A climate service to harness extreme weather risk: a demo application

Arctic Icebergs in the frozen North Atlantic Arctic sea. West Greenland, 70 degrees North. Image credits: DNV GL

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A climate service to harness extreme weather risk

Recognizing the changing Arctic

We all acknowledge the Arctic is changing, and our perception of icebergs and permanent ice cover is changing profoundly. The changes create opportunities as new territories and resources become accessible. Oil fields in the Barents Sea extend further North entering new territory, and ships may sail passages which were previously not accessible. The societal relevance and industrial impact is yet to be seen, but there are already signs of transformation as businesses and society adapt to a new Arctic reality. How will the changes materialize and manifest themselves? And how will people and wildlife adapt to inhabit a future Arctic?

Adapting to a future climate

We may not know what a future climate will look like, but there is strong evidence we will experience more extreme weather, storms lasting longer, with larger force and greater reach. The implications can be disastrous, and the industry needs to prepare for this.

Why are polar lows relevant?

Throughout history, seafarers of the North have told tales of unexpected encounters with fierce storms that appeared out of nowhere. These storms were well known to the coastal community and early tradesmen. The storms were generally recognized by abrupt changes in weather, heavy snowfall, gale force winds and rough seas. Records of impact witness substantial damage to infrastructure, havoc on the seas, disrupted fisheries and closed shipping routes.

A climate service to harness extreme weather risk

Although larger ships today are equipped to withstand polar lows, the storms represent an additional risk which needs to be managed. Polar lows may pose a high risk to smaller size fishing vessels, recreational activity, expeditions, and potentially cruise tourism. In Arctic voyage planning, the risk of polar lows encounter must be included.

DNV GL objectives

In Blue Action, we seek to better understand these changes along with their impacts. We want to understand how these systems play out, and we want to recognize, describe, and communicate these risks to industry, policy makers, and society.

- Investigate predictability of extreme weather events associated with marine cold air outbreaks in the Arctic
- Understand the linkages between a changing Arctic and its' connotations to climate variability
- Identify how improved forecasts can be used to mitigate risks of operating in polar waters

The Scientific foundation

Marine Cold Air Outbreaks (MCAOs)

- During certain synoptic-scale weather patterns, cold-air outbreaks may be triggered and the cold Arctic air masses become exposed to the relatively warm ocean surface.
- Such conditions are conducive to strong, deep convection and the formation of polar lows.
- MCAOs are recognized as one of several key forces which characterize a genesis environment for polar lows.
- Blue Action has investigated the causality of MCAOs looking into several drivers. We are beginning to understand them, but more science is needed.

Polar Lows (PLs)

- Intense mesoscale cyclones known as polar lows are frequently observed in the Atlantic sector of the Arctic ocean.
- They are commonly referred to as "Arctic hurricanes", displaying common traits with tropical hurricanes. They are, however, intrinsically different in some respects.
- Polar lows can appear suddenly, chaotic and random, last only a few hours (2-48 hours), and dissipate rapidly.
- They are generally smaller than their tropical counterpart, reaching "only" 200-1000 km in diameter.
- Polar lows are mesoscale cyclones notably related to MCAOs.

One way to look at this is to track past events and assume future events will appear similarly. Given the changes in Arctic weather regimes, this might be a wrong and misleading assumption. The nature of polar lows occurring irregularly and short-lived call for an attempt to incorporate new knowledge of how these storms develop and pass. Large scale atmospheric features such as the jet stream, the polar vortex, and even stratospheric influence, accompanied by alterations in the NAO and the AO, all shape a climate in which polar lows can form. A favorable environment for polar lows also involves attention to marine cold air outbreaks which is well recognized as a precondition for polar lows to develop.

The case study has analyzed 40 years of climate data to produce the MCAO index based on the ERA-Interim dataset. To explore a relation to polar low events, we have examined 20 years of historical records of polar low tracks in the PANGAEA inventory. Central to the study has been to understand the processes in play and to identify a set of predictors (or precursors), which eventually can lead to new insights and higher skill in prediction.

The Link between MCAOs and Polar Lows

- The case study has studied the relationship between MCAOs and PLs under the assumption that MCAOs are a precondition to PLs.
- A recent study (Terpstra et al., 2020) suggests two thirds (2/3) of MCAOs in the North Atlantic are accompanied by mesoscale marine cyclogenesis. The most intense of polar mesoscale cyclones (PMCs) are referred to as polar lows in the mature phase.
- Strength in signal (MCAO intensity) relates to likelihood for polar low development.

- Despite retreating ice cover, and increasing temperatures, we see an increasing trend in MCAO frequency and intensity [in the Barents Sea in winter months].

The MCAO Index and atmospheric stability

- The atmosphere is generally stable if potential temperature increases with altitude.
- The MCAO index measures **atmospheric instability condition** which causes convection within the boundary layer over open ocean (Kolstad, 2017).
- This atmospheric instability is believed to be a main cause to development of polar lows.
- The index describes air-sea **potential temperature difference** from sea level (potential ocean skin temperature) and an altitude corresponding to atmospheric pressure 850 hPa (about 1.5 km above sea level, just above the boundary layer).
- A positive MCAO index indicates atmospheric instability condition favorable for a development of PLs.

Other drivers to storminess in the Nordic Seas

To fully grasp the interconnectedness, and in context of this study, it is worthwhile to mention a few other drivers*:

- Atmospheric circulation and blocking patterns, Greenland blocking and Atlantic ridge blocking.
- The effect of polar jet stream meandering.
- Arctic melt and freshening of Arctic waters' influence on thermohaline circulation and the region's storminess.
- Polar vortex anomalies and associated sudden stratospheric warming (SSW) events.
- Arctic-stratospheric pathways and stratospheric-tropospheric coupling.
- The North Atlantic Oscillation (NAO); its' positive (negative) phase and influence on winter weather regimes in the Nordic Seas.

Industry Relevance

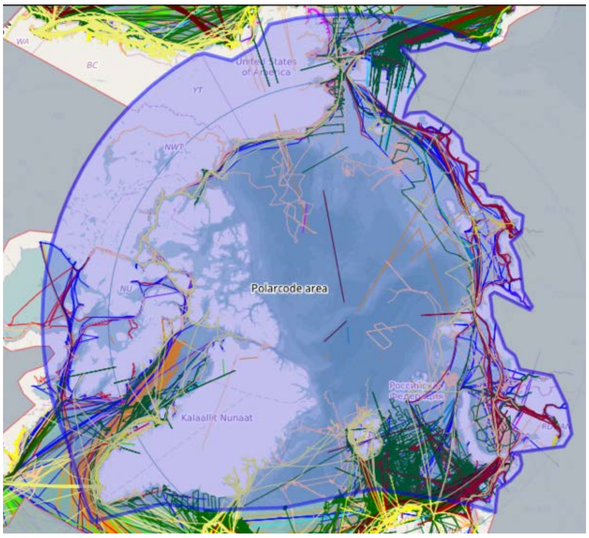
Climate resilience in offshore activity: Search and rescue operations offshore, transfer or personnel, installation, and loading and offloading operations all depend on suitable "window of opportunity". Arctic operations are often restricted by harsh environmental conditions such as rough seas, cold temperatures, and/or bad weather.

Why is this important? Will the polar low impact on the chosen route, and will navigational safety be affected. Are there alternative routes to avoid the storm?

A primary concern for ocean seafarers is safety at sea. All instruments of the organization must work towards preserving and maintaining safety at sea, in all aspects. Reliable weather information is one element which is crucial to make the right decisions with regards to the journey ahead and navigational safety.

Improved and longer forecasts (sub-seasonal to seasonal) enable the industry to plan their voyages with regards to severe weather, optimize weather related operations, and respond to events efficiently and appropriately.

Rising activity



In 2019, **1628 unique vessels** entered the Polar Code area. The majority of traffic is in September with 977 vessels sailing in the region.

The 2019 figure is a 25% increase in number of unique vessels engaging in Arctic shipping relative to 2013 (1298 vessels).

In the same period, PAME* [1]reports a 75% increase in total distance sailed for all vessels.

Notably, **fishing vessels represent 41% of all vessels** entering the area in 2019.

Traffic from bulk carriers has risen substantially. We also note a significant increase in number of cruise vessels present: In 2019, 73 cruise vessels entered the region.

Figure 1 AIS ship tracks of all ships sailing in the Polar Code area in September 2019.

Industry attention and needs - Arctic shipping routes

Arctic shipping routes are subject to many considerations nowadays. Safety of crew and passengers is imperative to all voyages, but also securing cargo and protecting integrity of the ship and equipment is of vital importance. All ships engaging in Arctic shipping must carry a Polar Waters Operating Manual (PWOM).

[1] According to *Arctic Shipping Status Report #1* issued by PAME. https://www.pame.is/projects/arctic-marine-shipping/arctic-shipping-status-reports

Seasonal variability in sea ice and weather conditions influences the risk of cargo transport. For bulkers, timeliness and a reliable delivery time is critical. Any delay can potentially amount to millions of dollars in lost revenue, extra fuel and worker costs, and the possible loss of assignments and contracts.

Hence, the *lookout* for a reliable and favourable weather window with calm seas is valuable.

Figure 2 Credits: Susie Harder - Arctic Council - Arctic Marine Shipping Assessment https://www.pmel.noaa.gov/arctic-zone/detect/documents/AMSA_2009_Report_2nd_print.pdf

Polar operations – New International Code for Ships Operating in Polar Waters effective from January 1st 2017

Enforcing stricter environmental regulations on shipping, the IMO adopted the Polar Code. The code sets clear requirements to vessel and crew for sailing in the Arctic.

Limitations to operations are defined by:

- Vessels Ice Class – actual ice condition
- Polar Service Temperature (PST)
- Level of Winterization
- Possible other design limitations

Purpose of The Code: To identify ship specific operational limitations, and make owner and crew aware of these. However, it is always the responsibility of the Master to ensure that the vessel operates within these limits. Goal and intentions behind the Polar Code¨ The goal of the *Code* is to provide for safe ship operation and protection of the polar environment by addressing risks present in polar waters and not adequately mitigated by other instruments of the Organization.

The Product

In shipping it is imperative to have the best possible information available describing the route ahead and the risks to consider.

Timely and accurate observation data along with forecasts elicit more precise estimation of the risks associated with a specific voyage.

Many factors can influence on risk, but an important factor, which is often neglected by the way, is to consider chance of human error. Human error can be a consequence of fatigue or disillusion, lack of technical knowledge of a ship's systems, poor communication, navigational failure, or other conditions, but it is often related to strain under extreme environmental conditions. Experience and knowledge among crew members on how to operate a ship safely under different circumstances is paramount.

- In this service, we have looked into the MCAO index along with other climate variables to assess the risk of polar lows.
- The study is based on a statistical analysis of climatology.
- If and when PL predictions become operational and accessible, continued co-design and co-development efforts should strive to harness these; to ensure sustainable and tangible "products" delivering valued end-user experience.
- All problems are not solved, but we've come a long way. The study finds, encouraging developments in understanding the influence of MCAOs and other drivers.

A model for communicating risk associated with polar lows

A demo application/climate service is in the development stage. The application is an interactive web map allowing users to assess the risk of polar lows in a region. It shall demonstrate the use of climate predictions in Arctic risk assessment and be made available online.

- The model identifies regions susceptible to polar lows.
- Using on an array of climate criteria and thresholds.
- Based on a statistical study incorporating past events and seasonal variability.
- Delineates high risk areas in **red,** and lower risk areas in shades of **yellow and green.**

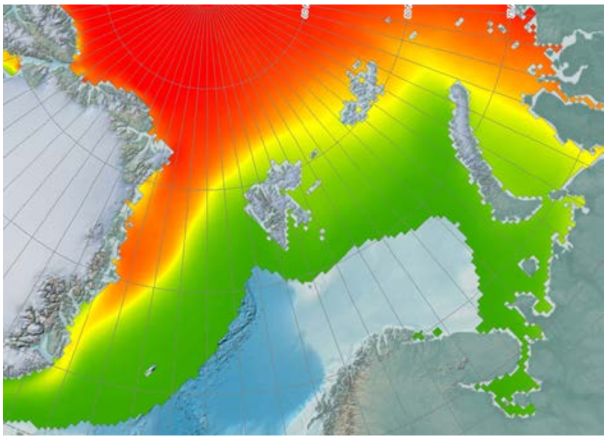


Figure 3 Risk of severe wind chill in December

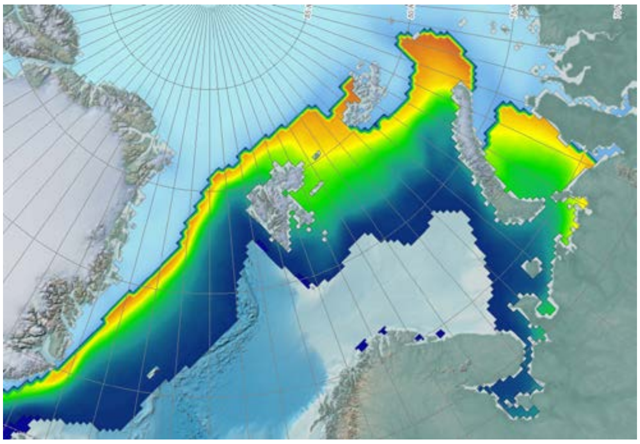


Figure 4 Risk of heavy icing in December

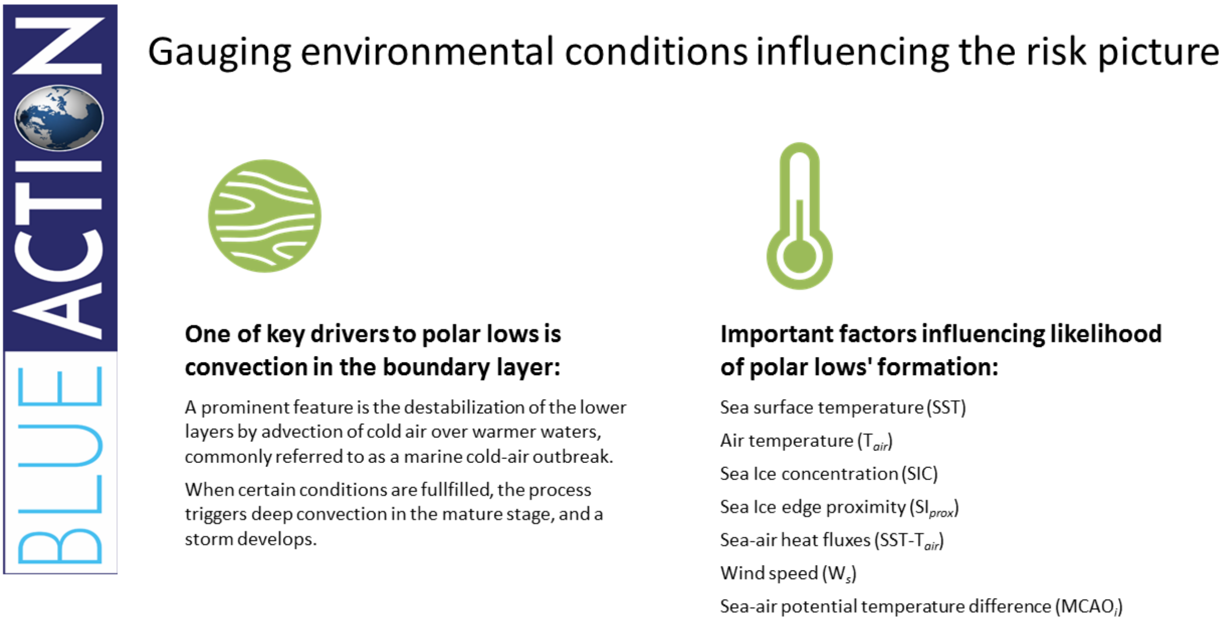
A climate service delineating risk from weather extremes

Polar lows typically engender strong winds, rough seas, and heavy precipitation. Together these factors influence the risk of operating in an area.

The risks associated with extreme weather are influenced by many factors incl. Gale force winds, heavy precipitation, agitated sea states, cold temperatures, etc. An important factor to consider, however, is the human factor. Extreme weather, sea ice, remoteness, and impaired visibility may cause distress and fatigue, and thus indirectly influence people's ability to make rational and just decisions. In navigational safety this is a particular concern.

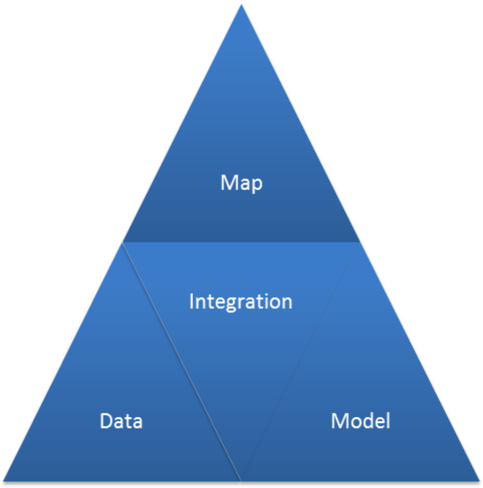
In addition, and as mentioned previously, extreme weather incl. polar lows can have severe and lasting impact on coastal infrastructures, local communities, fisheries, port operations, and search and rescue missions.

Fishing vessels in the Barents Sea often operate close to the ice edge where primary productivity is high and the prospects of large catches is good. As everything else, this involves risk. Although fishermen- and women are renowned for their ability to foresee weather, the ice edge, or marginal ice zone, is also a belt of rapidly changing weather conditions. Since most fishing vessels have no ice class, they are also vulnerable in the event of ice encounter. For this reason, more knowledge of seasonal variation in different regions is needed.

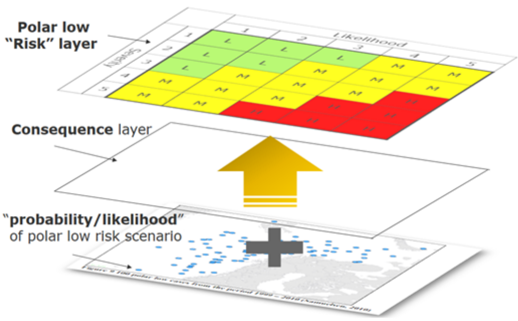


Service Architecture

- Inspired by data-driven design thinking.
- Agility and versatility in model integrations.
- Map powered by ArcGIS Image Server.
- Analytics featuring deep learning and spatial analysis/geoprocessing.



Methodology



- Risk can be expressed as the product of probability (*P*) and consequence (*C*).

  Risk = P(event) x C(impact)

- It follows that *Risk* multiplies with an increase in likelihood (*P*), consequence (*C*), or both.
- Overlaying a probability layer with a consequence layer to produce a risk layer illustrates the methodology.

Datasets employed

Product	Provider	Institution/Source/Author
Atmospheric reanalysis ERA5	Copernicus Climate Change Service, CDS	ECMWF
Atmospheric reanalysis ERA-INTERIM	Copernicus Climate Change Service, CDS	ECMWF
Seasonal Forecasts	Copernicus Climate Change Service, CDS	ECMWF, Met Office, Météo-France, the German Weather Service (Deutscher Wetterdienst, DWD) and the Euro-Mediterranean Center on Climate Change (CMCC)
Polar Low tracks in the Norwegian Sea and the Barents Sea from 1999 until 2019	PANGAEA	Rojo et al. (2019)
MCAO Index, Skill Assessment	NORCE/UiB, UHAM	King et. al (2020)

Demo application

The demo application will be freely available online (web) on a trial basis. It will not require any installation or download, but simply be accessible via a link and a PC browser, tablet, or handheld device. The application will be hosted by DNV GL for a period suitable to gather feedback and promote interest. Most importantly, this is also about driving public consensus to existing and emerging weather-related risks and Arctic impact. After a trial period, decision will be made to promote the product or reengineer into something else. A clear goal is to build upon the prototype, and to leverage predictions as capacity improves. Selected DNV GL customers will have access to the tool.

Based on buy-in and general interest, DNV GL may promote the tool to other stakeholders such as authorities, NGOs, and ideal organizations.

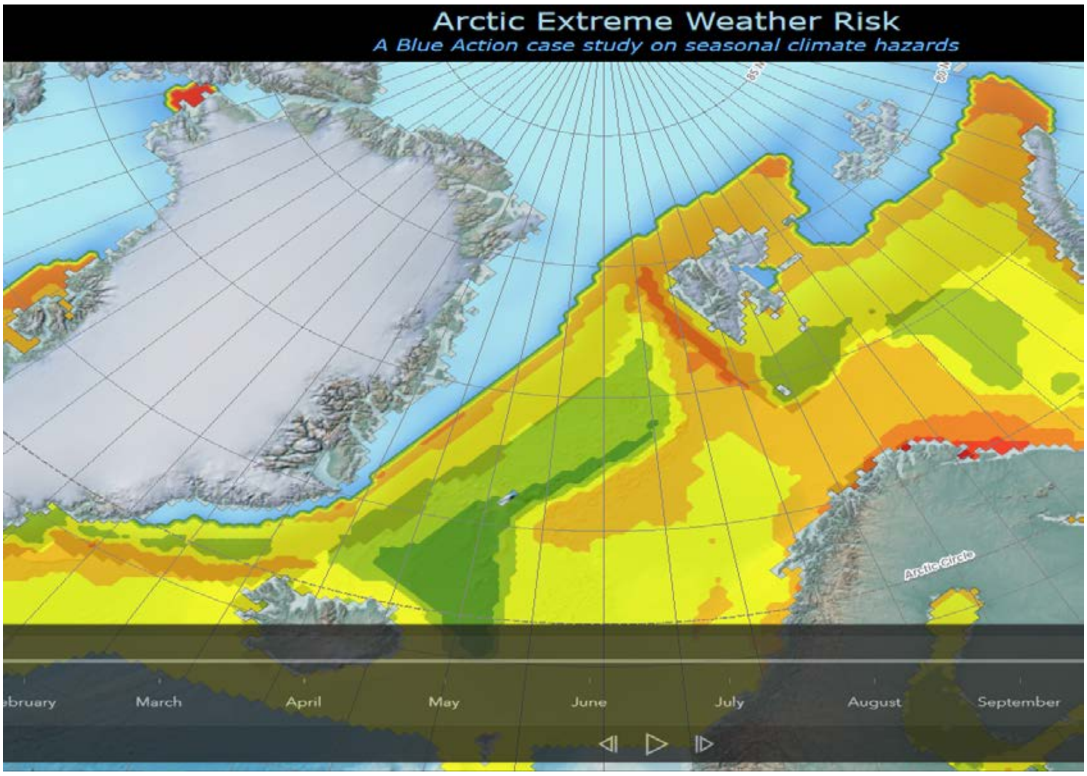


Figure 5 The CS3 demo application

Key features of the demo application

- Climate service freely accessible via web.
- Interactive map and simple to use user interface
- Classification and weighting of climate factors.
- Weighted overlay analysis.
- Dynamic risk picture capturing seasonal variation.

Future prospects

- Integration of Arctic specific forecasts and predictions.
- Flexible integration of new and enhanced predictors, balancing availability, predictive skill, and scope.
- Continuous improvement through parametric adjustments and calibration of [ensemble] model signals.

As a class society and independent expert in risk management, DNV GL sees a natural position in bridging academia and the industry. In this endeavour, we seek to contribute to making science available and accessible, and thereby create an environment where all can take part and benefit from its' rewards.