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Ice Intelligence Retrieval by Remote Sensing – Possibilities and Challenges in an Operational Setting

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ABSTRACT

Detecting ice drift velocity when operating offshore in ice-covered waters is crucial during marine operations, as ice actions affect station keeping and ice management. Furthermore, other ice data/intelligence such as ice concentration and thickness are important parameters to determine ice resistance, evaluate performance of icebreakers and predict ice actions on structures. Different sensors are available and capable of providing ice intelligence; however, no single sensor is capable of providing all necessary ice intelligence alone. Thus, an operational scenario depends on combining ice intelligence from several sensors. Previous studies have assessed potential sensors that detect ice drift; however, the practical implications of applying these technologies in operational scenarios are often disregarded. This paper reviews the various sensors currently available for sensing ice drift and other ice intelligence, and their abilities to provide ice information for operational scenarios. The sensors satellite SAR, marine radars and optical cameras are assessed qualitatively in a case study. The study considers the scenarios of drilling and production of hydrocarbons at the Korpfjell prospect in the central eastern Barents Sea, where the Norwegian Ministry of Petroleum and Energy recently awarded a license. The case study shows that during an operational scenario, ice intelligence must be provided by a combination of regional and local sensors. Furthermore, great potential exists to combine intelligence from different sensors to form an operational monitoring, detection and surveillance tool for operational decision support.

KEY WORDS: Ice Intelligence; Ice Drift; Ice Management; Remote Sensing; Decision Support; Case Study; Barents Sea; Arctic Marine Operations.

INTRODUCTION

Offshore operations are demanding, even in open waters. Operations in ice-infested waters need to consider, identify and manage hazards posed by various ice features. In order to avoid and/or reduce the frequency and consequence of collisions with hazardous ice features, ice management may be performed. Eik (2008) defined ice management as the sum of all activities where the objective is to reduce or avoid actions from any kind of ice features.

Detection, tracking and forecasting of sea ice and glacial ice are considered being part of the ice management. Parameters such as ice thickness, concentration and drift need to be determined in order to assess that loads do not exceed design values for a structure and then if so envisage efficient ice management for load reduction.

Ice intelligence may be obtained in several ways. Traditional methods for providing information on ice drift velocity include deploying physical trackers on the ice, commonly by means of helicopters. This deployment method represents a risk for crew and equipment, has limited operability due to weather and light conditions and has a high carbon footprint. Ice concentration and thickness are normally determined manually by experienced ice observers on board. However, manual observations lack consistence and suffer from low log-in frequency (Hall et al., 2002). Therefore, the motivation for the use of remote sensing technologies operationally to automate ice intelligence retrieval is high.

Physical ice management requires tugboats or icebreakers to tow or break the ice. These vessels are expensive to have on standby on location, and operators may choose to rely on vessels that serve several fields in vicinity of each other or are on standby in nearby ports. However, in remote locations, the mobilization and transit times for such vessels may be substantial. In order to ensure safe operations and avoid over-specification of the available resources, automatic ice intelligence retrieval coupled with drift prediction models of a certain time period may ensure optimal configuration of resources.

Hydrocarbon exploration and production in Arctic conditions have been performed since the 1960s. However, there are only a few places around the world where year-round offshore hydrocarbon production in icy waters have taken place. Recent licenses awarded on the Norwegian Continental Shelf opened new locations for drilling in the central eastern Barents Sea, where the presence of sea ice and threat of icebergs has to be taken into account.

This paper considers an operational case study on the Korpfjell location, central east in the Barents Sea. Statoil plans to perform drilling at this site in 2017. Through a case study, the ice intelligence requirements on different planning time horizons are established for the scenarios of drilling and year-round production. Several remote sensing technologies are evaluated in terms of their performance and possibility to provide the required ice intelligence.

The structure of this paper is as follows: Remote sensing technologies and platforms currently available are introduced, and their application to the remote sensing of ice intelligence are discussed. The framework for the case study of the Korpfjell prospect is described, along with the parameters according to which the remote sensing techniques are evaluated. The remote sensing technologies chosen are compared and evaluated applied to the case study. A "three-layer concept" of ice intelligence is presented. Lastly, the results are discussed, and the conclusions are presented along with suggested further work.

REMOTE SENSING OF SEA ICE

Remote sensing is defined by Elachi and van Zyl (2006) as *the acquisition of information about an object without being in physical contact with it.* Information about the object is acquired by detecting and measuring changes that the object causes in its surroundings, by either electromagnetism, acoustics or potential.

There are several sensor types and platforms relevant for remote sensing of sea ice. Such sensor types include synthetic aperture radar (SAR) and other satellite based technologies, marine radar, thermal/infrared and optical cameras. These sensors can be deployed on platforms such as satellites, unmanned aerial vehicles (UAVs), ships, bottom-mounted buoys and autonomous underwater vehicles (AUVs). For this paper, only sensors capable of providing real-time or near real-time information are considered. This section introduces each platform and their relevant sensors, with focus on sensors relevant for the case study.

The satellite platform

The development of satellite technology has made it possible to gain detailed information about the planet, especially in remote and logistically challenging locations such as the Arctic. Imaging radars are especially suited for the task due to their all-day, all-weather capability.

Most satellites used in meteorology and earth observation are deployed at high inclination or *polar* orbits (Lubin and Massom, 2006), where their ground tracks converge spatially at high latitudes. Thus, polar areas have frequent temporal coverage by the sensors.

Due to technological limitations, trade-offs exist between coverage and spatial resolution. High-resolution sensors tend to offer limited spatial coverage over a narrow swath (≤100 km). Medium to coarse resolution (>250 m) sensors typically operate on much wider swaths (>1500 km) (Lubin and Massom, 2006). This is a major issue in operation scenarios that require a high temporal and spatial resolution, such as monitoring of highly dynamic sea ice.

Data from satellite imagery have operational value for planning operations at a given location, as they can provide information on the historical climatic conditions and the regional ice conditions. Furthermore, current satellite images may be used to detect and monitor hazardous ice features and conditions in near real-time. For example, several providers use satellite data to create near-real-time sea ice maps and drift charts, of which examples are illustrated in Figure 1. Such maps are typically updated once per day, produced for large areas and have low spatial resolution.

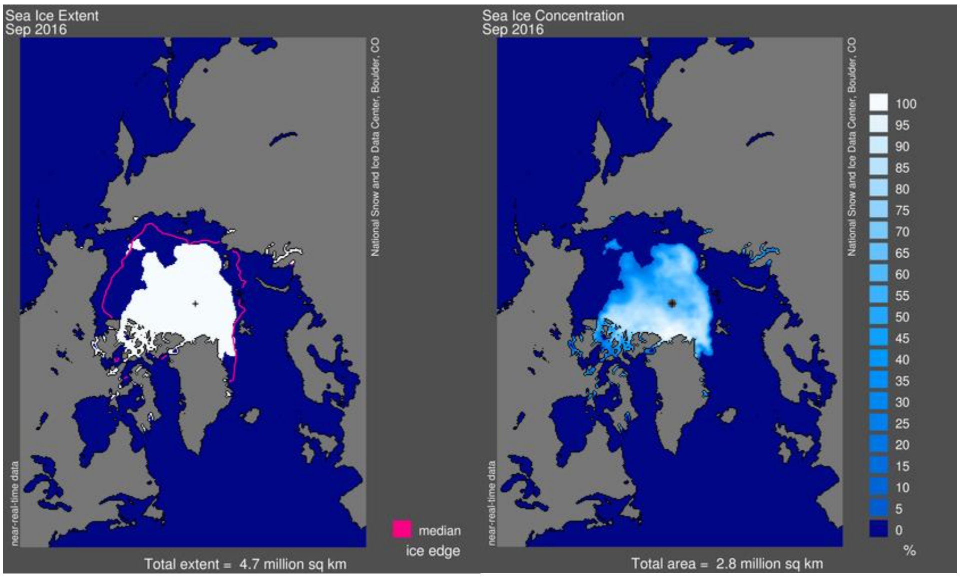

Figure 1. Monthly sea ice maps for September 2016, produced by the National Snow and Ice Data Center (NSIDC).

Several types of sensor technologies are used in satellite remote sensing. For the purpose of this study, the Synthetic Aperture Radar is of primary interest.

Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) is an active microwave sensor system, unhindered by darkness or cloud cover. The radar waves may penetrate dry snow to provide volume structure information about the underlying ice. This property makes it a useful sensor to discriminate different types of ice, such as distinguishing the saline first-year ice (FYI) from the less saline and harder multi-year ice (MYI).

SAR products are high-resolution images where the grey scale is determined by the strength of the received radar return. The strength of the signal is proportional to the roughness of the surface, which is proportional to the wavelength of the radar pulse and the incidence angle of the radar. Because the incidence angle varies over the scene, materials with the same properties may appear different over the same scene. This makes automatic classification and analysis of SAR images challenging. Figure 2 shows a SAR image taken by Sentinel-1 over the ice edge in the eastern Fram Strait. The image illustrates well the difference in backscatter from the open sea surface, ranging from virtually no backscatter (black) to very strong backscatter (white), depending on the incidence angle.

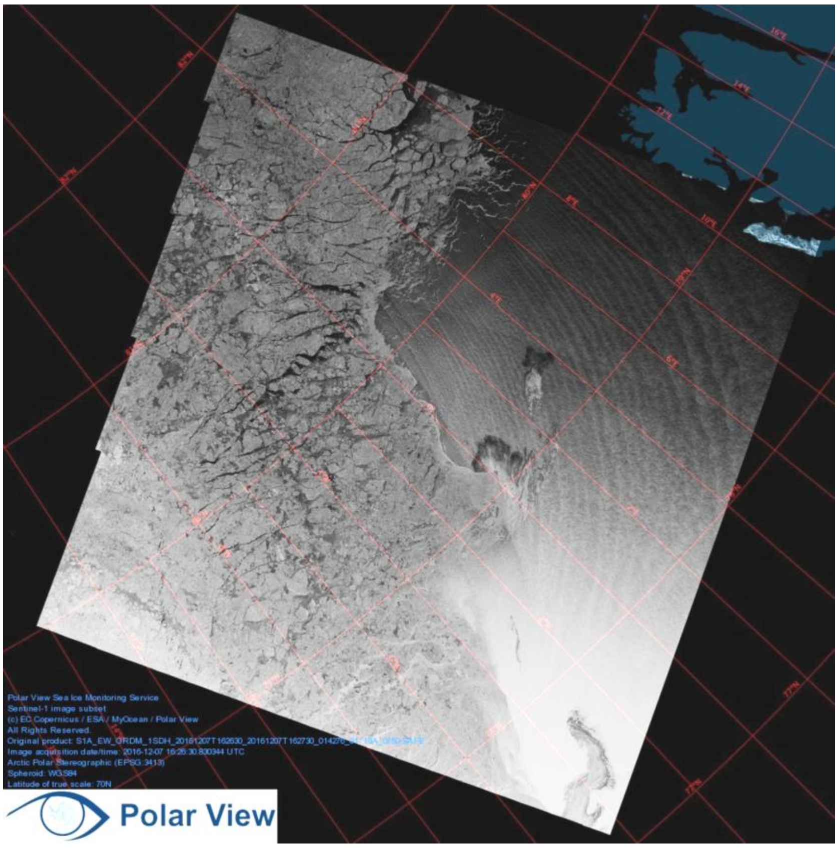

Figure 2. Example of a Sentinel-1 SAR extra wide scene from the ice edge north-west of Spitsbergen (masked in blue). In the image, sea ice can be seen to the left, while the sea closest to Spitsbergen is ice-free. Note the difference in ocean surface appearance over the incidence angle range of the image, ranging from almost white in the lower right corner to black at the top. (Image courtesy of Polar View).

Marine radar

The International Conference on Safety of Life at Sea (SOLAS) of 1974 require all ships to be equipped with marine radars. Several commercial brands of dedicated ice radars exist, however their primarily use is for navigation in ice.

As all vessels are required to have marine radars, there has been an interest in using this sensor to retrieved ice intelligence, to avoid installation of proprietary and potentially costly additional sensors. Kjerstad et al. (2017) have proposed an automatic real-time algorithm that estimates the local ice drift near a vessel in real time, using the marine radar. Here, local refers to an area of a few (0.5 to 6) nautical miles in radius. The algorithm uses image processing to detect and track the motion of N distinct features (DFs), and two Kalman filters to select DFs and decouple the vessel motion. However, the algorithm is not capable of identifying ice features.

Unmanned aerial vehicles

With the improvement of remote controlled technology, there are several attempts of using UAVs for ice observations. Their flexibility in geographic coverage and low investment cost paired with high potential spatial and temporal resolution of collected data make this platform a strong candidate for ice observation. However, UAVs are sensitive to extreme environmental disturbances such as low temperatures, high wind speeds and atmospheric icing, which make reliability of these platforms an issue in an operational setting (Haugen et al., 2011).

Autonomous underwater vehicles

AUVs operate underwater below the ice, which makes it independent of surface conditions such as light, wind and temperature conditions. These properties make AUVs a good candidate for ice monitoring during harsh conditions in Arctic and cold climate environments.

Norgren and Skjetne (2014) investigated AUVs as a potential platform for ice monitoring. An Acoustic Doppler Current Profiler (ADCP) instrument can be used for measuring the ice-instrument relative velocity. However, limited range and deep waters put limitations on the applicability in the Arctic.

Infrared and optical cameras

Cameras may be mounted on platforms such as the ship itself or on UAVs.

Infrared sensors detect difference in thermal emissivity of objects. This is especially relevant for iceberg detection, as icebergs in general are much colder than the surrounding water. However, camera images are of low use in conditions with low visibility. Furthermore, maintenance of the cameras in atmospheric icing conditions and/or snow can be an issue.

Optical cameras are practical for monitoring the close surroundings of a vessel. Lu et al. (2016) have demonstrated use of optical cameras mounted on a vessel to identify nearby ice conditions. The algorithms developed by the authors were able to determine local ice concentration and thickness, traditionally determined manually by trained ice observers on board. A 180° camera looking obliquely towards the ship transit direction was used to provide information on ice concentration. The concept is illustrated in Figure 3. A downward-looking camera on the ship's side captured events of tilted pieces of broken ice, and was used to identify ice thickness.

Furthermore, floe and brash ice size distribution may also be retrieved from optical cameras, i.e. as presented by Zhang and Skjetne (2014).

Optical cameras have the same limitations as infrared cameras, with the addition of limited or no applicability in low visibility and darkness.

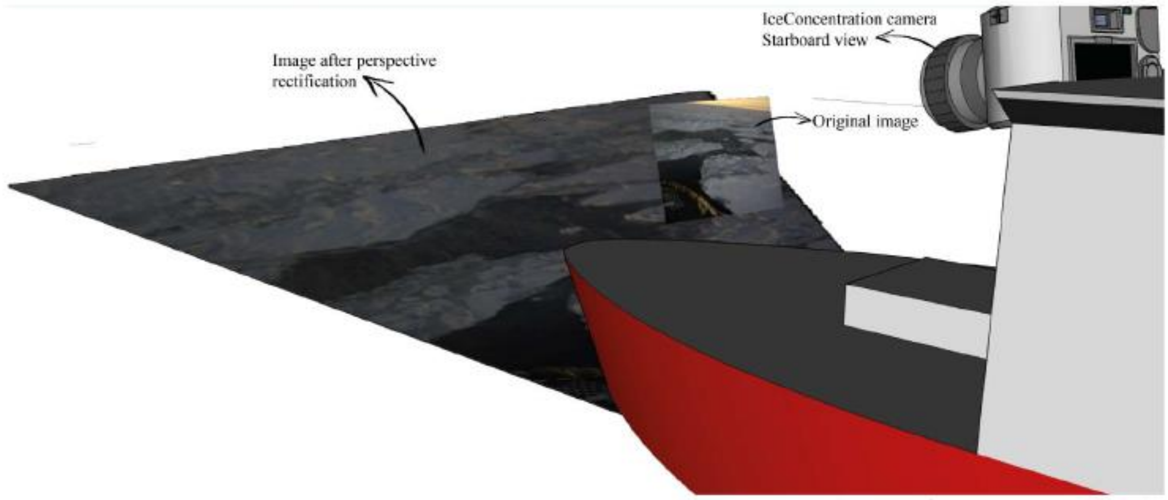

Figure 3. Illustration of the vessel-mounted forward-looking camera and perspective rectification in the method by Lu et al. (2016).

CASE STUDY: HYDROCARBON EXPLORATION AND PRODUCTION IN THE CENTRAL EASTERN BARENTS SEA

In 2015, the Norwegian Ministry of Petroleum and Energy (OED) announced the 23rd licensing round. Out of the 57 blocks announced, 54 of the blocks were in the Barents Sea. The Barents Sea licenses awarded in 2016 are illustrated in Figure 4. The most controversial blocks in the licensing round was the blocks PL 857, PL 858 and PL 859 in the central eastern Barents Sea, where sea ice may intrude during the winter months.

The location selected for the case study is the area PL 859 at 74º30'N 36ºE, known as the Korpfjell prospect. Statoil plans exploration drilling at this location in Q2/Q3 of 2017 (Statoil, 2017).

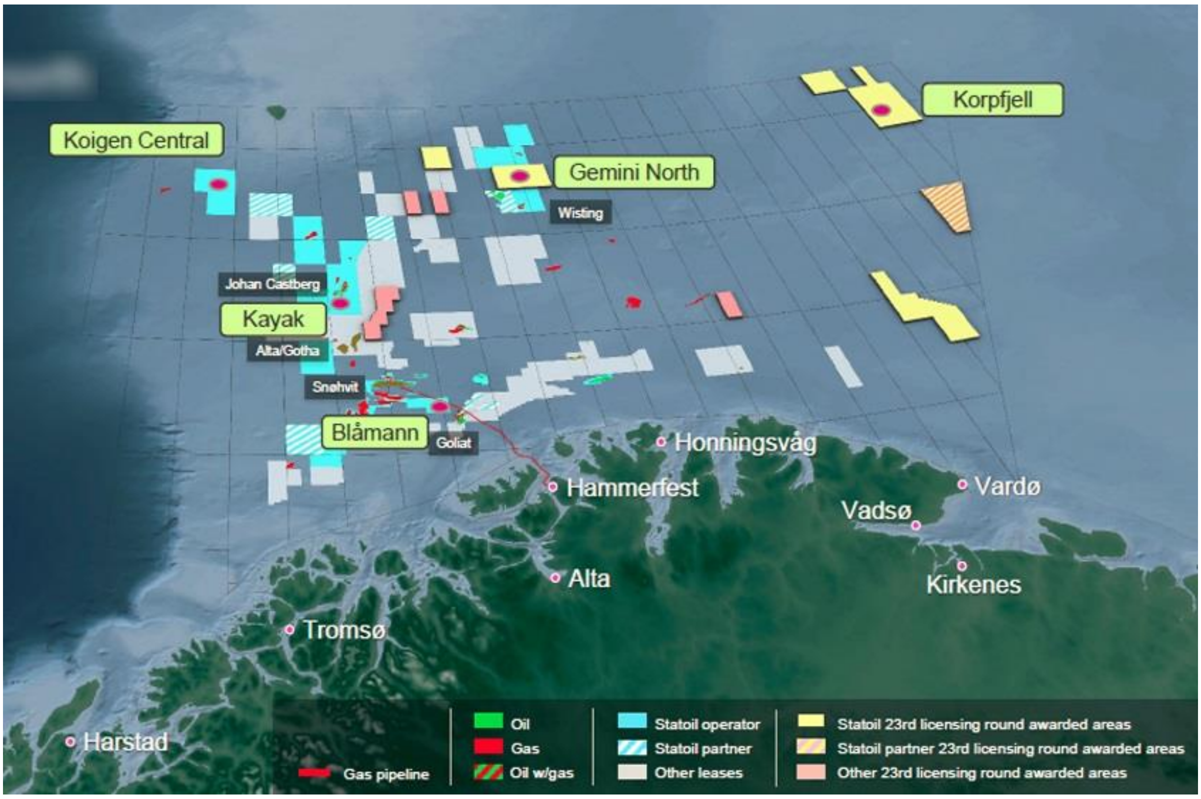

Figure 4. Barents Sea fields, discoveries, areas awarded and areas that have been opened for exploration activities. The locations of drilling in 2017 are indicated by name and red dots. (Image courtesy of Statoil.)

Due to the relatively warm water in the North Atlantic Coastal Current, the southern part of the Norwegian Barents Sea is usually ice-free year round. However, at 74ºN, sea ice occurs in some years as well as drifting icebergs (Løset and Carstens, 1996).

The major source of icebergs in the Barents Sea are the glaciers on Franz Josef Land, Novaya Zemlya and to a smaller extent Nordaustlandet on Svalbard (Løset, 1993). There are generally more icebergs in the northern and eastern parts of the Barents Sea than the western parts (Abramov, 1996). However, limited data exist for the Barents Sea compared to i.e. the Grand Banks.

The NORSOK standard N-003 gives limits of annual probability exceedance of sea ice occurrence and iceberg collisions in the Barents Sea based on satellite data as shown in Figure 4. From Figure 4, it is evident that the Korpfjell prospect is located north of the 10^{-2} contour lines for both sea ice and iceberg occurrence. Thus, both presence of sea ice and potential iceberg collisions must be considered in both structural design and operations.

The water depth on the location is 253 metres (Statoil, 2017). The deep waters limit the application of bottom-founded structures.

The closest port on the mainland is Honningsvåg, 519 km away from Korpfjell. Today, this is the most important base in the Barents region for rescue operations and port for vessels to wait for weather. A ship transiting to Korpfjell from Honningsvåg travelling at 13 knots will be about 22 hours on the transit.

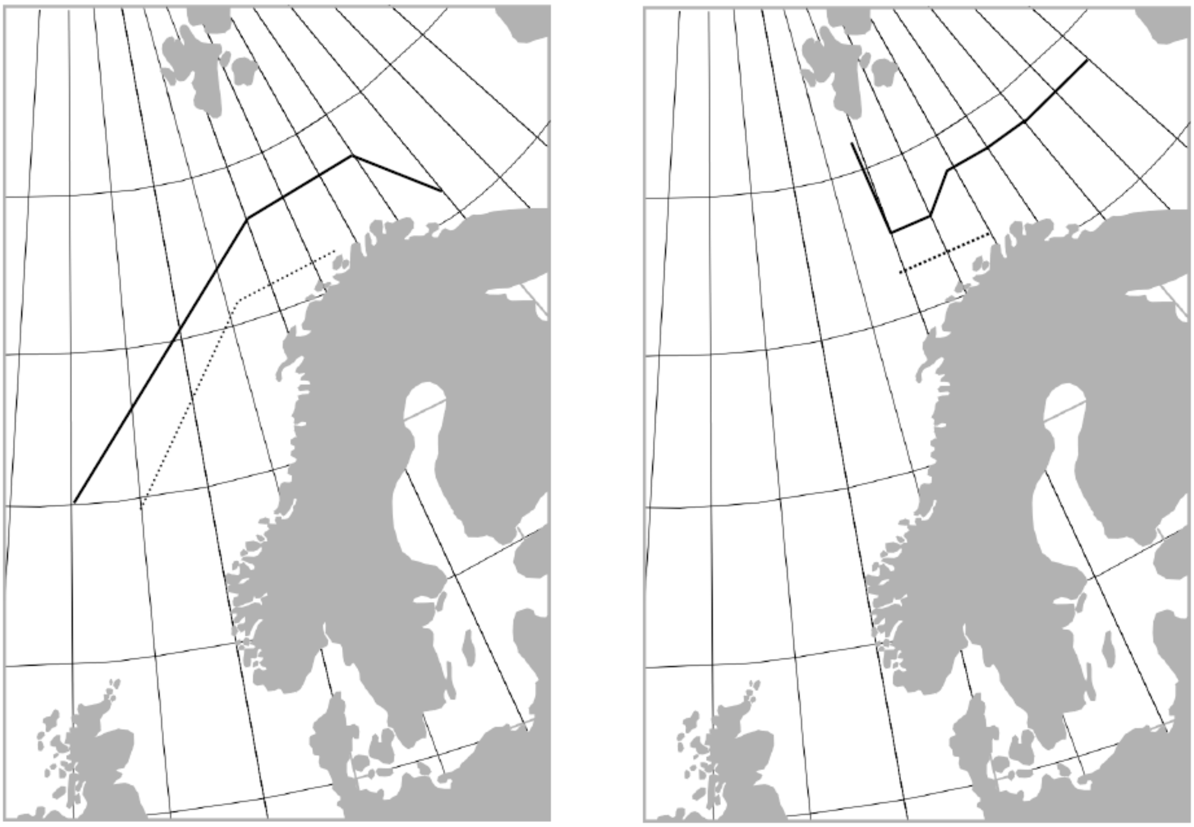

Figure 5. NORSOK N-003 southern limits of sea ice (left) and icebergs (right) with an annual probability of exceedance of 10^{-2} (solid line) and 10^{-4} (dotted line) (NORSOK N-003, 2007).

Drilling

Drilling operations are usually performed during open water and shoulder seasons, in order to reduce or eliminate the risk of operating in ice. Furthermore, drilling structures are usually temporarily present on the field, with a shorter disconnection time in case of emergency shutdown.

The semi-submersible rig Songa Enabler will be used for the exploration drilling in 2017 (Statoil, 2017).

In the licence requirements for the Korpfjell prospect, the Norwegian Petroleum Directorate (NPD) does not allow drilling if sea ice is observed closer than 50 km from the well location. In the emergency preparedness analysis for the Korpfjell prospect, Statoil states that they will perform ice surveillance before and during drilling operations and establish an ice management plan (Statoil, 2017).

Ice surveillance for a drilling operation in open water with possibilities for incoming ice features should be focused on detection of potential hazardous ice features that may drift into the location. Local ice surveillance is not necessary, as the rig would most likely disconnect and move off location in case of approaching ice features.

Production

Normally, a production structure will be present year-round and needs to deal with incoming sea ice and icebergs. Due to the water depth at the location, a production structure will most likely be a floater. An FPSO is one viable option, with other possible options such as a SPAR buoy or semi-submersible.

An ice intelligence retrieval system for a production scenario should be able to detect and monitor potentially hazardous ice features, as well as monitor the local ice conditions and drift for physical ice management on-site.

EVALUATION OF REMOTE SENSING TECHNOLOGIES

The remote sensing technologies satellite SAR, marine radar and optical cameras have been evaluated according to the criteria specified and described below.

Temporal and spatial resolution

As ice drift is highly dynamic, temporal resolution is of high importance to marine operations. Furthermore, spatial resolution of the sensor is of importance in order to evaluate at which scale ice features are identifiable. Table 1 lists the temporal and spatial resolution of the chosen sensor technologies, along with the coverage.

Table 1. Resolution and coverage of sensor technologies.

Sensor type	Temporal resolution	Spatial resolution	Coverage
Satellite SAR*	6-12 hours	>30 m	400 km
Marine radar	Second	Metres	1-3 km
Optical cameras	Sub-second	Sub-metre	100s of metres

* Parameters will vary depending on which satellite sensor is used. The data in the table are based on Sentinel-1 Extra Wide Swath mode, which is used for maritime, ice and polar zone operational services, where wide coverage and short revisit times is required.

As previously discussed, satellite SAR operates with a trade-off between spatial and temporal resolution and coverage. Furthermore, the highest temporal resolution available is on the few-times-per-day scale, and results in low spatial resolution due to a large swath width.

The marine radar has a high temporal resolution, in practice limited by the processing speed of the computer running the algorithm and the chosen frequency. Furthermore, the spatial coverage of the marine radar is limited by the operator setting, and can be in the range of 1 to 3 km (Kjerstad et al., 2017).

Optical cameras have high temporal and spatial resolution, but can only view the immediate surroundings of the vessel, and are limited in terms of areal coverage. They have high potential for identification of ice features, with sub-metre resolution.

Ice feature identification

The sensors ability to recognize hazardous ice features is of high importance for ice management operations. The assessment of the possibility to identify hazardous ice features from the sensor technologies are presented in Table 2.

Table 2. The sensor technologies' potential to identify ice features.

Sensor type	Ice floes	Icebergs	Ice ridges
Satellite SAR	Yes, large floes	Yes, free floating	Potentially
Marine radar	No	Potentially	Yes
Optical cameras	Yes*	Yes*	Yes*

* In light and fog-free conditions

Satellite SAR images are already widely used for sea ice monitoring on a large scale. Large, free-floating ice floes may be identified from satellite SAR images. The size of the floes depend on the spatial resolution of the image, at best 30 metres per pixel in wide swath mode. However, the operational resolution depends on the analysis post-processing of the images, and are generally lower than the pixel resolution.

The potential for identification of ice features from marine radars is generally lower than for SAR technology. The algorithm proposed by Kjerstad et al. (2017) is not capable of detecting ice features. However, commercial systems exist that claims to be able to identify and track ridges, icebergs and ice floes to some degree using the marine radar (FURUNO n.d., Rutter Inc. n.d.).

All ice features can be detected from optical camera images, given the right operating conditions for the camera. However, as discussed previously, the use of this technology may be limited by icing, fog and darkness.

Suitability of sensor technologies on different planning time scales

During an operation, different intelligence is needed on different timescales for ice management. In general, planning on the strategic time scale is for more than 48 hours ahead. On an operational time scale, planning between 2 to 48/72 hours ahead is performed. Real time planning is in the range of 2 to 10 hours ahead. The evaluation of the suitability of the different sensor technologies on different planning time scales is listed in Table 3.

Table 3. Suitability of the sensor technologies to provide ice intelligence on different time planning scales.

Sensor type	Strategic	Operational	Real time
Satellite SAR	Good	Intermediate	Poor
Marine radar	Intermediate	Good	Very good
Optical cameras	Poor	Intermediate	Very good

Satellite SAR images cover large areas, which makes it suited to provide intelligence on a strategic planning level with a long time horizon, and to monitor incoming ice. On an intermediate scale, the suitability of SAR images depends on when the image is received. As images are received potentially a couple of times per day, the images may or may not be useful, depending on current ice conditions and drift speeds. For real time monitoring, SAR images do not have an adequately high enough temporal or spatial resolution to monitor areas in close vicinity to the vessel.

The marine radar has limited range, and is thus not well suited to provide intelligence for long-term strategic planning. However, in the operational and real-time domains, with providing ice intelligence about conditions in proximity to the vessel in real-time, the marine radar has the possibility to provide valuable ice intelligence, especially on ice drift.

Optical cameras are mainly useful in the real time operational intelligence, for monitoring conditions close to the vessel. As previously stated, they are limited by factors such as darkness and visibility.

Availability and communication

Availability is assessed in terms of how easily the operator can access the intelligence, how easily understood the intelligence is and potential delays of the information. The results of the analysis are listed in Table 4.

Table 4. The availability, ease of interpretation of the product and delay of ice intelligence collected by sensor technologies.

Sensor type	Availability	Interpretation	Delay
Satellite SAR	Poor to intermediate	Difficult	Hours/days
Marine radar	Excellent	Intermediate	None
Optical cameras	Excellent	Easy to intermediate	None

SAR products have to be downloaded from specific data services or sent by ice monitoring services. High volume data downloads may be challenging at high latitudes with limited data links. The interpretation process of the SAR images is not trivial, requiring expert analysis and preparation. Even then, non-experienced users may not be able to make use of the images without input from an experienced user. Furthermore, deriving additional information such as ice drift or feature tracking also require separate expert analyses. The delay may also be considerable, as the data have to be transferred from satellites to Earth, processed, analysed, and then transferred to the end user.

Marine radars have, like SAR, high availability due to all weather and light capabilities. Furthermore, the intelligence has no delay for the operator, as the technology is shipborne and produce images in real time. The images may require expert analysis in order to identify features, if even possible.

Camera images have limited availability, as they depend on weather and light conditions. However, the technology is, like the marine radar, shipborne, and may be available to the operator instantaneously. Camera images are easily interpreted by looking at them, given ideal operating conditions under high-visibility conditions. Furthermore, algorithms can be incorporated to automatically identify ice parameters of importance, such as ice concentration, floe sizes and ice thickness.

APPLICATION AND COMBINATION OF THE REMOTE SENSING TECHNOLOGIES DURING OPERATIONS

The findings in previous sections generally apply for all marine operations in ice prone waters. Offshore activities at the Korpfjell location, given that the area is not ice-covered all year, particularly depend on hazard detection and monitoring.

As discussed, none sensor is capable of providing all necessary ice intelligence. The three sensors satellite SAR, marine radars and optical cameras represent three layers of information, based on different time and spatial scales. The “three-layer concept” is illustrated in Figure 6.

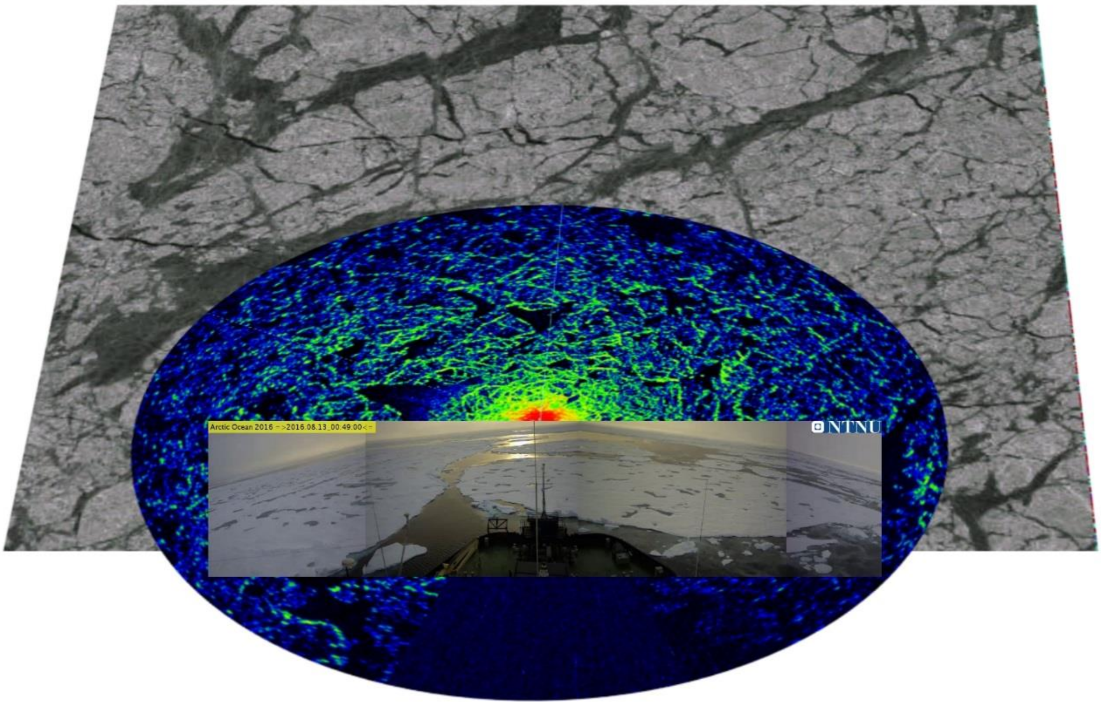

Figure 6. Visualization of the “three-layer concept” of ice intelligence; using satellite SAR, the marine radar and optical cameras mounted on the vessel can provide ice intelligence on different temporal and spatial scales to provide an overview of parameters of importance to the operation. (Satellite SAR image courtesy of Alaska SAR Facility.)

In the “three-layer concept”, the satellite SAR sensor comprises the outer layer. As discussed in previous sections, satellite SAR images may provide information on the regional ice conditions; distinguishing ice types (first-year/multi-year), providing ice floe sizes and concentration, and retrieving large-scale regional ice drift on a once-per-day basis.

The second layer in the concept is the marine radar. Using i.e. the algorithm by (Kjerstad et al. 2017), local ice drift can be tracked and used in ice management operations planning and support.

The third layer represents optical images retrieved from cameras mounted on the vessel or structure. Cameras can be mounted in different configurations, depending on the floater concept selected. In case of a ship-shaped floater with upstream heading, front-looking 180° cameras facing the incoming ice would be most applicable. For an omnidirectional floater, cameras should cover a 360°-degree view. As previously discussed, cameras can be used to extract information about ice concentration, floe size distribution and ice thickness.

The “three-layer concept” used in drilling at Korpfjell

Sea ice monitoring in a drilling operation at Korpfjell should mainly involve detection and monitoring of incoming hazardous ice features drifting in open water, such as large ice floes and icebergs. As no ice should be in the immediate surroundings of the rig (not closer to 50 km, according to the licence specifications), local surveillance sensors are of no use, and satellite SAR would be the most essential sensor for retrieving ice intelligence. Figure 7 displays an example of an operational ice surveillance scenario during drilling operations in open water at Korpfjell.

Satellite SAR images are used to monitor the pack ice and ice edge, generally to the north of the location. The chosen surveillance region will vary depending on the ice drift velocity, as the purpose is to monitor the potential incoming ice. However, due to “chaotic” current patterns in the Barents Sea, where several currents meet and interact, icebergs, which have previously drifted south of the location, may change direction and approach from the south. Thus, iceberg monitoring should be given close attention, and the satellite SAR surveillance region chosen accordingly.

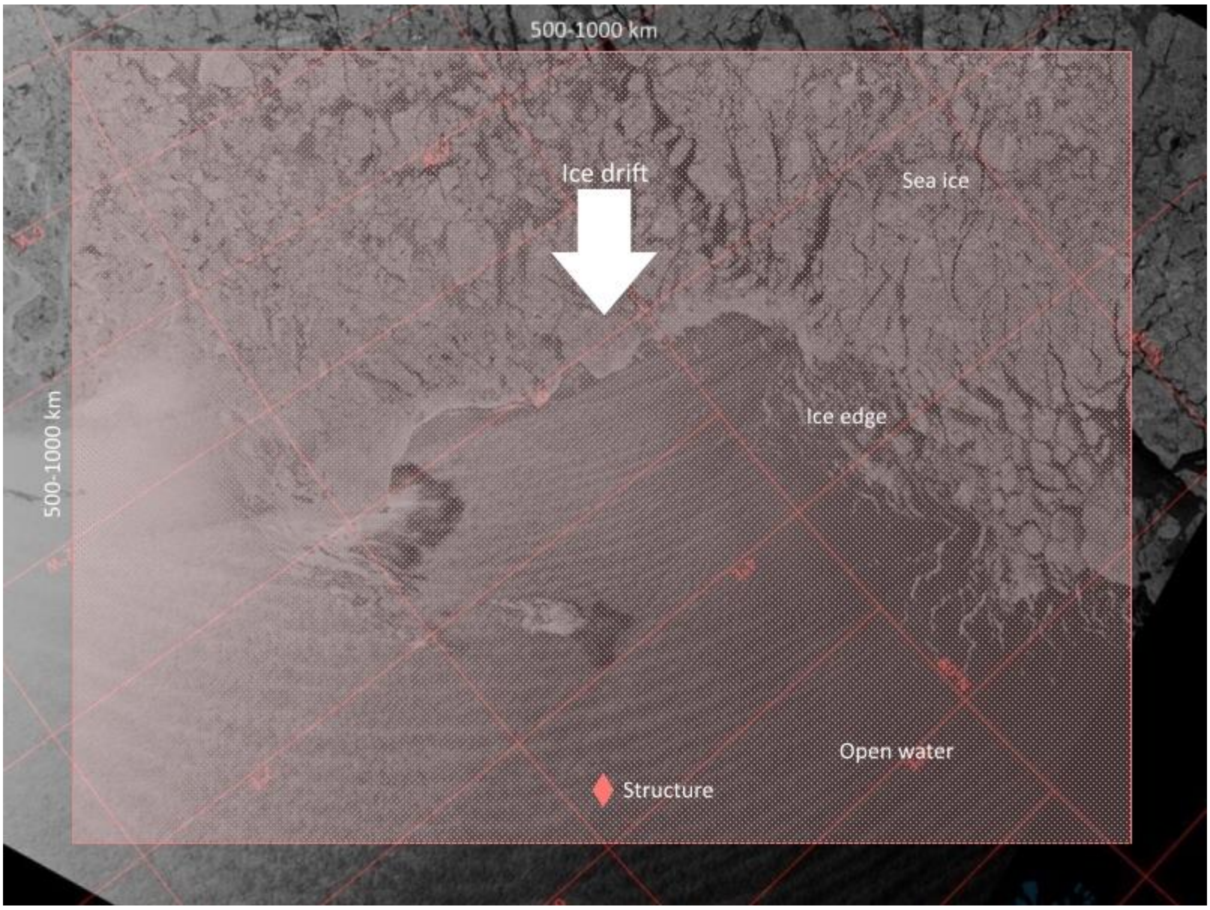

Figure 7. Surveillance region with satellite SAR represented in pink for a drilling scenario in the open water season on the Korpfjell prospect. The surveillance region will change depending on the ice drift velocity. (SAR image courtesy of Polar View).

The “three-layer concept” used in production at Korpfjell

For a production case, which normally is year-round, both hazard detection during the open water season (as for the drilling case) and ice drift tracking and feature detection when sea ice is present at the site, is of relevance. Thus, all layers of the concept should be in place in order to have a proper operational picture of the ice conditions.

Figure 8 presents an illustration of a “three-layer surveillance concept” used for production at the Korpfjell prospect during a season with the ice edge extending south of the location. Satellite SAR is used for retrieving regional ice intelligence. The surveillance region is chosen depending on the current ice drift. As ice approaches the structure, local ice drift may be tracked using the marine radar. Furthermore, ice concentration and ice thickness can be monitored using onboard cameras facing upstream.

Note that for production in the open water season, the same surveillance configuration as for the drilling case, relying mostly on satellite SAR monitoring of the ice to the north, may be used (see Figure 7).

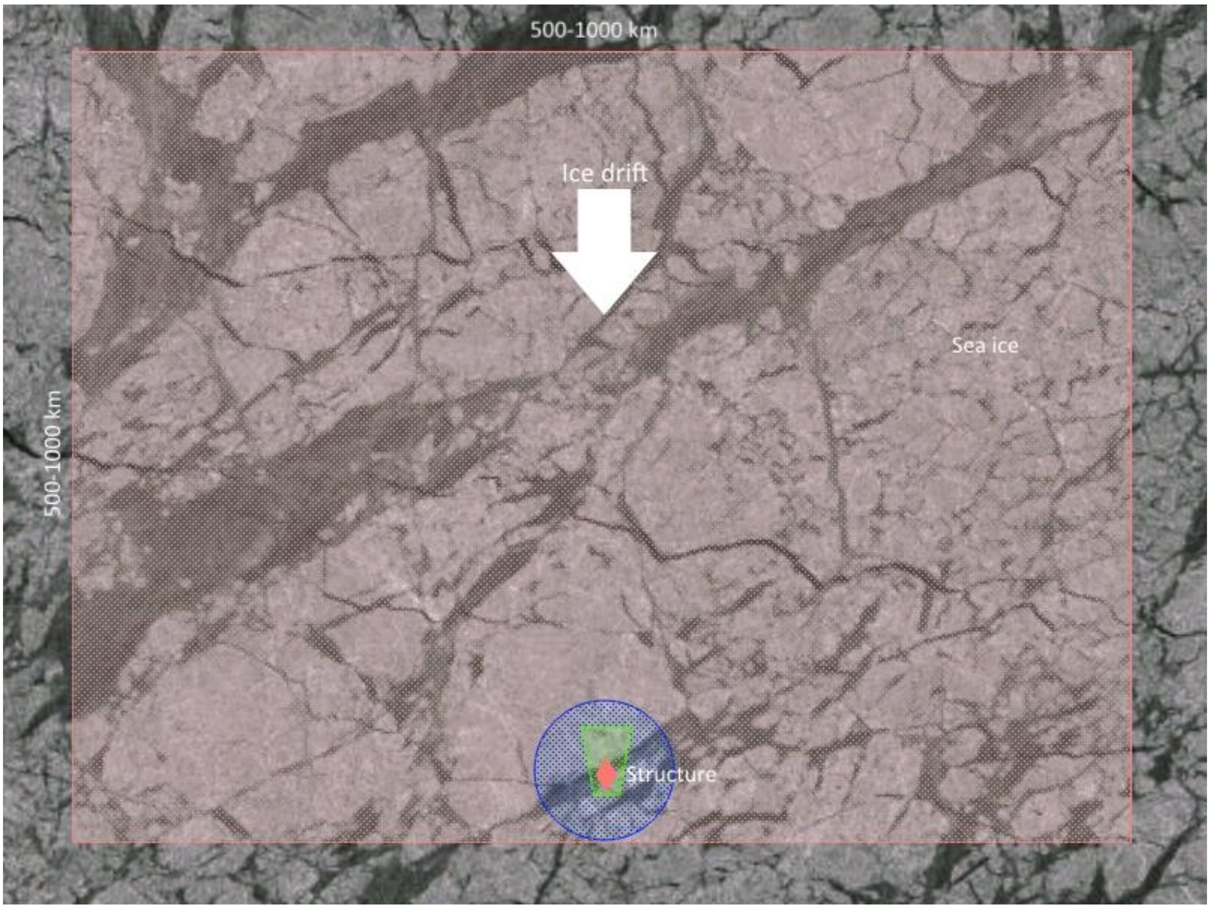

Figure 8. Ice surveillance regime for production at the Korpfjell prospect during a winter season with ice present. The pink area represents surveillance area with satellite SAR, blue indicates the marine radar surveillance region and green illustrates the camera surveillance region (not to scale). (Satellite SAR image courtesy of Alaska SAR Facility).

DISCUSSION

The evaluation of the different remote sensing technologies in previous sections shows that no single sensor is capable of providing all intelligence needed. Furthermore, all sensor technologies have trade-offs and limitations. Operational use of satellite SAR is challenging due to low temporal and spatial resolution. However, the sensor provide a good overview of the regional ice conditions and may be useful in planning operations on a longer time scale. The marine radar is currently capable of tracking ice drift, but no systems exist for feature detection.

The study evaluated and compared three different sensor technologies, satellite SAR, marine radars and cameras, for use in providing ice intelligence. These sensor types are considered most robust and viable for future development in ice intelligence retrieval. Sensors platforms such as UAVs and AUVs are promising, however at present they are not viable alternatives for operational ice intelligence retrieval.

Present-day operations would most likely use physical ice drift trackers to retrieve the local ice drift. However, with the advancement of remote sensing near-field technologies such as marine radar ice drift tracking, physical tracking technologies may be redundant in coming years.

In future scenarios, one could imagine development of a decision support tool, which incorporates ice intelligence from the different available sensors, and provided operators with detection, monitoring and forecasting of the physical environment. Such a tool, able to provide a common operational picture for the whole operation, would be of great support to operators in order to get a complete overview over the relevant parameters for different aspects of the operation. Furthermore, the information could easily be shared between the different decision makers involved, both on the floater but also for vessels supporting with ice management, land-based personnel and other relevant parties.

CONCLUSIONS AND FURTHER WORK

This paper presents different remote sensing techniques for retrieving ice intelligence in an operational setting. For all offshore marine operations, several sensors are needed to provide necessary ice intelligence on time planning horizons. No single sensor is capable of providing all intelligence required in an advanced marine operation.

In order to evaluate the potential of the remote sensing technologies in an operational setting, a case study was performed. The study considered the two operational scenarios, namely drilling and production on the newly awarded licence PL859 (also known as the Korpfjell prospect) in the Barents Sea. The conclusions of the case study are as follows:

- The main drilling operational window at the Korpfjell location is the open water season. The primary ice intelligence during drilling operations should be detection and tracking of hazardous ice features further north, which can pose a collision risk to the installation. The satellite SAR sensor is the best-suited provider of this intelligence.

- The Korpfjell location is prone to sea ice during some months of the year. Thus, year-round production at the Korpfjell location requires ice intelligence collected from several sensors;
    - In the open-water season, the ice intelligence is mainly the same as for the drilling scenario, with detection and tracking of potential hazardous ice features with satellite SAR technology as the key sensor to ice intelligence.
    - During the season when sea ice can be expected, ice intelligence from several sensors are needed to cover both regional and local ice conditions.

A "three-layer concept" of ice intelligence, using satellite SAR, marine radars and optical cameras on the vessel was proposed. Sensors and their intelligence are readily available and at low cost. Using ice intelligence from these sensors in combination will provide operators a holistic view of the ice conditions regionally and locally.

Combining ice intelligence from several sensors may provide possibilities for new tools for use in future operations. For instance, coupling the ice drift velocity retrieved with the marine radar with ice thickness and concentration could provide possibilities for tools predicting loads on the structure. Additionally, ice drift paired with ice thickness and floe size measurements could be incorporated in systems for planning and monitoring ice management performance.

Further work may be continued in forming an operational monitoring, detection and surveillance tool for use by the operators. Such a tool, which could provide a common operational picture that is available for key players in the operation, could provide major improvements to efficiency, safety and overview of the operations.

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