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Ice Surveillance for Equinor's Operations in the Southern Barents Sea

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ABSTRACT

Sea ice and iceberg surveillance is essential for safe operations in the parts of the Barents Sea where these ice features may occur. Until recently, this had only been implemented for temporary drilling operations. With the start of production at the Johan Castberg field in 2025, Equinor has implemented a permanent ice surveillance system. In collaboration with service providers, this system combines remote sensing of sea ice and iceberg object detection with atmosphere, ocean, and ice drift forecasting to continuously update the current and future ice risk picture. Regular object detection in SAR (Synthetic Aperture Radar) satellite images is carried out using multiple satellite platforms to obtain the required frequency and areal coverage. Detections that cannot be easily matched with a ship signature or AIS signal are considered potential icebergs, and their drift trajectories are automatically simulated using an ensemble approach. After a successful test campaign in 2023, a service for rapidly ordering additional satellite images to follow up with potential iceberg detections (Tip & Cue) was established. Both sea ice and iceberg surveillance data are integrated and displayed in a web-based portal alongside an automated assessment of ice threats based on pre-defined thresholds. This information supports operational decision-making, such as increasing surveillance activities with aircraft or vessels, and ensuring sufficient time for executing risk mitigation actions if ice comes close.

KEY WORDS: Ice Surveillance; Remote Sensing; Barents Sea; Iceberg Drift Modelling; Ice Threat Assessment

INTRODUCTION

The start of production of the Johan Castberg (JC) field in March 2025 coincided with the initiation of permanent sea ice and iceberg surveillance in the Norwegian sector of the Barents Sea for Equinor operations. Located at 72.48°N, 20.32°E, the JC concept is a Floating Production, Storage, and Offloading (FPSO) platform that is permanently moored to the seabed and designed for a production lifespan of 30 years. Equinor is fulfilling its commitment to continuously monitor the ice situation by implementing a comprehensive surveillance component as part of its Ice Risk Management (IRM) system. Since ice occurrences are statistically rare at the JC field, the focus is on maintaining awareness of ice presence, and managing the risks associated with ice rather than the ice itself, to ensure safe operations at all times.

Equinor is building on more than a decade's ice surveillance experience in the Barents Sea that has supported drilling and well intervention operations. For the JC FPSO, the IRM system has been improved by integrating multiple surveillance data sources and providing an automated assessment of threats to the offshore leaders, thereby supporting operational decision-making. The permanent ice surveillance activities for the JC FPSO will benefit all other Equinor operations in the Barents Sea, including temporary production and exploration drilling, survey and maintenance activities, and future permanent installations.

The IRM system at the JC FPSO comprises several components in addition to surveillance: a decision support system, governing documentation and procedures, as well as training of offshore and onshore personnel. The entire system, established operating limits and mitigation actions are described in the accompanying paper by Teigen et al. (2025). This paper focuses on the surveillance component of the IRM system including the surveillance strategy, chosen technologies and data sources used, and their integration and visualization in the decision support system.

SURVEILLANCE OVERVIEW

Surveillance Strategy

Equinor's surveillance strategy is based on safety barrier management principles, which highlights the need for multiple barriers to minimize the probability of an unwanted event, see e.g. Hosseinnia et al. (2021). It is acknowledged that any single solution for detection, tracking and forecasting of ice has inherent weaknesses and can fail under certain circumstances. In the context of ice surveillance, this means having multiple barriers, methods and technologies, in parallel to ensure redundancy in the system and minimize the probability of any ice coming close to assets without being detected. Surveillance solutions were selected considering cost and benefits in accordance with the ALARP (As Low As Reasonably Practicable) principle set out in the Framework regulations on the Norwegian Continental Shelf (Norwegian Ocean Industry Authority, 2011). The selected methods are based on qualified technology, most of which has been tested in previous Equinor operations. Continuous improvement of each barrier will reduce the probability of weaknesses in the system becoming aligned. The system is also designed to be flexible, allowing for the integration of new surveillance technologies as and when they become available.

Operating Parameters

Most assets located in ice-prone waters will have operating limits, with respect to distance to or interaction with ice, which should not be exceeded. To ensure safe operations, procedures must be in place to forecast when the operating limits will be exceeded and how to act and initiate risk mitigating actions in a timely manner. Specific parameters extracted from continuous surveillance activities are used to assess if the operating limits are reached.

For the JC FPSO, a range of values for such operating parameters is used in ice threat assessment. Threat levels ranging from TL0 to TL3 have been defined, where TL3 corresponds to operating limits being reached. Threat assessment philosophy, operating limits and surveillance zones are described in the accompanying paper from Teigen et al. (2025).

The first parameter for assessing the sea ice threat is the distance to the sea ice edge based on observed sea ice concentration data sources (Table 1). In alignment with MET Norway, for operations in the Barents Sea, the sea ice edge is defined as the boundary of 10% or more sea ice concentration. Other sea ice characteristics, such as floe size, thickness, and ridge presence, are not included in the assessment of the threat as they do not have an impact on the risk mitigation actions to be taken. The second parameter for assessing the sea ice threat is the distance to the closest point of approach (CPA) of the sea ice edge based on sea ice concentration forecasts.

Table 1. Operating parameters for sea ice and iceberg threat assessment at JC FPSO and values triggering threat level 3 (TL3).

Type	Parameter	Units	Description	Value for TL3 at JC FPSO
Sea ice	Closest distance to sea ice edge	km	Closest distance from the FPSO to the observed sea ice edge.	≤ 50 km
	Distance to closest point of approach (CPA) of sea ice edge	km	Minimum forecasted distance of the sea ice edge to the FPSO.	≤ 50 km
Iceberg	Observation type	NA	Type of observation with possible values: • Unconfirmed: an observation is made without type confirmation • Iceberg: confirmed by visual observation to be an iceberg • False: false positive from satellite images, no object in the sea • Other: confirmed object in the sea that is not an iceberg (e.g. trash, buoy)	Iceberg
	Distance	km	Distance between observation and FPSO	≤ 22 km
	Threat arrival time (TAT) to the iceberg reaction zone	hours	Time of forecasted arrival of the observation to the iceberg reaction zone (22 km radius)	≤ 48h

For icebergs, the parameters used to assess the threat are (1) observation type, (2) distance of observation from the FPSO and (3) forecasted time of arrival into the iceberg reaction zone (22 km radius) based on drift forecasts (Table 1). Since iceberg intrusions into the field are rare, iceberg characteristics such as size and shape are not considered in the threat assessment. This simplification enables the operational focus to be on mitigating actions to reduce the risks of adverse consequences of any possible ice-asset interaction. This removes the burden on offshore personnel to assess the damage potential of a given piece of glacial ice. Similar operating parameters and threat levels are used for IRM for temporary operations in the Barents Sea by Equinor.

Surveillance and Decision Support System Components

The IRM System is based on Boyd's OODA loop principles (Richards, 2020): Observe – Orient – Decide – Act, which allow for a dynamic response to changing conditions. As ice threat increases, surveillance efforts are intensified to obtain more detailed information on the ice conditions. Additional surveillance barriers are mobilized, and the frequency of observation is increased (Observe). All surveillance information is transferred to the decision support system for data integration, analysis, visualization and alerting of relevant entities (Orient). Operational decisions are made based on a continuous assessment of the ice threat (Decide, Act). This ensures there is enough time to take all necessary mitigation actions, such as adapting the activity plan and/or stop production, down-manning and/or moving off location, if possible.

An overview of the surveillance methods with associated service providers and their integration into the decision support system is illustrated in Figure 1. Remotely sensed data is combined with publicly available and authoritative data sources to obtain necessary information to assess the threat level. All information is integrated and displayed in the Barents Sea Operations portal; an instance of the web-based solutions provided by StormGeo that was customized to meet the ice surveillance needs. In addition to the weather forecast visualization and alerting functionalities, various tools for sea ice and iceberg data visualization and threat assessment were developed in collaboration with Equinor. A new database and API were also developed to manage iceberg observations and drift trajectories data.

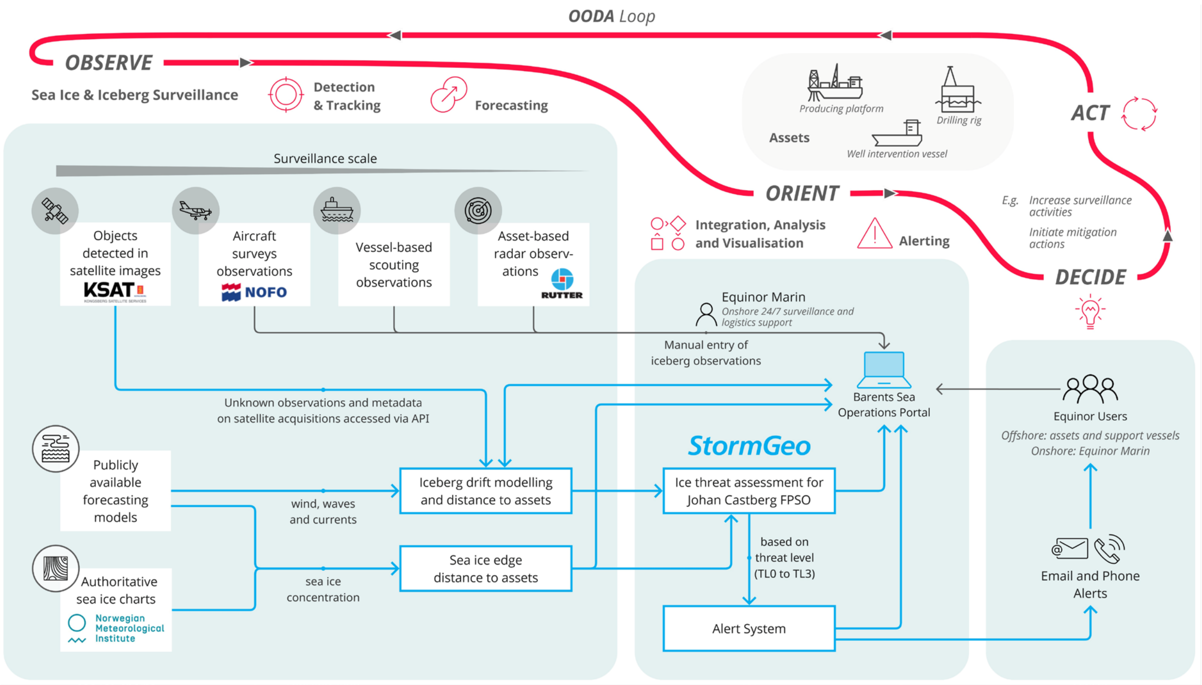

Figure 1. Overview of the surveillance and decision support components of the IRM System for Equinor's operations in the Southern Barents Sea.

For icebergs, the most valuable surveillance method is the detection of objects (treated as potential icebergs) in Synthetic Aperture Radar (SAR) satellite images. This method allows for regular observations over a large area independently of darkness and cloudy conditions. For sea ice, the main surveillance method is the use of authoritative and public sea ice concentration data products for the Barents Sea. As seen in Figure 1, three additional surveillance methods are available for detection and tracking of ice at a medium to small scale: aircraft surveys on-demand, vessel-based scouting on-demand, and continuous marine radar observations from the assets (e.g. JC FPSO or drilling rig). These methods are crucial to provide visual confirmation of the presence of ice, which is necessary to evaluate if the operating limits have been reached.

Aircraft surveys are already an important surveillance method for oil spill emergency preparedness. As part of establishing ice surveillance services for JC operations, the mandate of The Norwegian Clean Seas Association for Operating Companies (NOFO) was expanded to include ice surveillance. This allows the use of the fixed wing aircraft at NOFO's disposal for on-demand ice surveillance in addition to oil spill surveillance. The aircraft is equipped with Forward Looking Infrared (FLIR) cameras, Side Looking Airborne Radar (SLAR), and optical cameras which can effectively provide detailed information about ice conditions. Ice surveillance flights can be planned on short notice if the aircraft is already close to the Barents Sea and weather conditions allow for good quality observations.

Supply or emergency response and rescue vessels supporting the JC FPSO or temporary operations are the main surveillance resource at a medium scale. They can scout for ice on demand using their marine radar and can visually confirm the location and presence of ice. A typical use case would be to confirm a potential iceberg detection from satellite images that is within their operational range. Sending a vessel for scouting in this case can be the most time-efficient solution compared to requesting an additional satellite image analysis.

In close vicinity of the assets, marine radar is the main sensor for detecting and tracking ice, as well as for navigation. For icebergs, it provides coverage typically over an area of 20 to 40 kilometres radius. At the JC FPSO, detection capabilities have been enhanced by installing the Sigma S6 Ice Navigator radar-based system by Rutter Inc. (O'Connell, 2013), which is designed to detect slow and small moving targets like icebergs or rogue pieces of sea ice.

Ice observations from aircraft surveys, vessel scouting and marine radar on assets are currently not automatically integrated into the decision support system. Reported iceberg observations are added manually within the Barents Sea Operations portal for drift forecasting (see Figure 1).

SEA ICE SURVEILLANCE

Data Sources

The main data source used for calculation of distance to the sea ice edge is the authoritative sea ice chart from MET Norway Ice Services. All information available, including, satellite images, weather and sparse in-situ vessel-based or aircraft observations, is assessed by ice analysts and collated into the charts (Copeland et al., 2024). The sea ice charts are issued only on business days and are valid from 1500 UTC until the next publication. During non-business days, other non-validated observed sea ice concentration data products such as from AMSR-2 (EUMETSAT, 2023) can be accessed within the portal. The users are aware that these can contain artefacts and are not used in the automated threat assessment for the JC FPSO.

For information on sea ice CPA, two publicly available drift forecast models are utilized:

- Barents-2.5km: developed and operationally run at MET Norway, updated daily at 1300 UTC with a 66-hour forecast horizon (Röhrs et al., 2023)
- NextSIM: provided by the Nansen Environmental and Remote Sensing Center (NERSC), updated daily at 0930 UTC with a 120-hour forecast horizon (Rampal et al, 2016)

Both models output hourly sea ice concentration, drift direction, and speed, which can be viewed in the portal. Significant differences between the two models may arise when currents dominate sea ice drift, as they may struggle to accurately forecast local current behaviour. As a default, the most conservative CPA distance is considered for sea ice threat assessment.

Sea Ice Data Visualization

The sea ice information sources are integrated into the portal to provide a comprehensive view of sea ice conditions in the Barents Sea. These can be viewed as an interactive map layer and in a graph format (Figure 2). The sea ice distance map layer displays an arrow from the selected asset to the closest sea ice distance pixel in the chosen sea ice concentration data source. This layer allows the users to quickly visualize the distance and bearing to the sea ice edge and explore the evolution of the CPA in the coming days. The sea ice distance graph presents the same distance from the asset to the observed sea ice edge along with the forecasts for the next 5-7 days. This clear graphical representation of sea ice proximity trends allows users to quickly compare the available forecast models.

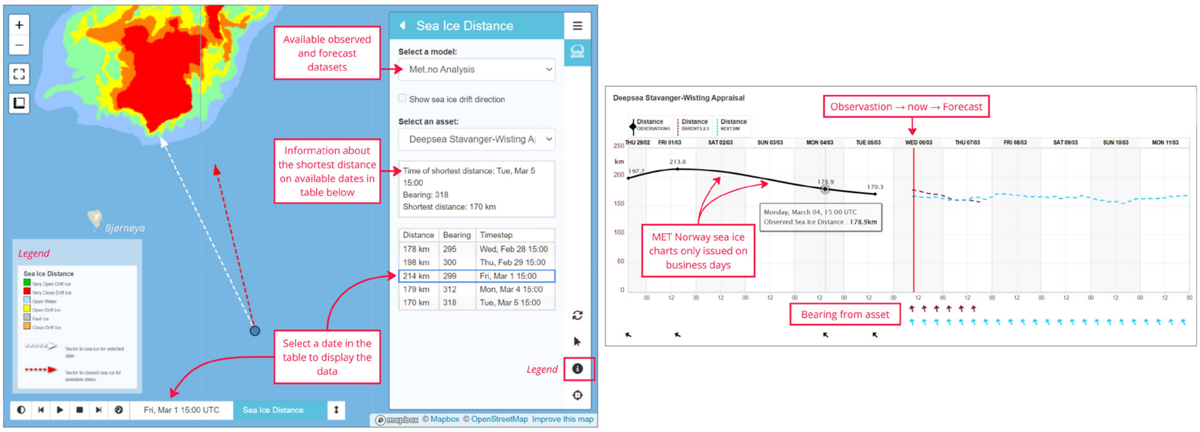

Figure 2. Sea ice surveillance visualization tools within the Barents Sea Operations portal. Left: Distance to sea ice map layer. Right: Distance to sea ice graph.

ICEBERG SURVEILLANCE

Satellite-based Object Detection

Large scale iceberg surveillance is conducted in the Southern Barents Sea through object detection in SAR satellite images. At this time, there is no authoritative agency providing an operational data product of iceberg locations in open water for this region. Equinor currently relies on a service provided by Kongsberg Satellite Services (KSAT), adapted from their vessel detection service. The area of interest for satellite surveillance extends from 50 km south of the JC field and up to Bjørnøya (~220 km due north of the JC field, see map in Figure 3). Routine object detection analysis is carried out with one SAR image of medium resolution (20-60 m) daily from January to June, when probability of iceberg occurrence in the region is highest (Abramov, 1996) and every third day for the rest of the year. KSAT has the responsibility for planning acquisitions to maximize the coverage of the area of interest, with X or C-band images in wide swath or scanSAR modes typically covering ~200 x 300 km. Both public and commercial sources are used, the most common ones being Sentinel-1A/1C, PAZ and RADARSAT-2.

Operators at the KSAT Tromsø Earth Observation Service (TEOS) centre manage the analysis process. Objects are detected with a machine learning algorithm trained for vessel detections and results are automatically compared with AIS (Automatic Identification System) data. Detected objects that cannot be easily matched with a vessel signature or AIS signals are classified as “unknown” and are treated as unconfirmed observations (Table 1), i.e. potential icebergs. In addition, the operators manually scan the image for suspicious reflections in open water that have not been flagged by the algorithm.

Depending on the image resolution, this methodology enables the detection of objects that are a minimum 15m in waterline length. Varying acquisition geometries and sea states affect the probability of detection of a given iceberg within an image. This is mitigated by monitoring a large area northward of assets, to maximize the probability of detecting an iceberg before it deteriorates beyond the image resolution. False positives can also occur with this methodology. These are speckles in the images or wave crests that create strong enough reflections to be labelled as objects. Procedures have been established to discard from the threat assessment any observations that cannot be linked to a new one in a minimum of two subsequent analysed images. All unknown detections and their metadata are made available via API, within a maximum of three hours after image acquisition. These are ingested by StormGeo for initiation of iceberg drift trajectory forecasts using the estimated width and length and the acquisition time (Figure 1). All detections are also shared via NOFO to other operators and actors in the region, supporting safe navigation and operations in the Southern Barents Sea.

Satellite orbits offer good coverage in this region, making it possible to increase the frequency of the routine service to twice per day when needed (acquisitions around 0600 and 1800 UTC). Additional images can also be rapidly acquired to follow-up a potential iceberg detection using the "Tip & Cue" method. After an initial detection during routine surveillance, the drift forecast from StormGeo serves as a guide for acquiring a higher-resolution image, a process referred to as "tipping" and "cueing". This additional on-demand service from KSAT allows for improved tracking and size estimates of the object with the second image delivered within 12-24 hours, which in turn improves the drift forecast. A test campaign was organized in collaboration with KSAT in Autumn 2023 to establish the service and multiple icebergs in the Northern Barents Sea were successfully tracked. The longest trajectory comprised 13 observations over 9 days and is presented in detail in Hermannsdörfer and Yang (2025). A total of 20 high-resolution images were ordered, delivered, and analysed for the cueing aspect of the campaign, demonstrating that the process can be effectively executed across various platforms and sensor modes. The most reliable acquisitions and optimal detection capabilities were achieved with stripmap modes (~3m resolution covering a ~40 x 40 km area) in HH polarization and with incidence angles between 35 and 60 degrees. These criteria are fulfilled by TerraSAR-X, PAZ or COSMO-SkyMed. The images for the Tip & Cue service are processed and detections are made available to StormGeo in the same way as for the routine service described above. In most cases, in-house processing with direct downlink at local ground stations from KSAT enabled observations to be available < 10 minutes after image acquisition, reducing time latency. An accurate estimation of a moving object's trajectory is crucial for the cueing part of the service, and this test campaign enabled a qualitative validation of the drift models implemented by StormGeo (see next section).

A typical situation calling for an intensification of satellite-based surveillance, either with increase in the routine service or with Tip & Cue, is if an object that is relatively far from an asset has been tracked over several days and appears to align with drift forecasts. Both services can be combined to improve tracking until the object is reachable by scouting vessels to visually confirm the observation as an iceberg.

DRIFT AND DETERIORATION FORECASTING

Forecasting the drift and deterioration of iceberg observations (potential or visually confirmed) is a critical component of any IRM system. An operational ensemble iceberg drift modelling system has been implemented by StormGeo, largely based on Keghouche et al. (2009). The model incorporates thermodynamic processes that contribute to iceberg melting, including bottom melting, lateral melting, and calving, driven by ocean currents, temperature variations, and the action of ocean waves. The iceberg trajectory is determined using a predictor-corrector scheme with a timestep of 120 seconds for a horizon of 5 days, factoring in the external forces of ocean currents including tides, winds, waves, and sea ice interactions. The model also utilizes the GEBCO 2019 bathymetry dataset to determine when icebergs are grounded or released from the ocean floor. In addition, it accounts for iceberg instability, allowing icebergs to rotate into more stable configurations. Various default configurations are implemented to initialize iceberg height and freeboard based on observed width and length. Icebergs are abstracted as rectangular prisms and are considered melted when height or width falls below 0.5 meters.

The forecast model uses a combination of atmospheric and wave forcing along with six possible ocean forcings for a total of 18 unique combinations. The ensemble of simulated trajectories is generated by varying three key parameters: wave radiation coefficient, ocean drag coefficient, and atmosphere-to-ocean drag ratio. This leads to a total of 162 ensemble member trajectories per observations, with hourly positions and size estimates to be visualized within the portal (Figure 3). Ensemble modelling allows for a comprehensive evaluation of the area where a given iceberg might drift in the coming days. The most conservative CPA from all ensemble member trajectories is used for threat assessment. When an iceberg is very close to an asset, continuous real time monitoring via marine radar and manual drift predictions will be possible making the ensemble drift forecast model from the portal secondary.

Iceberg Monitoring Tools

An interactive map layer has been developed by StormGeo for the Barents Sea Operations portal to visualize the iceberg observations, their drift trajectories and associated metadata (Figure 3). In the Iceberg Drift map layer, all active observations are displayed by default and the user can refine what is visible on the map with various option within the layer panel. To view operating parameters such as distance, CPA and time to CPA relative to an asset, the Iceberg Distance table was developed (not shown in Figure 3). This table is particularly useful for temporary operations such as drilling and vessel interventions, supporting them in their manual assessment of the iceberg threat.

Equinor Marin, a 24/7 onshore surveillance and logistics support centre, has a key role in the IRM system as described in the accompanying paper by Teigen et al. (2025). On request from the offshore assets, they coordinate with the service providers (vessels, aircraft from NOFO and KSAT) when additional surveillance is needed. They are active users of the drift map layers to communicate to the service providers the location of the potential iceberg at the planned survey time. A good example is determining the centre position for a cueing high-resolution image from KSAT.

Equinor Marin has editing rights within the Iceberg Drift Map layer to enter iceberg observations reported by aircraft or vessel (Figure 1). In addition, they are responsible for updating the status of observations to “archive” and type to “False” or “Other” when they are no longer a threat or believed to be a false positive reported by KSAT (refer to Table 1).

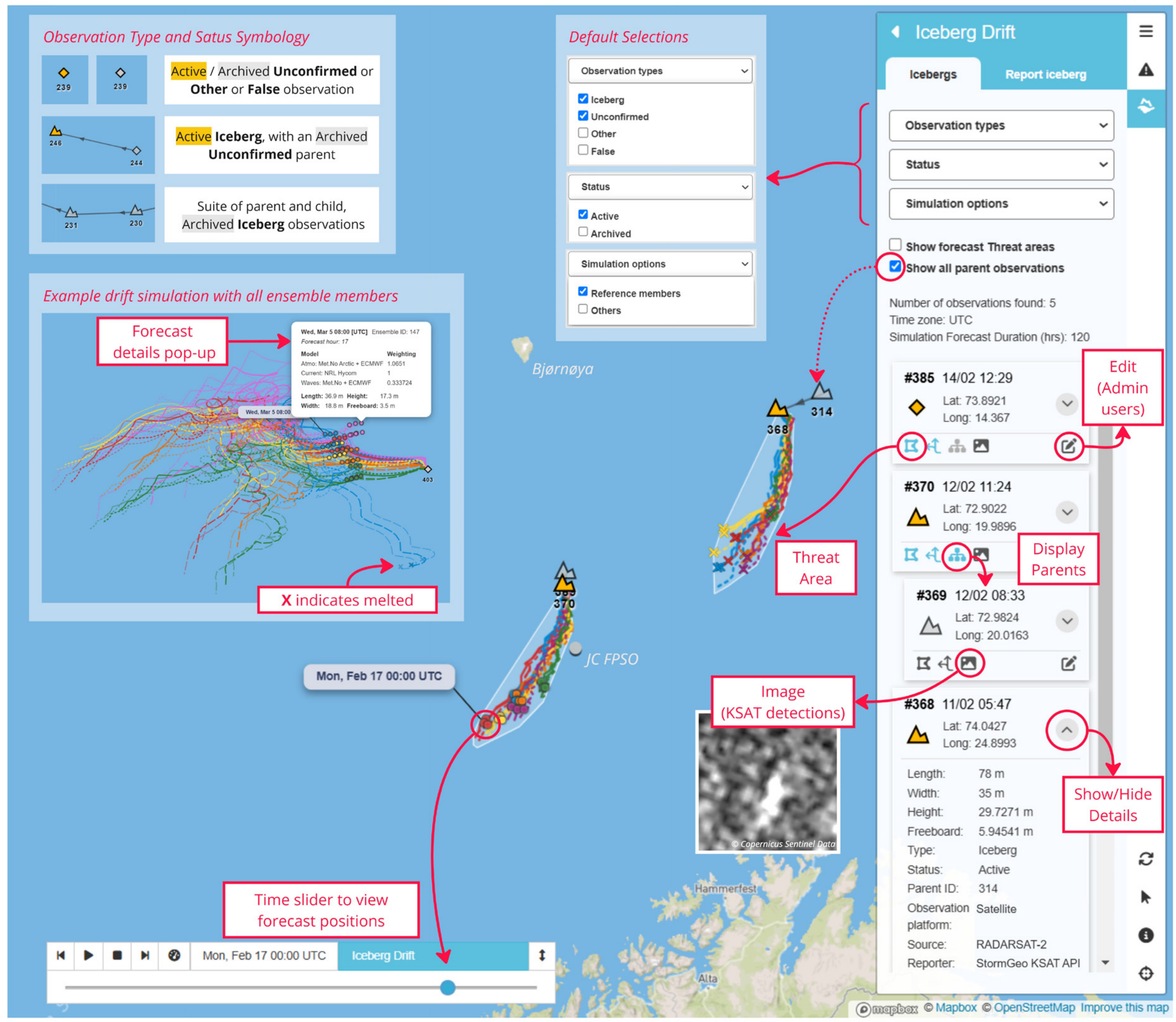

Figure 3. Overview of functionalities in the Iceberg Drift map layer in the Barents Sea Operations portal.

ICE THREAT ASSESSMENT AND ALERTING

All assets benefiting from ice surveillance as part of the IRM system access the Barents Sea Operations portal for situational awareness and decision support. Offshore personnel depend on the data integration and visualization tools described in the previous sections to evaluate whether their operating limits will be reached and to take appropriate actions. For the JC FPSO, an automated threat assessment process has been implemented in the portal to facilitate decision-making for the Offshore Installation Manager (OIM). The logic that relates operating parameter values to threat levels (TL0 to TL3) can be represented as a decision tree (see Figure 5 in Teigen et al., 2025). The threat level output for the JC FPSO is updated as follows:

- Sea Ice: Once per day after the MET Norway Ice Services sea ice chart and forecast models have been updated, typically around 15:30 UTC. During weekends and holidays, the threat level is assessed using the latest available data.
- Icebergs: When a new observation is added (e.g. when a new unknown object is reported by KSAT) or when the status of an existing observation is modified (e.g. when Equinor Marin manually changes the status from “Active” to “Archive” for a false positive).

The results of the automated threat assessment and the corresponding operating parameter values are accessible within respective sea ice and iceberg dashboards in the portal (Figure 4). The threat level output serves as guidance for the OIM, who is ultimately responsible for determining the threat level and should consider any additional information that is not integrated in the portal (e.g. other operational constraints and ongoing activities).

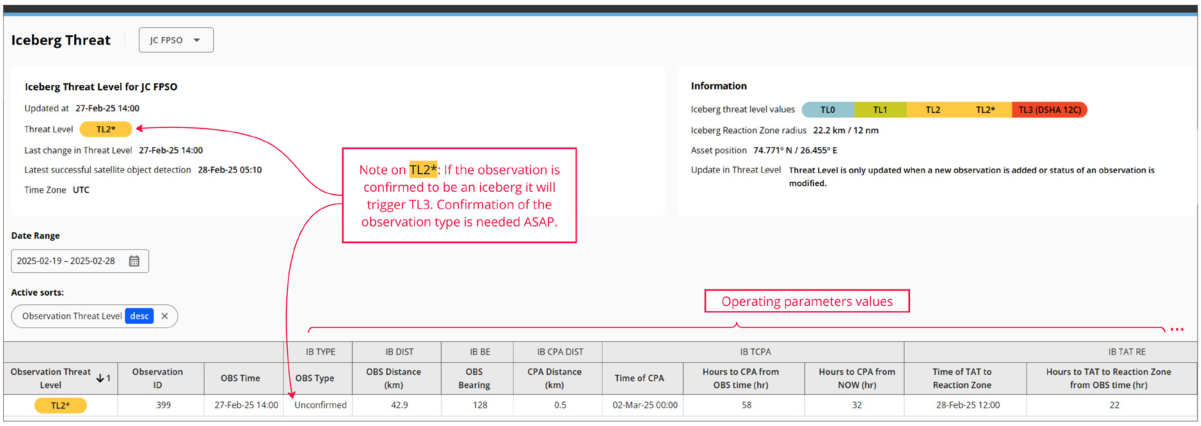

Figure 4. Iceberg threat assessment dashboard in the Barents Sea Operations portal.

A specific role on each asset, often the Dynamic Positioning Operators on drilling rigs or the Central Control Room (CCR) operators on the JC FPSO, is responsible for daily monitoring of ice conditions in the StormGeo portal and reporting to the Offshore Installation Manager (OIM). Alerts integrated in the StormGeo solution, are designed to inform onshore and offshore personnel of significant changes in ice conditions, prompting them to check the portal and reassess the situation. Automated email alerts are sent to all assets and supporting vessels when KSAT reports a new unknown object. Additional email alerts are sent out to key roles for the JC FPSO and Equinor Marin when there is a change in sea ice or icebergs threat level severity. Furthermore, automated phone calls inform the CCR when the threat level reaches TL3, with a redundancy feature that cascades to Equinor Marine if the call is unanswered. Sound alerts from the Rutter ice radar system are activated upon new detections and managed by CCR operators. This comprehensive alerting approach ensures effective communication of critical information, enhancing the overall functionality of the IRM system.

CONCLUSION

The establishment of permanent ice surveillance for activities at the JC field underscores Equinor's commitment to operational safety in the challenging environment of the Southern Barents Sea. By integrating various platforms and technologies for sea ice and iceberg monitoring, the IRM system enhances situational awareness and supports timely decision-making for offshore personnel. Collaboration with KSAT and StormGeo has enabled the implementation of fit-for-purpose services, where the automation of processes has reinforced the effectiveness of the IRM system. As it continues to evolve, opportunities will arise to include new surveillance barriers like automated surface vessels (ASVs) and unmanned aerial vehicles (UAVs). It is anticipated that these technologies will become cost-effective and qualified for offshore surveillance tasks during the lifetime of the JC FPSO. The comprehensive surveillance system in place will benefit other Equinor operations in the Barents Sea and contribute to the overall safety of maritime activities in the region.

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