Case Study 3: Forecasting Polar Lows

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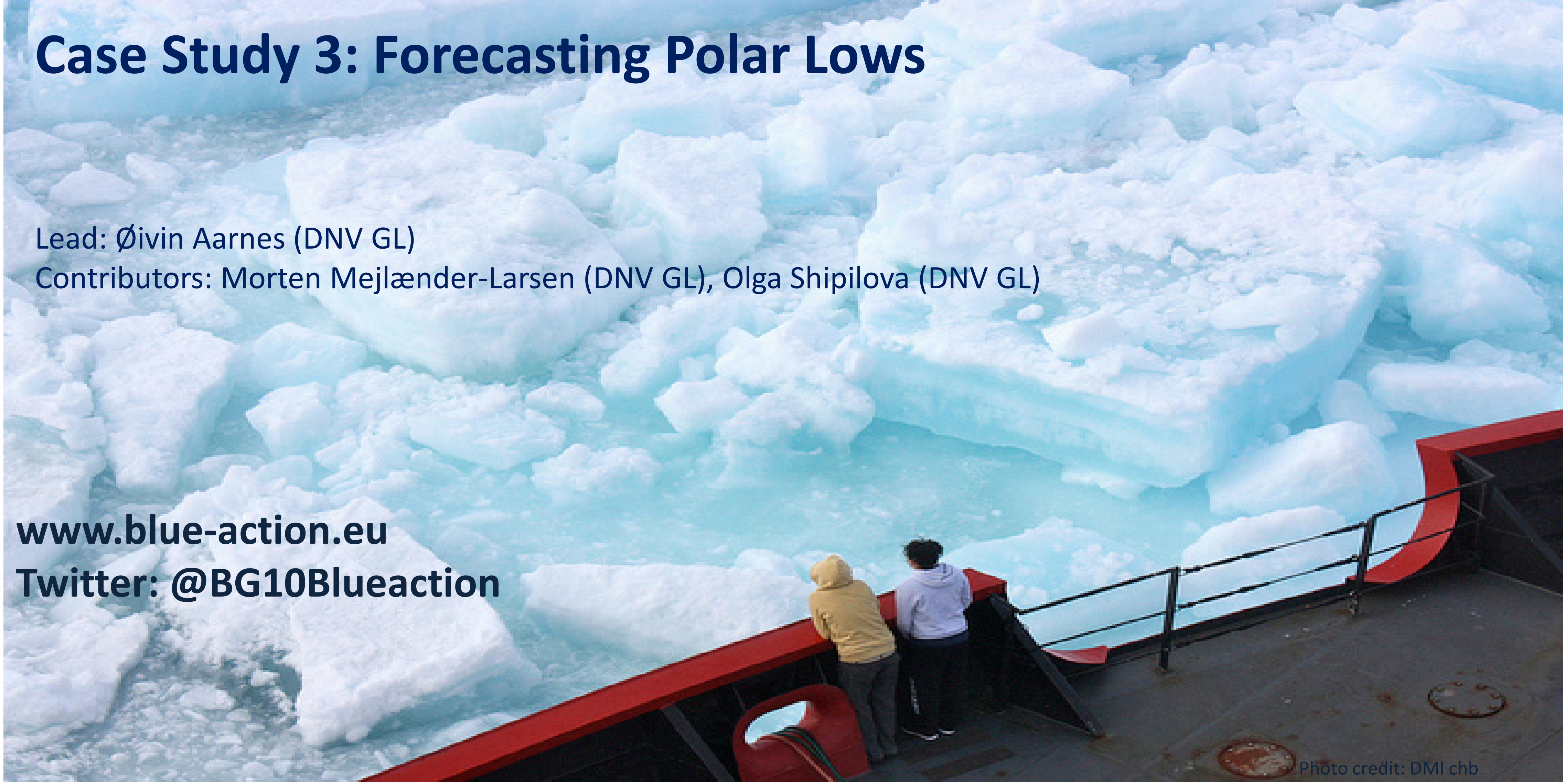

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End-user workshops on polar lows prediction (CS3), Summer 2020

The Arctic is changing

- The last decade has shown an accelerating pace of change in the Arctic region. Most people acknowledge the change is real.
- Arctic amplification is impacting on globale weather systems as a poleward shift of energy (moisture and heat), through remote processes, is accelerating warming in the region.
- The driving forces are complex and intertwined, yet they abide by principles of thermodynamics - conservation of energy and the law of entropy.
- The changes manifest themselves in processes such as melting of permafrost in Siberia and a gradual halt or slowdown of the AMOC.

Recognizing a changing Arctic

Arctic Icebergs in the frozen North Atlantic Arctic sea. West Greenland, 70 degrees North.

Image credits: DNV GL

…and adapting to a future climate

How will a future climate impact on marine operations and ship design?

Rogue Waves – Impact on ships and offshore structures. DNV GL Position Paper 05-2015
https://www.dnvgl.com/feature/rogue-waves.html

Why are polar lows relevant?

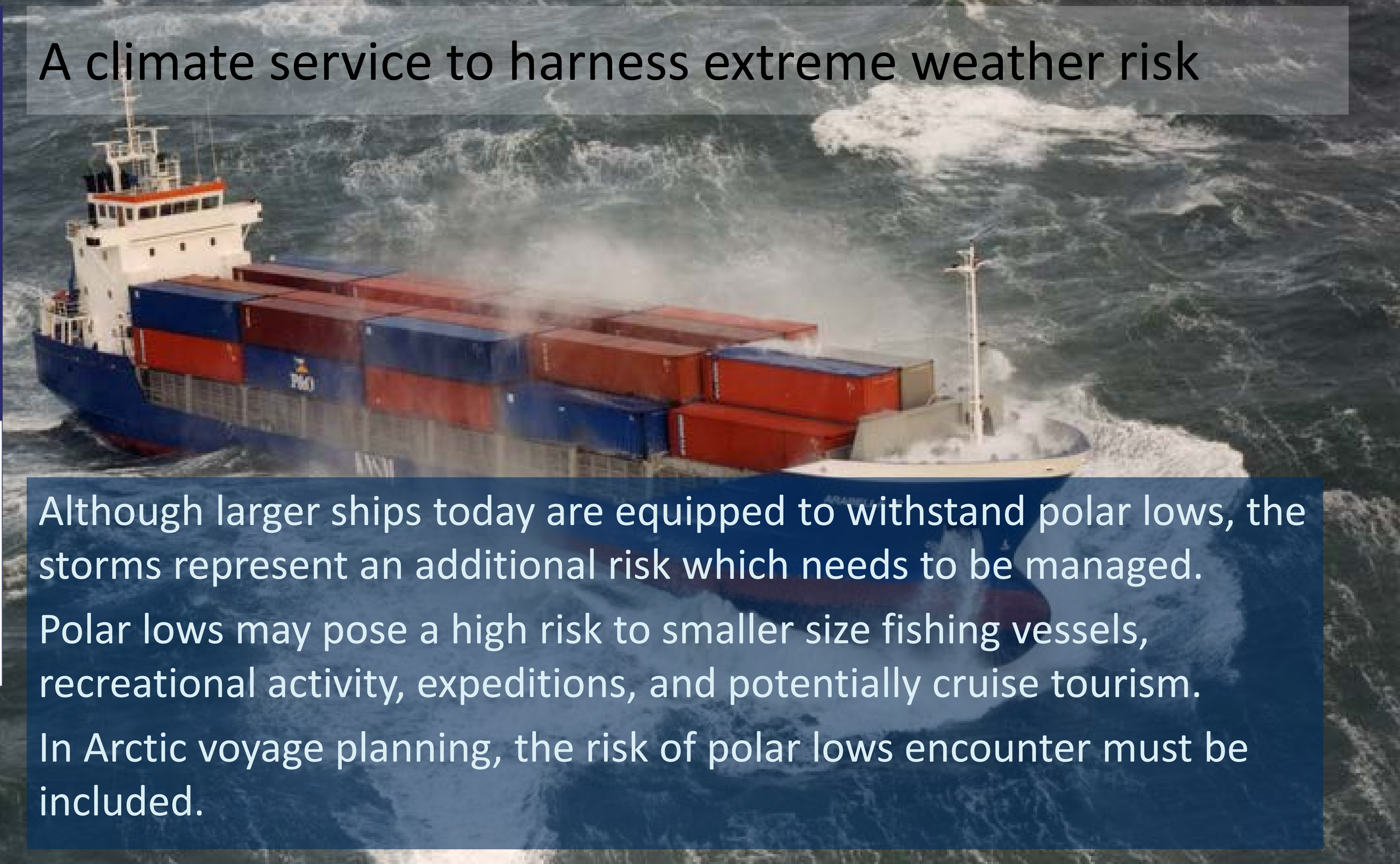
Throughout history, seafarers of the North have told tales of unexpected encounters with fierce storms that appeared out of nowhere. These storms were well known to the coastal community and early tradesmen.

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.

Photo: Stein Liland

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.

Case study objectives

- 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

Scientific foundation

Photo credit: SAMS

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.

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]*.

* Based on the atmospheric reanalysis ERA-INTERIM 1979-2018

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.

* For a comprehensive review of processes and links, see *Polkova et al., 2020*.

Industry Relevance

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Photo credit: DMI chb

Climate resilience in offshore activity

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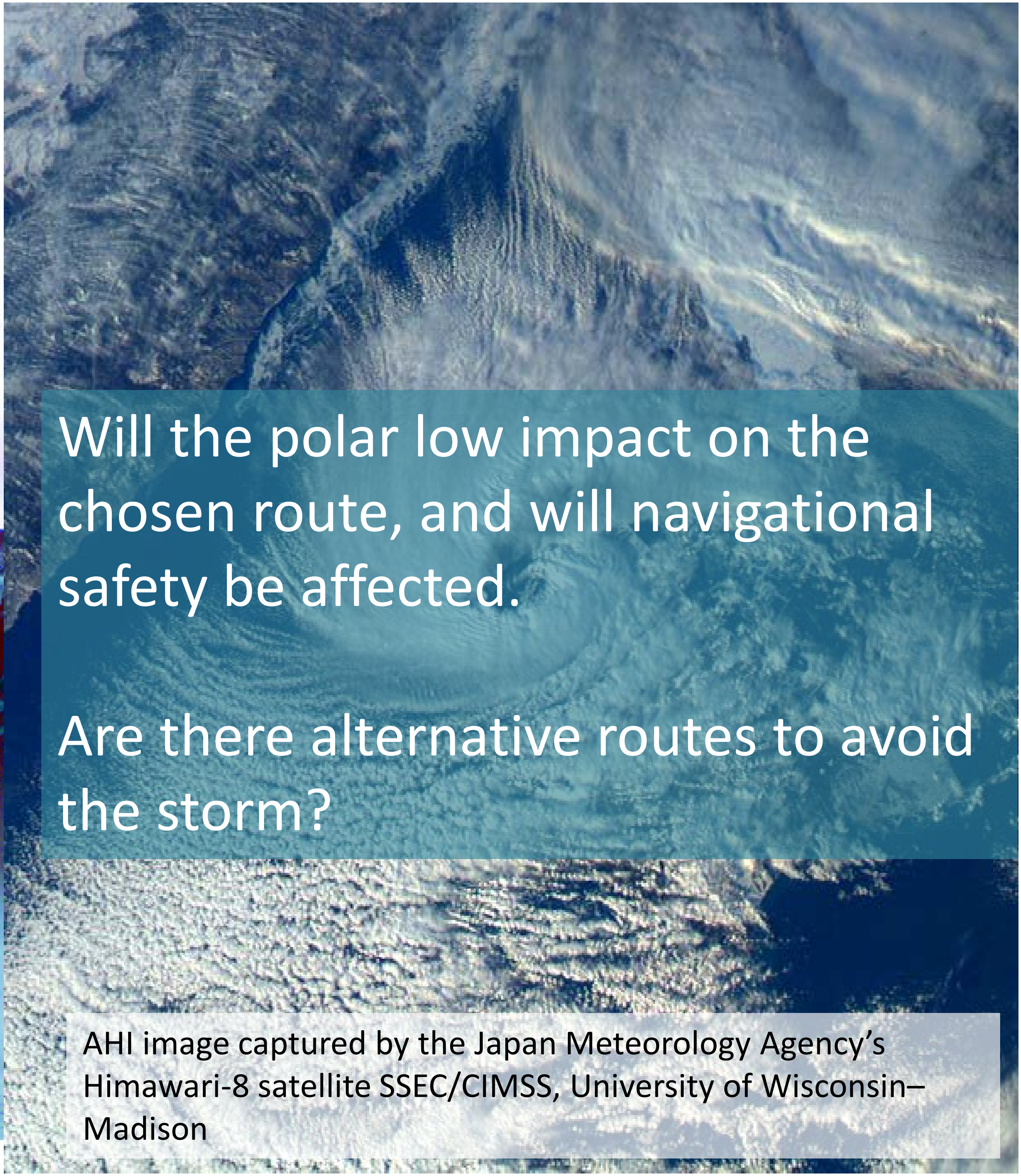
Why is this important?

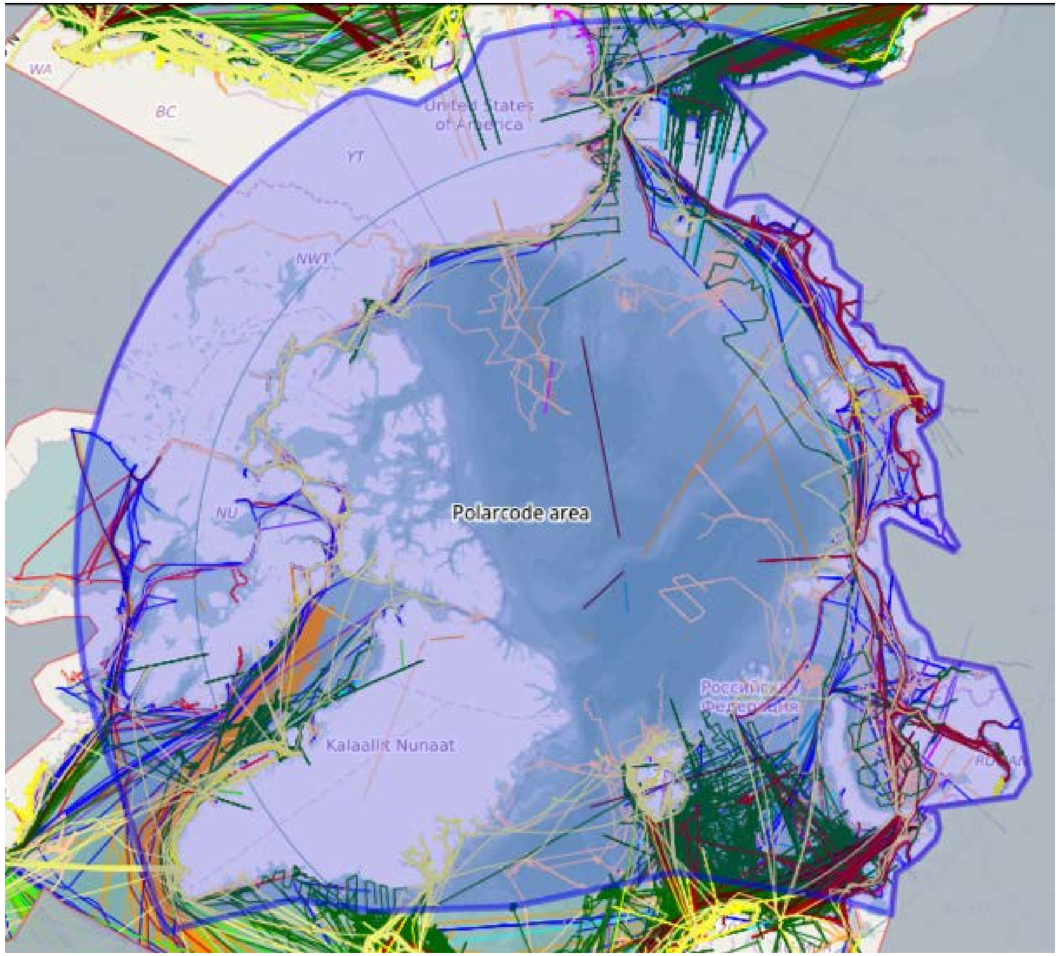


Will the polar low impact on the chosen route, and will navigational safety be affected.

Are there alternative routes to avoid the storm?

AHI image captured by the Japan Meteorology Agency’s Himawari-8 satellite SSEC/CIMSS, University of Wisconsin–Madison

Rising activity

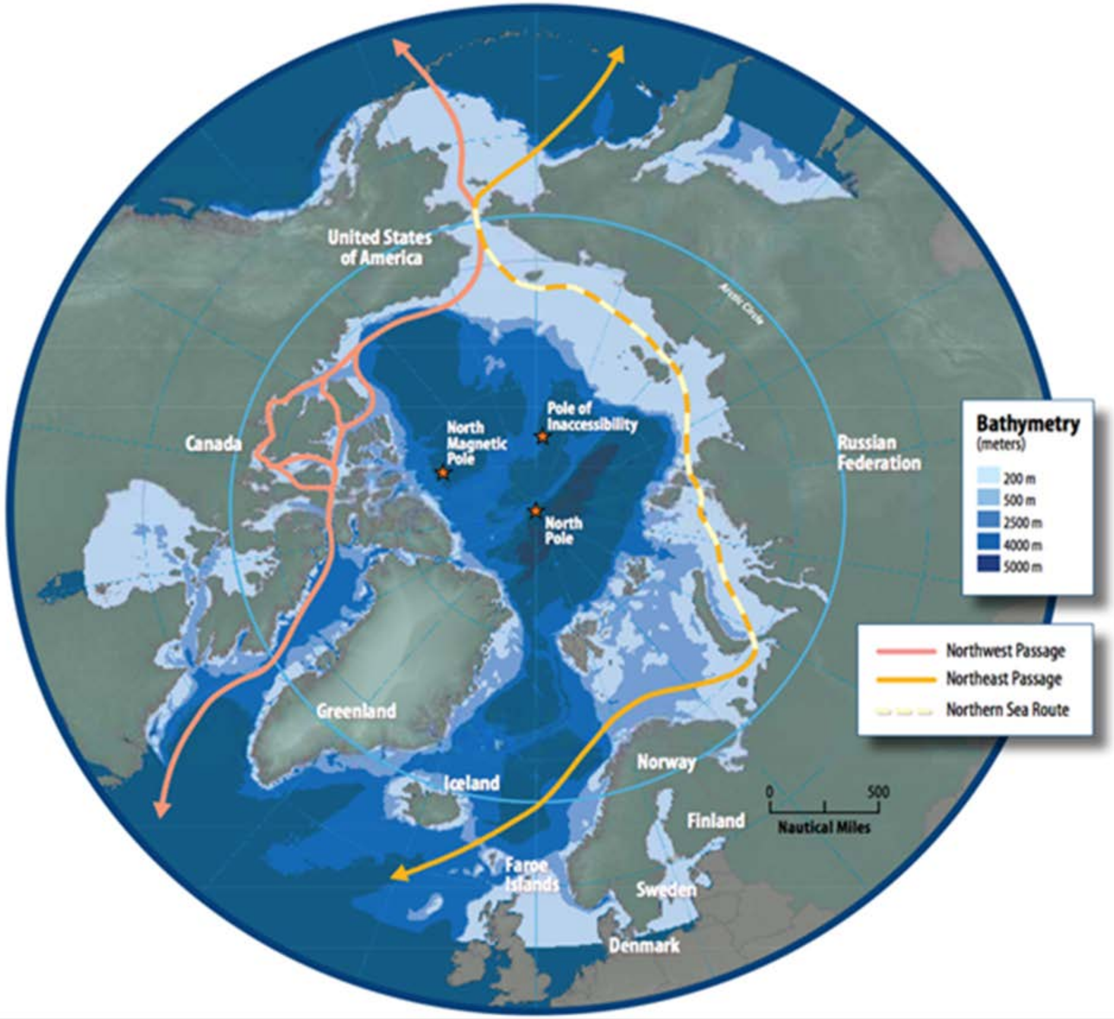


- In 2019, **1628 unique vessels** entered the Polar Code area. The majority of traffic is in September with 977 vessels sailing in the region.
- The 2019 figure is a 25% increase in number of unique vessels engaging in Arctic shipping relative to 2013 (1298 vessels).
- In the same period, PAME* reports 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.

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

AIS ship tracks of all ships sailing in the Polar Code area in September 2019.
Credit: Arctic Ship Traffic Data (ASTD), PAME

Industry attention and needs - Arctic shipping routes



In voyage planning; mariners sailing the Northeast Passage will want to reduce risk to a level *As Low As Reasonably Practicable* (ALARP principle).

This implies careful review of relevant risk influencing factors and possible mitigation measures.

For instance, this can imply a need for continuous monitoring risk of dangerous ice and severe weather conditions.

•The captain will evaluate need for ice breaker support, ice class requirements, and compliance with the Polar Code.

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

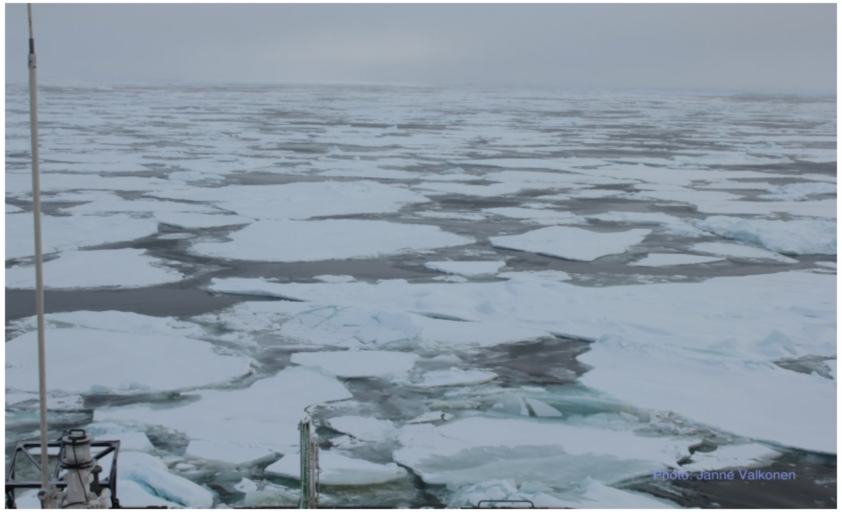
Polar operations – New International Code for Ships Operating in Polar Waters effective from January 1st 2017

Limitations to operations are defined by:

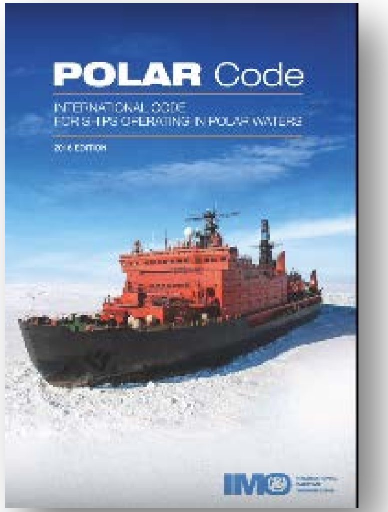
- Vessels Ice Class – actual ice condition
- Polar Service Temperature (PST)
- Level of Winterization
- Possible other design limitations

Purpose of The Code: To identify ship specific operational limitations, and make owner and crew aware of these.

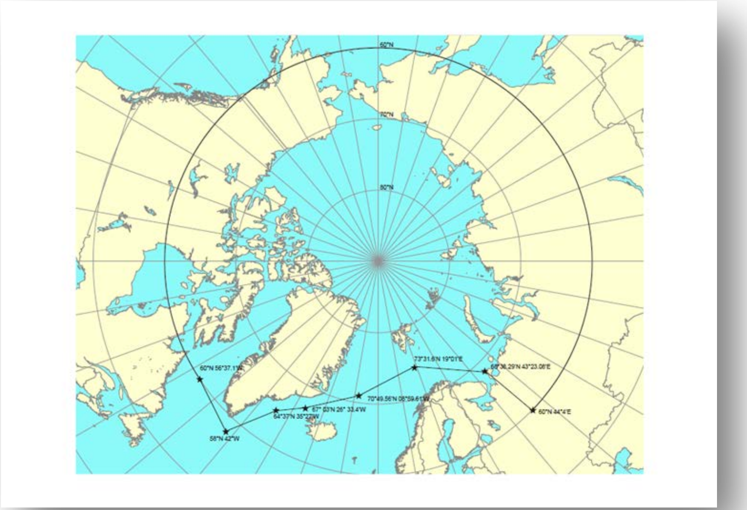
However, it is always the responsibility of the Master to ensure that the vessel operates within these limits.



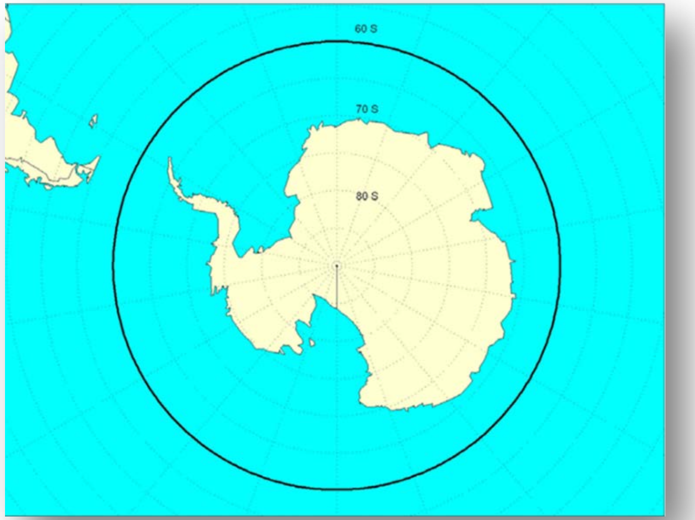
Goal and intentions behind the Polar Code



The goal of the *Code* is to provide for safe ship operation and protection of the polar environment by addressing risks present in <u>polar waters</u> and not adequately mitigated by other instruments of the Organization.



60 degree north
with exceptions



60 degrees south
circumpolar

The Product

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Photo credit: DMI chb

Introduction

- 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.

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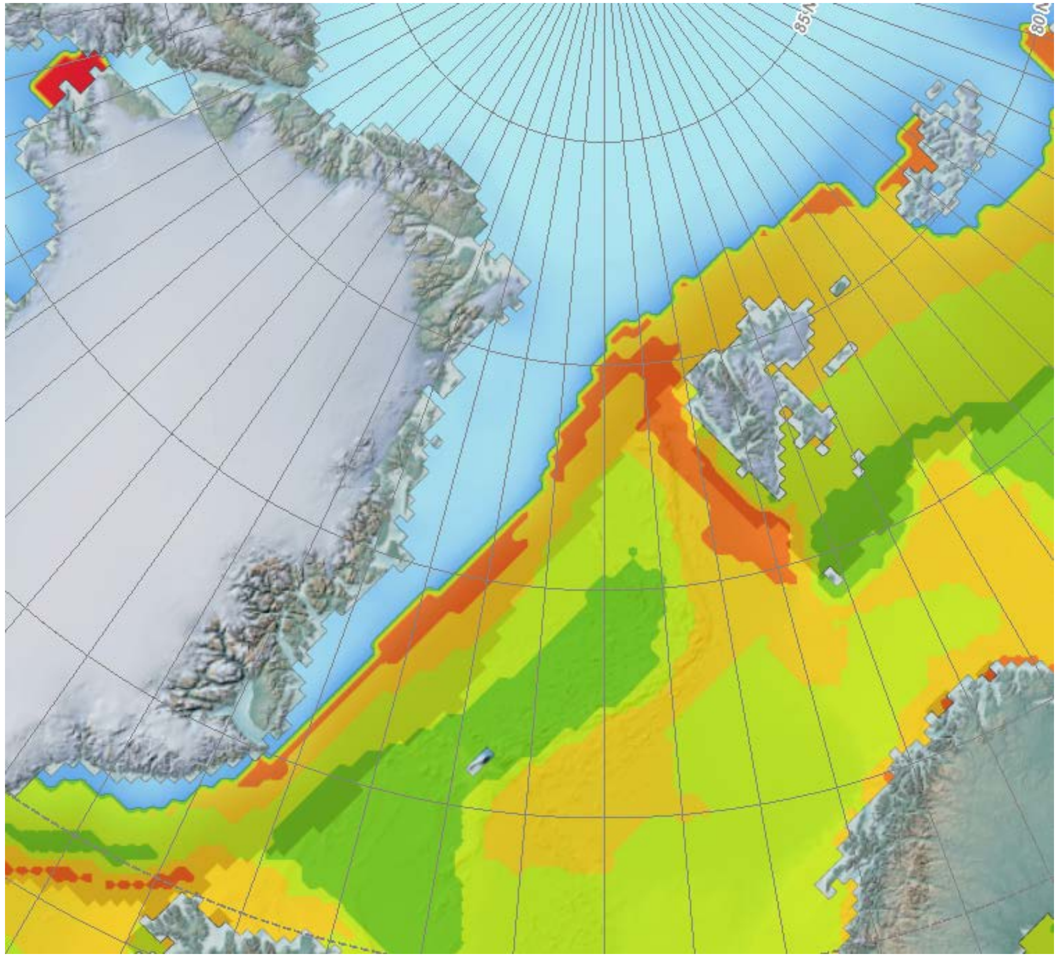
A model for communicating risk associated with polar lows



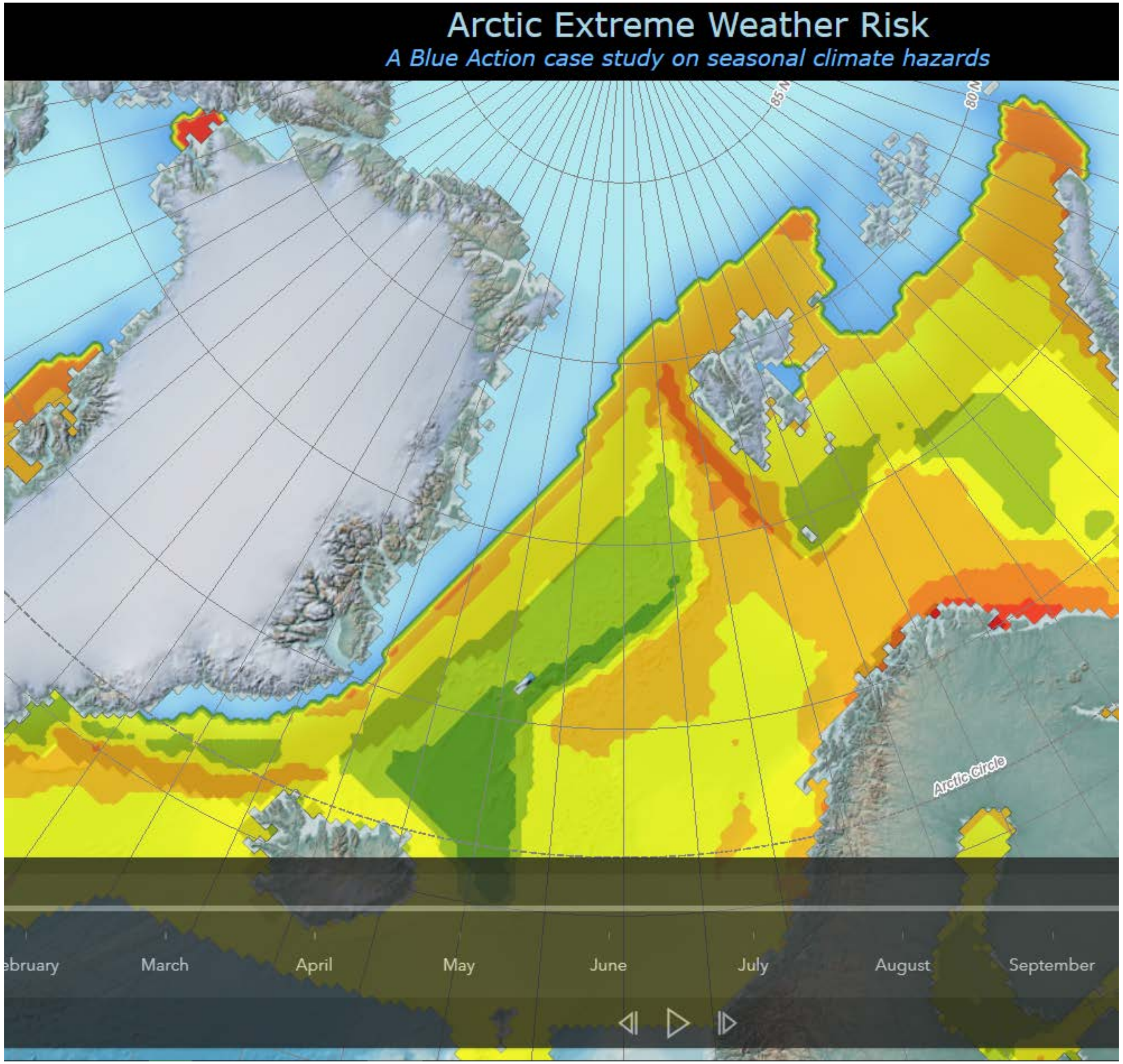
- The model identifies regions susceptible to polar lows.
- Using on an array of climate criteria and thresholds.
- Based on a statistical study incorporating past events and seasonal variability.
- Delineates high risk areas in red, and lower risk areas in shades of yellow and green.

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

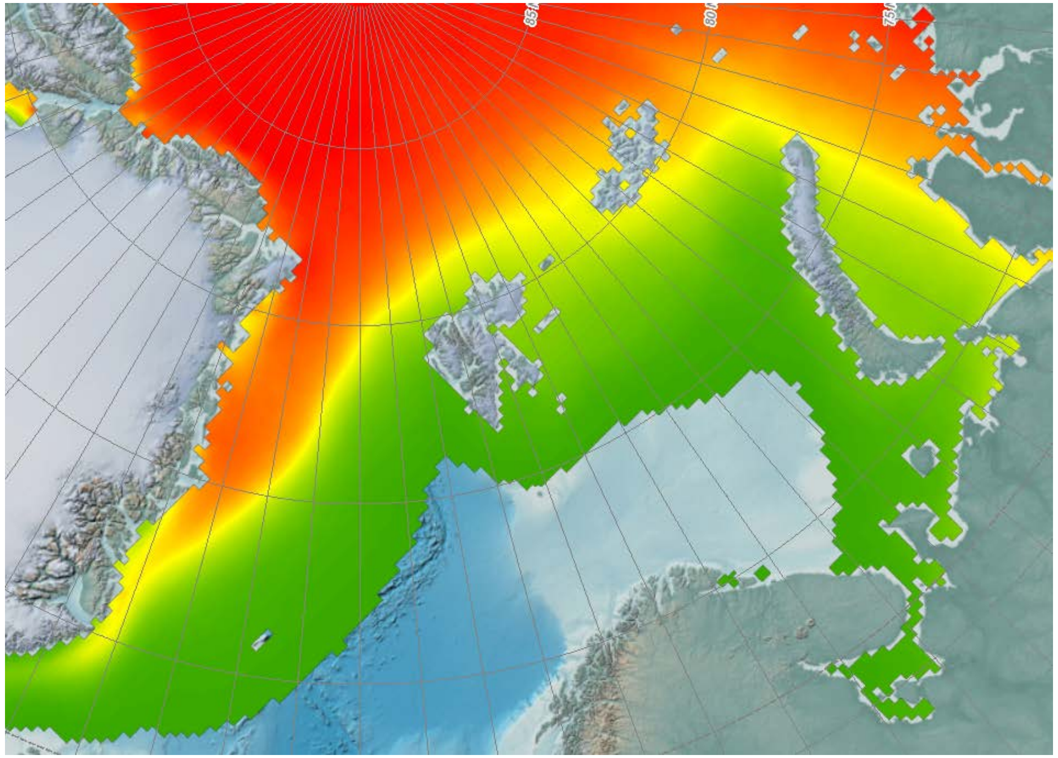
- Integration of Arctic specific forecasts and predictions.
- Flexible integration of new and enhanced predictors, balancing availability, predictive skill, and scope.
- Continuous improvement through parametric adjustments and calibration of [ensemble] model signals.



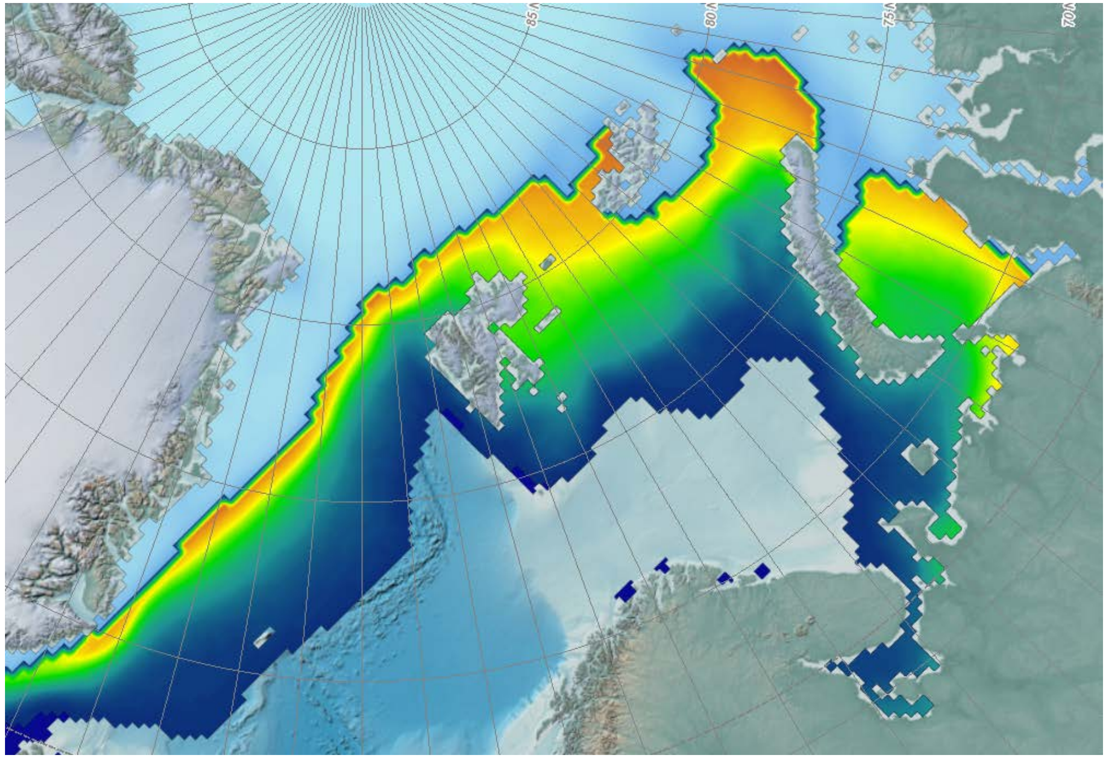
A climate service delineating risk from weather extremes

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

Risk of severe wind chill in December



Risk of heavy icing in December



Gauging environmental conditions influencing the risk picture

One of key drivers to polar lows is convection in the boundary layer:

A prominent feature is the destabilization of the lower layers by advection of cold air over warmer waters, commonly referred to as a marine cold-air outbreak.

When certain conditions are fullfilled, the process triggers deep convection in the mature stage, and a storm develops.

Important factors influencing likelihood of polar lows' formation:

Sea surface temperature (SST)

Air temperature (T_{air})

Sea Ice concentration (SIC)

Sea Ice edge proximity (SI_{prox})

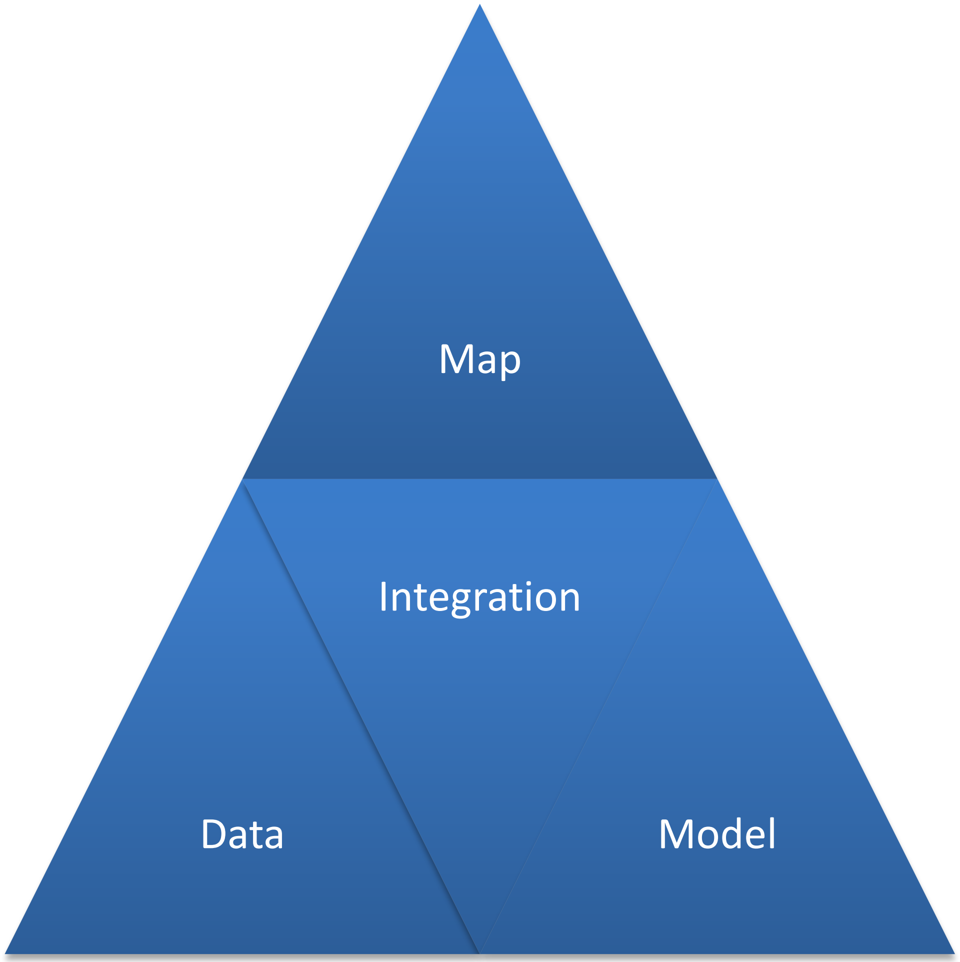
Sea-air heat fluxes ($SST\text{-}T_{air}$)

Wind speed (W_s)

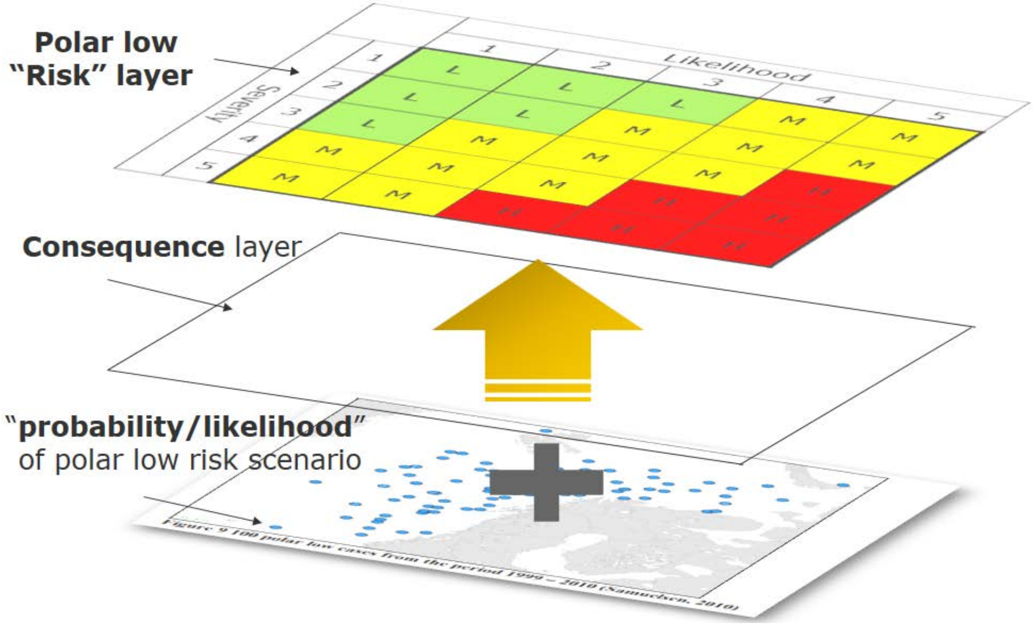
Sea-air potential temperature difference ($MCAO_i$)

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*).

$$Risk = P(event) \times C(impact)$$

- 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.

Example of consequence from polar lows

- **Marine icing** is a process of depositing and freezing of sea spray on structural surfaces.
- **Sea spray** is generated due to interaction between waves, structures and wind.
- Freezing of sea spray is activated if **air temperature is low and wind speed is high**.
- Accumulation of ice from precipitation and moisture, snow and freezing rain, referred to as **atmospheric icing** adheres to this.

Why icing is dangerous?

- Global icing jeopardizes stability and integrity of the vessel.
- Local icing of essential components impacts on safety and operability of the vessel.

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)

Evaluating Impacts

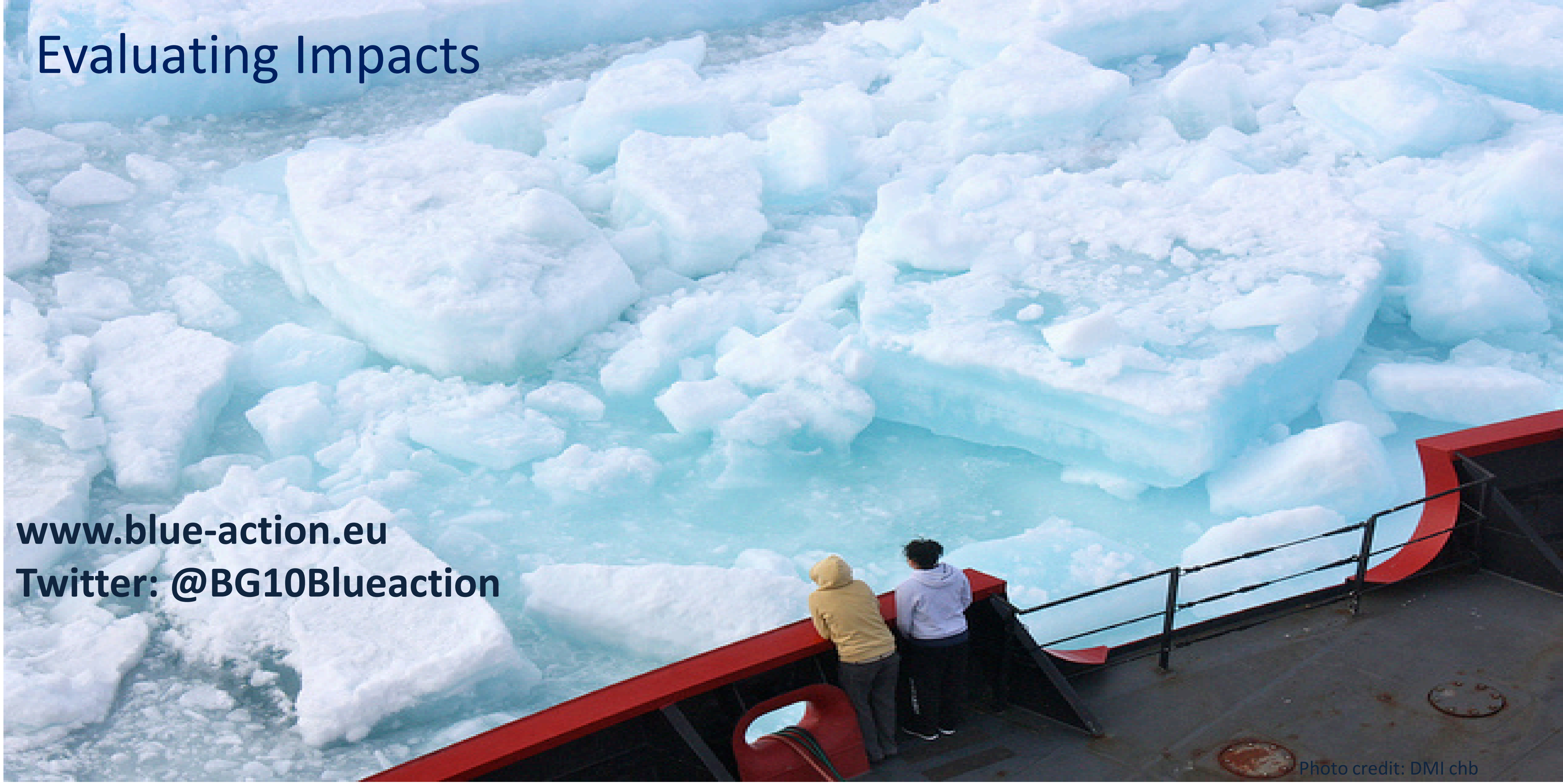


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Photo credit: DMI chb

Impacts Achieved

Improve the capacity to respond to the impact of climatic change on the environment and human activities in the Arctic

Predicting and communicating efficiently on extreme weather events helps the industry achieve risk awareness, mitigate impact, and ultimately endure more sustainable operations.

Improve stakeholders' capacity to adapt to climate change

Arctic fisheries and shipping are pivotal in adapting to Arctic weather extremes, but adaptation is equally pressing for communities and coastal infrastructure in parts of the Arctic region.

Providing sensible, tangible, and actionable information in a climate service "package" enables stakeholders to gauge climate risk and exposure, empowering people to respond to these risks.

Identified gaps to achieve desired impact

- Blue Action has identified a means of describing MCAOs through the **MCAO index.** The index has been assessed in terms of predictive skill and lead times. Efforts are being made to calibrate and improve this index.
- Although the index serves as a predictor, the link between an MCAO event and actual surfacing of extreme weather **is not entirely understood, yet quantified.**
- To achieve a coherent view, **other indicators (atmospheric and ocean features)** need to be included.
- In order to integrate severe weather forecasts into risk maps (the climate service), a **model for providing forecasts of MCAOs need to be operational.**
- What are likely implications of processes such as **Weakening of the AMOC, Arctic amplification, and Thermal instability in lower layers**?
- Can we relate these processes to more **storminess in the North seas, and what are the repercussions**?

Perspectives on future prospects and the way forward

- High interest in use of climate forecasts in the industry.
- Seasonal and sub-seasonal forecasts are in demand for planning both near-future and long-term.
- Safety at sea for seafarers remains the most important aspect of maritime risk.
- Accountability and reliability in shipping is vital. Just-in-time delivery, efficiency in port logistics, and reduced waiting time justifies the case for shipping as the most viable option for global transport of goods.
- Regulatory demands to lower emissions is reshaping seaborn trade. Climate resilience and adaptation is part of this momentum.
- Interdisciplinarity and connectedness is increasingly shaping decision making as sustainability measures and climate risks are integrated into long-term planning and financing.

Fishing vessels operating near Bjørnøya in the Barents Sea. Credit: DNV GL

Thank you!

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