Marine Operations in Arctic conditions

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ABSTRACT

Marine operations require careful early planning and thereafter detailed planning prior to project execution. The time from initiating an operation to finalization of the activity is typically several days. The activity can only be conducted during limited weather conditions. The planning prior to the offshore operations does, therefore, require accurate weather forecasting. The weather conditions may be of particular concern for operations in Arctic waters. During the season when polar low pressures can be expected in the Arctic, reliable weather forecasts exceeding one day may not be available. The paper will discuss the planning procedure to ensure safe operations and will discuss the reliability of arctic weather forecasts with emphasis on uncertainties related to polar low pressures. The main contribution of the paper is to document that the time between polar low pressures passing a location could be short, necessitating good communication with meteorologists. The effect of polar low pressures on fishing operations is, furthermore discussed. If possible, the fishing fleet should leave an area when the track of a polar low may pass a site.

KEY WORDS: Marine operations, Arctic conditions, Barents Sea, Alpha factor, Polar low pressures, Sea spray icing, Waiting on weather.

INTRODUCTION

In order to handle the uncertainties in weather forecasts, DNV (2011) introduced a factor limiting the allowable weather where a marine operation can be carried out, the OP_{LIM}, by an alpha-factor. The duration of the marine operation is called the reference period, T_R, which is the sum of the Planned Operation Period, T_{POP} and a Contingency Time, T_C. The weather forecasted (WF) for the Reference Period shall thus be $OP_{WF} = \alpha \times OP_{LIM}$, see Fig. 1. (DNV, 2011). For guidance regarding the development of an alpha-factor, see Wu and Gao, 2021.

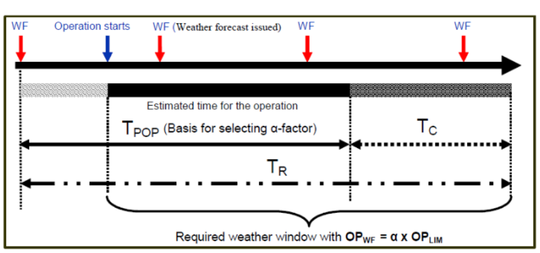

Fig. 1. Definition of Alpha Factor (DNV, 2011).

In areas where the weather uncertainty is large, the value of the alpha factor would have to be set to a low value, indicating a large reduction of the Operational limit of the equipment (vessel) used for the operation. In such circumstances, the possibility to carry our weather restricted operations is limited and long periods of waiting on weather (WoW) could be expected. Notice that the uncertainty may be reduced by employing a "meteorologist on site" or providing onsite data by employing wave measurements on site. It is also common to consult two different weather services to confirm the forecast.

During the winter season, the uncertainty in weather forecasts is very large in the Arctic, in this paper exemplified by discussing the Barents Sea (see also Gudmestad, 2017). The main concern is the occurrence of polar low pressures (small hurricane type of pressures) which are difficult to forecast with respect to track, magnitude, and wave conditions. Wilcken (2012), in her master thesis, concluded that it is not possible to identify suitable alpha factors for the harsh weather season in the Barents Sea and concludes that the alpha factor is not suitable to describe the uncertainty in the arctic areas related to the extreme weather caused by polar lows.

APPLICABILITY OF THE ALPHA FACTOR AND OTHER MEASURES OF ENVIRONMENTAL UNCERTAINTY

As previously discussed, DNV permits the use of the alpha factor to mitigate the uncertainty in the significant wave height due to forecast prediction errors. The factor is a number less than 1 which is applied to the design sea state: the sea state that defines the limiting conditions for the operation, to create the forecasted operational criteria: the sea state which is considered limiting towards the wave forecast, (DNV, 2011).

The rationale behind the alpha factor is to ensure that the operational limiting criteria, OP_{LIM}, is representing safe operations under forecast uncertainty, and it shall be clearly described in the marine operation manual. This alpha factor is estimated from historical records of forecasted significant wave heights compared with the measured value at locations of interest. The factor is tabulated (DNV, 2011) for combinations of Hs and operational duration, where the operational duration is closely linked to the forecast lead time, i.e., the duration from issuance of the forecast to the time when the operation is planned to be finalized. A limitation related to the use of the alpha factor is that the factor does not take the wave period into account and operations in long swells in case the vessel is in resonance with the waves, would limit the allowable weather for an operation more than when using the suggested alpha factors (DNV, 2011). Reference is further made to Wu and Gao (2021) regarding the development of a response-based correction factor (alpha factor) for allowable sea state assessment of marine operations considering weather forecast uncertainty.

In order to condense the forecast uncertainty into a single factor, it is necessary to make some significant assumptions. This is a limitation for the use of the alpha factor that should be closely considered, particularly when operating in arctic conditions. One of the main assumptions in creating the alpha factor is that the forecast prediction error is normally distributed and can be estimated using the sample standard deviation and mean of the historical records.

The prediction error caused by a polar low will, in fact, not follow a normal distribution. While the impact of a polar low on the prediction error is severe, it is relatively rare for a specific location compared to the large number of smaller deviations caused by the normal prediction error. The established alpha factors are furthermore based on historical records collected across all seasons. The impact of polar lows on the standard deviation and mean error which determines the alpha factor is therefore small. However, the changes in the weather conditions in case of a polar low pressure are rapid and large and the weather forecast during the period of the year when polar low pressures could be expected is very uncertain.

Ensemble forecasting is a different approach to quantify the uncertainty of the wave conditions that is not based on historical records. By introducing small perturbations in the initial conditions provided to the forecast models, this method produces a range of possible scenarios see e.g. Anderson (1995). Un-like the alpha factor, it reflects the stability of the weather systems in a specific situation. The use of ensemble forecasting to predict polar lows are described by Kristiansen et al. (2010). To adequately cover the occurrence of polar lows, the forecast service would need to:

1) Be based on a computational model with sufficient resolution to predict such a phenomenon

2) Include a range of ensemble members / initial conditions that adequately captures the possibilities for a polar low to occur

This type of prediction is currently not provided by general ensemble forecasting models. A more realistic scenario for operating under the threat of polar lows is to distinguish between the normal prediction error in the weather forecasts and the occurrence of polar lows. A separate warning service would be required, which is provided by The Meteorological Institute and published by Barents Watch. In the case of offshore construction work, it would be sufficient to issue a warning if the likelihood of being exposed to a polar low is more than the acceptance threshold level. The strength of the polar low system is of less importance, since most activities are very sensitive to weather conditions and must normally be suspended in any case. Accurate and early warning about the possibility of a polar low is however of high importance, since a short notice time will put severe restrictions on the operations.

Impact of polar lows on planning and execution of a pipeline installation activity

Offshore installation projects normally include a large variety of activities. Some can be completed within a short time interval or can be easily suspended, while other activities require a commitment to suitable weather conditions days ahead of completion. Because weather is a chaotic system, such that meaningful prediction is only possible a few days ahead, the latter type of operations requires planned contingency procedures for aborting the operations should the conditions deteriorate beyond the system's capacity. Operations that are planned for more than three days without the possibility to abort, must in any case be classified as weather unrestricted operations according to DNV rules (DNV, 2011) and tolerate weather conditions up to the seasonal extremes.

Pipeline installations often take several days to complete and are sensitive to wave conditions such that contingency procedures for suspending the operation during adverse conditions are needed. As a pipeline is being laid, the vessel is effectively tied to the seabed through the pipeline. A controlled abortion of the operation, which includes cutting and sealing of the pipeline and the controlled lowering to the seabed, may take as much as 48 hours to complete and requires adequate working conditions for the crew during that time.

If a polar low-pressure situation causes an unexpected and abrupt deterioration of the weather conditions, the vessel must either stay connected to the pipe or one must engage in an emergency procedure to cut the pipe. If the vessel stays connected, it could in some cases be possible to device a storm riding configuration for a severe wave condition where damage to the pipe is limited to a specific section, while the remainder of the pipe is protected. The damaged pipe can then be replaced when the conditions are calm. However, this is not in accordance with DNV rules (DNV, 2011) and only possible if the vessel can stay on position.

Should the vessel experience a sudden, unexpected, and potentially hazardous condition that is outside the vessels station keeping capabilities, the only option is also an emergency disconnection from the pipeline. While an emergency cutting of the line is possible, this is destructive to the pipe and will cause significant loss of value.

Acceptance of the risk is not possible in case there is loss of life at stake, for example the icing of a vessel to the point that it might capsize. If adequate measures are implemented to avoid such an extreme scenario, the likely worst outcome of a polar low is the destruction of the product being installed. An economic loss could be accepted, but the stakeholders should be aware of the risk. Additionally, there should be clear procedures for this scenario, to ensure that a potentially hazardous situation is not escalated due to delayed decisions and uncertainty with the offshore crew.

POLAR LOW PRESSURES

Polar low pressures, frequencies, and tracks

The main concern for planning of marine operations is the uncertainty in the weather forecast. In the arctic conditions the uncertainty is mainly related to the forecasts of low-pressure situations. A Polar low pressure is a well-known phenomenon in the northern regions, see Barents Watch (Internet page). A thorough explanation of the phenomenon can be found in EuMeTrain, (2019). Fig. 2 shows tracks for polar low pressures during the period 2015 – 2017 (Golubin et al., 2021).

It should be noted, that polar low pressures situations are rare in the period from May to August. From 1995/1996 to 2008/2009, the total number of polar lows observed in the Barents Sea was 637 (45.5 per season), however, variations in this number from season to season are large, see Fig. 3 (Smirnova et al., 2015).

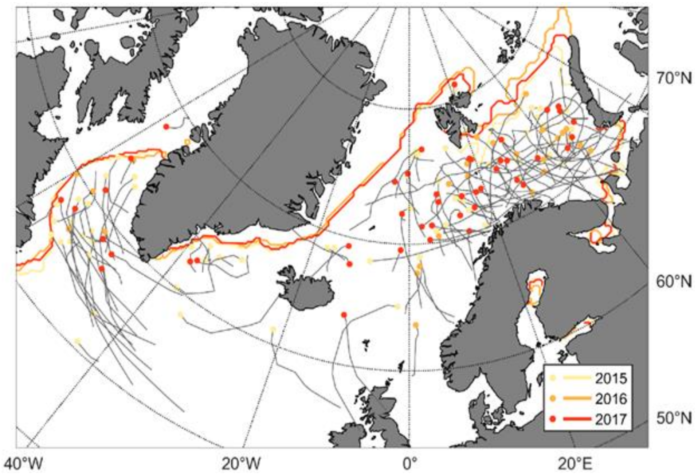

Fig. 2. Tracks for polar low pressures during the period 2015 – 2017 (Golubkin et al., 2021). Note that the further south an operation is going to be carried out, the lower is the probability of encountering a polar low pressure. Legend: Thick colored circles represent locations of the first observation of a polar-low, colored lines represent median sea ice extent. The thin grey lines indicate the trajectories of the identified polar lows.

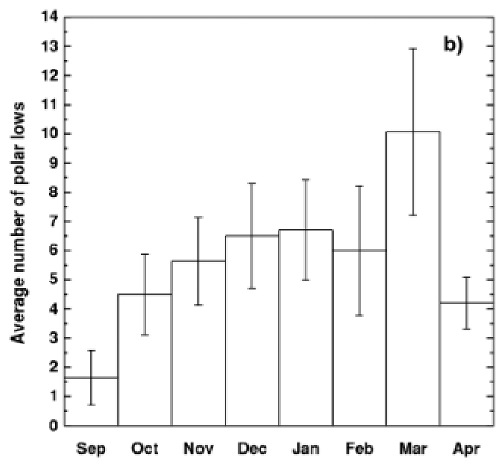

Fig. 3. Variation in the number of polar low pressures in the Barents Sea during the period from 1995/1996 to 2008/2009. The vertical lines show the standard deviation (Smirnova et al., 2015).

Considerable research efforts have been made to increase the knowledge about polar low pressures. The Metrological Institutes in Tromsø and Oslo have carried out several projects. Prominent Norwegian researchers are/have been Noer, Gunnar (See: Google Scholar) and Kristjánsson, Jón Egill (See: Google Scholar).

Barents Watch (Internet Page) advertises that "At Barents Watch you will find maps from the Meteorological Institute, which show the probability of polar low pressure hitting an area during the next 42 hours". This should give a certain time to prepare for a polar low pressure, but there are several aspects that make warning very problematic.

The tracks of Polar Low Pressures

The tracks of the low pressures are very uncertain, see Fig. 4. It is also uncertain whether *other polar low pressures* will form in the area.

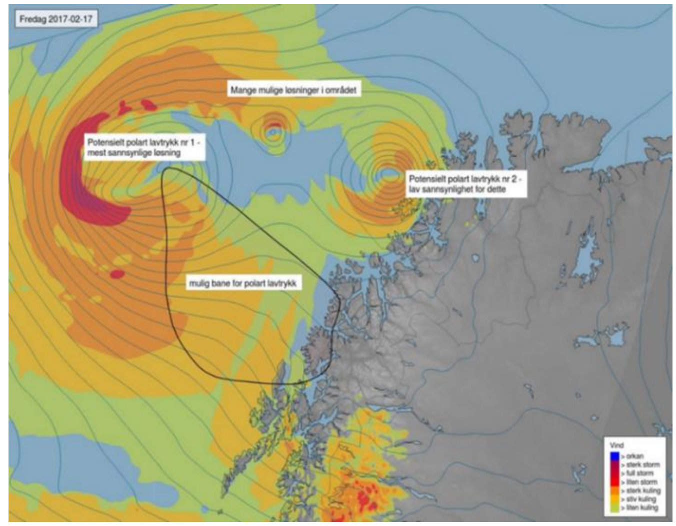

Fig. 4. Possible trajectories for polar low pressures. From the Newspaper Lofoten and Vesterålen (2017).

A forecast may look like that that given in Fig. 5 for the 5th March 2021; a large area might be affected within a day. One day later, this special warning was cancelled. If measures had been initiated in the area where the polar low could possibly pass, by stopping activities to limit any damage caused by this polar low pressure, the measures would have been wasted.

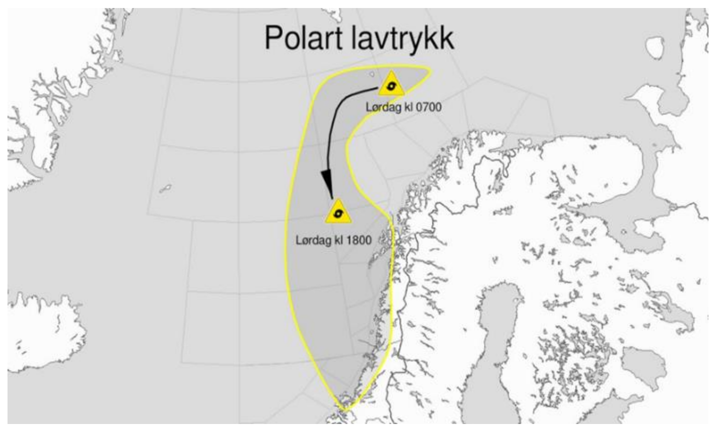

Fig. 5. Possible track for a polar low pressure (DNMI, 2021).

On 27th January 2022, a warning was sent out as given in Fig. 6. The warning was given with a very short time window available to act. Mobilizing comprehensive safety measures by stopping activities and returning to harbor in less than 12 hours for all vessels within the large area would be very demanding.

In some cases, probability assessments can be given for the path of polar low pressure, for example by creating ensemble tracks, but it is difficult to deal with the fact that the probability is from relatively high to very high within a wide area of the ocean.

Fig. 6. Polar low-pressure warning on 27th January 2022 (DNMI, 2022).

Dual and Multiple Polar Low Pressures.

It is, furthermore, uncertain whether several polar lows might form at the same time or close to each other, whether so-called "Dual polar lows" or "Multiple polar lows" will form, see Fig. 7 (Rojo et al., 2015) and Fig. 8 (Hallerstig et al., 2021). Fig. 7 shows two polar low pressures that follow right after each other (Dual polar lows), while Fig. 8 shows three consecutive polar low pressures. Several polar low pressures can also occur in the same area, Fig. 9. The question whether one can start an operation when a polar low pressure has just passed, is thus to be answered by the need to look for the next polar low that may appear at the site within a very short time following the passing polar low.

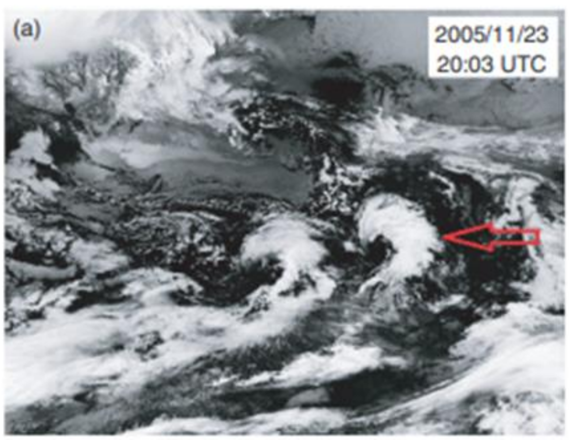

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Fig. 7. Two polar low pressures following each other (Rojo et al., 2015).

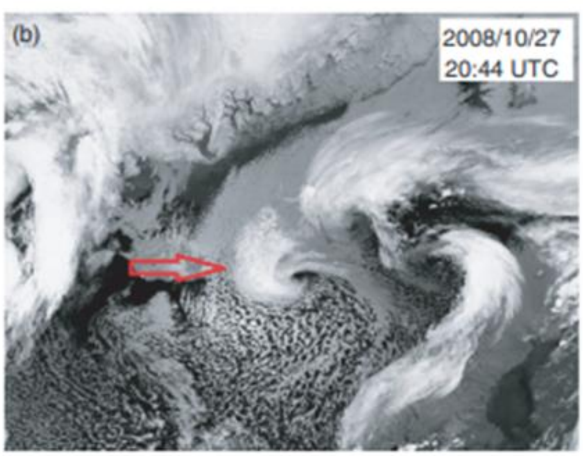

Fig. 8. Three consecutive polar low pressures (Hallerstig et al., 2021).

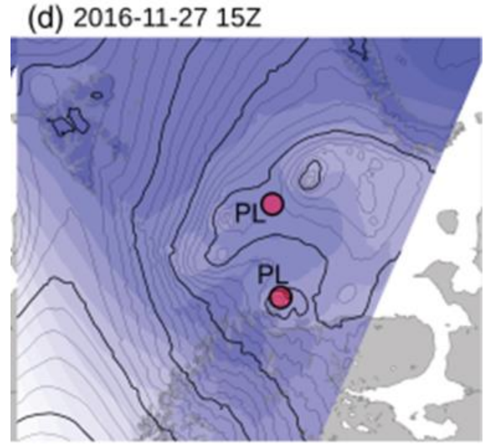

Fig. 9. Two simultaneous polar low pressures in an area, 27th November 2016 (Hallerstig et al., 2020).

Polar low pressures occurring few days apart

Polar low pressures can also occur a few days after each other in the same area. Fig. 9 shows that on 27th November 2016, two polar low pressures passed north of west Finnmark. Already on 8th December, two new polar low pressures passed the same area, see Fig 10 (Hallerstig et al., 2021).

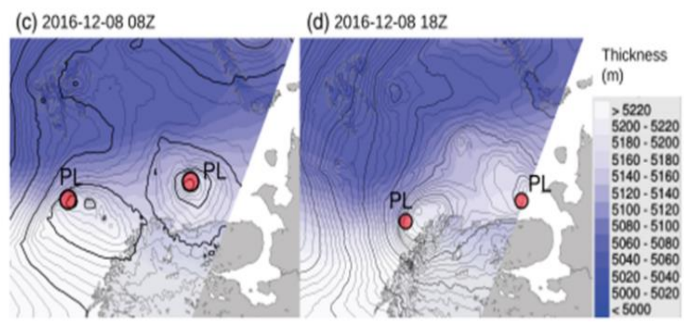

Fig. 10. Polar low pressures on 8th December 2016 (Hallerstig et al., 2021).

Through a more thorough review of the available literature, it is expected that one can identify several cases of simultaneous polar low pressures in a geographical area or a short time between passing of polar low pressures at a certain location. The concern is that the weather situation could be very uncertain during the period when polar low pressures are expected. When a polar low pressure has passed an area, another polar low pressure might appear within hours or within few days. Due to the uncertainty in the weather forecast, it is not possible to start planning of operations during the period when polar low pressures could appear. In case of stable high-pressure situations, the meteorologists might, however, forecast the weather with higher degree of stability and reliability. Note that the waiting time between stable high-pressure situations could be very long in the Barents Sea.

The potential for icing in Polar Low Pressure

Polar low pressures are associated with relatively large waves building up over a short period of time. These will then cause icing to form on vessels in the area. At the trailing edge of a polar low pressure there is also, often a lot of snow, and if the snow is wet, in addition to the icing from sea spray, heavy and wet snow will settle on vessels. This wet snow can freeze to ice. The consequences are that the center of gravity of the vessels can be raised and the vessels can lose stability and capsize (Johansen et al., 2020). A warning occurs prior to dangerous situations as the roll period of the vessel increases when approaching unsafe stability conditions, i.e., low GM values. Every year there have been ships that have gone down in the Barents Sea due to sea-spay icing (see, e g. Reuters 2020). The topic of vessel stability during an icing event can be elaborated in more detail and is treated thoroughly in the specialist literature (see e.g., Johansen et al., 2020).

DNMI; The Norwegian Meteorological Institute regularly issues warnings about the danger of sea spray icing. In this respect, it should be noted that fishing vessels and other vessels influenced by a polar low pressure is at risk of capsizing and more accurate weather forecasts are regularly being asked for. As the Arctic Seas are becoming ice-free longer periods of the year, the occurrence of polar low pressures shifts to new locations and Fig 2 shows the occurrence of initiation of polar low north of the Svalbard archipelago.

The amount of icing to be used to check vessel stability is unclear, reference is made in this context to Norsok standard N-003, Standards Norway (2016). This standard applies to permanently located facilities at sea and cannot be used without further analysis for vessels in transit. Ice thicknesses of up to 650mm are recommended, while ice thicknesses of up to 1100mm are recommended for extreme conditions. The standard also provides an expected average value for the number of days per year that heavy icing can be expected in the Barents Sea; 20 - 40mm per hour. Samuelsen et al. (2015) have investigated the amount of icing on the coastguard ship KV Nordkapp in 1987, an event where data was recorded. Meteorologist will issue warnings to fisheries to be prepared to leave the locations if potential tracks of Polar Lows are forecasted in an area.

It is worth noting that in some cases the speed of polar low pressure coincides with the phase speed of the waves that are generated. If so, the waves grow rapidly in a few hours and the potential for sea spray increases (Orimolade et al., 2016). A similar situation was also confirmed by G. Noer regarding a polar low pressure in 2012 (Wilcken, 2012).

CONCLUSIONS AND RECOMMENDATIONS

There is a low probability of forecasting the occurrence and the track of polar low pressures in the Arctic seas during the period from September to April. In this paper we have considered the conditions of the Barents Sea.

As the wind and wave conditions as well as the snow and sea-spray icing conditions in a polar low can be severe, any operations requiring limited weather conditions can be at danger, should a polar low pass close to the location of the operation. This calls for implementing very careful procedures for starting activities which require a weather window exceeding, say 24 hours.

Further research to enable the meteorologists to better predict the creation and track of polar low pressures in arctic areas would be beneficial to the fishing industry, to the commercial shipping industry and to marine construction work. In the meantime, the meteorologists issue warnings that limit operations and harbor are closed to ensure that smaller fishing vessels do not leave harbor.

The marine construction industry often carries out operations having a duration of up to three days based on weather forecasts. This is the length of an operation that can safely be carried out or safely be aborted within the three days period in many areas, for example in the North Sea Area. During situations when the meteorologists issue a forecast of a probable low pressure, marine operations having a duration of more than a considerably shorter time, say 24 hours could be at risk and procedures to wait on weather must be implemented. In case a quick abortion of the operation is possible with a safe recovery, operations may start for operations in excess of this anticipated time.

Given that a polar low has passed, there is a distinct probability that more polar low pressures may pass within hours or a few days after passing of the first event. In the paper, we have identified several occasions of dual or multiple polar lows and short periods between polar lows. The reason being that situations favorable for initiation of polar low pressures will be present over a certain stretch along the ice-water interphase and that this situation may last for several days. The meteorologists should be aware of such situations and research is called for to identify the probability of multiple or dual polar lows. At present, this calls for careful analysis when working in the arctic seas, regarding when or whether one should initiate the start-up of an operation following the passing of a polar low.

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REFERENCES

Anderson, J. L. (1995). "Selection of Initial Conditions for Ensemble Forecasts in a Simple Perfect Model Framework." *Journal of the Atmospheric Sciences*, Vol. 53, No. 1, pp. 22-36

Barents Watch https://www.barentswatch.no/tjenester/Prognose-for-polart-lavtrykk-/ (Accessed 27th November 2022).

DNMI, Det Norske Meterologiske Institutt, 5th March 2021. https://www.blv.no/nyheter/varsler-polart-lavtrykk-lordag/

DNMI, Det Norske Meterologiske Institutt, 27th January 2022. https://www.nrk.no/nordland/polart-lavtrykk-pa-vei-mot-nord-norge-1.15830779

DNV, Det Norske Veritas (2011). «DNV-OS-H101 Marine Operations, General". *Det Norske Veritas*, Høvik, Norway, Updated 2016.

EuMeTrain (2019). https://eumetrain.org/index.php/resources/polar-low

Golubkin, P., Smirnova, J. and Bobylev, L. (2021). "Satellite-Derived Spatio-Temporal Distribution and Parameters of North Atlantic Polar Lows for 2015–2017". *Atmosphere* 2021, 12(2), 224; https://doi.org/10.3390/atmos12020224.

Gudmestad, O. T. (2017). "Limitations related to Marine Operations in the Barents Sea." *Journal of Physics*: Conf. series (JPCS).

Hallerstig, M., Magnusson, L., Kolstad, E. W. and Mayer, S. (2021). "How grid-spacing and convection representation affected the wind speed forecasts of four polar lows". *QJR Meteorological Society* 2021; 147:150–165. https://doi.org/10.1002/qj.3911.

Johansen, K.; Sollid, M. P.; Gudmestad, O. T.; (2020). "Stability of Vessels in an Ice-free Arctic." *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation,* Vol. 14, No. 3, https://doi:10.12716/1001.14.03.19, pp. 663-671.

Kristiansen, J.; Sørland, S.L.; Iversen, T.; Bjørge, D.; Køltzow, M.Ø. (2010). "High-resolution ensemble prediction of a polar low development". *Tellus A: Dynamic Meteorology and Oceanography*, 63:3, 585-604, https://doi.org/10.1111/j.1600-0870.2010.00498.x

Kristjánsson, Jón Egill. Internet Page. Google Scholar: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=kristj%C3%A1nsson+j%C3%B3n&oq=Kristj%C3%A1nsson.

Lofoten og Vesterålen (2017). Map published by the newspaper "Lofoten og Vesterålen," 17th February 2017. Available in the Archives of the newspaper.

Noer, Gunnar. Internet Page. Google Scholar: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=gunnar+noer&btnG=

Orimolade, A.P.; Furevik, B.R.; Noer, G.; Gudmestad, O.T.; Samelson, R. M. (2016). "Waves in polar lows." *Journal of Geophysical Research - Oceans* 2016; Volume 121 (8) p. 6470-6481. Also published in: Journal of Geophysical Research – Oceans. Special Section: The Arctic: An AGU Joint Special Collection. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2016JC012086

Reuters (2020). "Russian trawler sinks in Barents Sea, 17 feared dead". *Reuters* 28th December 2020. https://www.reuters.com/article/uk-russia-trawler-idUKKBN2920C6

Rojo, M., Chantal, C., Mallet, P.-E., Noer, G, Charleton, A. W. and Vicomte, M. (2015). "Polar low tracks over the Nordic Seas: a 14-winter climatic analysis". *Tellus A: Dynamic Meteorology and Oceanography*, 67:1, 24660, https://doi:10.3402/tellusa.v67.24660

Samuelsen, E. M., Løset, S. and Edvardsen, K. (2015). "Marine icing observed on KV Nordkapp during a cold air outbreak with a developing polar low in the Barents Sea". *Proc. of the 23rd Int. Conf. on Port and Ocean Engineering under Arctic Conditions*, June 2015, Trondheim, Norway.

Smirnova, J., Golubkin, P., Bobylev, L., Zabolotskikh, E. and Chapron, B. (2015). "Polar low climatology over the Nordic and Barents seas based on satellite passive microwave data." *Geophysical Research Letter* 42, 5603–5609, https://doi:10.1002/2015GL063865.

Standards Norway (2016). "Norsok N-003; Actions and action effects". *Norsok Standard*, Oslo, Norway

Wilcken, S. (2012). "Alpha factors for the calculation of forecasted operational limits for marine operations in the Barents Sea". *Master of Science Thesis,* University of Stavanger, Norway. https://uis.brage.unit.no/uis-xmlui/handle/11250/182992.

Wu, M.; Gao, Z. (2021 "Methodology for developing a response-based correction factor (alpha-factor) for allowable sea state assessment of marine operations considering weather forecast uncertainty". *Marine Structures 79 (2021) 103050*. https://doi.org/10.1016/j.marstruc.2021.103050