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Minutes of the
Arctic Sea Ice Prediction Stakeholders Workshop

Date and Venue: The **Workshop** was held as a **side-event at the Arctic Frontiers 2018 Conference** (http://www.arcticfrontiers.com/) on **January 22, 2018, from 15:00 to 18:30, at the Radisson Blue Hotel, in Tromsø, Norway**.

Rapporteur(s): Jon Børre Ørbæk (RCN), Lawrence Hislop (ClIC), Malte Muller (MET), Gwenaelle Hamon (ClIC) and Lars Henrik Smedsrud (UiB)

Organiser(s): The event was organised by the Climate and Cryosphere (CliC) project of the World Climate Research Programme (WCRP), the University College London (UCL), the Arctic Research Consortium of the U.S. (ARCUS), the Norwegian Ice Service - MET Norway, the Bjerknes Centre for Climate Research - Bjerknessenteret – UiB, the Research Council of Norway, and EU-PolarNet.

Participants: See end of report

1. Executive Summary: Key messages from the workshop

Background
Increasing uncertainty about future sea ice conditions presents a distinct challenge to industry, policymakers, and planners responsible for economic, safety, and risk mitigation decisions. The ability to accurately forecast the extent and duration of Arctic sea ice on different timescales provides significant implications for the operation of wide ranging Arctic maritime activities.

Current Status
The Arctic sea ice prediction community has advanced rapidly in the past decade with many new sea ice forecast products and services that are targeted for different user groups. However, it is still unclear how well end users are able to utilize these products and services into their planning. There is a need for better engagement with a broad range of Arctic stakeholders and a need to tailor new products and services to end user-specific requirements.

Workshop Goals
This workshop brought together sea ice stakeholders and forecasters to:

- Assess the value of forecasts by the user community.
- Determine if and how ice forecasts are currently being used in decision making.
- Communicate the relevant metrics needed by various stakeholders.
- Identify where improvements in sea ice forecasts would help stakeholders make decisions.
- Communicate the limits and opportunities of current forecasting systems.

Outcome
A stakeholder-targeted guidance document or roadmap, where sea ice forecasters can draw on the expertise of users (e.g. policy makers, planners, community leaders) to better understand how different stakeholder groups factor sea ice forecast information into their decision-making processes. The outcomes will result in an article intended for publication in a journal such as Eos (Earth & Space Science News)

Key messages
There is still a basic need for sea ice forecasters and stakeholder user groups to find more common language and tools for communication. There is potential for more co-production of the products and services needed, and this should ideally be done in an iterative process where involved actors gain better understand of the varying needs for sea ice forecasts. There is an overall requirement for better visualisation tools and higher quality of the sea ice forecasts, as well as making sure that they are communicated in the right fashion with high accuracy. Thus, the emphasis going forward needs to be put on achieving better confidence in the forecast products by clear presentation of the uncertainties. Stakeholder groups also have distinct needs for tailored products for their particular industry (ex. tourism has different needs than fishing) and a 'one size fits all' approach of delivering forecasts is not an optimal approach. While the economic value of sea ice forecasts is difficult to accurately estimate it is clear that they directly contribute to the safety and security of the ice going vessel itself (and the crew) and this can be estimated in the millions of Euro if used to avoid serious accidents.

2. Introduction: Main motivation and background for the workshop

The Arctic sea ice prediction community has advanced rapidly in the past decade with many new sea ice forecast products and services which are targeted for different user groups. However, it is still unclear how well end-users integrate information from these services into their navigational planning and how they use sea ice forecasts. To improve the uptake and usability of sea ice information supplied by the operational community, there is a need for better engagement and dialogue with a broad range of Arctic stakeholders and a need to tailor new products and services to end-user specific requirements.

The organisers invited a multitude of producers and users of Arctic sea ice forecasts to join an exciting and interactive workshop designed to showcase the latest generation of forecast products, to share experiences from the user community, to dialogue with a cross section of stakeholders, and to influence the development of new products and services. Stimulated by an open discussion between sea ice stakeholders and forecasters on what is possible with the current forecasting systems and how to better meet stakeholder needs, the main goals of the workshop were to:

- Assess the value of forecasts by the user community.
- Determine if and how ice forecasts are currently being used in decision making.
- Communicate the relevant metrics needed by various stakeholders.
- Identify where improvements in sea ice forecasts would help stakeholders make decisions.
- Communicate the limits and opportunities of current forecasting systems.

Members from the following groups participated:

- Sea ice forecasting researchers
- Industry representatives (shipping, resource extraction, fishing, etc.)
- Ship operators
- Polar tourism representatives
- National / regional policy makers
- Local planners

The organisers will use the results and recommendations from the workshop to develop a stakeholder-targeted guidance document or roadmap, where sea ice forecasters can draw on the expertise of users (e.g. policy makers, planners, community leaders) to better understand how different stakeholder groups use sea ice forecast information into their decision-making processes. The outcomes will further result in an article intended for publication in a journal such as Eos (Earth & Space Science News).

3. Introductory and overview talks:

3.1 Part 1 - Introductory talks

3.1.1 Julienne Stroeve (UCL) - Introduction to workshop (objectives and agenda)

Julienne provided a brief introduction to the sea ice prediction network (SIPN) and the overall goals of the workshop. SIPN provides an international network to share sea ice forecasts as well as assess their accuracy and usefulness. The activity program of SIPN began in 2008 as an initiative of the US based Study of Environmental Arctic Change (SEARCH) and one of their first products was a series of annual sea ice outlooks. In 2014 SIPN took over the management of the sea ice outlooks and also expanded the range of forecasts.

Recognising that over recent years, the complexity of models used to make sea ice predictions have increased considerably with many new contributions from the modelling community, the main goal of the Arctic Frontiers workshop is to gather stakeholder feedback and get a better understanding of user needs for sea ice forecasts. Specific questions are centred around:

- What is possible to achieve with current forecasting techniques?
- How can new forecasts better meet stakeholder needs?
- The economic value of current forecasting systems
- How forecasts are used in decision making and if not, what can be done
- Gaps in metrics being forecasted
- Communicate limits and opportunities of current forecasting systems

The organisers will produce a workshop summary report (this report) and an article intended for publication in EOS or similar science based journal.

3.1.2 Uma Bhatt (Univ. Alaska): Sea Ice Prediction Network (SIPN) and motivation for the workshop

Uma presented the SIPN2 project, which has recently been funded by the US National Science Foundation (NSF) and various other sources (also beyond the US). The project started in January 2018 and will focus on a multi-prong approach spanning theoretical and user-inspired research, building on the original SIPN network. A multi-disciplinary international team will use dynamical and statistical methods, evaluate forecasting methods, develop new observation-based products (primarily satellite), evaluate socio-economic value of sea-ice predictions, and evolve the network further. Specific aspects of the SIPN2 will be to focus on the role of oceanic heat for subseasonal-to-seasonal (S2S) forecasts, particularly the role of the Pacific sector. The Polar Climate Predictability Initiative (PCPI) of the World Climate Research Programme (WCRP) will support longer term forecasts. More information of the status of this work will be presented at the 5th Polar Prediction workshop 7-9 May 2018 in Montréal.

3.2 Part 1 - Insight to Capabilities of Sea-ice Forecasting Products

3.2.1 Ed Blockley (UK Met Office): Arctic short-range forecasting: overview and capabilities:

Ed introduced sea ice forecasting on the basis of models being used in the UK Met office. He outlined his talk which focussed on current forecasting models, emphasising

- data assimilation and initialisation
- Arctic observations.

He highlighted that for short range models, initial conditions are very important for the precision of the forecasts, which can be improved by various approaches to data assimilation. Much effort is now put into the problem of achieving the best possible initial conditions to start the forecasts. An example of the UK Met Office Forecasting Ocean Assimilation Model (FOAM) system schematics was presented. With regards to model performance in Arctic sea ice forecasts, the short-range forecasts are often well constrained. However, the analyses in Polar Regions are generally worse and with lower quality than in lower latitudes.

Short-range forecasts can be used for operational planning, but it is important for users to understand what the model is doing and what the main needs of the users are. The following characteristics of sea ice forecasts were mentioned:

- It is currently difficult to model sea ice thickness
- Sea ice models are continuum models, meaning that models do not explicitly represent individual floes, leads, or ridges
- Errors are likely to be highest nearest the ice edge
- Models are mainly generated for climate use

3.2.2 Rick Allard (Naval Research Laboratory): Short-term and seasonal forecasts

Richard introduced the US Navy Global Ocean Forecast (GOFS) 3.1 ice-ocean coupled modelling system that also includes a data assimilation package. Work has recently started on including ice-thickness assimilation. The GOFS model has a 3.5km resolution at the pole and provides short term sea ice predictions out to seven days. An upgrade being implemented in GOFS 3.5 will have double the resolution (1.8km) and is intended to become operational in 2019.

The Canadian Ice Service, which delivers seasonal forecasts operationally with the 1.4° global ice-ocean prediction system (GIOPS) and with assimilation of RadarSat imagery, was also referred to. This service is a regional forecast model system providing ice concentration, thickness, velocity and pressure. The Los Alamos Sea Ice Model (CICE) has developed, a portable, efficient sea ice model that can be run coupled in a global climate model or uncoupled as a stand-alone ice model. The CICE model is included in many of the forecast and seasonal prediction models.

The US Navy contributes to SIPN through the use of the navy Earth system model that produces 45-day forecasts (one ensemble with four members each week). Preliminary experimental forecasts available for the Year of Polar Prediction (YOPP), both for the Arctic and Antarctic, is planned.

3.2.3 Wieslaw Maslowski (US Naval Postgraduate research lab): Seasonal forecasts

Short term and sub-seasonal to seasonal forecasts.

Wieslaw provided an overview of the Regional Arctic System Model (RASM) forecasting features. The main RASM components are hind casts from 1979-present on timescales from sub-seasonal to seasonal. Since the RASM predictions significantly underestimated sea ice in 2016 compared to observations, the team took a step back and looked at the problems and biases more carefully. They found that:

- there was a 3 million square kilometres bias
- the major bias was due to atmospheric clouds
- optimisation of RASM was needed to improve the initial forecast conditions

The forecasts for 2017 still underestimated sea ice on the western and eastern sides of the Arctic, but no bias correction was used for data assimilation in 2017. RASM is still underestimating in comparison to the other SIPN forecasts. A 2.4 square kilometre resolution version is now being tested.

3.2.4 Ingrid H. Onarheim (U Bergen/Bjerknes Centre): Seasonal to decadal forecasts

Ingrid introduced the modelling tools used by the Bjerknes centre, which mainly focus on the Atlantic Arctic and the Barents Sea. They use analytical methods (mainly using observations and focus on the propagation of ocean heat anomalies which impact sea-ice) and numerical sea-ice predictions (mainly using the Norwegian climate prediction model NorCPM). Multiple linear regressions are used to estimate 5-year tendencies to make predictions for winter sea-ice in the Barents region. Based on this statistical method, relatively good decadal predictions of sea ice are achieved. This system currently predicts increasing sea-ice extent up to 2020.

Bjerknes centre has a good understanding of the Barents Sea and an analytical approach is being used to predict the ice-cover in the region one year in advance, based on observed currents, the ocean temperature between Svalbard and Norway, and previous sea ice conditions. The method only produces an estimation of sea ice extent, not thickness, and it does not take winds into account, which can have large impacts on sea ice distribution and thickness. Work is underway to improve the system to make monthly predictions rather than just seasonal predictions for the winter as a whole. Winter sea ice for the Atlantic Arctic are skilfully predicted on timescales of up to 10 years.

3.3 Part 1 - Questions and discussion

The workshop offered time to take questions from the audience, for the first speakers. The most important questions were:

- *Marine biogeochemistry:* How does marine biogeochemistry affect sea ice conditions and the potential for accurate forecasting? Wieslaw noted that both the sea ice and the ocean are influenced by biogeochemical processes, but it is still poorly understood how biogeochemistry directly affects sea ice and its predictability. This is an emerging new field of research and stronger links will need to be made between forecasters and sea ice biogeochemistry community.
- *Model quality:* How is model quality judged in model intercomparison campaigns, and which is the best individual model to use? Ed clarified that it is mainly important to look at the large-scale averages and not focus too much on individual models. It is the general trend of the combination of models that give indication of what conditions will look like in the future.
- *Marginal ice zone:* Is there any effort in using a marginal sea ice model for the marginal sea ice zone? Ingrid noted that in Bergen, they are working on this using a combination of waves and floe size. However, there are still big data gaps and missing observations, thus a lot more research is needed to provide operational information. It was also noted that some of the models in the US have been implemented for the marginal ice zone.
- *Sea ice thickness:* What are the metrics that stakeholders really need - extent vs thickness? Julienne noted that there is still not much focus on sea ice thickness, and that there is likely much higher difference in the models regarding thickness.
- *Operational use:* The presenters were asked to explain how their models are used. Rick explained that the US Coast Guard and the National Snow and Ice Data Centre use their model. The US Navy model, providing 7-day forecasts, was used by the Maple ship with good results. He stressed that synergy with customers and their feedback are very useful. Ed replied that the UK Met office provides 5-day forecasts to the UK Navy, but it is not always clear how the information is used.

3.4 Part 1 - User and Stakeholder Needs from an Operations and Management Perspective

Sea-ice Needs and Practices for the Operational Activities and Industries

3.4.1 Kelvin Murray (EYOS): User Needs from the Polar Tourism Industry

EYOS Expeditions is a member of the Association of Arctic Expedition Cruise Operators (AECO). Kelvin underlined that AECO is an important organisation for tourism based operations in polar areas. The organisation is growing in membership as more tourists want to travel to remote Polar locations. Some indicators of this are:

- Medium sized tourist vessels (100-500 people on board) are on the increase, including smaller sailing yachts
- 24 new expedition vessels will appear in the next two years
- Svalbard is by far the most popular area, Greenland is 2nd, and Canada is also growing. Franz Josef Land is becoming more popular due to increasing dynamics in the ice cover near these islands, potentially allowing for easier transit.
- Companies are specifically building luxury yachts that are ice-strengthened in order to travel to new areas.

EYOS uses sea ice information to make tactical decisions during their cruises. Daily and weekly charts are used for short term and longer term planning, also in combination with drones and other emerging technologies. Short term planning also involves the following needs and requirements:

- Feasibility studies and seasonal planning
- Historical analyses (e.g. good for Svalbard, North-west passage)
- Compliance with the Polar code and insurance regulations
- Reliance on recent observations and recommendations (anecdotal evidence) from pilots / captains etc.
- Dialogue also with other ships etc.

For longer term planning:

- Seasonal ice charts are used to decide whether for example to go to Greenland or Svalbard
- Daily charts are used to consider if the ship can get through a particular passage
- Satellite imagery is of high value for someone in an office, but less practical on a ship due to the poor bandwidth in high latitude areas where there is dependence on using Iridium services.

The demand for detailed ice charts are increasing since more tourist ships are operating in Polar waters, and each ship is hoping to access exclusive areas where there are limited amounts of other ships. Canada and Russia are opening up their Arctic waters partly to address this demand. The following improvements and future needs are essential for the tourist cruise operators:

- Real-time analysis of current ice conditions is crucial (not just the general picture over the last 10 years)
- Small scale (regional) and high resolution (< 1km) imagery is necessary to know if the ship can get through a very specific area e.g. in straits, bottlenecks and essential waterways
- There is a need for consistent information on sea ice location, edge and ice types as well as agreed definitions of the ice edge.
- A clear definition of single year, multi-year and overall quality of ice in the ice charts, necessary to judge if the ship can get through a sector or not
- Access to near-real-time high resolution images
- Seasonal predictions and forecasting in an understandable and usable format (forecast models are challenging to understand).
- Access to data also requires access to high speed internet and communications systems

3.4.2 Tor-Arne Vaskinn (Fiskbåt): User Needs from the Fishing Industry

Tor-Arne explained that the nature of shrimp trawling brings boats especially close with sea ice. Many accidents occurred in the 1990´s in the areas around northern Svalbard. At that time, the marine charts of the area were of poor quality, the ice charts were only produced once a week, and the communication systems were poor for some fishing vessels. Today the situation has improved significantly with daily forecasts of sea ice, communications is better, and fish plotters help with getting information of bottom topography, which is important in icy waters.

The most important needs of the shrimp trawlers are access to:

- Better information about ice drift (12-48 hours). Longer term forecasts are not as much needed
- Ice thickness and strength in real time. Multiyear ice is a big and dangerous problem
- Iceberg drift in Greenland waters (as some Norwegian shrimp fishing takes places there as well)

Snow crab fisheries have the following requirements:

- They tend to avoid sea ice altogether. Fishing equipment can be lost if ice moves over the lines, as it did for several snow crab vessels in 2017.
- Better long-term warning could help the fishermen (a week or at least a few days).

Seal hunters (currently very few of these) need:

- They specifically look for sea ice but are trying to find the right kind of ice, and avoid multi-year sea ice
- Ice charts are currently being read by the skippers, along with weather reports and their own experience from previous years

A major problem for the fishing industry is communications. North of 79 degrees only the Iridium system is available with only 30kb/s data speed. Sea ice data producers should take these limitations into consideration and adjust their products accordingly. Access to a broadband system would significantly improve this. The benefits of providing better ice charts and forecasting will include:

- Safety for the crew
- More efficient time at sea
- Safe passage for the boat with minimal damage
- Better planning and overall efficiency, etc.

3.4.3 Lasse Rabenstein (Drift & Noise): Research and cruise industry needs

Lasse presented the work of the Drift + Noise polar services which is a spin-off company of the Alfred Wegener Institute (AWI) that focuses on producing near real time (NRT) sea-ice information. They also focus on automating services, data integration and visualisation, as well as customised processing.

An important prerequisite for the company is the access to publicly available satellite data. The company has a server that downloads satellite images and produces annotated SAR images. Only the most crucial images are sent to the ships. Their user needs, as seen from the company, are identified as follows:

- Safety: Companies need to be proactive and comply with the Polar Code. They also need to be reactive to ensure compliance.
- Cost saving: Good ice information can help save fuel and time as well as reduce costs of maintenance and insurance.
- Increased turnover of clients: The ability to go to an increasing amount of new sites for tourists or keep mining production running (oil, gas, etc.).

Lasse presented two user case studies.
Use case 1, a research ice breaker in dense ice, had the following characteristics:

- In very heavy ice, the ice breaker costs 70’000€ per day. Better ice information can help reduce these costs if they can find more easily navigable routes.
- They take the position of the ship into account and send 2-4 hour old images to the ship – this was very helpful for navigating the Polarstern (AWI). However, 2-4 hour images may also sometimes be too old since the ice can drift very quickly.
- Ice drift forecasts were generated using wind forecasts with remarkably good results
- They managed to guide a trip, which would normally take 4 days, in just 2 days, using 1-12 hour forecasts.

User case 2 (Antarctic cruise shipping):

- They want to safely reach attractive tourist sites
- Drift + Noise delivered sea-ice forecasts for a cruise ship going through the Weddell Sea (which is known for heavy ice even in summer).

Sea-ice Information Needs for Short and Long-term Planning and Business Development

3.4.4 Kenneth Johannessen Eik (Metocean & Arctic design, Statoil)

The oil and gas industry is still very active in the Arctic and sub-Arctic. Statoil is very active in many regions doing exploration (from boats) and development. They currently have one licence to drill oil off the east coast of Greenland, but haven’t done much drilling there yet – for cost reasons. They also have investments in a wind farm in the Baltic for which they also need sea-ice predictions. They have different operational needs a compared to many other sectors:

- When drilling, the need is to keep people safe at the main drilling station. Important to try to avoid contact with sea ice and try to keep min 50km away (in the Barents Sea) from ice that is 40% concentration and need to know also sea-ice thickness
- In production the design philosophy is different. Production period is much longer in time than just exploration. Structures thus need to be capable of resisting abnormal sea-ice with or without ice-breaker assistance. Damage to oil installations can cost huge amounts so good forecasts are crucial.

Statoil does not use ice forecasts on a daily basis, but use historical ice charts for planning purposes. They want to know on average where the Arctic is ice free for how long, etc.

- When they do use forecasts it is mainly short-term (<72 hours) to look at where the closest sea-ice will be. However, longer timescales would certainly be useful, in particular good forecasts 6-months out for planning their operations (but they expect the research community to provide nearly 100% reliable forecasts).
- They also have an aircraft that goes out to confirm sea-ice conditions.

3.4.5 Morten Mejlænder-Larsen (Arctic Operation, DNV GL)

Morten explained that there are large numbers of vessels that can go in sea ice, but they need to know about the ice thickness since there are several different ice classifications. The New Polar Code came into force from 1 January 2017. Limitations to operations are defined by:

- The vessel's ice class
- Polar service temperature (cold climate rating).
- Level of winterization – what the ice is like (current ice conditions are essentially the limiting factor)
- Possible other design limitations.

The Polar code applies north/south of 60° and a boat going in these waters need to apply for code classification. A risk assessment using sea-ice forecasts for the time period and area is required for any operation to get an application approved (includes statistical data for past conditions as well as up-to-date forecasts). In the end it's the responsibility of the ship's captain to decide where to operate, but they need to comply with the Polar Code:

- Most ships actually try to avoid ice as much as possible.
- A ship that does go through sea ice needs more detailed information on thickness, area, snow coverage, etc.

A decision support tool was developed, called POLARIS (Polar Operational Limit Assessment Risk Indexing System) with the following characteristics:

- Operating version with three colours like a traffic light. One feeds in the actual ice conditions, the ship's ice class, as well as the possibility for ice-breaker support – a colour comes out: go, there is some risk, or don't go.
- Requiring detailed information of the actual sea-ice conditions (but not necessarily forecasts).

4. Identify Stakeholder needs Part I

4.1 Session 1 - Breakout Group Exercise - Organisation and tasks

The group was divides into predefined breakout groups (see list of breakout groups at the end of this document) of "operators" and "managers" moderated by the selected participants from the science community.

1. Round of introduction
2. Use the following questions to provide feedback on your user needs (cards will be provided which can be pinned to a board)
3. Cluster answers (bring similar needs together)
4. Prioritise needs with feedback from the group (voting with sticky points)

The topics for breakout groups were:

4.1.1 Type of forecast: short-term, seasonal, and longer-term

1. What time of year are you most active in sea ice? In what area(s)

4.1.2 Sea ice metrics needed, and at what temporal and spatial resolution

2. What sea ice products are being used? What sea ice products are needed for route pre-planning? What is needed for en route planning?
3. What is the minimum and maximum spatial resolution needed for your planning and activities?
4. How useful are probability maps for portraying results from ensemble forecasts?

4.1.3 How forecasts are being used

5. How do you use operational sea ice products (e.g. ice charts, automated sea ice products, etc...)?
6. How do you use sea ice predictions?
7. How are short-term and seasonal forecasts used for ice management planning?
8. How are short-term and seasonal forecasts used for tactical navigation?
9. How reliable would a forecast have to be in order to be useful or make an impact in your planning? And at what spatial precision (e.g. how many nautical miles can there be a sea ice displacement in the forecast?)
10. Are there any in-house techniques that you use to make informed decisions?

4.2 Session 1 - Breakout Group 1 - summary

The group began with a round of introductions and it was noted that there were two participants who were end users of sea ice forecasts from the US Coast guard and the tourism sector. The rest of the group was composed of researchers, social scientists, and international organisations with thematic interest in sea ice science and forecasts. The following main points came out of the discussion:

- One of the main observation the group came up with is that forecast practitioners should try and provide more user-friendly formats and simplified terminology to describe their products and how they can be used.
- The users highlighted that the main products they need are sea ice charts and satellite images, and they mainly need localised high resolution products.
- Currently the longer scale sub-seasonal and seasonal forecasts are rarely used and they were unsure if such long scale products would be useful.
- One comment was that currently there are no drift models of sea ice available, or none easily accessible. And similarly any kind of forecast of waves could be very important.
- There may also be economic gains achieved for example in search and rescue, the operation could potentially be shortened which would reduce costs.

- There is also a need for capacity building and training in the use of forecasting products, so there can be a better understanding and dialogue between users and practitioners.

4.3 Session 1 - Breakout Group 2 - summary

The group participants introduced themselves and this was a relatively small group, composed of scientists from the Bjerknes Center, a forecast user from DNVGL (marine certification company), and participants from the research sector. The group had a lengthy discussion about the Polar code and how many ships are currently operating in the Arctic sea ice cover. Estimates vary between 150-300 ships, more during summer than winter, but they all now follow the Polar Code. The following needs and requirements were identified:

- Ships that are operating in Arctic waters need daily information, and the furthest they are looking ahead in time is up to 1 week. This is the most important timeframe for ships operation in sea ice conditions.
- The main metrics they are looking for are: the location of the sea ice edge, information about the ice age and finally the ice thickness. They would like to have any information about the quality of the ice, as well. This can vary greatly and have a big impact on the ships ability to navigate through ice covered waters. First year ice or weak ice vs multi-year thick ice can have a dramatic impact on the speed of the ship and the safety considerations for the boat and the crew change as well.
- The quality of the ice is an important factor for potential damage, and specifically pressure bending the ship hull. There is a direct economic cost of going slower and higher fuel consumption in thicker sea ice cover.
- Ridges can potentially damage the hull of the boat as well and should be avoided.
- The captain of vessels spends a significant amount of time to search for leads, and would prefer to travel through leads in the sea ice rather than breaking through sea ice.
- Indications about how long leads will be present, where they are, and where they may move, would be helpful.
- The main decision making tool that DNV GL uses is called POLARIS and is available on their website.

4.4 Session 1 - Breakout Group 3 - summary

The group discussed the needs of the modelling community, which together with the users needs to find one language. Other needs are:

- Customization of data is needed for the models
- The lack of data in the Arctic need to be address. Without better and more data we will not improve forecasts
- Two types of models with different user needs are:
  - Longer term: important for some countries due to for example the impact of the Arctic on climate and weather patterns
  - Shorter term: strategic use (making business decisions up to the next 3 years) / decision making while navigating in the Arctic
- Short-term data is available however users need skills to interpret the data
- We need to know: what are the tools that are available and who are the users for these tools?

The group also considered the value of the different modelling scales and the socio-economic benefit of the different models:

- Cruise tourism: Intermediate term (2-3 years) important for cruise tourism: Tour operators can plan what they can offer their customers. Would they pay for it? Probably not a lot. Maximum gain or minimum spend.
- Oil industry: Providing money, but at the moment the oil industry is moving out of the Arctic. There is however a potential for the rise in other energy services operating in the Arctic.
- Research icebreaker: you can save a lot of money if you save cruising days

- Transpolar Route/Northern Sea Route: Could be a big driver to investments in sea ice predictions

The group also posted a more general question for the final open discussion: Are high resolution models providing short-term, local data too expensive for a relatively small market?

4.5 Session 1 - Breakout Group 4 - summary

The group discussed what accuracy levels are needed in sea ice forecasts in order to be useful for the various needs.

- For Statoil in planning seasonal operations, they need to know the percent chance of reliability. Since it is difficult to know how good the products are, they use the average of their accuracy over time. Operators are interested in year-round information.
- Tourist operators and others need reliable seasonal forecast. They risk losing many potential days of operations (e.g., if forecast are for late melt and the actual opening is earlier.) An estimate of uncertainty for a forecast would be useful.

It was noted that an ensemble of model forecasts would usually best fit to the observations but improvements are necessary. One can compare freeboard from models and from satellite. This gives much better confidence of freezing/colder season than the minimum. A model can also be run for every month of the year to see where the model has skill and where it does not.

Stakeholders would like detailed resolution in sea ice forecasts, which is difficult to meet. The level of detail needed and requirements are:

- Operational forecast need to know where the ice is
- For Seasonal forecasts aggregates are ok
- Industry wants information in the public domain
- Big gaps exist between the data that is produced and what is available to the public
- Resolution is not the main issue, but detail nearshore is very important.

It was noted that high accuracy of model information for the shoreline does not yet exist. Thus, there needs to be specific products design for specific users. Statoil needs are different from fishing or tourist needs, as for Statoil the ice chart is basically the forecast needed. Statoil uses statistics over past +10 years for example to locate drill rigs. Blending of models is a good solution – improving information about uncertainties. Ensemble means of models is another possible solution. In order to proceed, one could take one industry as a case study, to look at the skill of models. Another idea is to focus an effort on one region.

The Sea Ice Outlook 2017 Post-Season Report was brought up for illustration (https://www.arcus.org/sipn/sea-ice-outlook/2017/post-season):

- Ex: Figure 11: Sea Ice Probability (SIP) June Forecast, with the observed September sea-ice extent edge overlaid, together with the ensemble mean of individual models' SIP, and the model uncertainty in the SIP forecast
- Figure 12: Brier scores (a metric constructed so that 0 indicates a perfect forecast and 1 indicates an erroneous, or zero skill, forecast) from each SIP forecast and the multi-model mean.

Most of the group had not seen the report and were impressed with the level of information provided.

The group finally discussed what parameters are needed in sea ice forecasts:

- Convergence/divergence
- Ice thickness
- Ice drift
- Timing of ice break-up

- Validation matrix

4.6 Session 1 - Breakout Group 5 - summary

The group discussed the following issues:

- ***Data availability:*** Data needs to be accessible, like Copernicus, with an open data policy. Data could be available on FTP servers, API interface. Need to improve accessibility and sharing of data among people that already know each other, networks.
- ***Network:*** A network to get insight into all available systems is desired
- Depending on the region or sector of operations, sometimes only one ice chart service is available
- ***Ice classes:*** It is hard to distinguish different ice classes, and experts also have difficulties. Software can detect certain ice classes, but experts really need to evaluate the ice class carefully. With the current satellite technology available human input is needed to classify ice
- ***New tools***: Captains could be assisted by a combination of ice radar (up to 5nm) and an overall ice map, larger images, higher resolutions SAR, etc.
- ***Communication:*** Contact between users and producer of ice charts is important for interpretation. Communication can be interrupted by poor bandwidth. Lack of communication between producer and user means that it is hard to get feedback from user
- ***Training:*** The conservative attitude of captains to put safety as the highest priority, requires a need to develop stronger trust in sea ice products. The next generation of nautical officers need to be trained to adjust navigation based on real-time forecasts. There may be a need for boundary organization to help dialogue between user- and producer. Intermediate users may help in the process as well. Translating of data is necessary (scientist-stakeholders).

Other aspects of sea ice needs, improvements and forecasting were discussed:

- Possibility to create local forecasting data (eg. Hinlopen Strait)
- Creating 400 m resolution charts will be available in 2020
- Services for detailed information are current bottlenecks
- Production of future sea ice images, realistic images are required
- Need seasonal forecast to be developed to be useful for commercial activity
- Scale of images in Europe (3 months out) are not good enough
- Scale for many US based operations are okay, but the scale in Alaska (3 months out) is not usable
- Prediction of weather is complicated due to climate change, and changing climate patterns
- Succession of polar lows and oscillation are very complex, often only a projection can be produced
- Better wind forecasts are necessary to predict movement of ice
- Interpretation and training on how to use other ice information and forecasts for customers is necessary
- Prediction of wind accuracy is crucial for ice prediction in terms of safety and responsibility

4.7 Session 1 - Breakout Group 6 - summary

The group involved both oil drilling and fishing industry. Their interests in sea ice forecasts were the following:

- Fishing needs:
    - Trawling in light ice, need to find areas of good ice conditions that won't damage the hull
    - Traps/crab fishing, need information approximately one week in advance to prepare equipment
    - Top priority: Economic interest, but also safety
- Drilling:
    - Dynamic positioning, physical ice management, assisting icebreakers upstream, need forecast combined with data assimilation, short term and deterministic forecast, need to know direction of ice drift

- Other users:
  - Seasonal forecasting useful for tourist industry
  - Insurance requirements

The group´s response to what type of forecasts are needed and at what temporal and spatial scales were described in the following:

- Daily information of met-service pressure maps
- Resolution needed (varies based on application)
- Wind forecasts
- 3 levels of information: Radar images from bridge: 3 nautical miles + camera system.

For the fishing industry, the special needs and use of sea ice forecasts are related to:

- High resolution forecast: Need to know the location of leads in satellite images for route planning
- Forecasts within the season: It is necessary to map out planned trajectory (forecast horizon a few days), and long term forecast which are not that important (next season, month, etc.).
- Accurate position of the ice edge when sailing outside the marginal ice zone (MIZ). If travelling within the MIZ, there is a need to have reliable ice distribution/leads/satellite imagery.
- Daily satellite imagery is used from Barentswatch, Norwegian Ice Service and Copernicus Marine Arctic Forecasting Centre sea ice forecasts.

The group also discussed what kind of sea ice metrics are needed

- Ice thickness, distribution, drift.
- Models producing hourly outputs with specified confidence.
- Short term, daily needs, must be deterministic. If planning a week ahead, probabilistic forecasting with ensemble modelling needed.
- Satellite data: Location of Ice Edge + drift, not ice thickness.
- Ice thickness info useful to improve sea ice models and the forecasts

5. Identify Stakeholder needs Part II

5.1 Session 2 - Round-up discussions and determine way forward

The rapporteurs from the breakout groups presented the results from each group. The final plenary included providing outcomes from the discussions on current needs of different industries, how these can be addressed, and the way forward. A general comment was that a strategy for continued engagement with establishing possible cooperation opportunities was needed.

5.2 Session 2 – Discussion and recommendations

It became clear throughout the day that there is still a basic need for sea ice forecasters and users to find more common language and tools. There was still somewhat of a disconnection between the more scientific perspectives on the production of the forecasts and the users who want simple products tailored to their needs.

The following points summarise some important recommendations from the workshop:

- Encourage more co-production of the various decision-making systems so that both sides become more educated about potential new products and services. Ideally sea ice forecasting products should be more user driven and tailored to industry needs (and these may be different per sector).

- Create an iterative process where the involved actors can develop synergies together and gain a better understand of each others skills, limitations, and promote better tools to communicate their needs.
- Establish common language between stakeholders, modellers, and observationalists.
- Provide incentives and encourage industry to hire sea ice scientists (and/or interns and early career researchers) to get a better perspective on the state of the art and focus on tailor made products.
- Create better visualisation tools, based on best available communications systems, recognizing there is the reality of low bandwidth in the Arctic, and that compromises on both sides will be necessary.
- Forecasters should concentrate on better communicating assumptions, limitations, expectations, and what is possible with current technology.
- Build in easily understandable confidence and uncertainty estimates in forecast products. The most important thing for industry is the quality of the forecasts and making sure they are communicated in the right fashion. Accuracy is the key. Jointly develop, share, and validate prototype products that can be refined and customised as needed.
- Link with complementary programmes and initiatives focussing on the links between industry needs and sea ice forecasts, ex. YOPP is also making some of these products available on their web page.

The question of establishing intermediate services, providing a list of services, forecast products available already, and a list of open data sources was not sufficiently elaborated.

6. Wrap up and social event

A social event was sponsored by the Norwegian Meteorological Institute and ARCUS with drink tickets and light snacks was provided. **Location: Skarven, Strandtorget 1, 9008 Tromsø.**

7. Workshop AGENDA

15:00 - 17:00 Overview (2 hours):

15:00 - 15:05 Julienne Stroeve (UCL) - Introduction to workshop (objectives and agenda)
15:05 - 15:10 Uma Bhatt (Univ. Alaska): Sea Ice Prediction Network (SIPN) and motivation for the workshop
15:10 - 15:45 **Insight to Capabilities of Sea-ice Forecasting Products**
Ed Blockley (UK Met Office): Presentation on current capabilities of short-term forecasts
Rick Allard (Naval Research Laboratory): Short-term and seasonal forecasts
Wieslaw Maslowski (Naval Postgraduate research lab): Seasonal forecasts
Ingrid H. Onarheim (U Bergen/Bjerknes Centre): Seasonal to decadal forecasts

15:45 - 16:00 Coffee Break

16:00 - 16:50 **User and Stakeholder Needs from an Operations and Management Perspective**
16:00 - 16:30 *Sea-ice Needs and Practices for the Operational Activities and Industries*
Kelvin Murray (EYOS): User Needs from the Polar Tourism Industry
Tor-Arne Vaskinn (Fiskbåt): User Needs from the Fishing Industry
Lasse Rabenstein (Drift & Noise): Research and cruise industry needs
16:30 - 16:50 *Sea-ice Needs for Short and Long-term Planning and Business Development*
Kenneth Johannessen Eik (Metocean & Arctic design, Statoil)
Morten Mejlænder-Larsen (Arctic Operation, DNV GL)

17:00 - 17:45 Identify Stakeholder needs Part I *(45 min)*

Session 1 - Breakout Group Exercise:

- Divide into predefined breakout groups (see list of breakout groups at the end of this document) of "operators" and "managers" moderated by the selected participants from the science community.
  1. Round of introduction
  2. Use the following questions to provide feedback on your user needs (cards will be provided which can be pinned to a board)
  3. Cluster answers (bring similar needs together)
  4. Prioritise needs with feedback from the group (voting with sticky points)

Topics for breakout groups:

Type of forecast: short-term, seasonal, and longer-term

1. What time of year are you most active in sea ice? In what area(s)

Sea ice metrics needed, and at what temporal and spatial resolution

1. What sea ice products are being used? What sea ice products are needed for route pre-planning? What is needed for en route planning?
2. What is the minimum and maximum spatial resolution needed for your planning and activities?
3. How useful are probability maps for portraying results from ensemble forecasts?

How forecasts are being used

1. How do you use operational sea ice products (e.g. ice charts, automated sea ice products, etc...)?
2. How do you use sea ice predictions?
3. How are short-term and seasonal forecasts used for ice management planning?
4. How are short-term and seasonal forecasts used for tactical navigation?
5. How reliable would a forecast have to be in order to be useful or make an impact in your planning? And at what spatial precision (e.g. how many nautical miles can there be a sea ice displacement in the forecast?)
6. Are there any in-house techniques that you use to make informed decisions?

17:45 - 18:00 Coffee break

18:00 - 19:00 Identify Stakeholder needs Part II *(60 min)*

Session 2 - Round-up discussions and determine way forward:

- Rapporteurs from breakout groups present the results: what are the needs and how can these be addressed?
- Plenary: what is the way forward? - Keld Qvistgaard/Penelope Wagner • Develop strategy on continued engagement
- Establish possible cooperation opportunities

Wrap up – Penelope Wagner

19:00 - Social Event

The social event is sponsored by the Norwegian Meteorological Institute and ARCUS. Drink tickets and light snacks will be provided. **Location: Skarven, Strandtorget 1, 9008 Tromsø**

8. List of Participants

Name	Affiliation
Aaboe Signe	MET Norway
Alfthan Bjorn	GRID-Arendal
Allard Rick	Naval Research Laboratory
Baer Kristina	Alfred Wegner Institute (AWI)
Bertino Laurent	NERSC / ESA
Bhatt Uma	Universirt of Alaska
Biebow Nicole	Alfred Wegner Institute (AWI)
Blair Berill	Wageningen University
Blockley Ed	UK Met Office
Bobby Pradeep	Memorial University
Borch Odd Jarl	Nord university Business School
Berivik Øyvind	MET-Norway
Dinessen Frode	MET-Norway
Eik Kenneth	Metocean & Arctic design, Statoil
Eldevik Tor	University of Bergen, Bjerknes Centre for Climate Research
Eltoft Torbjørn	CIRFA
Fournier Nicolas	UK Met Office
Graversen Rune	University of Tromsø (UiT)
Hamon Gwen	CliC
Hislop Lawrence	CliC
Hughes Nick	Norwegian Ice Service – MET-Norway
Ionita-Scholz Monica	Alfred Wegener Institute for Polar and Marine Research
Itkin Mikail	Norwegian Polar Institute (NPI)
Jeuring Jelmer	Umeå University
Jørgensen Frigg	AECO
Knol Maiite	University of Tromsø (UiT)
Lamers Machiel	Wageningen University
Lee Jason	G-Marine Service Co., Ltd.
Løset Sveinung	Arctic Marine Technology - NTNU
Maslowski Wieslaw	Naval Postgraduate research lab
Mejlænder-Larsen Morten	Arctic Operation, DNV GL
Metzger Joe	Naval Research Laboratory
Muilwijk Morven	University of Bergen, Bjerknes Centre for Climate Research
Murray Kelvin	EYOS Expeditions
Müller Malte	MET-Norway
Olason Einar	Nansen Center (NERSC)
Onarheim Ingrid	University of Bergen, Bjerknes Centre for Climate Research
Paulsen Steinar	University of Tromsø (UiT)

Potter Sarah	University of Tromsø (UiT) student
Qvistgaard Keld	Danish Ice Service
Rabenstein Lasse	Drift & Noise
Smedsrud Lars	Uni Bergen
Stokvik Kjell	CHNL Nord university
Stroeve Julienne	UCL / SIPN
Sylte Gudrun	Bjerknes Centre for Climate Research
Tummon Fiona	University of Tromsø
Turner-Bogren Betsy	Arctic Research Consortium of the U.S.
Vaskinn Tor-Arne	Fiskbåt
Wagner Penelope	Norwegian Ice Service – MET-Norway
Wang Keguang	MET Norway
Webb Paul	SAR controller for Alaska, US Coast Guard
Werner Kirsten	Alfred Wegner Institute (AWI) / Polar Prediction Project (PPP)
Wiggins Helen	Arctic Research Consortium of the US (ARCUS)
Ørbæk Jon Børre	Research Council Norway (RCN)