured or drifted. It was these stations that produced the extreme values in the data set (10 and 126 cm) and show up as purple or red markers in Figure 5; they are probably best ignored. A histogram of all depths (Fig. 6) can be fit reasonably well with a log-normal distribution, which has been noted for snow covers in other regions. In part, this fit reflects the fact that zero snow depth is usually rare, but deep drifts are not.

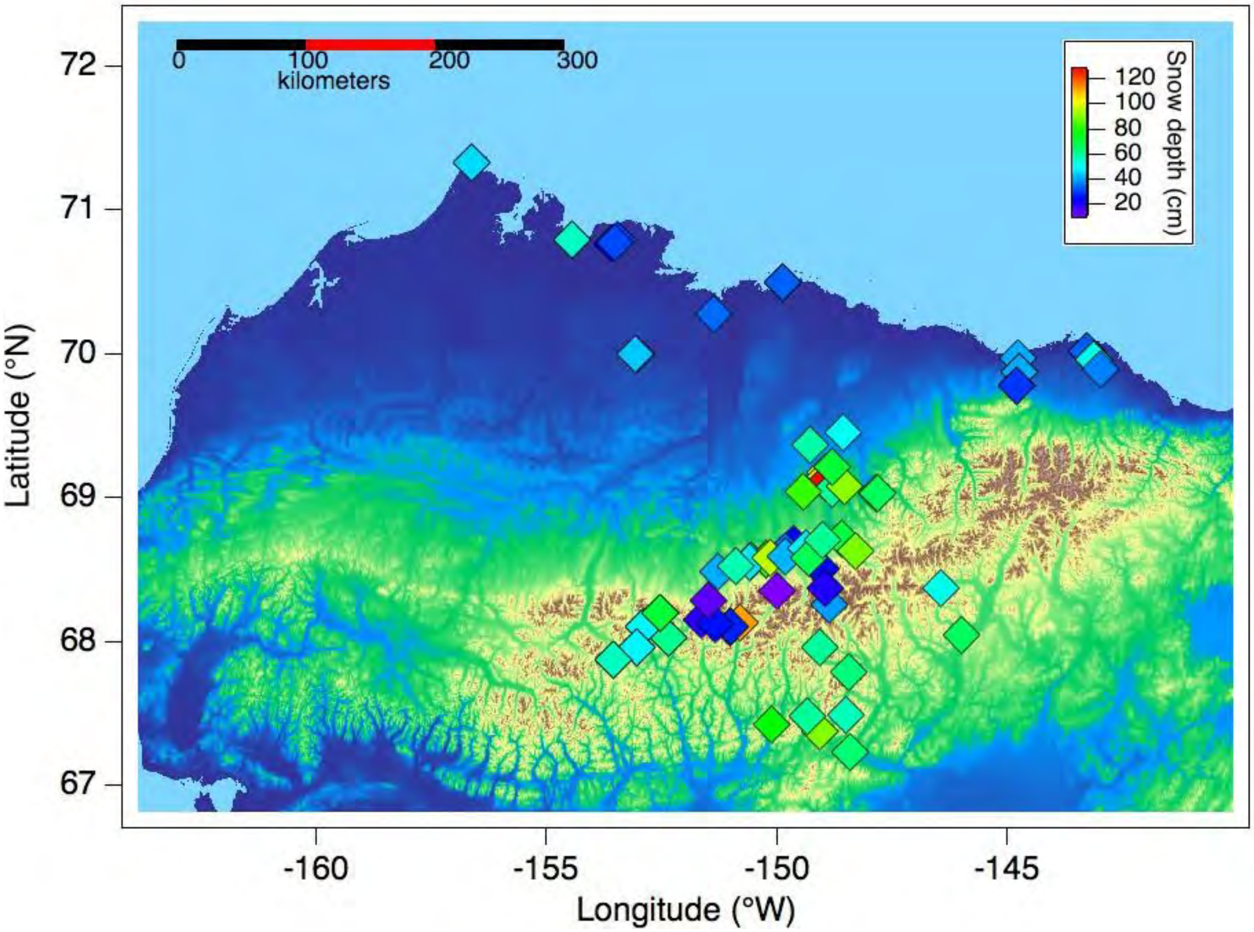

Figure 5: Mean snow depth values at all stations listed in Table I.

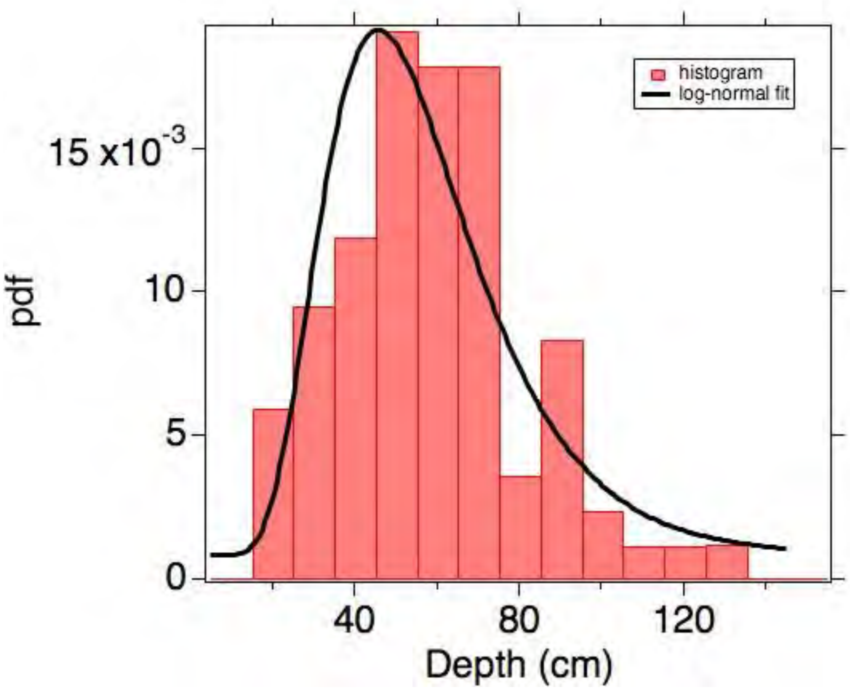

Figure 6: Probability distribution for all snow depth data shown in Table I. The mean value is 53.5 cm (n=39,972).

Table I: Average Snow Depths and Standard Deviations from All Stations

Site	Date	Observer	Location	Latitude	Longitude	num_obs	Ave_depth	Std_dev_depth	Landscape
1	4/14/18	Urban	Camden Bay	69.9718	-144.7707	875	40.2	14.4	
2	4/14/18	Urban	Camden & Mars	69.8693	-144.7323	406	60.2	24.2	
3	4/14/18	Urban	mden & Marsh, I	69.8693	-144.7323	281	56.1	19.8	
4	4/14/18	Urban	Camden & Mars	69.8693	-144.7323	353	40.17	10.4	
5	4/14/18	Urban	larsh Creek, Gec	69.7775	-144.7933	207	25.37	7.82	
6	4/14/18	Urban	h Creek, USGS (	69.7775	-144.7933	874	29.15	7.72	
7	4/15/18	Urban	Kaktovik, Geo2	70.0158	-143.2795	854	42.01	15.96	
8	4/15/18	Urban	Kaktovik, Geo1	70.0158	-143.2795	890	32.87	13.48	
9	4/15/18	Urban	Kaktovik & Nigua	69.9622	-143.1314	830	46.55	14.3	
10	4/15/18	Urban	Kaktovik & Nigua	69.9622	-143.1314	364	51.68	16.41	
11	4/15/18	Urban	Niguanak	69.8893	-142.9842	837	36.17	16.4	
averages:						**6771**	**41.86**	**14.63**	
12	4/30/18	Sturm	alley north end (I	69.1706	-148.9497	193	101.85	38.44	
13	4/30/18	Sturm	Valley cross wate	69.1226	-148.9449	1057	54.3	29.21	
14	5/1/18	Sturm	py Valley filled c	69.1426	-148.9520	271	95.137	32.27	
15	5/1/18	Sturm	valley crescent la	69.1052	-148.9466	160	126.44	45.77	
						1681	**94.43**	**36.42**	
16	4/28/18	Sturm	Imnavait Grid	68.6130	-149.3128	**3979**	**76.2**	**23.7**	
17	4/15/18	Arp	Ikp-001	70.7900	-154.4510	55		1	lake
18	4/15/18	Arp	Ikp-met	70.7940	-154.4350	51	55	8	tundra
19	4/14/18	Arp	Ini-001	69.9960	-153.0710	48		3	lake
20	4/14/18	Arp	Ini-002	70.0000	-153.0370	47		2	lake
21	4/14/18	Arp	Ini-met	69.9990	-153.0580	45	43	5	tundra
22	4/13/18	Arp	L9819	70.2700	-151.3550	52		3	lake
23	4/10/18	Arp	Tes-001	70.7660	-153.5630	50		8	lake
24	4/10/18	Arp	Tes-002	70.7890	-153.4700	51		5	lake
25	4/10/18	Arp	Tes-met	70.7700	-153.5230	46	31	10	tundra
26	3/27/18	Arp	Too-001	68.6750	-149.6270	47		6	lake
27	3/27/18	Arp	Too-002	68.6320	-149.8320	45		1	lake
						142	**43**	**7**	
28	5/3/18	Sturm	Oliktok by Gauge	70.4955	-149.8831	565	51.54	13.59	(not including DFIR drift)
29	5/3/18	Sturm	iktok south of roa	70.4947	-149.8814	605	33.32	10.99	
						1160	**42.43**	**12.29**	
30	5/2/18	Sturm	agvik (Barrow) A	71.3220	-156.6153	**1239**	**45.18**	**11.6**	ot including DFIR drift depths (>60 cm
31	3/8/18	Sturm	uk Divide, Line 1	68.5600	-150.5500	167	49.361	8.799	
32	3/6/18	Sturm	uk Divide, Line 2	68.5600	-150.5500	153	55.56	10.288	
						320	**52.4605**	**9.5435**	
33	3/9/18	Sturm	Ernie Pass, Line1	68.1000	-150.9967	101	84.37	18.08	
34	3/9/18	Sturm	Ernie Pass, Line2	68.1000	-150.9967	140	67.81	30.82	
						241	**76.09**	**24.45**	
35	3/10/18	Sturm	lime Headwall, L	68.1300	-150.8133	nd	nd	nd	
36	3/10/18	Sturm	lime Headwall, L	68.1300	-150.8133	98	110.69	39.89	
						98	**110.69**	**39.89**	
37	3/12/18	Sturm	Ekokpuk, Line 1	68.0217	-152.3517	276	68.022	17.64	
38	3/12/18	Sturm	Ekokpuk, Line 2	68.0217	-152.3517	399	60.34	9.78	
						675	**64.181**	**13.71**	
39	3/13/18	Sturm	niloyak Lake, Lin	68.1017	-152.9000	222	46.76	11.38	
40	3/13/18	Sturm	niloyak Lake, Lin	68.1017	-152.9000	218	47.676	5.0265	
						441	**47.218**	**8.20325**	
41	3/14/18	Sturm	Agiak, Line 1	67.9600	-153.0367	232	64.97	19.89	
42	3/14/18	Sturm	Agiak, Line 2	67.9600	-153.0367	252	47.745	9.23	
						484	**56.3575**	**14.56**	
43	3/15/18	Sturm	Creek Divide, Li	67.8683	-153.5400	282	55.293	5.76	
44	3/15/18	Sturm	Creek Divide, Li	67.8683	-153.5400	370	55.32	6.52	
						652	**55.3065**	**6.14**	
45	3/16/18	Sturm	ularak Divide, Li	68.1950	-152.5217	188	63.159	16.07	
46	3/16/18	Sturm	ularak Divide, Li	68.1950	-152.5217	271	69.85	7.735	
						459	**66.5045**	**11.9025**	
47	3/18/18	Sturm	Creek Divide, Li	68.5683	-150.2350	102	71.035	11.15	
48	3/18/18	Sturm	Creek Divide, Li	68.5683	-150.2350	216	82.522	17.36	
						318	**76.7785**	**14.255**	
49	3/6/18	Pedersen	aktuvuk Pass, Nc	68.5526	-150.6051	753	46.42	28.66	Low-shub tundra
50	3/6/18	Pedersen	Nanushuk River	68.4801	-151.2765	598	40.17	30.44	Tussock tundra
51	3/9/18	Pedersen	Vest of Ernie Pas	68.1053	-151.0138	557	26.49	29.90	Low-shub tundra
52	3/9/18	Pedersen	tuvuk River NPS	68.1488	-151.6389	504	19.02	12.47	Low-shub tundra
53	3/10/18	Pedersen	Anaktuvuk Pass	68.1168	-151.3449	527	25.05	21.03	Low-shub tundra/Tussock tundra
54	3/10/18	Pedersen	aktuvuk Pass, Sc	68.2822	-151.4873	494	13.58	7.05	Tussock tundra
55	3/11/18	Pedersen	lik River and Ana	68.5208	-150.8942	544	57.00	10.04	Low-shub tundra
56	3/12/18	Pedersen	of Itkillik River V	68.5776	-150.1452	427	94.70	13.30	Low-shub tundra/Tussock tundra
57	3/14/18	Pedersen	tkillik River, North	68.5919	-149.8277	525	41.31	17.89	Low-shub tundra/Tussock tundra
58	3/15/18	Pedersen	killik River, Sout	68.3501	-150.0011	442	10.46	4.91	Low-shub tundra/Tussock tundra
59	3/18/18	Pedersen	irktok River Valle	68.2563	-148.8718	746	38.82	16.06	Low-shub tundra/Tussock tundra
60	3/18/18	Pedersen	irktok River Valle	68.5067	-149.0421	526	24.45	10.37	Low-shub tundra
61	3/19/18	Pedersen	r Valley at moun	68.3724	-148.9459	576	19.23	12.41	Low-shub tundra/Tussock tundra
62	3/20/18	Pedersen	on River Valley, S	68.7126	-148.6031	412	68.67	19.89	Low-shub tundra/Tussock tundra
63	3/21/18	Pedersen	on River Valley, I	68.6329	-148.2913	374	87.93	9.57	Low-shub tundra/Tussock tundra
64	3/22/18	Pedersen	ishak River, Sou	69.0345	-147.6586	299	88.44	16.77	Low-shub tundra
65	3/22/18	Pedersen	ishak River, Nor	69.0326	-147.8049	372	66.00	24.28	Tussock tundra
66	3/23/18	Pedersen	Lupine River	69.0617	-148.7950	462	58.51	8.34	Low-shub tundra
67	3/23/18	Pedersen	k River, South of	69.0753	-148.5257	535	89.60	10.08	Low-shub tundra/Tussock tundra
68	3/24/18	Pedersen	k River, North of	69.2106	-148.8103	441	69.48	11.02	Low-shub tundra/Tussock tundra
69	3/24/18	Pedersen	iktok River, Pump	69.3632	-149.2688	485	58.33	8.37	Tussock tundra
70	3/25/18	Pedersen	Toolik River	69.0416	-149.4281	419	81.14	10.88	Low-shub tundra/Tussock tundra
71	3/25/18	Pedersen	Vest of Toolik Riv	69.4491	-148.5743	495	49.80	8.54	Low-shub tundra/Tussock tundra
72	3/25/18	Pedersen	per Kuparuk Riv	68.6503	-149.3640	453	47.37	11.49	Low-shub tundra/Tussock tundra
73	3/26/18	Pedersen	Creek, Sveta Stu	68.5848	-149.3056	476	66.89	11.84	Low-shub tundra
74	3/28/18	Pedersen	Wiseman	67.4233	-150.1110	10	75.67	2.64	Spruce forest
75	4/1/18	Pedersen	Chandalar Lake	67.4926	-148.5077	308	56.41	10.61	Spruce forest
76	4/1/18	Pedersen	alar Shelf, north	67.9816	-149.0650	456	59.73	12.97	Low-shub tundra
77	4/2/18	Pedersen	Fork of Chandala	67.7891	-148.4330	390	62.35	7.31	Spruce forest
78	4/2/18	Pedersen	rth of East Butto	67.3758	-149.0574	606	88.53	16.87	Spruce forest
79	4/3/18	Pedersen	Crow Nest Creek	68.0423	-146.0044	551	65.43	6.04	Spruce forest
80	4/3/18	Pedersen	Lake, Junjik Rive	68.3701	-146.4519	886	50.96	8.23	Low-shub tundra
81	4/4/18	Pedersen	Chandalar River	67.2273	-148.4153	620	63.80	14.38	Spruce forest
82	4/4/18	Pedersen	lob Johnson Lak	67.4793	-149.3278	1062	59.66	13.01	Mixed spruce forest/low-shrub tundra
83	4/5/18	Pedersen	t of Slope Moun	68.7078	-149.0046	1137	60.01	35.09	Low-shub tundra
						18468	**55.21**	**14.08**	
84	5/3/18	Sturm	: Point just S. De	70.4947	-149.8812	**605**	**33.3**	**10.99**	low tussock tundra
85	5/2/18	Sturm	Barrow near ARM	71.322	-156.62	**1239**	**45.18**	**11.6**	low tussock tundra

Shifting focus to the data collected in the area shown in Figure 2, we can explore the character of the snow cover in greater detail. For these stations two orthogonal depth transects were measured, along with SWE and stratigraphy. The data are summarized in Table II. As these stations were near or in the Brooks Range, the mean depth value (67.3 cm) is higher than in Figure 5, but well-matched by the mean snow pit depth (67.9 cm, *n*=13), suggesting in general snow pit locations were representative of the larger surrounding neutral areas where we chose to measure.

Table II: Near-Brooks Range Station Snow Statistics

Station	Latitude (N)	Longitude (W)	Snow Pit Depth (cm)	Core Ave. Depth (cm)	Pit Bulk Density (g/cm3)	Core Bulk Density (g/cm3)	Mean-All Probe Depths (cm)	Std. Dev. - All Probe Depths (cm)	***n*** (All Probe Depths)
Nanashuk Divide	68° 33.6'	150° 33.0'	54	54.6	0.280	0.239	52.6	10.6	320
Nanashuk Bottom	68° 33.1'	150° 36.4'	36						
Barchan A	68° 28.8'	151° 17.0'	89		0.437				
Barchan B	68° 28.8'	151° 17.0'	78		0.405				
Ernie Pass	68° 06.0'	150° 59.8'	102	84.5	0.377	0.308	74.8	27.5	241
Greylime Headwall	68° 07.8'	150° 48.8'	139	125.7	0.297	0.297	110.7	39.9	98
Ekokpuk	68° 01.3'	152° 21.1'	50	62.2	0.258	0.253	62.8	13.2	676
Amiloyak Lake A	68° 06.1'	152° 54.0'	45	54.2	0.265	0.224	47.2	9.3	393
Amiloyak Lake B	68° 06.1'	152° 54.0'	55		0.296				
Agiak	67° 57.6'	153° 02.2'	53	40.4	0.255	0.232	56.0	17.5	484
July Creek Divide	67° 52.1'	153° 32.4'	69	49.7	0.214	0.176	55.5	7.3	532
Kollutarak Divide	68° 11.7'	152° 31.3'	53	61.5	0.269	0.222	67.1	12.3	459
May Creek Divide	68° 34.1'	150° 14.1'	60	62.6	0.296	0.240	78.8	16.5	318
AVERAGES			**67.9**	**66.2**	**0.304**	**0.243**	**67.3**	**17.1**	**3521**

Using the two orthogonal lines measured at each station, we have examined how much the local depth statistics might have been altered due to a minor shift in sampling location (Fig. 7). The results suggest a consistency in mean depth and standard deviation between the two adjacent lines of ±10 cm (for mean) and ±5 cm (std. deviation) respectively. These results would indicate that care needs to be taken when assuming that a depth value from a single spot location is used to represent the depth over a larger area. Small shifts in instrument location could readily introduce differences in depth of greater than ±10 cm, and that is when making several hundred depth measurements. When considering the potential error in the mean when a ***single*** measurement is made (like from a sonic sounder), a simple statistical experiment with real data (Fig. 8) suggest the size of the error: at the Ekokpuk Creek station, the mean depth was 62.8 cm (*n*=676). The distribution curve for these data is shown in Figure 8, and is basically normally distributed. Hence there would be a 32% probability of a single spot measurement being at least ±13 cm different than the mean, and a 5% chance that it will differ by ±26 cm (±41%). This is a point we return to later when examining the data reported by existing autonomous networks as compared to the field results.

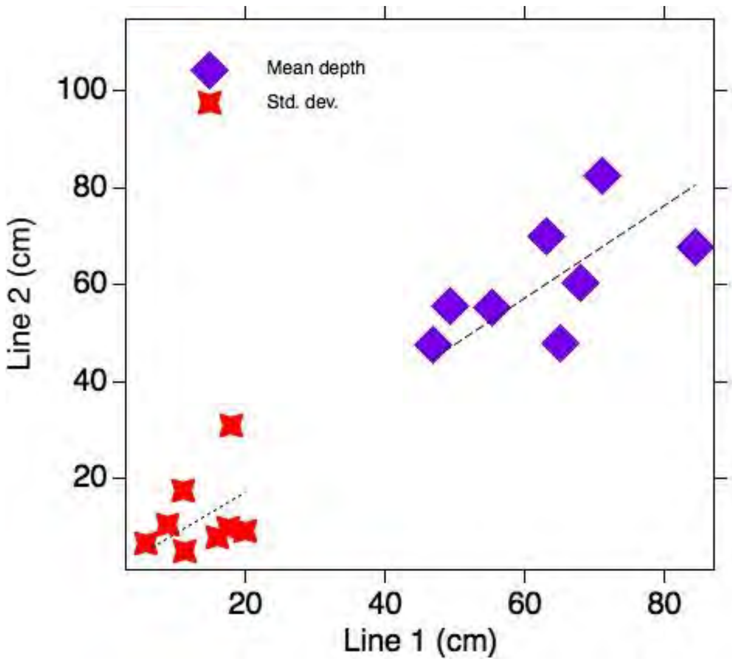

Figure 7:Depth statistics from the two orthogonal lines measured at each near-Brooks Range station. The black dashed lines are the 1:1 lines for the data. The results suggest that differences of ±10 cm in the mean (or more) occurred, but that the high or low bias varied in a random way from one station to another.

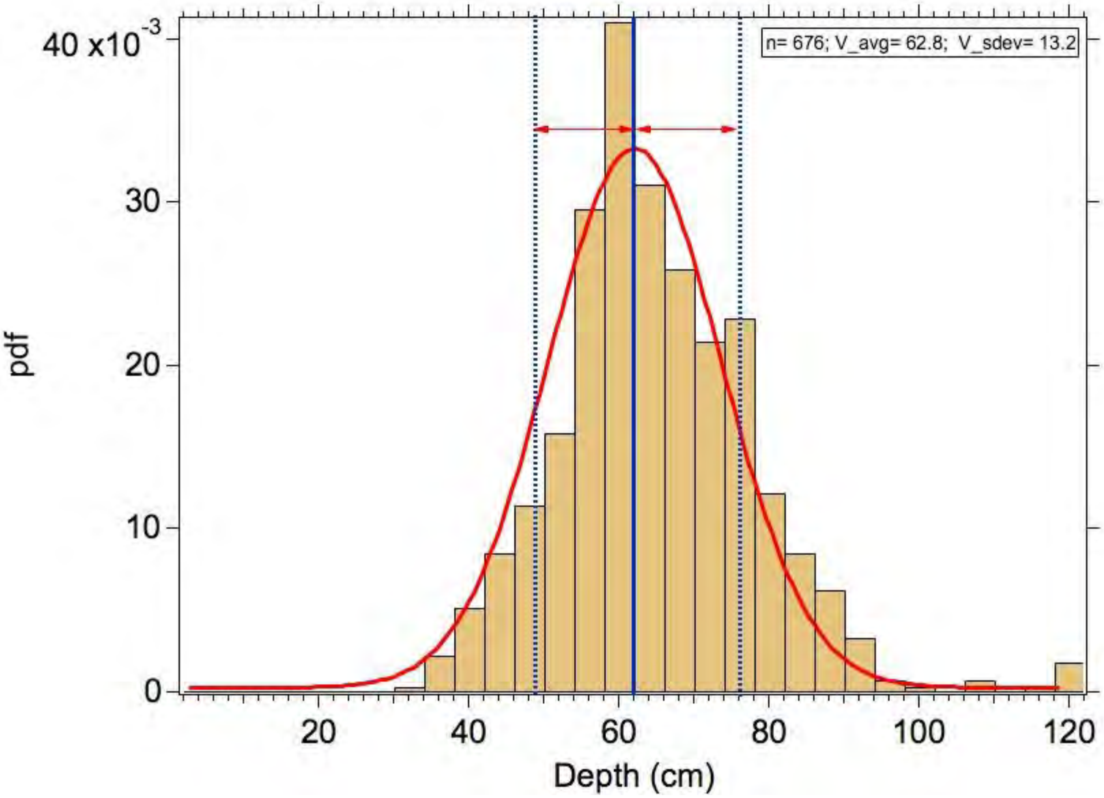

Figure 8: Depth distribution for measurements taken at Ekokpuk Creek along several probe lines, showing that spot depths differing from the mean by ±13 cm would have occurred 32% of the time.

The mean bulk snow density from these stations was 0.304 g/cm^3. This value is not surprising as the mean bulk seasonal snow density across all of North America typically falls around 0.3 g/cm^3 The stations for which we have density valies lie mostly in the foothills and Brooks Range where the snow is less wind-affected and less dense than closer to the coast. The mean bulk density for snow closer to the coast, based on data taken in 2014-2015 is often closer to 0.35 g/cm3 (Fig. 9).

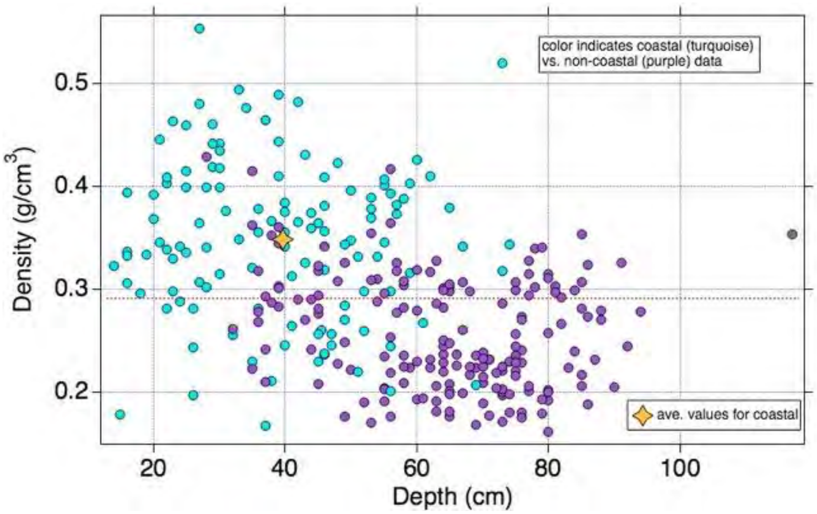

Figure 9: Bulk snow pack densities from Federal coring data collected in 2014 and 2015 in the Arctic National Wildlife Refuge by the lead author, showing the difference in bulk densities nearer the coast than in the foothills and the Brooks Range. The red dotted line is the mean for all data.

Density values in 2018 determined by coring were consistently lower than those computed from snow pit layer densities, most probably due to the high percentage of fragile depth hoar comprising the lower part of the snow pack. Even though we rejected all core samples that did not have a plug, it is likely that the downward travel of the core barrel through the snow forced some of the loose depth hoar away from the barrel, reducing the sampled mass. We have corrected this core low bias (see below) based on the pit densities, which we believe to be more accurate. For the 10 snow pits for which a direct comparison could be made, we found this regression equation did an adequate job of correction:

*Corrected Core Density = 1.142 * Measured Core Density* (r^2=0.95) [1].

Essentially, the core-based densities were 14% low. Using the corrected SWE values from coring, and the measured depth values, we then fit the resulting data with a quadratic function:

*SWE (cm) = 6.8 + 0.002451*Depth (cm)^2* [2],

which captures the fact that the deeper snow (>80 cm) was denser than the shallower snow, primarily because the deeper snow contained more drift layers. The slope of the fitted curve for depth values less than 80 cm is about 0.26 (essentially a bulk density in g/cm^3), but for the deeper snow (> 80 cm), the slope is 0.47 g/cm^3, a value consistent with the higher density of drift snow we have measured elsewhere.

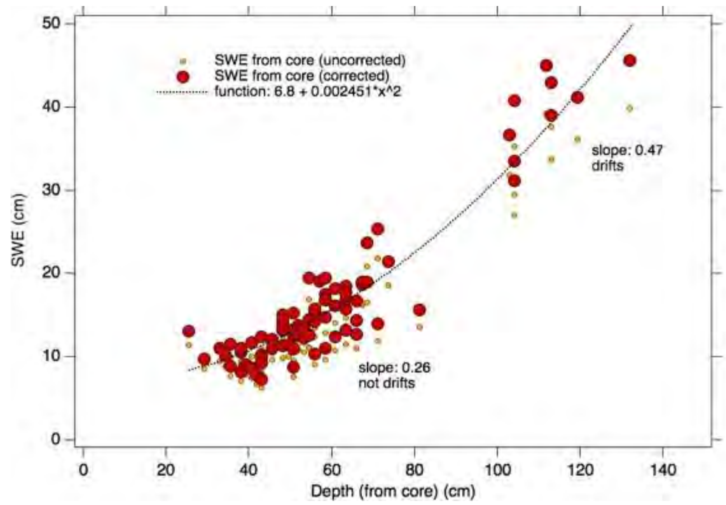

Figure 10:Corrected core-based SWE values plotted against the measured depth at each core. The quadratic fit (black dotted line) is given in Equation [2] and captures the fact that deeper snow is generally comprised of more drifted snow, hence denser. The slope of the fitted line gives (roughly) the bulk density for that depth value and can be used to convert depths to SWEs.

We can use the results from Tables I and II and Figure 10 to make a general statement about the SWE of 2018. The mean depth of the full data ensemble was 53.5 cm, which when multiplied by the measured core bulk density (0.304 g/cm^3) suggests an ensemble mean SWE of 16.3 cm. Allowing for the fact that much of the full area is not in the Brooks Range or foothills, we might compute a slightly higher value using the coastal density of (53.5 cm X 0.350 g/cm^3 (Fig. 9)), suggesting a mean SWE value closer to 18.7 cm. For the Brooks Range and foothills, this value is slightly greater due to the deeper snow: (0.304 g/cm^3 X 67.3 cm), or 20.5 cm. Perhaps the most representative way to compute the region-wide value is to convolve the log normal depth probability distribution in Figure 6 with the power function for converting depth to SWE (Figure 10). This produces an average region-wide SWE value of ***17 cm***. From this, we can then estimate how much snow (in the form of water) was residing across the study area by late-April 2018. Multiplying the SWE with the regions area we find about ***42 km^3*** of water in the form of snow. Since the sampling did not include drifts, which are deeper and denser 50% higher, or over ***60 km^3.***

The stratigraphic results from the snow pits are summarized in Table III and shown in Figures 11a and 11b. On average, the pack had 9 distinct, recognizable layers, each averaging about 7.8 cm in thickness, and on average the SWE (cm) was 22.2 cm for the pit, a value just slightly higher than that determined by coring (with correction). The measurements show that on average the pack was comprised of 66% depth hoar, 26% wind slab, with new/recent snow and some fine-grained soft layers making up the small remainder. The highest slab fraction, 65%, was measured at Ernie Pass, where two thick slab layers, already somewhat metamorphosed into compact and indurated depth hoar, comprised 54 cm of the total 102 cm depth of the pit. We suspect that even a slight relocation of the pit would have reduced this slab fraction considerably due to the pinching and swelling common in such wind slabs. We find it notable that in an area generally considered windy, such soft, friable depth hoar layers, not wind slabs, were the predominant snow texture. This is a fact that has important bearing on the survival strategies of many of the local sub- and supra-nivean wildlife, and suggests the value of obtaining textural values for the Arctic snow pack.

While we lack data from nearer the coast, prior work indicates we could expect the slab percentage to rise and the depth hoar percentage to fall with increasing distance north. In that prior work, the depth hoar fraction ranged from 34 to 44%. This difference should not be weighted too heavily: the classification of the layers in a pit into depth hoar and wind slab is complicated by a common feature of the snow in this region, which is wind slabs that have metamorphosed into depth hoar. Depending on the degree of metamorphism, these can be classified by observers as slabs, or as depth hoar, creating some ambiguity in the fractional distribution of snow layer types. These slabs are often compact, under a hand hardness test may be finger- or pencil-hard, and may register 0.4 g/cm^3 or higher in density, yet the grains in the layer may be more than a centimeter in length and show strong and skeletal faceting typical of depth hoar. From an traverse done in 1994 where many snow pits were measured for texture, we have constructed a south-to-north cross section of snow texture (Brooks Range to Arctic Coast) that shows the increasing amount of wind slab with distance north, as well as the issue with indurated depth hoar (Fig. 12).

Table III: Stratigraphic Results

Station:	Total thickness (cm)	Number of Layers	Ave. layer thickness (cm)	Bulk Density (g/cm3)	SWE (cm)	Wet/Icy Fraction	New/Recent Fraction	Other Fraction	Hoar Fraction	Slab Fraction
Nanashuk Divide	54	9	6.0	0.280	15.1	0.01	0.00	0.08	0.70	0.20
BarchanA	89	7	9.9	0.437	38.9	0.00	0.00	0.00	0.44	0.56
BarchanB	78	7	8.7	0.405	31.6	0.00	0.00	0.00	0.56	0.44
Ernie Pass	102	12	11.3	0.377	38.4	0.02	0.00	0.04	0.29	0.65
Greylime Headwall	139	9	15.4	0.297	41.3	0.00	0.12	0.00	0.74	0.14
Ekokpuk Creek	50	11	5.6	0.258	12.9	0.00	0.02	0.00	0.92	0.06
Amiloyak Lake A	45	10	5.0	0.265	11.9	0.00	0.02	0.07	0.62	0.29
Amiloyak Lake B	55	10	5.5	0.296	16.3	0.00	0.02	0.07	0.51	0.40
Agiak Creek	53	9	5.9	0.255	13.5	0.00	0.06	0.04	0.87	0.04
July Creek Divide	69	10	7.7	0.214	14.7	0.00	0.07	0.10	0.70	0.13
Kollutarak Divide	53	10	5.9	0.269	14.3	0.00	0.08	0.08	0.79	0.06
May Creek Divide	60	9	6.7	0.296	17.8	0.00	0.05	0.00	0.78	0.17
	70.6	**9.4**	**7.8**	**0.304**	**22.2**	**0.003**	**0.036**	**0.039**	**0.661**	**0.261**

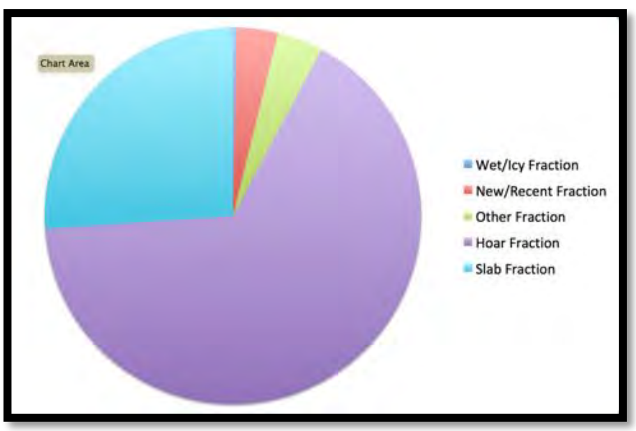

Figure 11a: Snow layer textures based on pit measurements.

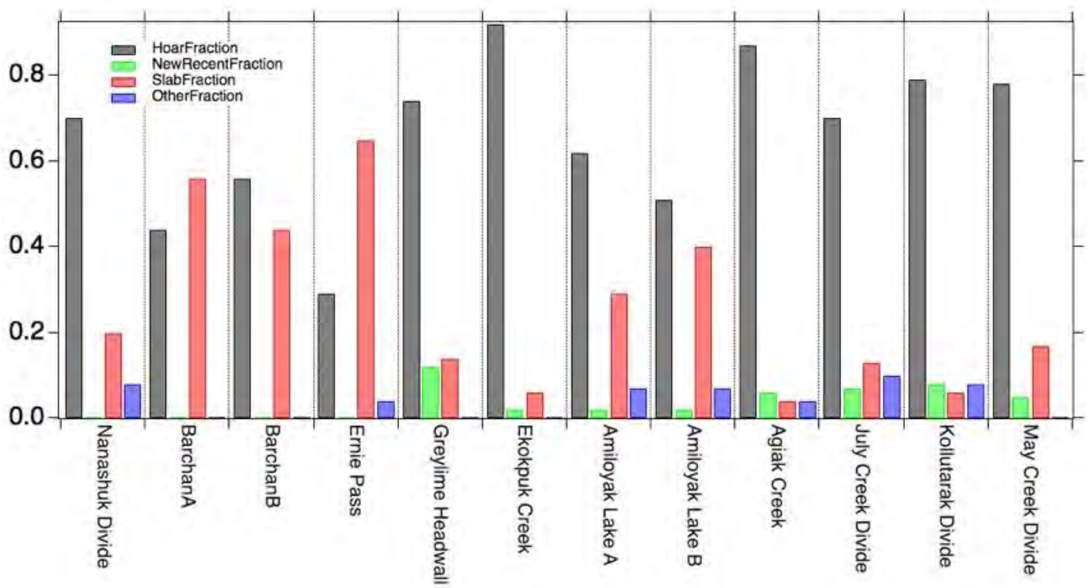

Figure 11b: Layer textures by snow pit and station.

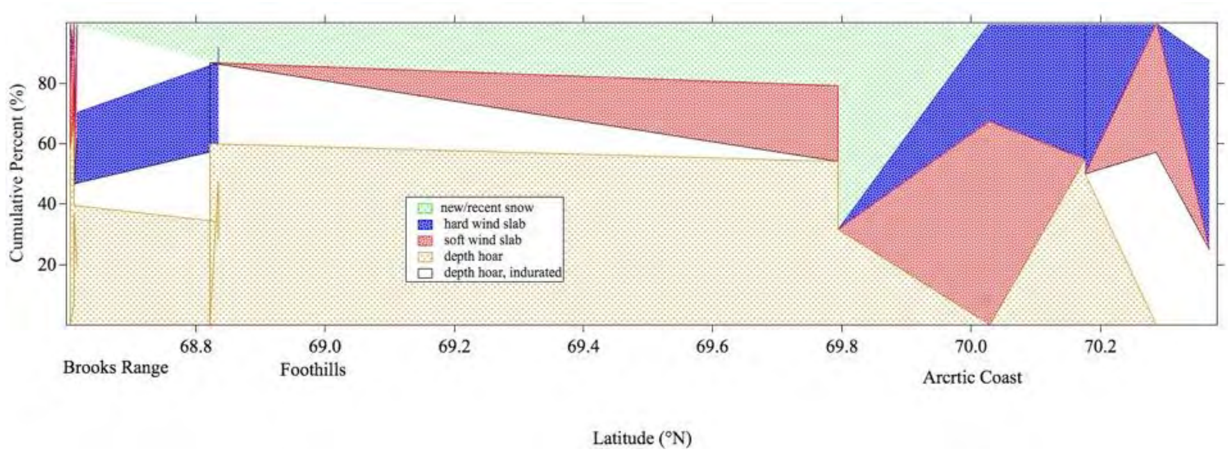

Figure 12: Wind slab and depth hoar percentages from the Brooks Range to the Arctic Coast, April 1994.

While this lower-than-expected fraction of wind slab layers in and near the Brooks Range is a bit surprising, it is useful to examine the stratigraphy of one of the hard dunes encountered during the 2018 field work to understand something of the nature of these slabs. A notable feature of the snow landscape in 2018 was the presence of large barchans. These were more common than in previous years. Barchans are crescent-shaped dunes that form during wind transport of snow and are transitional between snow waves and circular or elongated dunes that are more common. We encountered fields of these barchans during our March traverse, and again in April near Toolik Lake. These barchans were quite hard (walking over them left no footprints: Fig. 13) and fairly extensive. At one location, we sectioned a barchan (Figs. 13 and 14) to see if the hard layers extended to depth. The cross section shows that an exceptionally dense slab (0.59 g/cm^3) capped the dune (note that the upper theoretical limit on seasonal snow density in the absence of melting is about 0.56 g/cm^3), but below, the layers were not as dense or as hard. Even in this exceptionally hard drift, two soft depth hoar partings were present, and the basal unit, which had at one time been a hard slab, had metamorphosed into a hoar layer that near its base was quite friable and weak. We infer from the cross section that during the 2017-2018 winter there had been unusually strong transport winds and abundant snow to supply the wind-blown flux, a fact confirmed (see below) from drift surveys.

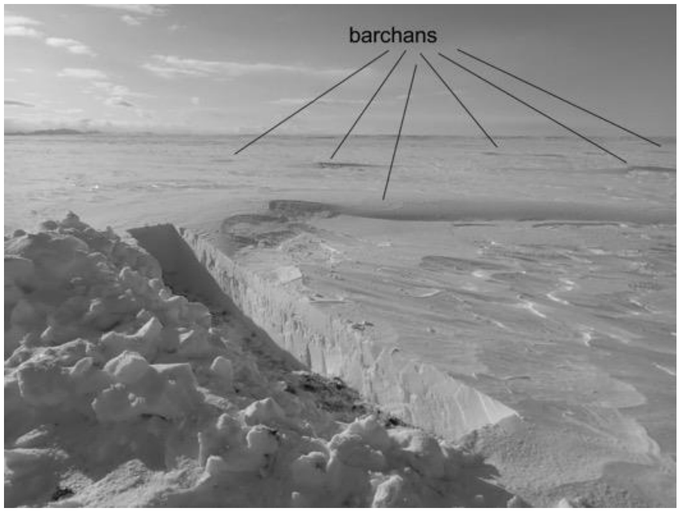

Figure 13:The barchan dune field and the barchan we sectioned using a saw and axe. The trench is 1 m deep.

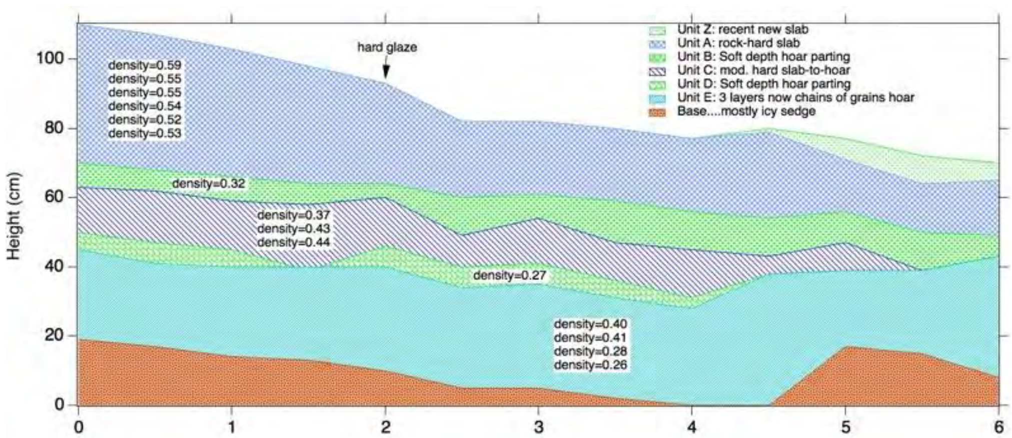

Figure 14: Cross-section of the dune shown in Figure 13, showing the density of the layers. Horizontal axis is meters; vertical axis is cm with 3X exaggeration.

The second to final results from the field work concern wind direction. Two factors govern the nature of this regional snow cover: 1) ***time***, in that long periods of residence under strong temperature gradients create depth hoar from virtually any snow that has been deposited, and 2) ***wind***, which a) determines where there will be scour or drift, and b) creates dense hard layers that resist depth hoar development, hence has some control on the ***time*** effect. Given that there are few locations where the wind direction is actually measured, modeling snow numerically (with wind speed and direction as an input) can be problematic. Fortunately, wind direction (if not wind strength) can be deduced directly from features in the snow: dunes and sastrugi, cornices, and crag and tail features to name a few (Fig. 15).

Figure 15:These crag-and-tail features that formed around shrub clusters are at the headwaters of Easter Creek and indicate the wind was from left to right.

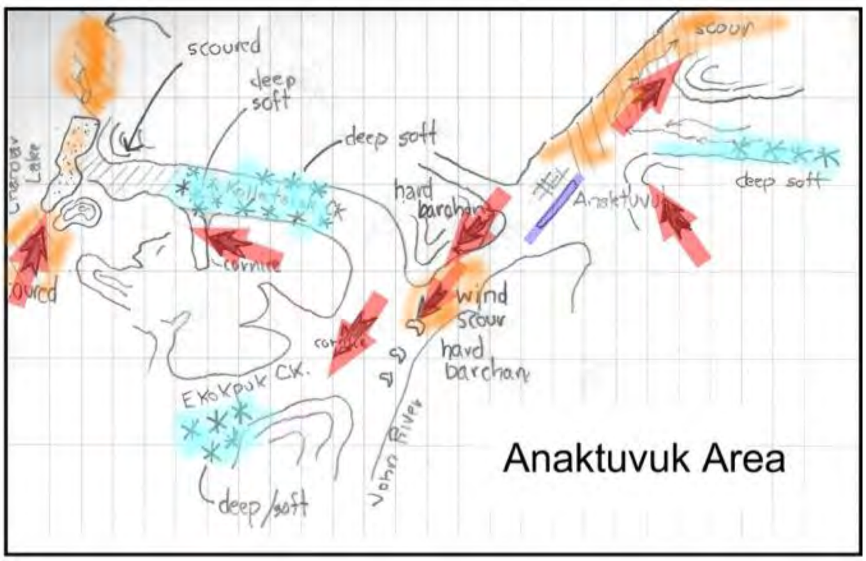

Figure 16: A field sketch (modified) of drift and scour features near Anaktuvuk Pass made in March 2018. Red arrows indicate wind directions deduced from drift features. Blue areas were deep, low-density snow; tan areas scour zones. Note that wind directions are complex and unlikely to be correctly indicate by measurements made at the local airport (purple strip).

In Figure 16, one of our field sketch maps of observed features and implied wind directions is shown. A first impression following this mapping suggests the following points that have modeling implications:

1. Katabatic flow dominates in the northeast-southwest trending valleys, but vectors indicate transport occurs in both directions. The dividing line between the flow directions is uncertain. We have similar effects in the Arctic National Wildlife Refuge, particular in the Marsh Creek area where scour on the north (downslope) side of the Sadlerochit Mountains is pervasive.
2. East-west trending valleys had deeper, softer snow…and more shrub vegetation…but there were still local areas of wind scour in these valleys in unexpected locations.

3. Considerable "turning" of the wind could be deduced from the observations, with wind directions being altered by flow over ridges, across slopes and down valleys. This turning was clearly indicated by cornice size and direction.
4. While we could map wind directions from snow features, new snow obscured some of these features, and we could not ascertain when snow from earlier in the winter had drifted in a different direction than the snow later in the winter.

Lastly, we present a sample of the SfM snow depth mapping we conducted during the 2018 field work. This photogrammetric technique for snow mapping requires that a snow-free digital elevation map (DEM) be produced (one time only) then subtracted from any subsequent DEM mapping done in winter to produce a snow depth map. One area we measured (April 23-26, 2018) is the area shown in Figure 17, a swath running from Camden Bay a south to Marsh Creek across the 1002 area of the Arctic National Wildlife Refuge, with the Sadlerochit Mountains just south of the swath.

Figure 17: Location map for the aerial mapping of snow depth shown in Figure 18. The mapped area is shown in red.

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The mapping results (Fig. 18) show an extremely heterogeneous snow cover with depths ranging from near-zero to more than 5-m in the drifts lining the cutbanks of Marsh Creek. This is an area where seismic exploration is proposed for 2018-2019. The katabatic scouring from the Sadlerochit Mountains is clearly evident in the southern part of the map area (red colors), where considerable areas of the tundra have < 25 cm (9.8") of snow cover, despite the fact that 2017/2018 was a year of record deep snow. Such a snow cover poses significant issues for human over-snow travel and work.

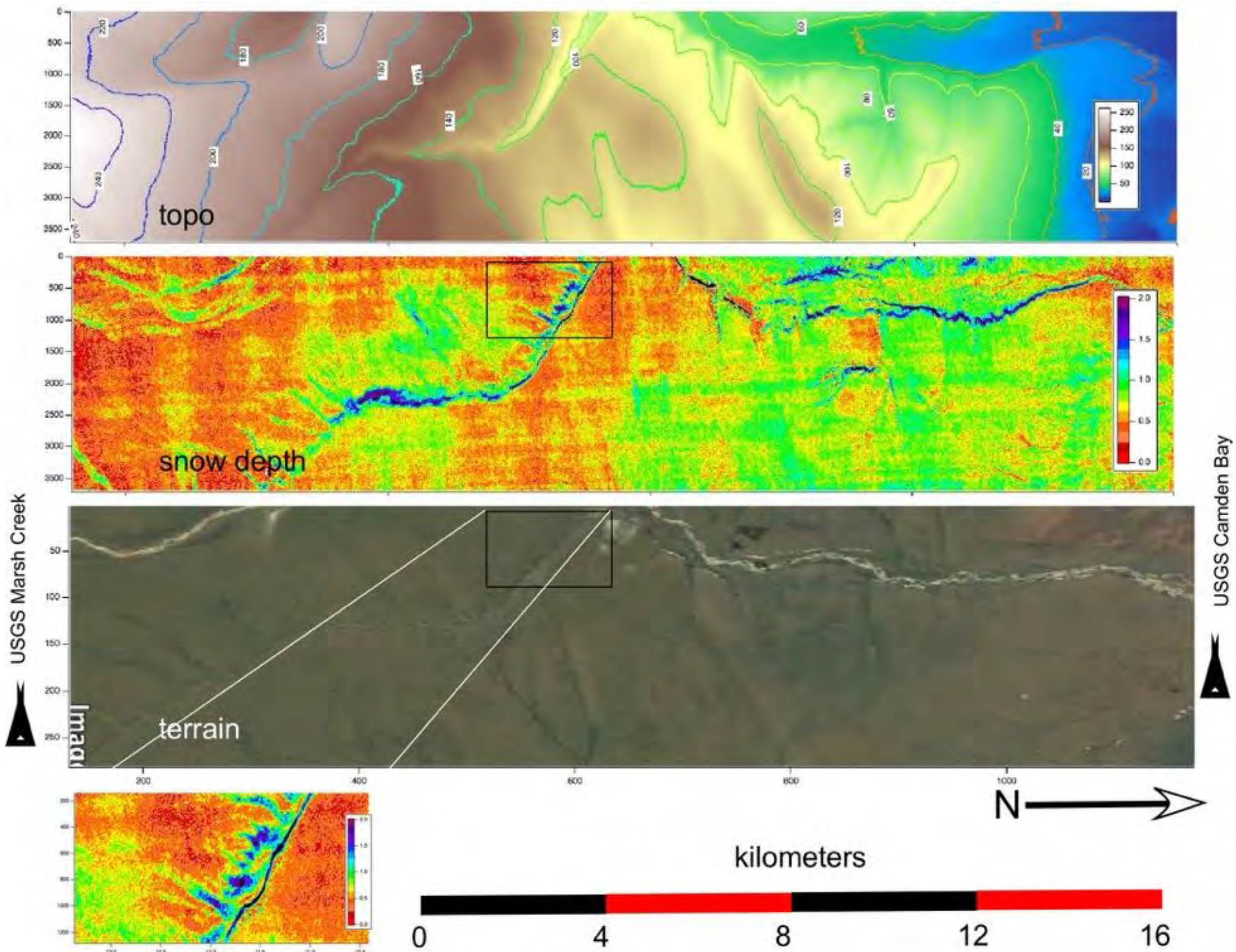


Figure 18: April 2018 structure from motion snow depth map for the swath shown in Figure 17 crossing the 1002 area of the Arctic National Wildlife Refuge. The top panel is the topography; the middle panel the snow depth (accurate to ±10 cm), and the lower panel the same area in a Landsat image. The snow depth ranges from near-zero (red) to more than 5 m deep (black) and varies over short (<20 m) distances. Note the extensive scour zones on the south (left side) end of the swath, as well as scour zones downwind (NE) of the large drifts lining Marsh Creek. North is to the right.

Comparison of Field and Autonomous Data: The results of the traverse provide a rare in-depth view of the snow cover of the region, but for only a single moment in time. We would ask whether we would be able to derive a similar perspective from the autonomous weather stations operating in the region. To answer this question, we polled the snow depth data from the RAWS stations lying within several hundred kilometers of the traverse region for the month of March (Fig. 19). Table IV lists these stations. Of the 13 stations examined, four (4) were not equipped with a sonic snow depth sensor nor precipitation gauge and had to be discarded. Three (3) additional stations had sonic sensors, but these were not working, leaving six (6) stations for which snow depth data was obtained. On top of the daily depth values from these stations we have plotted the values obtained during our March traverse (each plotted on the dates the measurements were made). We note that during this month there was little additional snowfall, and relatively little wind, so drift transport was limited, hence little reason to expect temporal variation in RAWS depths.

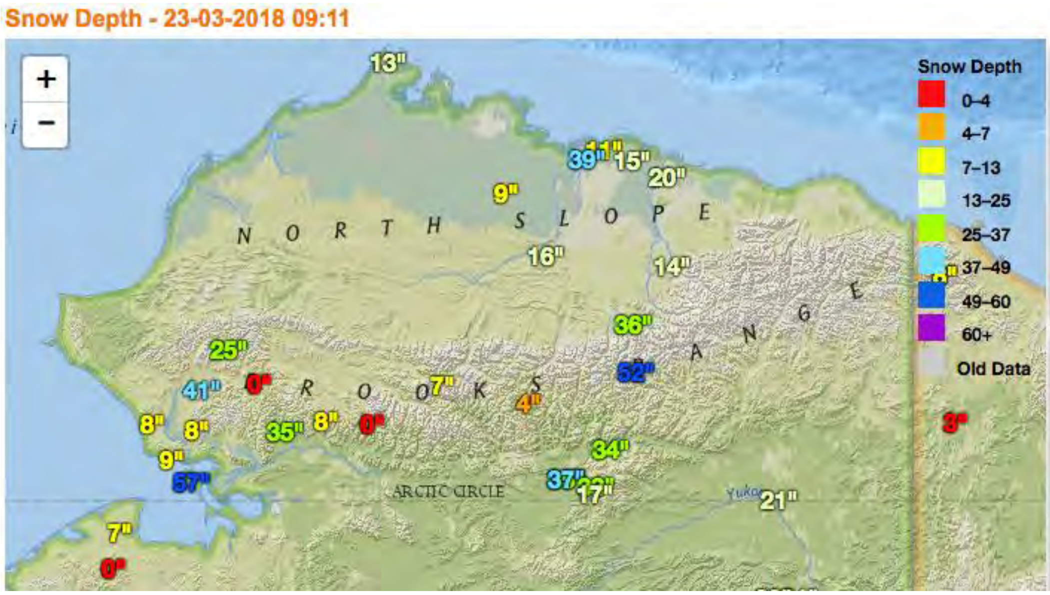


Figure 19: Screen shot from the NOAA-National Weather Service website showing the limited amount of snow data available for the Brooks Range (source: https://www.weather.gov/aprfc/Snow_Depth).

Table IV: RAWS Stations Used in Comparison with Field Data

Station	NESS ID	Latitude	Longitude	Status
Killik Pass,	3961C1E8	67° 58' 13"	154° 55' 27"	data available
Umiat	326B17F6	69° 22' 12"	152° 08' 10"	data available
Pamichtuk Lake	3961E704	67° 46' 19"	152° 11' 42"	data available
Imelyak	3961316C	67° 32' 46"	157° 04' 09"	data available
Inigok	32522240	70° 00' 13"	153° 05' 01"	data available
Kugururok	396203F8	68° 19' 00"	161° 29' 31"	data available
Chimney Lake	3961F472	67° 45' 21"	150° 29' 36"	not working
Ram Creek	3961D29E	67° 41' 07"	154° 28' 23"	not working
Howard Pass	39617266	68° 09' 22"	156° 53' 45"	not working
Noatak	FA601340	68° 04' 15"	158° 42' 15"	no sonic depth sounder
Norutak Lake	3246B586	66° 50' 00"	154° 20' 00"	no sonic depth sounder
Helmut Mountain	126006F2	67° 44' 29"	144° 07' 21"	no sonic depth sounder
Kanuti	1260A60A	66° 05' 36"	152° 10' 12"	no sonic depth sounder

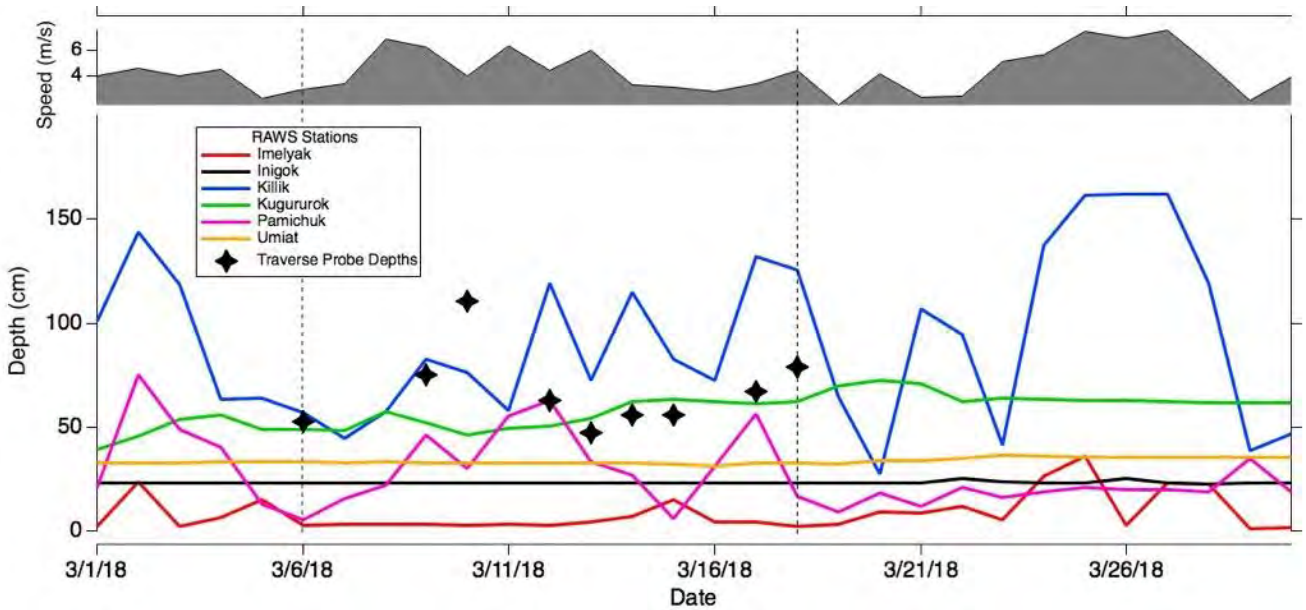


Figure 20: RAWS snow depth data (colored lines) compared to depths measured at traverse stations (black symbols). The variation in the traverse data is spatial in nature, while the variation in each RAWS station depth is temporal. Considering that little snow fell during March, and the wind was generally less than 6 m/s (transport speed), the large variations in depth for the Pamichuk and Killik RAWS stations are likely to be spurious.

The results (Fig. 20) show large (±50 cm) near-daily variations in depth at the RAWS Killik station and almost as large (±30 cm) variations at the Pamichuk station, fluctuations that are unlikely to be real. The Umiat and Inigok stations lie well north of the mountains out on the Arctic coastal plain, and show, as we would expect, shallower snow. The extremely steady values at Inigok (black line) are suspicious. Imelyak records almost no snow, probably not a real result for a station in the Brooks Range. The Kugururok station provides the best match to most of the traverse data, and appears quite believable. The issue, however, would be whether a user would know to use the Kugururok data while discarding the other stations. It is unclear how that data decision might be reached without ancillary data.

The NRCS runs three totalizing precipitation gauges spanning the east edge of the traverse area: Atigun Pass, Imnaviat Creek, and Sagwon, all sites we have visited and at times monitored in collaboration with the NRCS. At Atigun Pass, the March and April snow depth values (134 cm) were the same because there was little snowfall during the month. This value compares favorably with our measured value from the Greylime Headwall traverse station, which is at about the same elevation, and in the same physiographic position as the Atigun NRCS station. The Imnavait NRCS station increased from 89 to 96 cm depth over the month of March, suggesting a mid-March value of just over 90 cm, a value that is a bit high compared to our local station data for comparable elevations and physiography. The NRCS Sagwon site was registering 35 cm of snow depth throughout March. Like the more northerly RAWS stations, this value is lower than any of the traverse depth data, but the lower value is consistent with its position well north of the Brooks Range. SWE was not available for these stations at the time of this writing.

Our conclusion from this brief comparison is that while the autonomous data available for the traverse region could provide a "picture" of the regional snow pack, data reliability causes difficult problems in achieving that result. In some ways, using the NRCS data alone currently would provide a better snapshot of the snow depth in the area than using all the data because they appear to be more reliable. This is not a surprise. The RAWS sites were not designed to capture snow depth data; they are typically on a local hilltop (Fig. 21), a good place to measure the local wind, but a poor place to measure snow because it is often scoured away by the wind. It is also unclear if when the RAWS sites were installed, much care was taken to ensure that the rock piles holding the tower did not create drifts or scour under the sonic sounder. Finally, it is unclear why large fluctuations in depth values were observed when the snow was unchanging, but we suspect this is due to some electronic issues.

Figure 21: The Howard Pass RAWS station (courtesy DRI website). Snow depth sensor is on the arm projecting left. The gold-topped bucket is an unshielded precipitation gauge.

This issue of using data from autonomous stations has direct management implications across the entire region, both for human activity and wildlife management. Absent some human "check", it is clear to us that relying on the autonomous instruments could lead to erroneous decisions. For example, opening the tundra for seismic exploration based on a spot measurement from a sonic sounder that has produced a false positive (or negative) could lead to an opening when in fact management stipulations have not been met.

The Winter of 2017-2018: A Climatological Context

The deeper snowpack observed at Imnavait Creek in April 2018 as compared to April 2017 is consistent with higher precipitation measured at the Imnavait Creek Snotel site (Fig. 22), and supports the idea that the 2017-2018 winter had higher than usual precipitation. As assessed over the period 1 October through 30 April, total precipitation over the 2016/2017 snow year was 2.9 inches vs. 4.5 inches over the 2017/2018 snow year. Note that because of gauge under-catch, these measured values (both winters) are likely low by a factor of around 2.3X. The most notable event during the 2016/2017 snow season was a 0.4 inch event recorded for January 3, 2017 (Fig. 22 left) associated with a low pressure system in the Beaufort Sea. In contrast, during the 2017/2018 snow season there were more precipitation events (Fig. 22 right) with a large number of events early in the season. Of note was an event of 0.3 inches precipitation on October 14 (Fig. 23). The synoptic pattern giving rise to these events is not especially clear, but a deep low pressure over eastern Siberia seems to be involved; note the upward (negative) omega at 600 hPa over the Imnavait Creek area, which is a measure of the upward motion of air masses, consistent with cooling, condensation and precipitation. This was followed by an event of 0.2 inches on October 17-18 of 2018, associated with a low over the eastern Beaufort Sea (on the 17th) and (apparently) formation of a new low to the west on the 18th. These, and several other events, produced deeper snow cover over much of northern Alaska; the results highlight that just one or two large events can produce significant increases in snow depth in this generally thin-snow region.

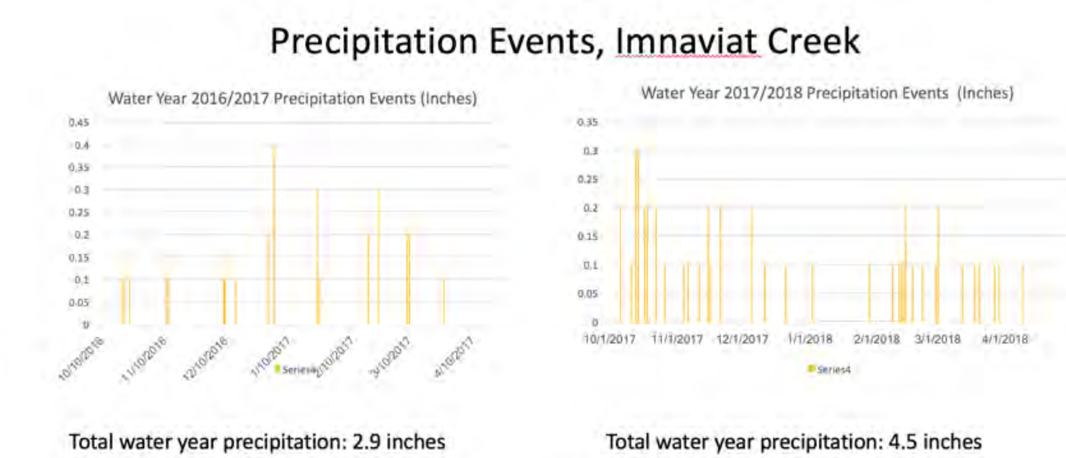


Figure 22: The measured precipitation at the Snotel site at Imnavait is low by a factor of about 2.3. This is based on comparisons with measured SWE at Imnavait in April, and assumes that all precipitation that falls from 1 October through 30 April accumulates as snow, Using this factor, the total precipitation for the 2016/2017 and 2017/2018 snow season, respectively, is likely to have been closer to 6.7 inches and 10.3 inches (17.0 and 26.2 cm) respectively. Based on average recorded snow depths of 62.7 and 76.2 cm, this yields mean densities of 270 and 340 kg m-3, respectively.

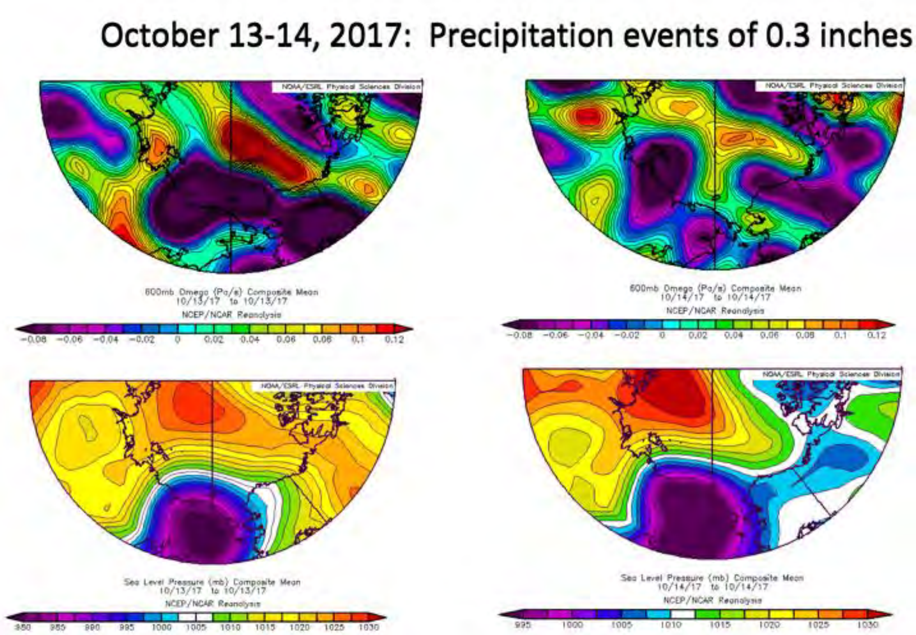


Figure 23: The first of two back-to-back large precipitation events early in the 2017/2018 winter.

Despite a limited ability to place the snow cover of 2017/2018 in a climatological context, there are other indicators besides the precipitation record that indicate it was an exceptionally heavy snow year, and a year when wind transport was near-record high. One measure that suggests this is a comparison of the April 2018 snow depth value for the 1-by-1 km test grid at Imnavait Creek near Toolik Lake (Fig. 24). We have been making measurements in this area since 1983. The 2018 value is the highest on record (though there are some gaps in the record). Near the test grid we have also been monitoring a large drift that forms in the lee of a cutbank (called the S-2 drift). It was the second largest on record over a 28-year period (during which we managed to survey the drift 15 times). In Barrow, the drift in the lee of the Cakeater Road snow fence was also all-time record largest (Fig. 25), and the snow depth at the local NWS weather station on April 1 was 10 cm higher than the 30-year norms (35.6 cm vs. 25.9) (http://climate.gi.alaska.edu/stations/barrow).

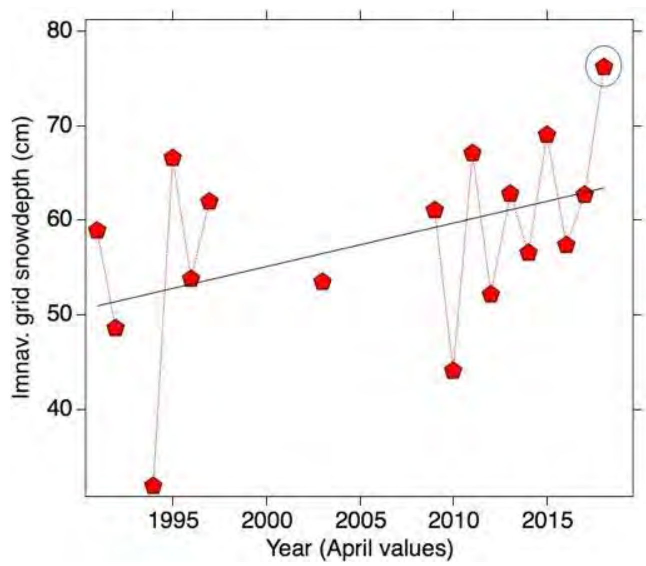


Figure 24: The mean snow depth from measurements made in the 1-by-1 km grid at Imnavait Creek. Not only is the 2018 value the highest in the record, but also there appears to be a trend for increasing snow depth.

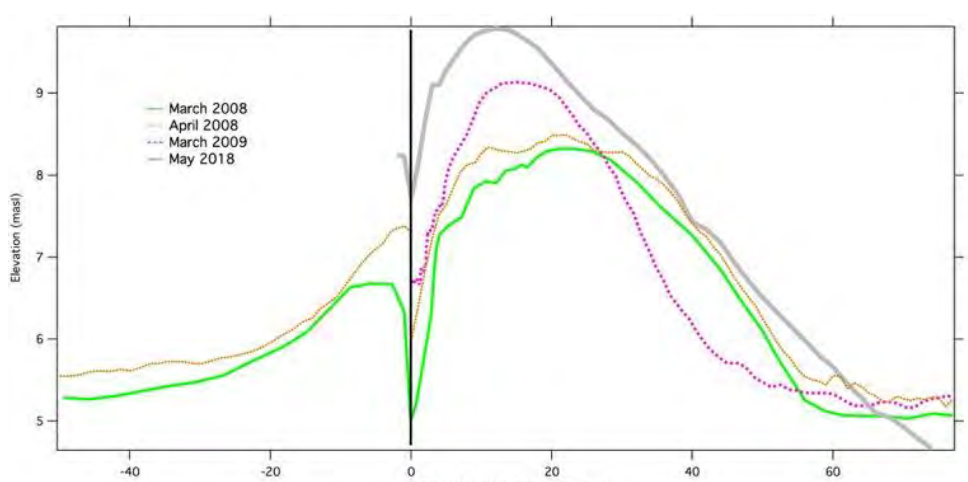
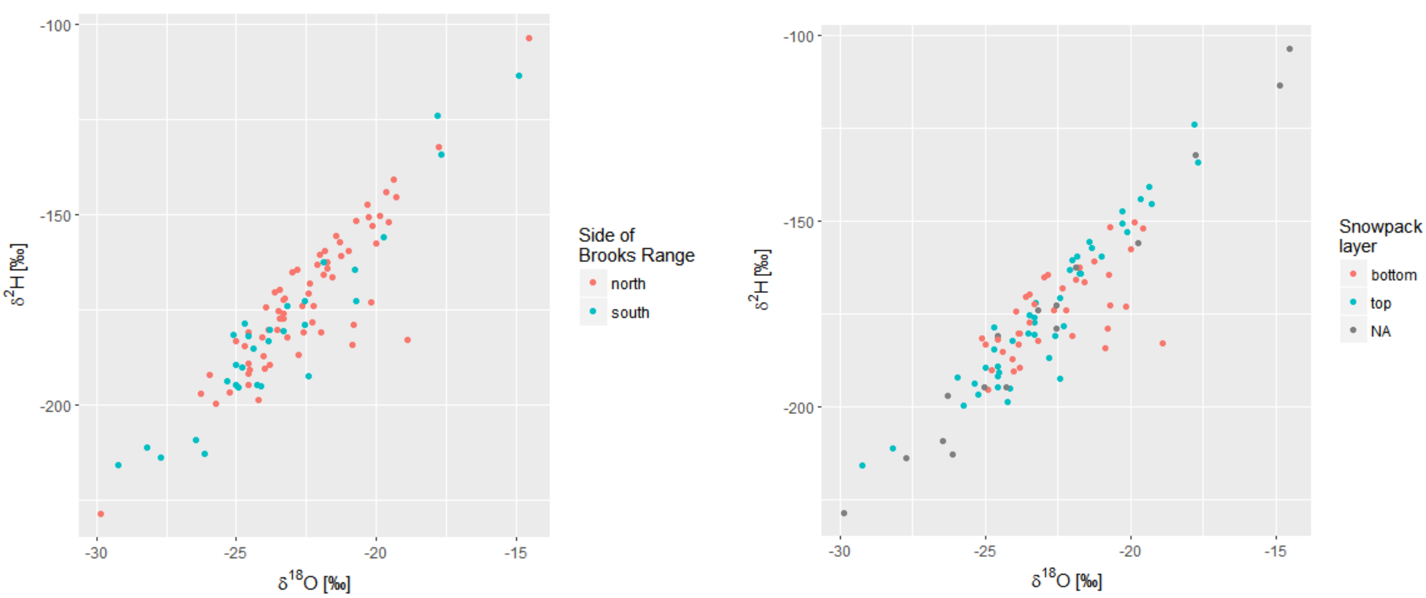


Figure 25: Cross section profiles from the Cakeater snow drift near Barrow showing the very large drift (record) from 2018.

Isotope Results and Storm Tracks:
The isotope results indicate that:

- isotope ratios on the south side of the Brooks Range were generally depleted compared to those on north side (Fig. 26a and Table V).
- there was greater variability in isotopic values late in the winter (top layers) as opposed to the earlier in the winter (bottom layers) (Fig. 26b and Table V).
- there was evidence that snow in late winter on the south side of the Brooks Range was the most depleted in $\delta^{18}O$.

These results suggest that the winter moisture sources differ between the north and south sides of the Brooks Range in early winter, but this difference fades as the winter progresses (Table V). Specifically, *d-excess* values from early winter (5.8 on the north, 7.7 on the south) indicate different moisture sources N. and S. of the range, but these values then converge later in winter. Our interpretation is that early winter the moisture source on the N. side of the Brooks Range is in part the largely open ice-free (and humid) Chukchi Sea. This produces the lower *d-excess* values. The S. side of the Brooks Range receives early winter snow sourced from the interior of the eastern Yukon Territory (Canada), which is relatively cold and arid. As winter progresses, the cold interior Yukon moisture sources continue on the S side of the Brooks Range hence the *d-excess* values vary little throughout winter (Table 5). However, there is ***a moisture source switch*** on the N side of the Brooks Range that leads to changes in isotopic values there: that snow pack it is more oceanic in the early winter and then switches to moisture from the Yukon region later in winter.



Figures 26a (left): Co-isotope plot with north (red) and south (blue) sides of the Brooks Range in different colors. Fig. 26b (right): Co-isotope plot with samples from the early winter (bottom) and the late winter (top) snowfall. 'NA' are samples from layers in between top and bottom.

Table V: Averages for $\delta^{18}O$, δ^2H, and *d-excess* for all samples north and south of the Brooks Range, with ± indicated by the standard error of the mean (SE), and then the values separated by north vs. south and the bottom (early winter) and the top (late winter) of the snow pits.

	North	South	North: bottom layer	South: bottom layer	North: top layer	South: top layer
n	68	30	29	9	34	10
Average $\delta^{18}O$ ±SE [‰]	-22.5±0.3	-23.5±0.6	-22.2±0.3	-23.7±0.6	-22.6±0.3	-23.8±1.2
Average δ^2H ±SE [‰]	-171.8±2.3	-181.0±4.5	-171.9±2.1	-181.6±3.0	-172.1±3.0	-181.3±9.5
Average *d-excess* ±SE [‰]	7.9±1.1	7.1±1.4	5.8±2.2	7.7±2.5	9.1±1	9±3.2

Conclusions: The Brooks Range and North Slope winter of 2017-2018 produced a record snowfall, and (possibly) record large drifts. This occurred due to just a few additional, and slightly stronger, precipitation events. Whether the drifts were larger because there was more snow, more wind, or both, is uncertain. We might have been able to reach this conclusion about the snow conditions from the various autonomous instrument that operate in the area, but because they produced conflicting (and erroneous) results, working from those data alone would have resulted in a high degree of uncertainty at best, or perhaps complete wrong conclusions. Moreover, those autonomous instruments and measurements are unable to tell us about the density, texture, and other aspects of the snow that directly affect human activities (like over-snow travel) and wildlife (like caribou cratering). Currently, that appears to be possible only by putting humans on the ground, and argues for human monitoring in concert with the other instruments.

Despite the record snowfall, large areas of the domain exhibited patchy and often thin snow (Fig. 18) late in the winter of 2017/208 due to the action of the wind. These thin areas exist adjacent to deep drifts in the lee of cutbanks, and the two extremes can be thought of as conjugates since they are linked by wind transport processes. Such extremes in depth pose serious issues for proposed seismic activities related to oil and gas development.

Finally, some land management agencies, for a number of reasons, find the permitting of snowmobile enabled ground measurement programs problematic, but the necessity for measurements at many locations makes similar aerial-based campaigns extremely dangerous. Our view is that a) we need humans on the ground to measure snow if we are to really understand the winter environment of northern Alaska and how it is changing, b) that the safest way to do this is via snowmobile traverses, and c) that such activities are necessary to meet the monitoring and inventorying requirements for these public lands. Such human monitoring is particularly important at this time because massive changes in the sea ice conditions across the Arctic Ocean appear (Figs. 24a and 24b) to have already altered the winter environment of the region.

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The Geonor precipitation gauge at Oliktok Point in April 2018, completely drifted over by the winter's heavy snow…but still sending out (erroneous) autonomous data.