On weather limitations for safe marine operations in the Barents Sea

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Abstract. The Barents Sea wave conditions and the weather conditions that often accompany fully developed polar lows are presented in this paper. The studies on the extreme waves showed that the extreme waves in the Barents Sea decreases as we move further north. The Barents Sea wave conditions are found to be more accessible for marine operations in the summer months compared to the North Sea and the Norwegian Sea wave conditions. However, the quality of actual weather forecasts and the contribution of long periodic swells to the total sea in the Barents Sea could negate the longer weather windows observed in the area. Further, the weather conditions that often accompany fully developed polar lows represent limitations to marine operations in the Barents Sea. It was found that the significant wave height in polar lows could be up to 9 m. In addition, snow and ice accretion in polar lows are deemed operation and safety hazards. Overall, marine operation may not be carried out within the period when a polar low is likely to occur.

1. Introduction
With increasing activities in the Barents Sea, the improved knowledge of the various metocean conditions (meteorology and oceanography) that are peculiar to this area of the Arctic sea, will aid in planning and execution of safe marine operations, and in designing reliable offshore structures. The main objective of this paper is to contribute to the knowledge of the wave conditions, and the occurrences of polar lows in the Barents Sea. The findings presented in the paper are an abridge version of the summary of the PhD thesis titled “Weather limitations for safe marine operations in the Barents Sea” [1].

We have studied the Barents Sea wave conditions from two perspectives: the extreme wave conditions for design purposes, and the relatively calm wave conditions for marine operations. The studies on the extreme wave conditions are driven mainly by the availability of wave hindcast data. Here, we have considered 57 years wave hindcast data for four locations, the locations are shown in Figure 1 as BS1 – BS4. The hindcast data are from the NORA10 (Norwegian Reanalysis 10 km) database, and are made available courtesy of Birgitte Furevik of MET Norway (Norwegian Meteorological Institute).

The studies on the wave conditions for marine operations are sub-divided into three categories. These are; study of the probable weather windows in the Barents Sea using wave hindcast data, study
of the quality of wave forecasts in the Barents Sea comparing wave forecasts and wave observations, and study of the contribution of swell waves to the total sea in the Barents Sea using wave hindcast data. For the probable weather windows, we have considered the 57 years wave hindcast data for BS1 – BS5, Heidrun in the Norwegian Sea, and Ekofisk in the North Sea, see Figure 1. Consideration is given here to Heidrun and Ekofisk for comparison. For the quality of wave forecasts, we have considered wave forecasts and wave observations at BS6 (Figure 2), the results are compared with the quality of wave forecasts at Heidrun. The contribution of swell waves to the total sea is studied using the 57 years wave hindcast for BS1 – BS4 (Figure 1). The wave observations, wave forecasts, and wave hindcast are also made available courtesy of Birgitte Furevik of MET Norway.

With regards to the occurrences of polar lows, our focus was on the weather conditions that often accompany the fully developed polar lows, and how such weather conditions may limit marine operations in the Barents Sea. Here, we studied the probable significant wave heights that may accompany the fully developed polar lows, the probable additional snow and ice (from sea spray icing) loads that a vessel caught up in polar lows may experience, and the effects of the additional loads on the stability of different vessels.

The study of the probably significant wave heights is driven by the records of wind speeds in polar lows from 1999 – 2015, and a wave prediction model proposed by [2]. Also studied is the accuracy of wave forecasts during the passage of polar lows, using wave forecasts and wave observations during the passage of two polar low events near the location Goliat (Figure 2). The studies on the probable additional snow and ice loads is driven by few metocean observations and previously published papers.

Overall, the studies summarized in this paper showed that the extreme waves in the Barents Sea decreases as we move further north, this is in agreement with [3]. The 57 years wave hindcast suggested good possibility of carrying out marine operations in the summer months, here defined as the periods from May – September. The quality of wave forecasts for the Barents Sea is also found to be good at lead times less than 30 hours. However, the contribution of swell waves to the total sea may further limit the observed weather windows. In addition, it was found that the significant wave heights in polar lows would limit most marine operations, particularly in the winter months (October – April) when polar lows usually occur. However, when compared with the 100-year wave conditions in the Barents Sea, the significant wave height in polar lows is not as large. The additional snow and ice loads that a vessel at sea may experience during polar low occurrences are deemed both operation and safety hazards.
2. The extreme wave conditions
The sea state may be characterized by a set of integrated parameters, including the significant wave height \( H_s \), the spectral peak period \( T_p \), and the direction of propagation \( \theta \). Among these parameters, the \( H_s \) is commonly used to describe the severity of the sea state. Often, the sea state is a combination of wind sea and swell waves. In the study of the extreme wave conditions for the Barents Sea, we have considered the omni-directional total sea. The extreme waves are analyzed by considering the marginal distribution of \( H_s \), and the joint distribution of \( H_s \) and \( T_p \).

Figure 3. Relative frequencies of the significant wave heights \( (H_s) \) for locations BS1 – BS4 (1957 – 2014): the data is bin using the class interval of 0.5 m [1].

2.1 Marginal distribution of \( H_s \)
The relative frequencies of the \( H_s \) for the locations BS1 – BS4 is shown in Figure 3 based on a class interval of 0.5 m. The values of the \( H_s \) are from 0.1 – 17.0 m for BS1 and BS4, 0.2 – 17.0 m for BS2, and 0.2 – 17.9 m for BS3.

To predict the 100-year \( H_s \) at the locations, three commonly used extreme wave prediction methods are adopted. These are, the initial distribution (ID) method, the peak over threshold (POT) method, and the annual maximum (AM) method. For the ID method, the 3-parameter Weibull distribution is selected as the candidate probability distribution [4] that is fitted to all the 3-hourly wave hindcast data at each location. The parameters of the 3-parameter Weibull distribution are estimated using the method of moments (MOM).

For the POT method, peak excesses above a threshold of 7 m, and above a threshold of 9 m are considered. The threshold selection is based on two of the threshold selection techniques described by [5]. The generalized Pareto distribution (GPD) [5], the exponential distribution, and the 2-parameter Weibull distribution [4] are considered as probable candidate probability distributions for the peak excesses. The parameters of the GPD are estimated using the maximum likelihood estimation (MLE) method [5], while the parameters of the exponential distribution and the parameters of the 2-parameter Weibull distribution are estimated using the MOM. A comparison of the estimated parameters and the visual goodness of fit of the probability distributions to the peak excesses suggested that the 2-parameter Weibull is sufficient.

For the AM method, annual is defined as the period from September to August. The generalized extreme value (GEV) distribution [5], and the Gumbel distribution [4], are considered as probable
candidate probability distributions for the annual maxima wave hindcast data. The parameters of the GEV distribution are estimated using the MLE method, while the parameters of the Gumbel distribution are estimated using the MOM. The Gumbel distribution is adopted in this study, as the shape parameter of the GEV distribution does not deviate significantly from zero.

The 100-year $H_s$ at the locations BS1 – BS4 are estimated from the parameters of the adopted probability distributions. A summary of the estimated 100-year $H_s$ at the four locations is shown in Table 1. Generally, the estimated values suggested a decrease in the extreme wave further north. The differences in the estimated 100-year $H_s$ when using the different methods give an indication of the probable uncertainty that may be associated with the estimates.

It is difficult to select the best estimate from the three extreme wave prediction methods used in this study. This is because, each of the methods has its limitations. We find the estimates from the POT method to be dependent on the selected threshold, and the selection of the suitable threshold to be rather challenging. Further, we find both the POT method and the AM method to be sensitive to the few extreme significant wave heights in the wave hindcast data. We therefore adopted the estimates from the ID method.

2.2 Joint distribution of $H_s$ and $T_p$

The joint frequencies of $H_s$ and $T_p$ based on the 57 years wave hindcast data for the four locations is shown in Figure 4. The figure shows that the $T_p$ at the locations can be up to 24 s.

From the joint frequencies presented in Figure 4, the long-term joint distribution of $H_s$ and $T_p$ are established using the Conditional Modelling Approach (CMA) [4, 7 – 9]. In this approach, the marginal distribution of $H_s$ is modelled by a 3-parameter Weibull probability density function, and the distribution of $T_p$ conditional on $H_s$ is modelled by a lognormal probability density function.

Extrapolating the parameters of the lognormal distribution (mean and variance) to extreme sea states require fitting of continuous functions to the point estimates. Over the years, a 3-parameter continuous function or a 4-parameter continuous function has been found to be a good fit to the variance point estimates [4, 8, 10, 11]. In this study, both the 3-parameter and the 4-parameter continuous functions are compared, and the 3-parameter continuous function is found to be sufficient.

For the four locations, the estimated parameters of the joint distribution of $H_s$ and $T_p$ are summarized in Table 2. These parameters can be used in estimating the joint $H_s$-$T_p$ for any return period, in generating contour plots of long-term joint distribution, or in generating environmental contour lines.

Using the inverse first-order reliability method (IFORM) described by [11], environmental contour lines are generated for the four locations based on the parameters in Table 2, the contour lines are shown in Figure 5. These can be used in selecting short-term sea states for an approximate long-term response analysis for the locations.

3. Wave conditions for marine operations

Marine operations can be classified into weather restricted and unrestricted marine operations [12] described weather restricted marine operations as operations with planned operation period of less than 72 hours (3 days), while unrestricted marine operations are of longer duration. Safe planning and execution of weather restricted marine operations are dependent on reliable weather forecasts, while unrestricted marine operations could be planned using statistical data.

In this study, we have examined the wave conditions for marine operations in the Barents Sea from three perspectives; the probable weather windows for an operation that required that the $H_s$ is less than 3 m, the quality of the forecasted $H_s$, and the contribution of swell waves to the total sea in the area.
Table 1. Estimated 100-year $H_s$ for locations BS1 – BS4 using the three extreme wave prediction methods, the maximum value at each location is shown in italics; $H_s$ (m). (Table from [6])

| Method  | BS1    | BS2    | BS3    | BS4    |
|---------|--------|--------|--------|--------|
| 1D      | 16.09  | 15.83  | 15.11  | 14.46  |
| POT (7 m) | 15.98  | 15.89  | 15.25  | 14.24  |
| POT (9 m) | 15.96  | 16.26  | 16.47  | 15.95  |
| AM      | 16.03  | 16.09  | 15.92  | 14.95  |

![Logarithmic contour plots of $H_s$ and $T_p$ over the 57 years period (BS1 – BS4) [1].](image)

Figure 4. Logarithmic contour plots of $H_s$ and $T_p$ over the 57 years period (BS1 – BS4) [1].

Table 2. Estimated parameters of the joint probability distribution, the variance coefficient $b_1$ is fixed at 0.001 [1])

| Marginal $H_s$ 3-parameter Weibull | Conditional $T_p$ Mean coefficients | Conditional $T_p$ Variance coefficients |
|-----------------------------------|-------------------------------------|----------------------------------------|
| $\alpha$, $\beta$, $\gamma$      | $a_1$, $a_2$, $a_3$                 | $b_2$, $b_3$                           |
| BS1 1.12, 1.58, 0.77              | 1.46, 0.58, 0.34                    | 0.134, 0.318                           |
| BS2 1.16, 1.69, 0.76              | 1.38, 0.64, 0.31                    | 0.113, 0.275                           |
| BS3 1.24, 1.85, 0.70              | 1.42, 0.60, 0.32                    | 0.092, 0.239                           |
| BS4 1.24, 1.79, 0.73              | 1.42, 0.58, 0.34                    | 0.107, 0.252                           |

$\alpha$ - shape parameter, $\beta$ - scale parameter, $\gamma$ - location parameter
$a_1$, $a_2$, $a_3$ – coefficients of the fitted mean continuous function
$b_1$, $b_2$, $b_3$ – coefficients of the fitted variance continuous function

3.1 The weather windows
The probable weather windows for marine operations is investigated using the 57 years wave hindcast data. It should be noted that the presented weather windows are only useful for planning purposes, giving the planner an idea of what is likely from historical data. Actual weather forecasts at the locations are required for safe execution of operations.
Persistence analysis is used to estimate the probable weather window in each month, here, we defined persistence as a continuous duration in which the significant wave height ($H_s$) remains below (calm duration) or above (storm duration) the defined limiting significant wave height (e.g. $H_s(\text{lim}) = 3$ m) in each month. The monthly average calm duration ($\tau_c$) is defined as:

$$\tau_c = \frac{T_c}{N_c}$$

(1)

where $T_c$ is the total calm hours in a month < $H_s(\text{lim})$, $N_c$ is the number of calm windows in the month < $H_s(\text{lim})$.

For the limiting $H_s$ of 3 m, the monthly average calm duration estimated from (1) is presented in Figure 6 for BS1 – BS4. The figure shows that July is the month with the probable longest weather window for a limiting $H_s$ of 3 m. As indicated by the blue line in the figure, it may be difficult to find a 3-day weather window for a weather restricted marine operation in these areas in the winter months (October – April).

A comparison of the weather windows at BS5, Heidrun, and Ekofisk suggested that there is a higher probability of finding a 3-day weather window in the Barents Sea in the summer months, compared to the North Sea and the Norwegian Sea. Details of this comparison is presented in [13].

### 3.2 Wave forecast accuracy

As noted in Section IIIA, reliable weather forecasts are very important for safe marine operations. Considering the limited infrastructures in the Barents Sea, and its Arctic conditions, it may be more difficult to find reliable weather forecasts for the Barents Sea compared to the Norwegian Sea and the North Sea. In this section, we present the accuracy of wave forecasts for a location in the Barents Sea (BS6), compared to Heidrun in the Norwegian Sea.
Figure 6. Monthly average calm duration for a limiting $H_s$ of 3 m, using the 57-year wave hindcast for locations BS1 – BS4; a 3-day weather window is difficult to find in the winter months indicated by the blue line [1].

We have considered the available buoy wave observations from February – September 2010, for the Barents Sea location. Wave observations from a radar aboard the Heidrun platform have been obtained for the same period. Wave forecasts from the WAM10 model at 10 km resolution are obtained for the two locations.

The wave forecasts are then compared with the wave observations for each location, to estimate the accuracy of the forecasted waves. The measures of accuracy adopted are the mean absolute error (MAE) and the root mean square error (RMSE). Generally, the lower the estimated values of these measures of accuracy, the higher the accuracy of the forecast.

The estimated values of MAE and RMSE for the two locations are presented in Figure 7 when considering all the available wave observations. In Figure 8, we presented these values when considering only significant wave heights less than or equal to 3 m. A comparison of Figure 7 and Figure 8 shows that the accuracy of the forecasts do not change significantly when using only wave observations less than or equal to 3 m.

From the figures, it is observed that the accuracy of the wave forecasts at the Barents Sea location is higher in the summer months (May – September), compared to the winter months (February – April). For the Norwegian Sea location, no particular trend is observed in the forecast accuracy, and the accuracy appears even lower in July compared to some winter months. It is not straightforward to explain the observed trend for the Norwegian Sea location; however, it is noted that the wave observations are from different sources.

The inferences that can be drawn from the wave forecast accuracy are: the wave forecasts for the Barents Sea are of good quality at lead times less than 30 hours, the accuracy then decreases rapidly beyond this lead time. However, these findings may not be generalized, considering that the analysis is based on only one year data, which does not reflect inter-annual variability in the wave observations.
Figure 7. Comparison of wave forecasts accuracy at the locations BS6 and Heidrun using all the available wave observations in 2010 [1].

MAE – mean absolute error, RMSE – root mean square error. The legend represents the different forecast lead time.

Figure 8. Comparison of wave forecasts accuracy at the locations BS6 and Heidrun using only wave observations less than or equal to 3 m in 2010 [1].
3.3 Contribution of swell waves to the total sea
Swell waves are long periodic waves generated by distant storms. Compared to a young wind sea generated by local storm, a “swell is rather regular and long-crested”, and therefore has a narrow banded spectrum [14 - 16]. On the other hand, a “young wind sea is irregular and short-crested”, having a much broader spectrum [15, 16].

The knowledge of the swell waves at a location for marine operations is of importance. This is because, even for a very calm sea state ($H_s < 1\,\text{m}$), the presence of swell waves may limit the operation, and lead to long waiting on weather (WOW). A practical example is given by [16]. In addition, the knowledge of the swell waves at a location will aid in selecting a suitable wave spectrum for the planning of marine operations.

For locations in the Nordic Seas (North Sea, Norwegian Sea, and Barents Sea), [17] showed that swells are more prevalent in the Norwegian Sea, followed by the Barents Sea, with the least swell occurring in the North Sea. In this study, we investigated the contribution of swells to the total sea in the Barents Sea, using the 57 years wave hindcast data for BS1 – BS4.

For the four locations, the contribution of wind waves and swell waves to the total sea, based on their direction of propagation are shown in Figure 9 and Figure 10. It can be inferred that the contribution of southwesterly/westerly swells to the total sea in both winter and summer is significant. Therefore, swell waves should be well accounted for when planning for marine operations in the Barents Sea.

On the selection of wave spectra for marine operations: When planning for marine operations, the foregoing suggests that a double peaked wave spectrum is better suitable to describe the wave environment in the Barents Sea. The Torsethaugen wave spectrum [18] is therefore recommended.

However, it should be noted that the choice of the Torsethaugen spectrum is not a rigid one, the JONSWAP wave spectrum [19] may also be applicable for certain classes of $H_s$ and $T_p$ combination as shown in [20]. Further, the Torsethaugen wave spectrum does not account for wave directionality, in detailed analysis therefore, one must model the wind sea and the swell components separately. In such analysis, a combination of the Torsethaugen and JONSWAP wave spectra could be considered.

4. Polar lows
The polar low is one of the meteorological phenomena that are considered as additional challenges to marine operations in the northern Norwegian Sea and in the Barents Sea. The definition of a polar low that is commonly adopted is “a small, but fairly intense maritime cyclone that forms poleward of the main baroclinic zone” [21]. They have horizontal extents approximately between 150 and 600 km, and are referred to as mesoscale. They have been likened to hurricanes due to their appearances on satellite images [22]. However, polar lows are of smaller scales and are less intense compared to hurricanes. A satellite image of a fully developed polar low over the Barents Sea is shown in Figure 11.

An average of 12 fully developed polar lows have been observed in the Nordic Seas yearly, with a majority of these occurring in the northern Norwegian Sea and in the Barents Sea. Figure 12 shows the locations where fully developed polar lows are first observed in the Nordic Seas from December 1999 – October 2015. It is seen from the figure that a majority of the polar lows are observed in northern Norwegian Sea and Barents Sea.

Due to their mesoscale nature, and the limited infrastructures, polar lows are difficult to forecast. In many instances, the meteorologists do not identify a polar low until fully developed. See [23] for an example of a polar low event where the meteorologist did not identify the polar low until it hits a semi-submersible rig in the Barents Sea.
Figure 9. Winter wave roses for the four locations, based on the 57-year wave hindcast data: the length of each rose petal shows the frequency of occurrence of waves (wind sea/swell) from different directions [1].

The polar lows are considered a challenge to marine operations because of the weather conditions that often accompany them, including high wind speeds, heavy snowfall, poor visibility, and possible large waves. In this section, we focused on the wave growth in polar lows, the probable snow and ice accretion that a vessel caught up in polar lows may experience, and their effects on the stability of vessels of different sizes.

Figure 10. Summer wave roses for the four locations, based on the 57-year wave hindcast data: the length of each rose petal shows the frequency of occurrence of waves (wind sea/swell) from different directions [1].
4.1 Waves in polar lows

 Generally, wave growth is associated with wind speed and fetch. Considering the limited horizontal extent of polar lows, one may not expect large waves in polar lows. However, a wave moving along the path of a translating polar low can experience the fetch winds for a longer duration, if the wave group velocity matches the polar low velocity. Such a wave may therefore grow larger than a wave in a rather stationary fetch. The described phenomenon is termed group velocity quasi-resonance, effective fetch, dynamic fetch, trapped fetch, or extended fetch [2, 24 - 27].

\[ l_{\text{max}} \gg l \]

\[ 0.25 < V/U < 0.50 \]

\[ l > 8.13 \times 10^4 \cdot (V^4 / gU^2) \]

where \( l \) is the fetch associated with the polar low, \( l_{\text{max}} \) is the maximum fetch along a relatively linear path, \( V \) is the polar low velocity, and \( U \) is the wind speed associated with the polar low.

By adopting the wave prediction model by [2], we find that the waves in a majority of the fully developed polar lows in the Nordic Seas could have experienced an extended spectral evolution, if the polar lows velocities, \( V \), have been between 8 – 10 m/s [29]. We also find that the significant wave
heights at the end of the spectral evolution could be greater than 9 m [29]. As earlier noted, such large waves could not have developed if the polar lows are rather stationary.

4.2 Wave forecast accuracy in polar lows
In Section IIIB, we presented the accuracy of wave forecasts in the Barents Sea using the data for one location. No polar lows were observed at the location in the periods covered by the data. In this section, we examined the accuracy of wave forecasts in polar lows, using two specific polar low events from December 2015. The polar lows under consideration have passed near the Goliat platform in the Barents Sea.

The wave forecasts used in the study are from two sources, the WAM10 model earlier mentioned, and a recent model, AROME-Arctic at 4 km resolution. We compared the wave forecasts to the buoy wave observations at Goliat, using data from one day before the arrival of the polar lows, up to one day after the polar lows have passed the location of the observations (Goliat), see [29].

The comparison showed that both wave forecast models under predicted the observed waves in the two polar low events, especially at the time when the waves are observed to reach their maximum values. This observation is not surprising, as wave forecasts in polar lows is considered a complex problem, considering the nonlinear relationship between the stationary storm factors of wind speed, duration, and fetch, and the translating speed of a wave generating polar low.

4.3 Snow and ice accretion in polar lows
The amount of snowfall in polar lows are usually referred to qualitatively, mainly as heavy, moderate, or light snowfall. Heavy snowfall often accompany fully developed polar lows; see for example [21]. According to [30], a warning of heavy snow signifies the possibility of snowfall of 15 cm or more in 12 hours, or 20 cm or more in 24 hours.

In the study by [31], we concluded that up to 30 cm snow could accrete on the horizontal surfaces of vessels at sea during polar low occurrences. This is based mainly on reviewed papers, as there are very sparse information about snowfall at sea. The 30 cm snowfall is equivalent to the recommended 10000-year characteristic snow load by [3] if the snow density is 400 kg/m³.

The accretion of sea spray icing on vessels at sea during polar low occurrences is attributed to the high wind speeds that often accompany polar lows in combination with low air temperatures. It is noted that severe ice accretion is often associated with sea spray icing resulting from wave-structure interaction, compared to sea spray icing resulting from wind. Therefore, a vessel in transit during polar lows may experience more ice accretion than a rather stationary vessel.

Using a few metocean observations, and a review of past icing experiences, [31] concluded that up to 25 cm ice could accrete on a vessel at sea during polar low occurrences. For a ship-shaped vessel, the 25 ice is considered in the vessel’s maximum ice accretion zone, with a reduction factor considered at the other zones.

We have examined the effect of the additional 30 cm snow and 25 cm ice on the stability of three ship-shaped vessels of similar geometries but different sizes. We find that the stability of the smallest vessel is the most affected by the additional snow and ice loads. In our study, we have considered only symmetrical snow and ice distribution on the horizontal surfaces of the vessel. However, as shown by [32], asymmetrical snow and ice load distributions could be of higher concern.

In the study by “in press” [33], we also examined the effect of the additional snow and ice loads on the stability of semi-submersibles, using a sixth generation DP3 and moored harsh environment semi-submersible drilling rig as a case study.

By considering the snow load on all the semi-submersible horizontal surfaces, we find that the snow load could be very significant. For snow thicknesses of 15 and 30 cm, the resulting snow loads are 369.56 and 739.18 tons, respectively. However, we find that such symmetrically distributed snow loads will have little effect on the intact stability of a semi-submersible.

Ice loads resulting from sea spray icing are considered to accrete mainly on the windward side of the semi-submersible. We find that the ice load may not exceed 300 tons in any of the semi-
submersible loading conditions (transit, operation, survival), even for ice thickness up to 25 cm. However, the ice load may exceed 600 tons if the sea spray icing event extends to the main deck of the semi-submersible, this is possible when the semi-submersible is on deep draft.

The case with the sea spray icing extending to the main deck is found to be the most dangerous, with the semi-submersible heeling about 12 degrees. It should be noted that heeling above 5 degrees will be of significant concern to personnel aboard a semi-submersible, and such heeling will generally hinder drilling operations.

5. Summary of findings
The estimated 100-year $H_s$ from the four Barents Sea locations indicate a decrease in the extreme $H_s$ further north, this is in agreement with the expected spatial trend in the wave climate in the Barents Sea.

Longer weather windows are observed for marine operations in the Barents Sea in the summer months, compared to the North Sea and the Norwegian Sea. Further, the wave forecasts for the Barents Sea are found to be of good accuracy, especially at forecast lead times less than 30 hours. However, in polar low situations, the wave forecast accuracy is deemed poor.

Although, waves in polar lows are not as large as the 100-year design wave for the Barents Sea, however, waves in polar lows will limit most marine operations. The probable snowfall and vessel icing in polar lows are additional limitations to marine operations in the area, generally snow and ice accretion are deemed both operation and safety hazards.

Overall, the weather conditions that often accompany fully developed polar lows represent limitations to marine operations in the Barents Sea. Marine operations should not be carried out within the periods when polar lows are likely to occur, even if the probability of occurrence is small.

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