Working Document of the NPC Study:
Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources
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Paper #6-8

ICE MANAGEMENT

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)

6-8	**Ice Management**
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SUMMARY

All marine operations taking place in an ice regime that are required to maintain their position due to the nature of the work event will require some form of an ice management system to maintain safe operations. The following document provides a high level example of ice management systems that have been developed over time to allow safe operations in a number of seasonal ice regimes. These systems were successfully applied during the 1980's and 1990's in the Beaufort Sea drilling campaigns and the same elements have been applied offshore Sakhalin Island and in iceberg-infested waters off Newfoundland and Greenland. Today's technology in ice detection, monitoring and ice event forecasting along with improved vessel capability continue to improve the capability and reliability of ice management systems.

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Introduction

Ice management systems are unique to the nature of operation, number and capability of the support vessels and the ice regime characteristics. There are a few main elements in all ice management systems, such as;

1) Ice and weather forecasting, detection and monitoring for situational awareness to support the ice management system
2) A working ice alert system that supports the nature of the operation
3) Support Vessel(s) conducting physical ice management by breaking, pushing, washing, towing or providing ice reconnaissance

The ice management system must support an ongoing safe work process in an ice regime. If conditions change in a negative way there must be an alert system that stops the work process in a timely manner, and if needs be, allow for a safe abandonment of equipment from the work site.

In all ice management systems proper planning and preparation, having the right equipment and support services along with experienced personnel are essential factors for a safe and successful operation in an ice regime.

Successful Historical Ice Management Operations in Ice Regimes

Experience has shown that ice management systems can provide for safe and reliable operations in ice regimes. The following are historical examples of successful operations in ice regimes along with a brief description of their ice management systems;

CANMAR Floating Drillship Operations (1976 to 1990, Canadian / USA Beaufort and Chukchi Sea)

Operations conducted in seasonal pack ice and new light first year managed ice conditions using one to five ice management vessels depending on the nature of the ice regime and availability of support vessels. The physical ice management techniques were based on the number and capability of the support vessel(s), the ice capability of one of four drillships, and the ice regime characteristics. An ice alert system supported by ice and weather forecasting, detection and monitoring for risk assessment was used to conduct safe operations. Operational disconnect from the eight point mooring system was through standard anchor recovery methods using one or two AHTV (Anchor Handling, Tug, Supply Vessel(s). In an emergency an RAR (Remote Anchor Release) system was used to disconnect from the moorings.

Beaudril / CANMAR Kulluk Drilling Operations (1983 to 1993 Canadian / USA Beaufort)

Ice management operations were similar to CANMAR Drillship operations, however because of the design of the Kulluk, operations were conducted in much more challenging ice conditions. The physical ice management techniques were based on four, purpose built, ice capable management vessels. Again, an ice alert system supported by ice and weather forecasting, detection and monitoring for risk assessment was used to conduct safe operations. Operational disconnect from the twelve point mooring system was through either standard anchor recovery methods with the AHTV or by a RAR system.

Sakhalin Energy, Molikpaq Production Operations (1999 to 2007, East Coast Sakhalin Island)

The nature of this operation took place in two stages. In 1999 the CSO Constructor installed the pipeline from the Molikpaq facility to the offshore loading buoy system (SALM) position. Physical ice management was used to assist the Constructor to station keep along with a strong reliance on ice and weather forecasting, detection and monitoring for risk assessment purposes.

From 2000 to 2007 the operation centered on open water seasonal production from the Molikpaq production facilities through an offshore loading buoy system (SALM), into an ice strengthened FSO and then onto ice strengthened tankers. The seasonal ice management system for the most part was designed around springtime ice conditions for the raising of the SALM buoy from it's winter storage on the seabed and again for the lowering of the SALM buoy to the seabed for winter storage. The operation of raising and lower the SALM required the work of a small non-ice class work vessel which was the weak link in the over all process. The ice management system had a strong focus on ice and weather forecasting, detection and monitoring for risk assessment as well as vessel and fixed wing ice reconnaissance to confirm locations of potentially hazardous ice conditions in the ice regime. Support vessels conducted physical ice management to support the small workboat operations.

Sakhalin BP (2005 and 2006, NE Coast of Sakhalin Island)

Rosneft and partner BP conducted exploration drilling operations from semi-submersible floating rig "Transocean Legend." The Transocean Legend being a semi-submersible had zero tolerance for ice and the ice management system focused primarily on ice and weather forecasting, detection and monitoring for risk assessment as well as vessel and fixed wing ice reconnaissance to confirm locations of pack ice in the ice regime.

Expedition 302 – Arctic Coring Expedition (2004, Lomonsosov Ridge, 250 km from the North Pole

The coring operation took place off the deck of the ice strengthened AHTS "Vidar Viking" with physical ice management support from ice breakers "Oden" and "Sovetskiy". Ice and weather forecasting, detection and monitoring for risk assessment purposes along with the experience of vessel crews were a key to the success of this project. While coring was being conducted, the Soyuz operated 'upstream' breaking large floes into smaller floes that were further managed by the Oden to allow the Vidar Viking to conduct coring operations in deep water.

Grand Banks and NW Greenland Iceberg Management Programs (1970s to now)

Iceberg management programs have evolved since offshore oil exploration activities commenced in the early 1970s on the Grand Banks of Canada. Industry operating in iceberg waters continue to utilize an ice management system that includes ice and weather forecasting, detection and monitoring for risk assessment purposes, an ice alert system and physical ice management in way of washing and towing icebergs.

Industry Ice Management Trial Programs

Imperial Oil and ExxonMobil conducted physical ice management trials in Fram Strait in 2009, and Statoil conducted trials in NE Greenland in 2012. Both events allowed these operators to understand the capability of newer marine support vessels such, as Oden and Fennica, to manage particular seasonal ice regimes for a station-keeping vessel. Exercises such as these allow industry to confirm historical operations and improve on the capability and needs for a modern ice management system.

Ice Management Research

There is a number of relative research programs associated with the process of ice management, both through academic institutions and industry sponsorship. The following is a list of some of these programs and information sources taking place today;

1) Canada NRC models of managed ice loads on floaters
2) NTNU (Norwegian University of Science and Technology), modeling work
3) MUN (Model United Nations), modeling work
4) PRNL (Petroleum Research Newfoundland), sponsored research programs
5) Published papers by companies such as and not limited to ExxonMobil, Statoil, Shell, ConocoPhillips and Chevron

Hazardous Ice Events

"Hazardous ice is any ice regime condition that exceeds the capability of the work process to safely operate. Ice management systems are designed around this work process to deal with a hazardous ice event and maintain safe operations. A few examples of hazardous ice events are as follows:

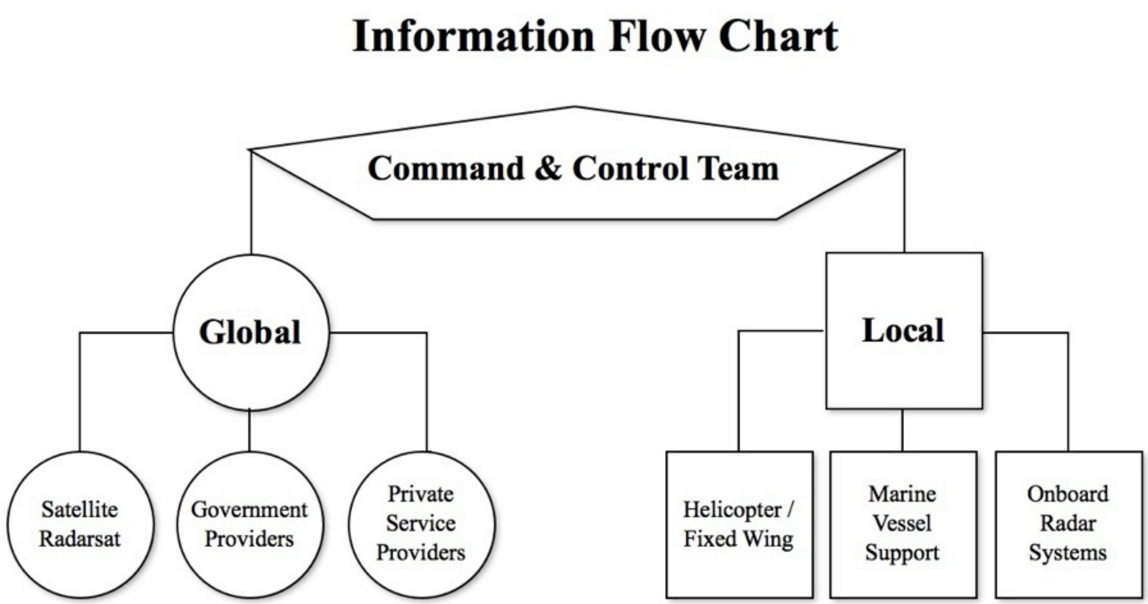
1) Hazardous ice can simply be an unmanaged ice feature forecasted to approach the work site that exceeds the capability of the work process to continue
2) Hazardous ice can also be physically managed ice that cannot be safely managed sufficiently before forecasted to arrive at the work site.
3) High drift rates can cause a physically managed ice regime to become a hazardous ice event
4) Non-hazardous ice can become hazardous if one of the support vessel suffers mechanical failure or inexperienced bridge crews fall behind on the physical ice management process

Seasonal Operation Lengths for Arctic Floating Systems

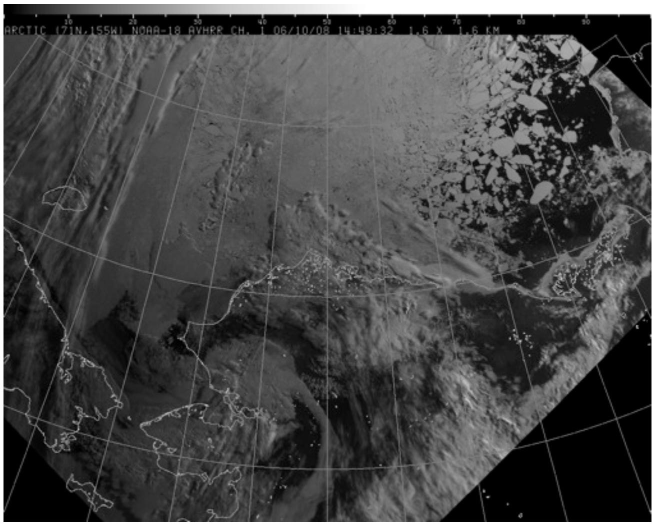
The overall ice management system and area of operation will drive season lengths for floating exploration and development systems. Though an exploration project may take place between early July to early November in the US Chukchi / Beaufort, the ice management system in an emergency should be able to provide safe ice management support much longer than the planned intended exploration period.

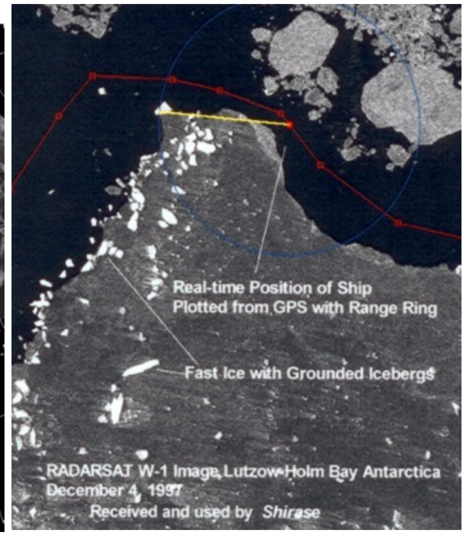
Ice & Weather Forecasting, Detection and Monitoring

Reliable ice and weather forecasting is paramount to the success of an ice management system. There may be limited capability to break ice so it is important for ecological and capacity reasons that only that ice that will impact the operation needs to be broken. Thus determining the accurate ice drift direction is one of the pre-eminent aspects of an ice management operation. Early detection and continuous monitoring of a potential hazardous ice event through the various information sources noted in this section allows the command and control team to conduct an over all risk management plan and manage the plan through the ice alert process.

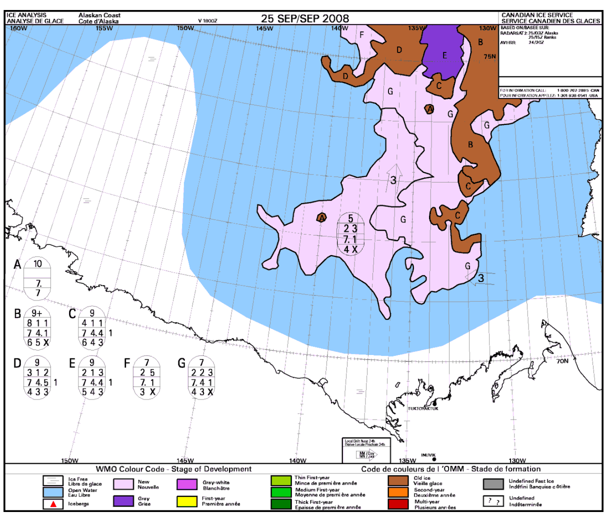


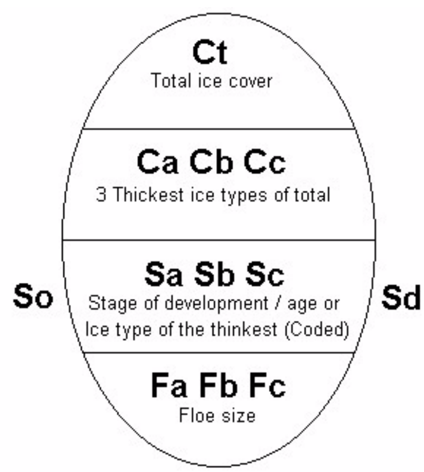
NOAA Satellite & Radarsat Images



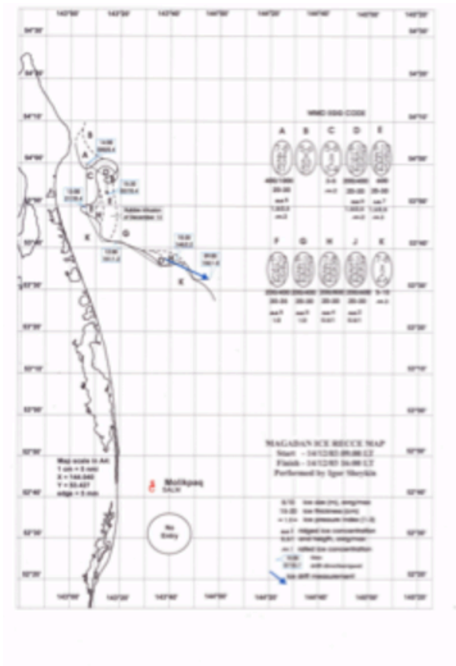


Ice Analysis Maps



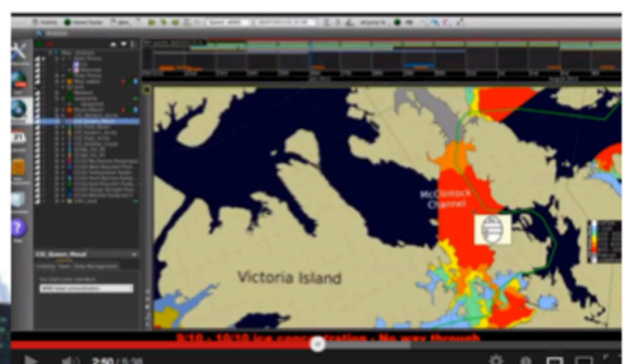


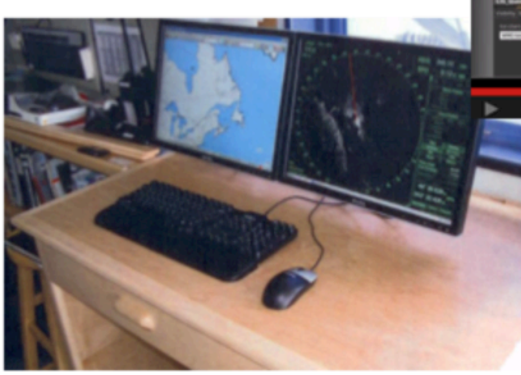
Vessel, Helicopter & Fixed Wing Reconnaissance



Ice Radar Detection & Monitoring Systems

Such as Enfotech and Narwhal





New Technologies on the Horizon

It has been some time since a full-blown ice management operation has been active. The Kara Sea is probably the most likely recent locale and even there, the focus is on ice avoidance much more than working within an ice regime that is constantly changing. The exceptions perhaps being Sakhalin and the iceberg management programs active off Canada's east coast and West Greenland. Since the 1980s when companies such as Beaudril and Canmar produced a flood of innovations it has been much quieter.

But what was once the typical offshore ice management operation using live tracking of incoming ice floes and ice bergs using shipboard radar and managed by ice strengthened anchor handlers is now a lot more sophisticated. The use of short-term, primarily reactionary skillsets, to handle immediate ice challenges no longer exists and is simply not acceptable by either industry or regulators.

With entry to Arctic regions becoming easier, a much greater focus by exploration companies has brought an emphasis on new innovations being developed, much of it through the declassification of military technologies. The commercialization of satellite sensors such as RadarSat (MDA), TerraSarX, Pleiades, CosmoSkyMed and the availability of open-source platforms like Modis (NOAA) and Envisat/Sentinel (ESA), has made near-real-time ice imagery available for every ice challenged area on the planet on a near-daily basis. The development and use of ice radars such as Rutter's Sigma 6 and others and the recent growth of data management and control systems such as Narwhal, Saab and others are online now or soon will be and all show some promise.

Development of high-speed remote satellite communications such as CapRock; sea-floor fibre-optic networks of sensors all providing live data back to ice management command and control systems; long-range fixed wireless networks; UAVs (drones) such as Boeing's ScanEagle; wave gliders; inexpensive passive/active gates that use advanced upward looking sonar to find ice bergs, bergy bits and growlers entering a perimeter defense area; lighter than air kites (e.g. Hellikite) or aerostats, with a variety of onboard kite and drone carried sensors from visual to IR to SAR; and many others will radically change the game by allowing much greater control of data to assist with immediate operations, short and long term planning ice alerting and to mitigate risk to health, safety and the environment.

Perhaps the next step, and hopefully available within a year will be replacing the long-standing helicopter ice reconnaissance with semi-autonomous UAVs that can monitor ice conditions over a much wider area through greater endurance, less susceptibility to weather, less reliant on ship motion if launched and recovered from a vessel and immune to darkness if using SAR. This is certainly much less risk than flying humans in often-harsh conditions.

Coming next, that promises the next generation of monitoring are SAR sensor satellite clusters providing almost continuous coverage of specific areas. And this will likely replace the UAV options being explored today.

But the major challenge with many of these new technologies, especially the aerial options, will be regulatory approval from agencies, which through no fault of their own, be incapable of fully evaluating the benefits that can be realized due to their own internal organizational limitations and challenges.

Ice Alert Systems

Ice alert systems will vary in detail depending on the nature of the operation. The main concept is to capture what is globally taking place in the ice regime and ensure that operations fit with the level of alert.

An ice alert system for working in an iceberg regime usually incorporates a three-zone system, zone distances being relative to ice support vessel capability.

An example of an ice alert system for an Arctic offshore drilling project in pack ice is as follows:

1) (HT) HAZARD TIME - The time for a potentially hazardous ice event to arrive at the operation
2) (ST) SECURE TIME - The time required to stop well operations and secure the well. Also known as T-Time (Modified for other operations)
3) (MT) MOVE-OFF TIME - The time required to safely secure mooring systems and safely evacuate the work site
4) (CDT) CLEAR DECK TIME - For mooring recovery only, the time required to ensure that both anchor handling vessels can be made available at the rig with decks clear for anchor handling

In the event that a hazardous ice event is projected to be approaching the operation, the alert system will progress through an established series of numeric / colour alert levels of increasing severity. They can be described as follows:

ALERT LEVEL	TIME CALCULATION	ACTION
0	HT- (ST + MT) = (Greater Than 24 Hrs)	Normal Operations
1	HT - (ST + MT) = (Less than 24 Hrs / Greater Than 12 Hrs)	Operate With Caution
2	HT - (ST + MT) = (Less Than 12 Hrs / Greater Than 6 Hrs)	Restricted Operations
3	HT - (ST + MT) = 6 Hrs	Secure Well Operations
4	HT - MT = 6 Hrs	Recover Anchors
5	HT = (Less Than 6 Hrs / Greater Than 2 Hrs)	Move Rig

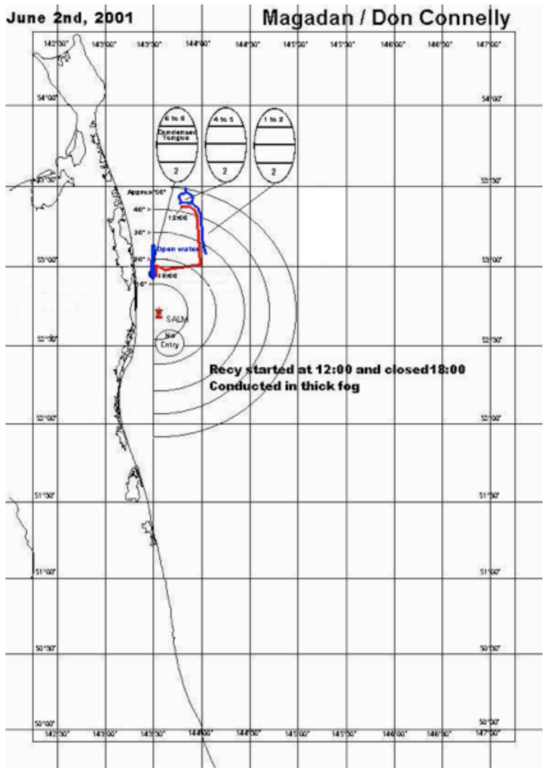
Physical Ice Management Operations

Offshore projects working in an ice regime will need to understand where the hazardous ice is and have protection for a hazardous ice event; this will drive the need for physical ice management. Support can be as simple as providing ice reconnaissance in an open water scenario, to surveillance and towing of icebergs, to physical ice management in pack ice. The variables are significant and having procedures in place supported by experience and knowledge of the overall systems capability and a full understanding of the ice regime is a significant factor for a safe and successful operation. There are a number of ice management techniques that will come into play depending on the operational variables. These techniques will be discussed in this document.

Ice Reconnaissance

Gathering global ice regime information allows the work process to maintain an ice alert system, which is a key part of a successful ice management system. The ice regime's condition and forecasted conditions will come from a number of sources such as; governmental and private service providers using technology such as satellite imagery analyzed by experts, fixed wing or helicopter reconnaissance where ice experts fly a pattern and construct ice information maps and from support vessels with experienced bridge crews or ice navigators. All should be used together to maintain the best level of understanding of the working ice regime. One element of the support vessel reconnaissance that truly adds value to the risk analysis process is the ability to actually sample the ice conditions to get a feel for it's manageability. Also of value is the ability to conduct reconnaissance in restricted visibility to understand manageability conditions and changes to the existing satellite or fixed wing ice information.

Sample of a Support Vessel Ice Reconnaissance Map



Support Vessel Physical Ice Management Process

There is a number of ice breaking patterns, pushing and washing techniques used by ice breaking support vessels to support a fixed working process in a pack ice regime. The ice management process and when to use it, is driven by a number of variables such as the type of ice regime and the number and capability of the support vessel(s).

Management of Icebergs is unique and includes monitoring the global regime, and if need be intentional deflection by various towing or washing methods.   For towing these methods include a one or two tug response process, using either a large-diameter buoyant towing hawser or net arrangement.

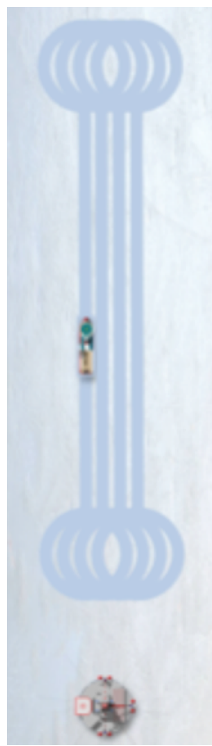
Ice Management Patterns

The following ice management patterns are used to physically work an ice regime. Subject to ice regime conditions there may be times that two or three patterns might be used by a fleet management process. Other times only one pattern may be used. Support vessels may need to work tight patterns close to the fixed structure if drift rates are high and changing, yet the fleet may spread out working further up drift if drift rates are slow and constant. It all depends on the dynamics of the regime and what will work best for the support vessel configuration and capability of the support fleet.

Linear Ice Management

Linear ice management is where a support vessel breaks ice up-drift of the fixed structure in straight lines that are parallel to the direction of ice drift. In light ice conditions, utilizing the ice breaking vessels at high speed can result in significant areas of ice being broken by the wake from the vessel. This icebreaking pattern is typically used:

1) When the ice drift direction remains relatively constant
2) In high concentrations of thin or lightly deformed ice that is moving very rapidly, such as new first year ice
3) In low concentrations of fast moving, heavily ridged, small ice floes that are easier to break than to push



Sector Ice Management

Sector Ice Management is a pattern that provides a wide coverage of managed ice on either side of the drift line. The procedure entails running back and forth across the drift-line between two designated bearings that create the sector. This pattern is typically used:

1) For pushing and breaking
2) In high concentrations of thick or heavily ridged ice
3) When drift directions are variable or rapidly changing
4) As an up-drift search pattern for ice in poor visibility

Circular Ice Management

Circular ice management is a procedure that requires the support vessel to run in a circular pattern in a position up-drift of the fixed structure or alternatively, in circles around the fixed structure. The diameter of the circles will vary with distance away from the fixed platform, the speed of the ice drift and the running speed of the support vessel. This pattern is typically used:

1) When working new ice closer to the fixed structure
2) When the ice drift is rapidly changing, unpredictable
3) Around the fixed structure when the ice has stopped drifting

Pushing Ice Floe

Pushing rather than breaking can be a very effective way of removing medium and large heavily ridged hazardous ice floes from the drift line. The pushing direction is usually at right angles to the approaching ice as described in sector pattern management. The benefit of pushing ice instead of breaking it is by pushing an ice floe the threat is removed, whereas, if the ice is broken then the remnants of the broken floe may still pose a threat to the fixed structure unless they are broken into sufficiently small pieces. There have been cases of two or three icebreaking support vessel, all pushing on a large heavy floe well up the drift line, deflecting the hazardous floe away from the fixed platform. A word of caution, a reliable forecast on ice movement is needed before attempting this procedure as otherwise the floe may drift back towards the fixed platform.

Washing

There are two types of propeller washing, traditional and pod propulsion and they are primarily used to clear ice buildup on the fixed structure or wash ice floes off the drift line.   Close in washing from support vessels in the event of ice pressure can also provide benefits in some situations.

Close in Washing to Relieve Pressure

Traditional Propulsion Washing

This method of physical ice management from traditional linear twin-screw propulsion systems works well on well-managed small ice floe and thin first year ice. Typically this type of management takes place close around the fixed structure. It is not recommended for large icebreakers that do not have good maneuverability to work in close quarters to the fixed structure for washing.

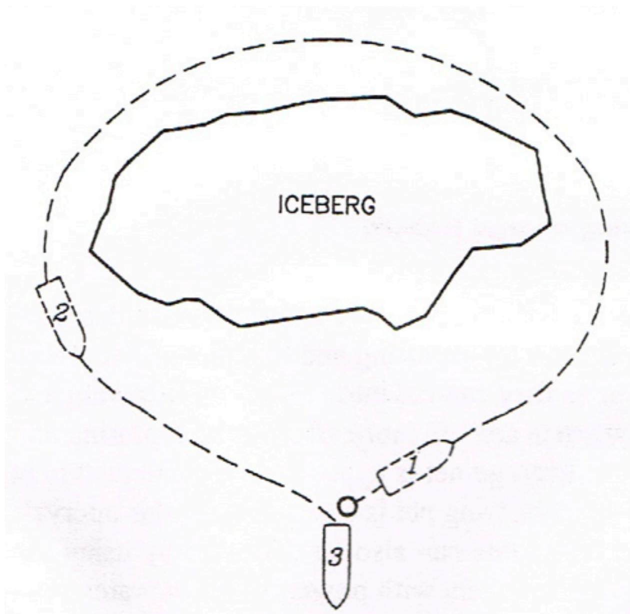
Pod Propulsion Washing

One of the big advantages of a Pod propulsion system is its superior capability to provide ice clearing with propeller wash while maintaining position. Large ice management vessels with this type of propulsion are very maneuverable and can work in close to the fixed structure for washing operations. If a physical ice management system incorporates at least one pod propulsion vessel in the system this vessel should be the vessel working close quarters for washing.

Iceberg Towing

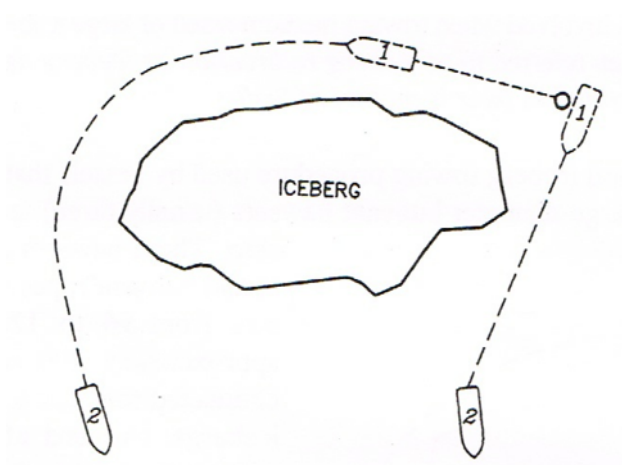
Single Towing Vessel

The towing hawser or towing net is deployed with a sea anchor and pickup line at the pick up end of the hawser or towing net, while the towing vessel encircles the iceberg and reconnects up the hawser or towing net into the main towing wire.



Two Tugs Towing

The main concept is two tugs connect up to each other to deal with larger icebergs.



Support System Capability

The question of "*how does one know that the ice has been managed or can be managed sufficiently*" is extremely important. In general terms, the ice management command and control team responsible for situational awareness on the fixed structure decides this using tools such as load monitoring instrumentation, weather / ice forecasting and feedback from the ice management vessel Masters working the ice regime. The command and control team must understand what the operation can safely handle in a managed ice regime and keep the OIM / Rig Manager updated. This comes through experience, not just calculation. The ability to say, yes this can be managed to meet an acceptable ice regime condition, is an ongoing exchange process between the support vessel masters and the professional command and control team on the structure.

A lot of the time this can be decided in a global strategic review of the regime with knowledge of the systems capability. On some occasions it is prudent to have one of the support vessels investigate an ice feature of concern from a tactical perspective and conduct a trial breaking of the ice feature to determine its manageability.

Support Vessel Deployment Tactics in Pack Ice

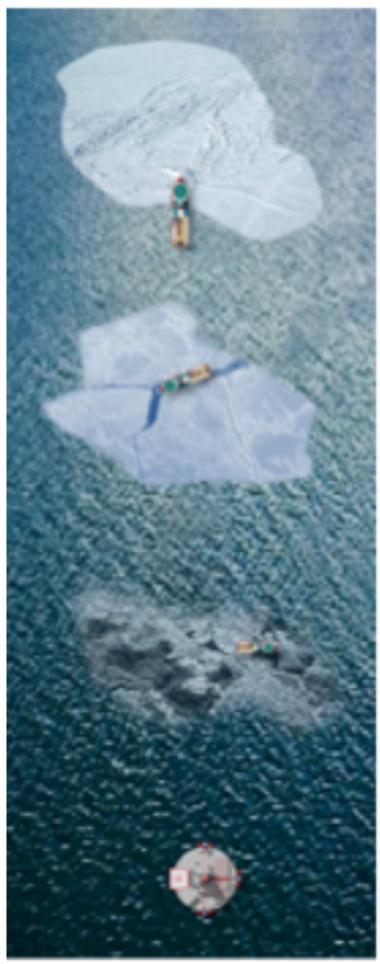
The time of year and area of operation will drive the type of ice regime you will work in. Support vessel selection and ice management tactics will have to fit the ice conditions forecasted and being experienced. A standard rule for working in pack ice is the smaller or more maneuverable support vessels work closer to the fixed structure and the larger vessels work outside the smaller vessels. If all support vessels are of the same size and capability the vessels rotate their position in the ice management deployment, typically having the Master on the bridge while working close quarters to the structure. For the purpose of this document we will look at two Arctic seasonal conditions that have distinct methods of physical ice management and vessel deployment. These two seasonal ice regimes are "Spring Break Up" and "Winter Freeze Up".

Spring Break Up

Spring break up conditions is usually a mixture of pack ice conditions, invariably blanketed with fog for a significant amount of the time. Ice floes will vary in size and age along with rubble and ridge deformation. The following is an example of a three-vessel deployment in pack ice conditions. All with standard ducted propeller propulsion, one large ice management vessel and two smaller.

Three-vessel Support Fleet

Unlike winter freeze up; the two outside vessels in these conditions do not usually use "Circular" ice management, as the ice features are usually heavy and more suited to "Sector" ice management techniques. A typical operation might have the outside ice management vessel breaking up the larger floes, with the middle again breaking or pushing, while the inside vessel is pushing or washing.



Winter Freeze Up

Winter freeze up means new ice forming that can still have remnants of the previous winter's ice mixed in with the new ice. Working conditions will now be mostly in darkness, in very cold temperatures and with frequent storms. Vessel deployment usually consists of all vessels spaced out up drift working circular patterns with the outside vessel possibly working a linear if conditions are right. The following is an example of a three-vessel support configuration.

Three-vessel Support Fleet

In new ice conditions it is important to maintain maximum speed to have the greatest destructive force using the wake of the vessel to break the light first year ice. One method of doing this with the outside support vessel is to maintain a straight line of transit on the drift line. The length of this transit is relative to the drift speed. The higher the drift speed the shorter the transit before turning on the outer point on the drift line. (See Linear Pattern) The outside vessel maintains this pattern while the inside management vessels work a circular pattern to address any drift directional fluctuations. The higher the drift rates the tighter the pattern. If broken ice starts to build at the site the inside support vessel performs a wash. Washing operation is most effective when it is a podded vessel.

Conclusions

1) When and where to conduct physical ice management in an ice management system is based on a risk exposure of the global (Strategic) and local (Tactical) ice conditions along with knowing through experience what the capability of the over all ice management system is.

2) Knowing basic methods of physical ice management and applying the best method to the ice regime that is in force at the time determine how to conduct physical ice management.

3) The make-up and capability of the support fleet, along with the type of offshore operation will drive how ice management will evolve. The best method to be used should be determined by the nature of the regime being worked in and the support vessel make up.

4) The ice drift direction needs to be accurately determined to avoid unnecessary breaking of ice and wasting resources

5) Feed of actual metocean conditions to be given to forecast providers to enable better calibration of weather models for remote areas.

6) There is always risk when working in an ice regime, especially in pioneering operations where the ice regime may not be fully understood. One must learn to understand the risk through prudent over reaction and the use of a realistic ice management system that fits the ice regime being work in. This prudent over reaction may then be gradually reduced as any peculiarities of the ice regime begin to be better understood. History shows that offshore operations using ice management systems can be conducted in a safe and reliable manner.

7) An ice management system with procedures such as an ice alert system and an ice / weather risk assessment system should be designed specifically for each type of operation and reviewed on a regular basis. Data collected should be recorded carefully and in standard formats to allow cross-reference to data from previous years to assess analogues to determine how a particular ice event may progress.