Working Document of the NPC Study:
Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources
Made Available March 27, 2015

Paper #6-4

EXPLORATION DATA ACQUISITION IN THE ARCTIC OFFSHORE

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper (Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)		
6-4	**Exploration Data Acquisition in the Arctic Offshore**	
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Date: August 20, 2014		**Revision:** Final

SUMMARY

The acquisition of modern seismic data is an early step in the E&P life cycle and provides the knowledge base from which modern well planning and drilling technologies can be applied. Exploration data acquisition in the Arctic is not new as it has been ongoing for many years, and new projects are being planned and acquired today. It is being performed safely and with deference for sound environmental stewardship. The data gathered and the resultant images are truly advancing the understanding of the geology and resource potential. However, the operations are currently limited to deployment of conventional seismic equipment in the traditional open water seasons, where there is potential overlap and conflict with other stakeholders; or where we have advanced into the more difficult ice covered regions, the seismic technology and methods available limit us to 2D data acquisition.

Technology planning and development is underway, but investment and resources available are limited. The equipment technologies and methodologies necessary to acquire modern, advanced seismic data (3D and 4D) in and under the arctic ice are not available today. In order to truly explore and develop the resources in the Arctic, these will need to be developed. Seismic data will provide the knowledge base necessary to identify, drill, and produce Arctic resources in a socially, environmentally, and economically responsible manner.

I. INTRODUCTION

Acquisition of seismic data has been conducted in the various Arctic regions for at least five decades. Early offshore efforts included acquisition of 2D seismic profiles (reflection and refraction) utilizing both land acquisition equipment operated on the ice during the winter, and towed marine streamer during the summer. Towed 2D marine streamer data was typically acquired during the open water seasons where the vessels and equipment could operate in areas where the ice was not present, or in some cases operating in the open leads of the ice pack.

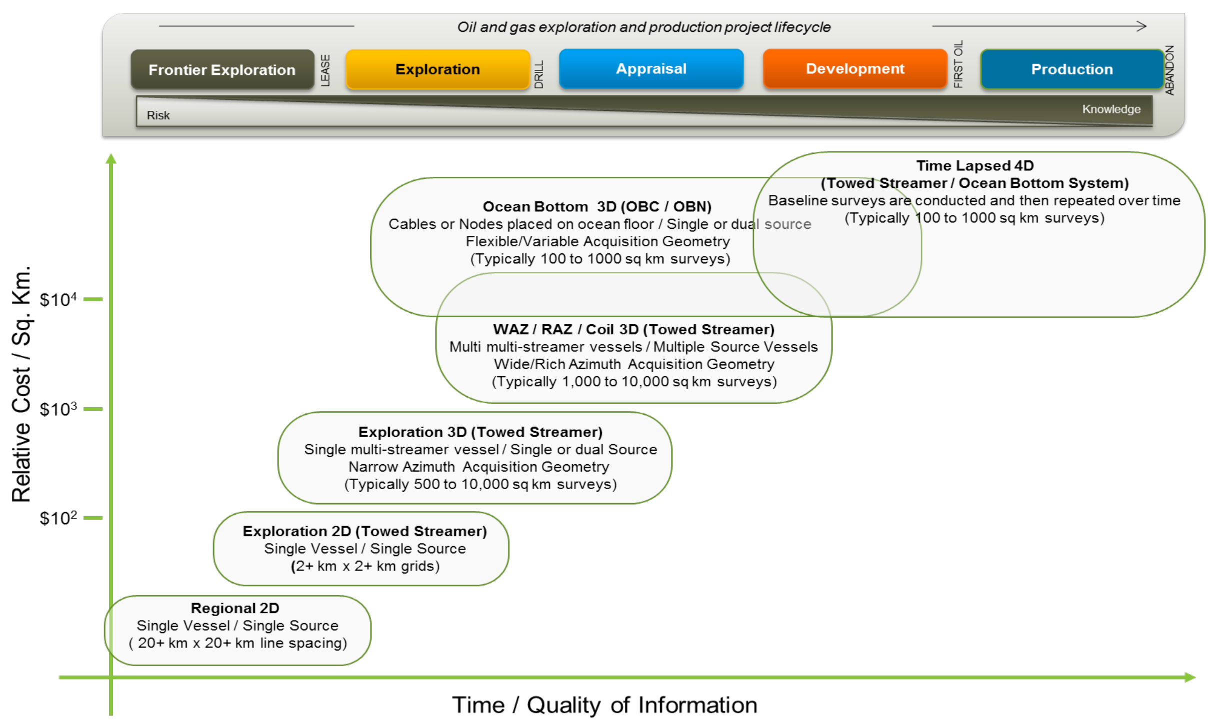
Since the introduction of 3D seismic technology and methodologies in the 1980's, there has been an exponential growth in exploration data acquisition, including 4D or time lapsed seismic. These technologies have been recognized as one of the most significant developments for reducing risk and improving drilling and production success in the E&P industry. With the exception of conventional 2D and 3D seismic techniques, many of these advanced seismic technologies and methodologies have not been adapted for utilization in the Arctic. There have been a number of reasons for this, including but not limited to the lack of development of the required downstream technology for safe and efficient drilling and production operations. These reasons have restricted the need for exploration seismic data acquisition in the Arctic. Coupled with lower risk prospects in other regions of the world and the overall economics have not necessitated the need to seriously advance the effort to explore and develop hydrocarbons offshore in the Arctic.

This paper will describe current seismic technologies and methodologies as they are applied today in the general E&P lifecycle, and more specifically how they are applied in current exploration projects conducted in the Arctic. It will consider the latest developments in supporting technologies which are required for safe and successful seismic prospecting in the Arctic, as well as identify potential gaps and future development opportunities.

II. OFFSHORE SEISMIC METHODS AND TECHNOLOGY

Before discussing specific Exploration Acquisition technologies related to the Arctic, it is worth taking a few moments to consider the various acquisition techniques and their place in the E&P lifecycle.

The chart below shows acquisition technology and methodologies as they are applied currently in the various phases of the E&P lifecycle. The actual choice of seismic acquisition system (land/marine towed streamer/ocean bottom system (OBC/OBN), and the specific acquisition methodology/geometry can vary based on the resolution of the information required, as well as the area being operated in.



The value, as well as the cost of the information/knowledge derived from each of these technologies and methodologies generally increases as you move later into the E&P lifecycle. Regional 2D seismic data can provide information relative to general geologic trends and structures, basin architecture and extent, source rock potential and potential hydrocarbon migration pathways, whereas Exploration 2D grids tend to be more focused on evaluating potential over lease blocks, including early prospect identification and targeting for additional studies. 3D surveys provide enhanced imaging quality of complex geologic structures and stratigraphy and reduced uncertainty compared to 2D data alone. As noted in the diagram above, there are a number of variations of specific 3D technologies and methodologies that can be applied currently, covering a significant range of the E&P lifecycle. Specific choice of 3D technology and methodology to be deployed can be based on the required resolution of geologic complexity (subsalt / stratigraphy / complex faulting) and/or the area and project timing and logistics (multi-use areas / environmental requirements / cultural constraints / existing wells and platforms). Time lapse, or 4D seismic, are 3D surveys that are repeated in the same location over specific time intervals during the production phase of the E&P lifecycle and provide valuable information relating to critical changes in the reservoir related to production which allows for planning of infill drilling or other interventions to improve overall hydrocarbon recovery rates and ultimately improving the overall field economics.

III. HISTORY OF SEISMIC ACQUISITION IN THE ARCTIC

To date, significant offshore data acquisition effort has been conducted on the fringes of the Arctic utilizing conventional technologies and methodologies taking advantage of open water periods. However, as described earlier, seismic acquisition has been an ongoing effort in the Arctic for many years. These surveys were split between the E&P industry in search of potential hydrocarbons, and acquisition activity funded and conducted by government and academic research groups and consortiums. These latter projects utilized private and government assets and the majority of these studies were focused on developing knowledge and understanding of macro geologic structure and history, and in some cases to help develop estimates of the potential for carbon based resources. These regional type surveys were well planned and produced significant learnings. However, they were sparse, covered large aerial extents, were very expensive, generally non-repeatable, and provided insufficient focus and resolution for advanced E&P exploration requirements.

Early seismic work in the Sverdrup Basin of Northern Canada was conducted utilizing land seismic technology placed on top of the ice. This method was utilized in Alaska in the 1990's conducting offshore exploration in the late winter on the sea-ice to map potential near shore prospects. These on-ice methods are limited to conditions of stable or landfast ice. Traditional marine 2D streamer data was collected offshore in the US and Canadian Beaufort Sea throughout the 1980's and early 90's. Beginning in 2006, extensive regional 2D streamer (and some OBC) seismic data was acquired throughout the Beaufort and Chukchi Sea, using primarily conventional acquisition systems and methods. There were greater than 50,000 line kilometers of modern 2D exploration grade seismic data acquired over a 4 year period. Since 2009 there have been three exploration grade 3D streamer surveys and at least two smaller 3D OBC projects conducted over specific lease blocks. These projects produced greater than 8,000 square kilometers of seismic data. In Eastern Canada, Russia, Norway, and Greenland there have been similar type efforts to acquire exploration grade seismic data north of the Arctic Circle utilizing mostly conventional technology, taking advantage of the traditional summer open water seasons. For comparison, in 2014 there is no activity in the North American arctic, while there are currently 8 3D surveys ongoing in the Barents and Kara Sea.

IV. CURRENT PRACTICE - OFFSHORE EXPLORATION DATA ACQUISITION IN THE ARCTIC

Conventional towed seismic streamer configurations utilize either solid, or fluid filled streamers, and surface referenced floats for maintaining proper positioning of the streamers and sources. This would include floats on the paravanes that are used to create the lateral spread of the streamers and sources, head floats for the streamer lead-ins, source floats for the airgun arrays, and tailbuoy floats for the tail of the streamers. Any or all of these may have GPS or acoustic positioning equipment attached for maintaining accuracy of positioning during the survey. In the Arctic, the presence of sea-ice becomes a major hazard for the vessel(s), surface referenced seismic floats, as well as for the streamers, paravanes, wires, lead-ins and umbilicals as they transition from the vessel and into the water column. Contact between the sea-ice and the vessel(s), and/or any of the seismic devices or cables could be potentially catastrophic in terms of equipment damage and mission scope. Given this risk and limited technology to overcome it, exploration data acquisition using conventional open water methods has generally been conducted in ”ice free” conditions. Some of the more recent arctic surveys have utilized a number of special mitigations including, but not limited to, ice classing of vessels (seismic, chase, etc., etc.), emergency preparedness, and special environmental considerations, in an effort to reduce any potential risk from the sea ice.

For purposes of this discussion, seismic data acquisition in the Arctic can be defined by the operational requirement of the mission relative to the sea ice. Three specific mission types are referred to as, ”ice free”, “ice avoidance”, or “under” ice.

“Ice free” references the use of conventional seismic equipment and technology deployed in an operating environment that will require the operation to be carried out proximal to broken and/or pack ice, but at no time actually operate in an environment where ice can be considered a hazard.

“Ice avoidance” references the use of vessels and seismic equipment and technology deployed in an operating environment that may require the operation to be carried out proximal to broken and/or pack ice, and/or in waters that may contain scattered broken ice that may require the vessel to plan operations so as to avoid the requirement to work in ice and/or to deviate from its prescribed course in an effort to avoid contact with the ice. Vessels and equipment need to be selected/adapted for the operating conditions. Chase/Ice management vessels may be used as well.

“Under” ice references the use of conventional and/or nonconventional seismic equipment and technology deployed in ice covered waters with the expectation that the vessel(s) and in-water seismic equipment will likely come in contract with the ice during the course of normal operations.

The majority of Exploration data acquisition to-date has been conducted as “ice free”, and has used conventional seismic equipment and methods. These are subject to the limits of the vessel and equipment utilized and the ice extent and conditions over the specific project area at the planned time of the operation. While these types of surveys are planned to reduce as much risk as possible, the underlying assumption is that if there is an unusual or bad ice-year, the opportunity to acquire data for any given specific project will be at the mercy of the ice conditions present during the specified operating window. These projects and the resources utilized are not designed to operate “in” or “under” any ice.

Recent examples of “ice free” surveys would include:

- 2D Regional programs in the US Chukchi Sea (2006 / 2009) conducted by ION Geophysical and TGS utilizing a towed marine streamer and conventional seismic airgun array.
- 2D Regional programs in the US & Canadian Beaufort Sea (2006-2010) conducted by ION Geophysical utilizing a towed marine streamer and conventional seismic airgun array.
- 3D Exploration programs in the Canadian Beaufort Sea for Imperial/Exxon (2008) conducted by WesternGeco; BP (2009), conducted by CGG; and Chevron (2012) conducted by WesternGeco, utilizing conventional 3D marine towed streamer arrays and conventional seismic airgun arrays.
- 2D Regional programs in the Russian Arctic (Laptev, Eastern Siberian, and Chukchi Seas), conducted by ION Geophysical (2010-2012), utilizing a towed marine streamer and conventional seismic airgun array.
- 2D Exploration programs in the Russian Arctic (Laptev, Eastern Siberian, Chukchi, and Kara Seas) conducted by Russian Geophysical Companys (DMNG, SMNG, MAGE), on behalf of Russian E&P companies (Rosneft, Gazprom, etc.)

“Ice avoidance” surveys have been much more limited in extent and scope. These surveys may utilize conventional seismic vessels with some ice-class and/or weatherization, in-water seismic equipment adapted or configured so as to help mitigate catastrophic failure in the event there is incidental contact with sea ice, and with enhanced onboard ice management systems, personnel and support. The goal is to be able to strategically forecast ice movements, and tactically locate all proximal ice, so as to ultimately avoid any contact between the vessel and in-water seismic equipment and the ice.

Recent examples of “in” ice surveys would include:

- Shell Chukchi Sea (2006) and Beaufort Sea (2007) 3D surveys, conducted by WesternGeco
- Statoil Chukchi Sea (2010) 3D survey, conducted by Fugro-Geoteam
- Exploration 3D in Western Greenland (2012), for Shell, conducted by Polarcus, utilizing 2 conventional multi-streamer/multi-source seismic vessels operating in tandem, with enhanced onboard ice forecasting and management tools and personnel.
- 2D Regional program in Labrador (2013), conducted by ION Geophysical utilizing a conventional 2D towed streamer and airgun source, with ice breaker escort.
- For both of these projects, the key was avoidance of the many icebergs, growlers, and bergy bits that were present in the prospect area.

“Under” ice surveys conducted by the E&P industry for Exploration purposes have been very sparse given the risks discussed earlier. However, there have been technologies and methodologies developed to reduce the ice contact risks with the in-water seismic equipment and have resulted in the successful execution of several 2D data acquisition projects in ice covered regimes. These developments have included a methods approach which has utilized a conventional 2D seismic vessel with some ice-class rating, and equipment deployed in such a manner as to reduce, but not eliminate the surface footprint of the in-water seismic equipment; and a technology based approach which has focused on development of new equipment which provides a means for the complete elimination of any surface footprint of the in-water seismic equipment behind the seismic vessel. To date, these approaches have been applied to both conventional 2D seismic vessels with some ice-class rating, as well as to an arctic-classed icebreaker converted to tow an exploration grade seismic streamer and source array.

Recent examples of “under” ice surveys would include”

- 2D Regional seismic projects, NE Greenland (2009-2011), conducted by ION Geophysical utilizing a conventional ice-classed seismic vessel, kitted with the under ice technology, and escort by an ice breaker.
- 2D Exploration seismic projects, NE Greenland (2010-2012), conducted by TGS, utilizing a conventional ice-classed seismic vessel, escorted by an icebreaker.
- 2D Regional seismic project, Russian High Arctic UNCLOS project (2011), with ION Geophysical, converting/outfitting an arctic classed icebreaker with under ice seismic kit, escorted by a nuclear icebreaker.
- 2D Regional seismic project, Russian Eastern Siberian and Chukchi Seas, as well the US Beaufort and Chukchi Seas (2012), conducted by ION Geophysical, utilizing a conventional ice-classed seismic vessel, partially kitted with under ice technology, and escorted by an icebreaker.

There have been a number of additional “under” ice surveys conducted since the 1990’s, but the majority were academic/government based and utilized a very short streamer and a very small source, so the applicability of the data acquired for E&P exploration purposes is limited.

V. Key Risks Associated with Offshore Exploration Acquisition in the Arctic

Barriers to the acquisition of marine seismic data in the Arctic can be summed up in two major categories, ice and metocean conditions and environmental sensitivity. Operating conditions including limited or no daylight, high winds and seas, extreme cold temperatures, and variable ice conditions (proximity, type, and concentration), all shorten the time window for conventional seismic operations, pose extreme risks to in-water acquisition equipment, require careful selection of maritime vessels of an appropriate ice class and in the case of ice introduce unwanted noise into the data. These operating conditions also introduce unique health, safety, and environment risks, while remoteness introduces attendant logistical issues. Respect for the customs and traditional lifestyles of the indigenous population, including their dependence on marine wildlife, further limits seismic activities, both in terms of timing and type of equipment used.

The following sections describe specific considerations and state of established practice for surveys in and under ice.

A. Ice Classed Vessels

Operations in polar waters demand special considerations on ships to ensure they are suitable for the rigors of the arctic environment. The key parameters are low air and sea temperatures, and the presence of ice. It is essential to conduct operations in remote cold-ocean environments with special measures to address these unique demands on crews and equipment. The classification of the ships for service in ice (ice class) is an essential reference in selecting ships for such operations. The capability of the proposed vessel, both in terms of its hull strength and machinery rating should be compared with the ice conditions expected to be encountered in the proposed area of operation. Classification Societies have rule requirements for ice classification. Whilst approximate equivalencies can be drawn between differing Classification Societies this should be undertaken with caution as required criteria, as well as requirements within such criteria, may differ. Classification requirements prescribe structural and machinery requirements.

The International Association of Classification Societies (IACS) has developed a set of unified requirements for polar ships constructed of steel and intended for navigation in ice infested polar waters. Ships that comply with the IACS unified requirements can be considered for a Polar Class notation as listed in the table and text described below. This standard is comprehensively described in IACS's "Requirements Concerning Polar Class" standard published on their website. For ease of reference a table from this source is reproduced below.

Ships that are also to receive an "Icebreaker" notation may have additional requirements and are to receive special consideration. "Icebreaker" refers to any ship having an operational profile that includes escort or ice management functions, having powering and dimensions that allow it to undertake aggressive operations in ice-covered waters, and having a class certificate with this notation. Icebreaker notation allows repeated ramming of ice features. Without it vessels are only permitted occasional ramming.

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Although usual, it does not necessary follow, that a vessel that has been assigned an ice class will have been winterized to enable effective management and operation of such a vessel in the harsh climate likely to be encountered. Winterization should, therefore, be considered when selecting vessels for polar operations.

Failure to select a vessel with an appropriate ice class and level winterization could jeopardize the safety of the personnel embarked, the safety of the vessel and success of the venture. Operation of the vessel beyond of its ice class limitations will effectively render the vessel out of class and potentially invalidate its insurance.

Very few seismic ships are built to transit in ice and those that are would generally be PC 7 equivalent ships or in many cases less. To conduct under ice seismic, special modifications and support considerations are essential as will be addressed later in this paper. This means few seismic ships are currently suited to arctic ice conditions. Ice free seismic has been successfully prosecuted in arctic waters with low and non-ice classed ships, however, these are relegated to open water only and must vigilantly monitor ice conditions to avoid equipment damage or entrapment by ice. The proposed IMO Polar Code will further restrict non Polar Classed Vessels from waters North or South of 60N and 60 S respectively. Additionally it will impose measures to ensure ships operating in polar waters are matched to and prepared for the demands of the environment and competently crewed for basic navigation in these environments. Ice class is a significant consideration in selecting ships for service in polar waters. The conduct of seismic vessels in polar waters demands prudent consideration of escort / support / ice management vessels to ensure these are fully capable of the intended mission and the rigors of the polar environment.

B. Seismic Vessels

Seismic ships operating in the arctic must be fully prepared for remote cold-ocean work. This demands careful consideration of the ships selected in terms of their physical capabilities to deal with the environment, risk management mitigations and redundancy protection. Key technologies can be employed to enhance operational capabilities and to mitigate risks. In addition to ice-class the key considerations are powering and control systems, fuel capacity, sea-suction arrangements and the ability to make adequate fresh water when operating in cold sea-water. Fuel types and specifications must be suitable to the lower temperatures and avert waxing and clouding issues, as well as be compliant with environmental legislation. Ice-management systems and ice informational support systems are other key ship components peculiar to such operations.

The physical environment must be fully assessed to ensure vessels selected for ice free, ice avoidance, or under ice seismic operations are suited to the demands of that service. This winterization assessment helps ensure the seismic ship and escort ship(s) are matched to the mission requirements and the rigors of the ice and addresses other environmental factors. In general, higher ice-classed vessels are advantageous from an ice risk mitigation perspective. Powering of selected ships must be adequate not only to provide the necessary bollard pull for the in-water seismic equipment but also to deal with the rigors of ice resistance and stress of weather. This requirement may impose significant consideration if the survey is to take place in rigorous ice or significant ridges. The hull form and control features must provide for stability and adequate maneuverability in both open water and in ice fields. Adequate means of protecting the in-water equipment from ice damage, such as an ice-skeg must be provided. This provides subsea towage points near or below the bottom of the keel as well as protection to the umbilicals and streamers from these tow-points to the gun and streamer decks.

In order to adequately address the mission requirements for a ship conducting under ice seismic it may well require consideration of a conversion of an ice-classed vessel, up to and including icebreaking vessels, to the seismic ship role. This has been overwhelmingly the case regarding in the seismic operations conducted in support of UNCLOS missions in arctic waters.

Ocean Bottom Cable Operations in ice similarly demands an approach based on risk assessment and environmental factors. Ships used to deploy armored bottom cable suitable for this form of ice-seismic must also be well-founded and capable in ice. The operational deployment of seismic ships to in ice avoidance or under ice seismic missions, including ice classed vessels modified for this role, will also demand the support of an escorting ice management vessel to provide an ice-escort or pre-break for major ice features such as ridges and other ice that would compromise the constant forward progress required of the seismic vessel to avoid damage or loss to the in-water towed equipment.

C. Escort / Guard Vessels

An escort ice management vessel will generally be required to support ice-seismic surveys both for towed streamer and bottom cable approaches. The selection of an ice management vessel is often driven by availability as few icebreakers are offered for such work. In the case of towed streamer ice-seismic, both the seismic ship and the icebreaker must operate very closely together to achieve a fully coherent and integrated capability. The selection of an adequate ice management vessel is dependent not only on the physical environment but also upon the seismic ship to be escorted and the full range of ergonomic factors. The capability of the two-ship system must address the essential element of compatibility. In general, the seismic ship must be able to easily follow the escorting ship in all ice conditions to be surveyed.

Ice-seismic escort differs considerably for conventional icebreaker escort in that it is imperative they be managed to avoid the escorted vessel halting in the ice or even slowing below minimum survey speed. This demands a very high level of collaboration and coordination between the icebreaker and the ice-seismic ship. This puts the lead icebreaker in a significantly different role than in traditional ice escort missions, in that it is now required to break ice along a specific track so the seismic vessel can tow the streamers over the desired pre-plotted lines, and without compromise to the forward progress of the vessel.

Other considerations for the selection of an appropriate escort icebreaker are redundancy protection, displacement, maneuverability, directional stability, track clearing characteristics, surplus power management, icebreaking capabilities, hull form, draft, bow form, propulsion type, and control systems.

D. Integrated Multi-Vessel Navigation System

An integrated navigation system can increase the operability period and under certain situations is essential for safe operation. While this is not necessarily unique to many other seismic operations, the challenges for the system in an Arctic environment include the ability to integrate a number of specific inputs including information from the ice-management system (radar and satellite images, tracking specific ice features, multiday forecasting, interpretation by ice management professionals etc.) as well as seismic vessel track prediction. It is not always a simple task of just navigating vessels, but also to understand the movement of the ice field that surrounds the vessels and the risk that that ice field imparts on the seismic equipment.

The requirements for positioning of seismic equipment working in the Arctic may also be different from open water areas because many of the normally used sensors may not be available in the Arctic environment. Tailbuoys, for example, which are used to position the distal end a seismic cable via GPS will usually not survive a collision with ice. Removing the tailbuoy will result in an open traverse calculation, meaning that there is no direct positioning measurement to ensure that the cable location can be calculated.

Likewise, the use of source GPS positioning equipment can be a problem if surface source floats must be removed and substituted with some form of sub-ice source float. This results in utilizing other means of non-GPS positioning such as acoustic triangulation.

A third major reduction in positioning quality is the degradation of compass measurements along the cable in certain areas of the Arctic. As the magnetic inclination reaches above about 85 degrees, compasses start to fail, resulting in yet another obstruction in the ability to properly position the seismic spread. This is not strictly a function of latitude but of the shape of the earth's magnetic field. It is expected that two areas will have problems, north of Siberia's Taymyr Peninsula and north of Canada's Queen Elizabeth Islands. On top of this, solar activity is more prevalent at high latitudes causing rapid and high amplitude fluctuations in the magnetic field. The cable compasses are highly affected by these phenomenon.

GPS positioning can also be degraded in the Arctic. It is standard for vessel GPS positions to be aided by corrections to the GPS data. However, due to satellite communication limits, the reception of these corrections can be problematic, degrading the positioning accuracy of the seismic vessels and spread. Because most suppliers of GPS constellation corrections use geostationary satellites to transmit their data, it is a certainty that both vessel positions and seismic spread positioning will be degraded when those corrections are lost due to latitude.

All of these conditions make Arctic navigation difficult and new ways to overcome these limitations must be sought. Industry work has been done to aid the cable positioning by measuring the magnetic declination in real time and applying those corrections to the cable compasses. As well, new means of transmitting GPS corrections are now available via Iridium satellites which follow a polar orbit.

E. Specialized Equipment Handling Systems

All seismic surveys involve a source and some configuration of receivers or sensors. To manage this type of equipment, a combination of specialized procedures, vessels, and handling systems are required to deploy and recover the in-water seismic equipment. As described above, there are two principal categories of exploration seismic surveying; two-dimensional (2D) seismic surveys and three-dimensional (3D) seismic surveys. 2D can be described as a fairly basic survey method, which, although somewhat simplistic in its underlying assumptions, has been and still is used very effectively to find oil & gas. 3D surveying is a more complex method of seismic surveying and involves greater investment and much more sophisticated equipment. 2D acquisition involves a single streamer towed behind the survey vessel together with a single sound source, whereas the 3D method of seismic surveying requires multiple streamers and sources.

Multi-streamer operations require a significant amount of in-sea equipment, a vessel capable of towing 16 or 20 streamers, and may have 96 - 120 kilometers of streamers being towed behind the vessel. Consequently, the back deck of the vessel becomes very busy due to the activity involved in the handling equipment including streamers, sources and the related control devices. The handling system is a complex arrangement of carefully designed equipment which enables the streamers and source arrays to be positioned accurately behind the vessel, and depending on the survey design, allows for different source and streamer separation distances. Organizing and operating such a set-up in a safe and efficient manner requires a very high level of knowledge and skilled personnel.

Contact between sea ice and the in-water equipment is one of the major risks with Arctic exploration seismic. At minimum, the potential of snagging and separating the auxiliary equipment such as birds and streamer recovery devices (SRD) is very high, and the potential for separating and/or losing part or all of a streamer or source array is real.

The use of solid streamer technology versus fluid/oil filled streamers eliminates environmental concerns associated with streamer fluid leaks or spills. Armored lead-ins and source umbilicals provide greater protection against separation by ice contact.

For an Ocean Bottom system, the ability to place the sensors on the seafloor eliminates the risk associated with towing streamers, however current limits in battery technology, cold weather/water technology, and positioning are some of the major hurdles that need to be overcome with this type of deployment.

Use of an ice skeg on the vessel can help negate some of the problems by stopping the ice flows getting caught under the umbilical's and lead-in. When the lead-in and the umbilicals are towed from the ice skeg there is no air gap where the ice can get caught. Additionally, the skeg provides a protected channel for the seismic equipment to pass through the ice infested water column so as to avoid being cut or severed by the ice. This approach has been successfully used by ION in their 2D under ice surveys.

Specific to ION's approach:

In normal acquisition (i.e. seismic vessel not equipped with an ice skeg), the gun umbilical's and streamer lead-in are towed from the stern of the seismic vessel, usually the tow points are between 3 to 5 meters above the water line of the vessel. From the initial tow point the lead-in and the umbilical gently slope back into the sea, finally reaching the correct towing (operational) depth 100 to 150 meters behind the vessel.

The gun floatation systems in use today have source sub arrays suspended from large surface floats and were matched to specific gun arrays to maintain a specific depth despite variable vessel speeds. Any ice that comes underneath the umbilical can get caught in the cables connecting the sub arrays to the floats and eventually one of three scenarios can happen; the ice twists and falls away, the guns force the ice to tumble and the guns get dragged over the ice, this causes failures to the electrical wires and air hoses, or the ice flow succeeds in ripping off the guns, causing massive failure to the source arrays.

At minimum, there may be little of no damage to the in-water equipment but there is most likely significant degradation to the quality of the data being acquired, and at worst case there is a catastrophic loss of equipment which could result in the shutdown and termination of the entire mission.

Consideration for the addition of an Ice Skeg, and submerged source floats should be given as being critical to the success of any marine seismic acquisition planned for under ice. The Ice skeg provides a fixed tow point 7 to 8 meters below the water line for the lead-in (head of the streamer) and the gun umbilical's connections, well below any surface ice. The subsea tow points are located on the horizontal plate of the skeg, one on the centerline and up to four other winch controlled tow points, four meters to port and starboard respectively. The tow weight of the streamer and airguns is borne by towing wires to these tow points, cables from the tugger winches provided on the deck will pull the umbilical's and the lead-in into the protected area behind the skeg.

In addition to this the use of submerged sub-array floats that allow seismic sources to be towed at a specific depth under the ice (provided by the ice skeg) which can only be successfully towed and operated from a tow point below the ice greatly reduce the possibility of ice getting caught between the source and the floats, thereby reducing the possibility of equipment failures. In order to produce and transmit consistent seismic source signals to maintain data quality and integrity, it is important that the air gun sub-array is maintained at a constant depth below the water surface and in a consistent position relative to the streamer array. The submerged floats reduce the risks of damage described above, and provide the stable platform necessary for quality exploration grade seismic data.

F. Ice Management System

Ice management is another critical enabler for safe operations in the arctic. Elements of ice management important for seismic acquisition are detection and forecasting of ice hazards. Ice management is implemented by seasoned ice management professionals, both embarked and supporting from ashore, supported by a host of remote sensing technologies.

Examples of these systems are IceNav™ or Narwhal™. These systems include integration with shipboard systems and encompass Ice Hazard Radar and integrated use of ice imagery and other ice informational systems. The ergonomic sharing of ice radar information and other datasets among all ships in an operation strengthens the management system and further reduces operational risks. Ice Management systems support the replacement of uncertainty of ice conditions ahead with solid NRT and real time information. Such knowledge is essential to risk management for ice-seismic. As such operations are often under-taken outside of the coverage area of V-Sat, Iridium Open Port (IOP) communications systems must be used which necessitate careful file management for effective use. Algorithms have been developed to effectively compress radarsat files into 2Mb files for ease of transmission to ships using IOP. The Narwhal system automatically interrogates the operations FTP site and downloads the information for use in the system. The overlaying of geo-referenced ice charts, imagery and other met-ocean products is another important feature of these systems.

Onboard ice management can be facilitated by the provision of information from short range helicopters and fixed-wing aircraft but generally speaking the system in supporting ice-seismic cannot be rendered heavily reliant on such information as its provision is weather dependent .

Other forms of metocean data such as information from ice-drift beacons, weather system maps, ice-pressure charts, satellite pictures and similar products all contribute to an enhanced knowledge of the physical operating environment and effective operations in all ice regimes. Contemporary top-end ice management systems embrace further enhancements and tools beyond the intent of this description.

The area of Ice Management Systems is a key growth area as new software and hardware systems now facilitate the integration and fusion of datasets and real-time ice and metocean inputs. Such systems could better enable use of such information and other pertinent datasets that otherwise would prove too cumbersome for and lacking from ergonomic perspectives.

Current systems include:

- IceNav: This is proprietary system owned by Enfotec of Montreal, Canada. This system is a more recent generation of earlier developments of the Star Vue of over 30 years ago.

  IceNav was designed specifically for ice navigation vessels operating in ice-covered waters. With IceNav, owners can provide their fleets with clear, accurate, and up-to-date ice information and satellite imagery . Using Inmarsat, VSAT, or Iridium-OpenPort, a ship outfitted with IceNav can retrieve and manipulate satellite imagery as well as ice and weather information, enhancing the safety and efficiency of navigation.

  The IceNav system consists of two completely integrated modules: a navigation module and the Virtual Marine Radar (VMR), running on a single station with dual display capability. Route plans created with the navigation module can be displayed on the radar image. Likewise, radar data can be overlaid on satellite images and ice information produced can also be used in a shore-based setting, for the planning of fleet operations.

- IDNS: This is a proprietary system developed for tracking and monitoring icebergs. It is owned by Provincial Aerospace (PAL) of St. John's Newfoundland.

  The IDNS system is a software system which supports data collection, analysis, threat assessment, and reporting functions for iceberg tracking using Windows XP on a personal computer. This system is provided by PAL and is not normally available to third-parties. This system is not intended for the management of pack ice.

- Narwhal is a top-end and new generation Ice Management System developed and marketed to third-parties by Concept Systems Ltd. of Edinburgh, Scotland. It is very powerful and includes an Ice Hazard Radar and is capable of ergonomically managing huge amounts of data and presenting same in a variety of user-selected presentations.

  Narwhal was specifically designed to meet the needs of ice-seismic, offshore drilling, site survey ice management, ice navigation, and shore management applications. This system provides visualization, tracking analysis, forecasting and risk mitigation tools for offshore ice management applications in or near ice such as seismic exploration, site surveys , drilling operations and operational re-supply.

- Other Systems: A number of other ice-management systems are currently at some stage of development.

G. Communications

A further challenging issue for exploration data acquisition is the lack of reliable, high bandwidth communication satellite systems. Two categories of satellite systems are available to the exploration industry, geostationary earth orbit (GEO) and low earth orbit (LEO).

GEO satellites maintain a fixed location over the earth's equator, matching their speed to the rotational speed of the earth. They are used to transmit the bulk of all seismic exploration communications data, transmitting in the L (1-2 GHz), C (4-8 GHz), and Ku (12-18 GHz) bands. But because of their equatorial position, reception at high latitudes can be problematic. For instance, a vessel at 75 degrees latitude will see a GEO satellite at an angle only 6 degrees above the horizon.

Latitude	Elevation of GEO satellite	Reception Quality
85º	-4º	Below the horizon and not visible
80º	1º	Very poor signal quality
75º	6º	Reduced signal quality
70º	11º	Acceptable signal quality

LEO satellites fly at high speed and low altitude orbit from pole to pole hence providing full coverage to the earth. Because they are only visible to the ground for a short duration (9-10 minutes), they must continually hand off their data and ground connections to their neighboring satellites. They are limited in their up/down link capabilities to mainly voice and low levels of data, transmitting in in the L band (1.6 GHz).

It has become commonplace in the seismic industry for vessels to communicate via VSAT (very small aperture terminal). However all high bandwidth systems like VSAT (typically Ku band) utilize geostationary satellites that are positioned over the equator. This limits their effectiveness at high latitudes because, due to their line of sight transmission paths, they are invisible to the vessel at near or below horizon elevations.

Only Iridium, operating on LEO satellites, can be relied upon for full coverage communications in the Arctic due to their orbital satellite paths. But because of their low data rates, their use is limited to mainly voice and email, with small levels of continuous low-bandwidth data transmission.

Due to these limitations in the current fleet of orbiting communications satellites, it is not possible for commonplace (sub 70 degree latitude) communications to be had. However, a new generation of LEO satellites is set to be launched. Iridium NEXT will keep the same constellation of satellites but upgraded to deliver a 9 times increase in L-band speed as well as new Ka (26-40 GHz) band service. Scheduled deployment of this system is between 2015 and 2017.

H. Geophysics for shallow hazards

Arctic areas are complicated by the existence of various ice related shallow hazards and geophysically anomalous near surface obstacles.

Of primary significance to the final geophysical product is the existence of permafrost both on land and in the near-shore marine areas. Permafrost is a layer of frozen ground with varying thickness. The permafrost can extend to the surface in Winter and reside under a thawed surface in Summer. Since ice has a very high velocity (11,000 ft/sec) as compared to water or wet soil (5000 ft/sec), these high velocity lenses can cause difficulty in the processing of seismic data. Similarly, the Arctic land areas are often pocked with “ice lakes” that experience these same anomalous velocities. Velocity anomalies typically manifest themselves as time shifts during the processing stage which must be properly accounted for.

For shallow, ice covered waters where land or marine operations can take place, a phenomenon known as a flexural wave can overwhelm the typical compression wave energy propagating to the surface. Flex waves propagate horizontally within the ice layer and are high amplitude and dispersive, generating broadband noise that can severely degrade the quality and usefulness of the acquired data.

Other physical hazards can come in the form of pingos, which are mounds of earth covered ice. These can be especially hazardous offshore where they are rarely charted. Ice scours can also be a source of anomalous surface conditions, formed by the movement of large glacial flows as they scrape along the sea floor.

I. Marine Mammals

With the passage of the Marine Mammal Protection Act in 1972, seismic exploration has come under intense scrutiny as a potential threat to the well-being of undersea life. Currently 125 species are “protected” under the MMPA, and any interference to their existence must be characterized as a “take”, either in terms of physical harm or behavioral changes. Although this is a world-wide issue, focus on the Arctic is especially stringent because of the summer migratory paths of marine mammals and/or their natural ice-field habitats. While there are a number of concerns for marine mammals relative to seismic acquisition, the most significant relates to the use of conventional seismic sources. These will be discussed in the subsequent sections.

J. Marine sound

Marine seismic sources are typically airguns which emit a high amplitude, short duration pulse. In terms of frequency content, these transient pulses tend to have a wide bandwidth extending into the auditory range of marine mammals with the potential to cause temporary or permanent damage to hearing.

Airguns may also be problematic to migratory behavior because the lower frequencies that are generated (below 1000 hertz) can travel over long distances.

Regulatory agencies have determined the levels of acoustic energy an organism (primarily marine mammals) can withstand. These thresholds are based on levels that could affect behavioral changes (e.g. altered migration or feeding behavior), cause temporary hearing impairment (temporary threshold shift or TTS), or cause permanent physical injury (e.g. permanent hearing loss or other damage).

In most jurisdictions the sound threshold used for a seismic airgun array shutdown is 180 dB for a cetacean, an area inside of which it is thought that TTS or (at closer distances) permanent injury could occur. For other types of marine animals, these thresholds can occur at different sound levels, e.g. 190 dB for TTS in phocids (seals), but many mitigation requirements focus primarily on cetacean thresholds.

Several sound threshold metrics are in use, sound pressure level (SPL) and sound exposure level (SEL) as well as many mathematical interpretations of these levels (e.g. zero-to-peak SPL, peak-to-peak SPL, rms SPL, 90% rms SPL, 90% SEL, M-weighted filtering, etc.). The chances of miscalculation of the metrics, misinterpretation of their meaning, and errors in the science of cetacean behavior can be large.

K. Sound Modeling

Sound modeling of seismic arrays is the estimation of sound transmission and prorogation loss with increasing distance from the sound source. It is used in environmental assessments which are required for project permitting in most Northern and Arctic jurisdictions. In several areas, such modeling is a specific requirement of the Regulator's permitting process.

The overall objective of the modeling is to estimate and predict the levels of acoustic energy that a specific seismic airgun array would impart and that a submerged organism might receive at varying distances from the sound source. The results are often presented as expected levels (usually expressed as dB re 1 μPa) within various distance intervals (isopleths) or at specific distance from the seismic ship or array. The predictive sound modeling is produced through the application of computer algorithms based on the physics of sound transmission and attenuation in fluids. Various factors affect the sound attenuation in the local marine environment, such as the specific airgun array geometry and its aerial frequency response characteristics, the airgun array depth, water temperatures and layering, salinity, presence or absence of surface ice, presence or absence of subsea permafrost, bottom type/material, and water depths. Of the various environmental characteristics that are considered, water depths seem to have the most influence on marine sound attenuation; deep water allowing for more rapid attenuation versus shallow water. However, changes in any one of the parameters can affect the model outputs and results.

The modelling outputs typically include tables and maps that indicate the distances from the array that key sound energy levels would be expected to occur based on the various factors considered in the modelling. Because environmental and oceanographic features (such as bottom type and depth) can change significantly over a large project area, the key sound energy distances may change significantly as well. For instance the 180 dB safety /shutdown zone in ION's Canadian Beaufort Sea 2010 Project Area was determined to range from within 900 m of the array in deep water to 3,520 m from the array in some shallow water areas (Figure 1 below).

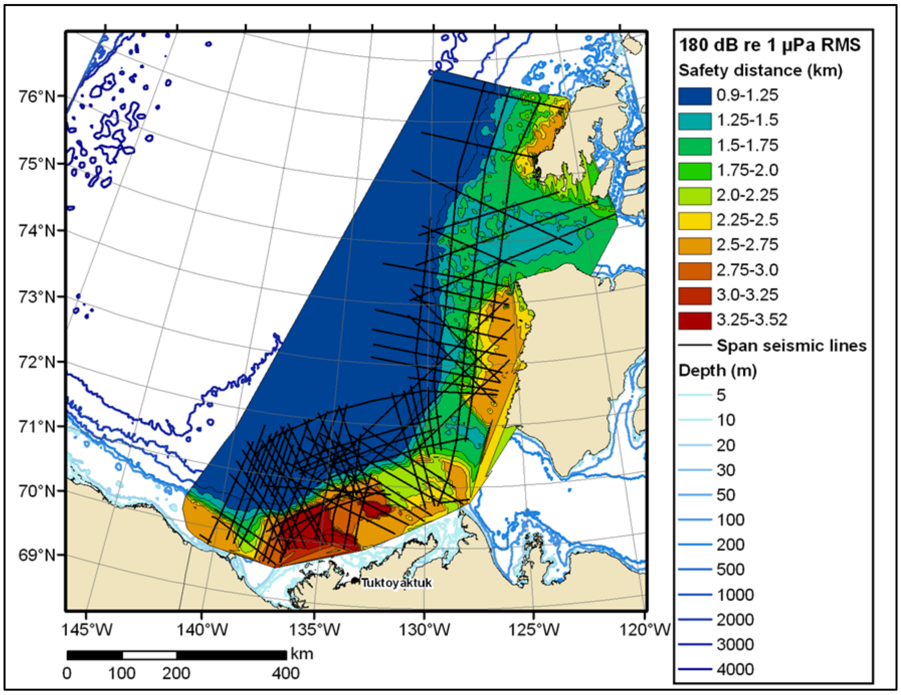


Figure 1: JASCO modeling of full Project Area for ION's Beaufort 2010 offshore 2D program in relation to permitted survey lines.

L. Sound Verification

Sound model verification (often called sound source verification, SSV), is a means of "ground truthing" the model by sound measurements taken at sea before or during the actual seismic acquisition. In most jurisdictions where sound modeling is required, such a process of on-site / at-sea verification or validation of the modeled predictions is required. In Alaska and Northern Canada this is done at the start or just before the survey, with a report on the findings (and any necessary adjustments to the model's predictions) coming within a few days so that this can be incorporated within the mitigation plan for the rest of the survey. In Greenland however, current guidelines allow for sound field measurements to be collected throughout the survey, and an analysis of the data and the conclusions about the model accuracy can occur after the survey is complete.

There are different methods for doing the verification, though in Alaska and Canada this is usually accomplished by readings from purposed hydrophones deployed from a support ship at various distances from the seismic ship and under different oceanographic conditions with the aim of collecting real-world data under representative Project Area conditions. In Greenland, proponents have more options such as monitoring conducted over the total or a substantial part of the survey period, by means of deployed autonomous dataloggers, or measurements can be obtained from a measuring vessel during a representative part of the survey.

M. Ice Experienced Maritime Professionals

Competent crews are essential to ice-seismic operations. In some regards the operation is very similar to current multi-vessel open water seismic operations conducted in other regions of the world, but with the added challenge of managing all the risks associated with the ice. Generally, the crews of seismic ships will have little or no ice management knowledge or skills. This is a specialist world. On the escorting icebreakers ice management skills are strong however; the conduct of ice-seismic demands unique applications of ice management. The requirements for specialist ice management knowledge can to some extent be addressed by training prior to the operation. In addition, it has been found necessary to augment the crews of both the seismic ships and the escorting icebreakers with specially trained ice-pilots familiar with ice-seismic. These generally have several decades of experience in ice-breaking or ice management and special training in imagery interpretation and ice management systems.

Many of the ice-specialists and ice-pilots available today gained their experience in icebreaking fleets of industry in support of arctic drilling activities and in government icebreaker fleets. As offshore drilling activities in Arctic waters declined or halted in the 1990's that feeder group has been lost. As a consequence the Ice Pilotage cadre in North America is facing retirement and few new candidates have the requisite experience.

N. Remote Operations

Seismic operations in the arctic will demand special recognition due to the remoteness and cold-ocean environment. Support infrastructure is almost non-existent which then necessitates advanced levels of operational planning, redundancy protection, risk management and preparedness for all operational activities. The cold-ocean aspects of the environment demand additional considerations for crew selection and protection from the elements. Similarly equipment designed for operation in warmer waters may be problematic in the cold-ocean environment. Due consideration needs to be given to crew change, crew health, and emergency preparedness.

O. Impact on Personnel

Arctic offshore operations expose workers to cold, windy, wet and icy conditions. Working in extreme arctic environments can cause adverse effects on human performance including potential for cold-related injuries and illness, as well as on work productivity, quality and safety. Operators need a comprehensive strategy of risk assessment and management practices for offshore work in cold environments such as the Arctic. Training is an important aspect for all operations, but especially important for operation in harsh and Arctic environments. The recent development of the ISO Codes (TC67 SC8 – Arctic Operations) codifies some of the best practices to promote safe operations.

The main philosophy for reducing exposure to the cold is to keep outdoor operations to a bare minimum. As a guide, this means limiting the time that an individual is exposed to a wind chill factor of –10°C or colder. Frequently manned areas should be sheltered without exceeding the allowable explosion risks. Strategies and practical tools for assessing and managing cold risks in the workplace may be found in (ISO standard 15743 and 15265). These standards support good occupational health and safety, and are applicable to offshore work in the Arctic. They include:

- a model and methods for risk assessment practices in cold work
- a model and method for occupational health care professionals to identify individuals having symptoms which increase their cold sensitivity, plus optimal guidance and instructions for individual cold protection
- informative guidelines on how to apply different international thermal standards and other validated scientific methods when assessing cold related risks
- a model and methods for cold risk management practices
- Practical examples of working in cold conditions.

P. Extended work sets and Fitness for Duty

Because of the remoteness and general absence of support infrastructure crew changes are often impractical or impossible. Whereas typical seismic crews operate on 4 or 5 week rotations, a common practice for arctic surveys has been to extend the worksets to 8 weeks or more. Consequently voyages are commenced with fresh crew who are prepared for longer than usual work periods. In order to address limited arctic access windows and the constraints imposed by limited coastal infrastructure it is often necessary to transport joining crews to offshore operational sites for crew change rather than to discontinue operations to voyage to a distant port.

- **Crew Fatigue** - Whether traditional or extended worksets are employed on any given survey, crew fatigue is a concern for any remote operation, and in particular for the arctic where the harsh environmental conditions make working on deck much more difficult, and require ever more vigilance to ensure safe operations.
- **Expedition Medicals** - A key aspect of crew selection is having crew that are prepared and fit to endure the longer workset, and to reduce to potential for a medevac. This has resulted in the consideration of 'Expedition grade' medicals, which would be conducted well before the start of the project. Crew members are subjected to a more rigorous medical than is normally applicable in other waters. This measure is intended to identify pre-existing medical conditions and facilitate stronger screening of candidates for the intended voyage.
- **Dental** - Dental assessments are a component part of Expedition Medicals and are necessary to avoid dental-related situations which can otherwise cause a halt to an arctic operation.
- **ERP / Medevac** - Emergency Response Plans are developed and tested for each intended arctic operation. These are critically important given the general absence of support infrastructure existing in arctic regions. Medevacs in arctic regions are especially difficult as operations are often outside of helicopter range and far from maintained airstrips. Suitable medevac aircraft are sparsely located throughout the region, or may not be available during the project timeline. Serious consideration for consistent and even dedicated industry standards and support needs to be developed in this area. Increased medical capacity in the form of additional embarked personnel and the provision of tele – medicine need to be considered.
- **Crew Change** – Long distances from shore give rise to use of crew boats for crew change rather than helicopters. While reducing helicopter risk this does give rise to need for vessel-to-vessel transfers and need for specialize procedures.

Q. Supplemental Personnel

As exploration seismic in the arctic involves remote and long tours, there is a requirement for additional personnel beyond the normal maritime and seismic crew required for seismic operations. Specifically, advanced medical personnel and Senior Ice Pilot professionals are needed to maintain the overall health and integrity of the mission.

Given that a medevac can take a number of hours, or even days depending upon the project location, it is essential to support operations in the remote arctic with qualified medical personnel with experience in triage and general medicine. Enhanced medical kits are provided commensurate with the voyage under consideration. Communications with medical experts ashore facilitates case management.

Ice management professionals are essential to arctic seismic operations and play a key role in officer training in addition to their roles as ice management system operators and ice management advisors. The ice management skill sets for this role goes far beyond that which is proposed as an STCW requirement and includes; an intimate knowledge of ships, their characteristics and capabilities in ice, ice management techniques, ice-seismic icebreaker escort, ice regimes, icebreaking and escort practices, ice management systems and imagery interpretation.

R. Fully Integrated Team/System Approach

Uncertainty is inherent in offshore operations and this uncertainty is magnified when working in ice and under ice. The weather, along with ice conditions and ice movement present additional hazards that must be understood and all associated risks must be mitigated to conduct safe and productive day to day seismic operations in the arctic.

Accordingly, a comprehensive approach needs to be undertaken to ensure safe, responsible, and efficient execution of the seismic programs. To achieve these goals and to work in Arctic environments an integrated team of experienced professionals are required, specifically an integrated team that encompasses a well-seasoned maritime ship's crew and seismic crew for navigating and acquiring seismic data along with experienced ice specialists armed with Arctic-proven monitoring technology and adequate surveillance tools. The team not only provides the day-to-day oversight of the program but also provides the leadership and experience necessary to react effectively to dynamically changing circumstances.

The key advantages of the integrated team approach:

- Initial selection of the most appropriate vessels, equipment, support services and personnel.
- Improved execution certainty and efficiency by having access to experience arctic personnel and specialist.
- Risk management strategy that includes a proactive and systematic identification and analysis of Quality and HSE Hazards and subsequent minimization of associated Risks.
- Reduced risk mitigation by involving technical, logistics, and HSE functions in key planning and assessment activities.
- The knowledge gained in the Hazard Identification & Risk Management process shall be integrated into daily work activities and shared with all project personnel.
- Contingency plans in place that addresses failures or loss in mission critical operational services or support.
- Risk assessment and management practices for offshore workers operating cold environments.

S. Non-Technical Issues

Understanding and managing the environmental and social impacts are license to operate issues. This is important for meeting regulatory requirements as well as being a good neighbor and minimizing impacts on local individuals and communities. The process required to secure the permissions and regulatory authorizations required to conduct seismic acquisition activity in the Arctic can be rigorous and lengthy. Regardless of the specific country involved there are sensitivities around the risks associated with seismic acquisition activity, and specifically the use of conventional seismic airgun sources and their potential impacts on cumulative ocean noise, marine mammal and endangered species, and indigenous population traditions. For the data acquisition projects this translates into writing of comprehensive Environmental Assessments for each given project, extensive computer modeling of sound propagation levels for the proposed source and for the specific area and water depths and sea floor composition, and for the specific marine mammals or other protected species being considered, as well as potential cumulative effects from other types of operations in the area; followed by actual sound verification testing before the start of acquisition, all focused at establishing minimum operating safety radii between the seismic source and any marine mammals that may be present.

Current methods and technology deployed to ensure compliance to these established safety radii include:

- the use of Marine Mammal Observers (MMO) / Protected Species Observers (PSO) conducting visual observations from the vessel;
- Passive Acoustic Monitoring (PAM) systems;
- Forward Looking Infrared Radar (FLIR) systems;
- and Night Vision Equipment.

While these are accepted and approved to provide the mitigations necessary to ensure compliance, there is opportunity for improvement. Specifically in the arctic where low light conditions, fog, and ice-covered waters could significantly impair the quality and effectiveness of these methods.

All of these methods involve having additional human resources deployed onboard the operating vessel, operating with isolated systems for recording/logging any observations. For operations that are focused on minimizing risk, placing additional personnel onboard these vessels should be seriously reconsidered. Systems and processes need to be considered which will improve the quality of the observations and better ensure the safety of the marine mammals and the operations respectively.

VI. POTENTIAL TECHNOLOGY ENHANCEMENTS

Given the difficulty that surface ice conditions cause in marine seismic acquisition, many alternative technologies have been discussed to circumvent the problem, mostly related to keeping above or below the ice.

An obvious alternative to towed marine streamer would be the use of Ocean Bottom Cable (OBC) or Ocean Bottom Nodes (OBN). Each rely on deploying either seismic cable, autonomous recording nodes or a hybrid solution of autonomous nodes mounted on a cable. These solutions have their limitations in acquisition productivity but can be the only feasible solution when surface seismic is not viable.

Several seismic contractors are trying to modify surface streamer equipment to work below the ice, using fully submerged equipment. Buoyancy for this type equipment is typically mated to the seismic gear to provide near neutral buoyancy with control surfaces to provide trim buoyancy. However this can be problematic because GPS cannot be used in the positioning of the seismic receivers. The alternative is to use a fully submerged acoustic solution.

To reduce the effects of seismic acoustic pulses on marine mammals alternative sources can be considered that either spread the acoustic amplitude over a longer time period (marine vibroseis) or limit the frequencies that are generated by airguns (e-guns). Each have some drawbacks and need further development, but could be used either ice obstructed and non-obstructed waters.

Autonomous Underwater Vehicles (AUV's) have been in Arctic use for many years now, mainly for hydrographic use. Talk of using submarines to pull streamer cables has been written about for 20+ years but still viewed as impractical or cost prohibitive.

Unmanned Aerial Vehicles (UAV's) have been discussed for use in ice scouting, and marine mammal observation. They deploy from a surface ship, transmitting visual, infrared or radar images in real time and being retrieved onboard. These can be extremely useful during time of cloud cover when satellite imagery may be limited. UAV technology is now mature although not used extensively in the Arctic yet.

A few technology enhancements that would support safe and responsible seismic data acquisition in the arctic would include:

- Alternative seismic sources (marine vibroseis, or other), focused at reducing cumulative ocean noise effects, as well as mitigating any potential negative impacts on marine mammals and endangered species.
- Purpose built, fully arctic capable, ice classed seismic vessels
- Improved ice imaging, modeling, and forecasting systems and database
- Improved battery/power technology to extend the useful cycle time for ocean bottom based seismic sensors.
- Improved acoustic transmission capabilities for command/control/QC and real time collection of seismic information from ocean bottom based seismic sensors.
- Improved high bandwidth, high latitude communication systems
- Improved subsurface handling and towing equipment and capabilities to allow for the safe and consistent collection of towed seismic data in and under ice obstructed waters.

- Improved satellite imaging technology to provide faster and better images for ice management systems.

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