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ICECAT-1-2-3: Operational Ice Chart for Seismic Planning

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ABSTRACT

2016 was the sixth and final season of TGS' 2D seismic acquisition program in the ice infested waters of North-East Greenland. Since the start of operations in 2011, it was clear that the standard WMO ice charts would not provide ice information in a form sufficient to support our efforts.

To work around this short-coming, an all-new ice chart product and procedure was developed, aimed directly at supporting ice management operations. Created in-situ, several iterations resulted in a simple and highly intuitive ice categorization product. Based on observed ice conditions data merged with satellite imagery and helicopter ice reconnaissance data, the information was then coalesced into an operational ice chart, relying heavily on the experience of the onboard ice management team. As well, the process weighted the capabilities and limitations of both the ice breaker and seismic vessel.

The target audience for this new ice chart was management… both onboard and shoreside. Its intuitive stop-light analogy made it obvious which areas would allow operations to occur, using a clear green-through-red color scheme. It readily showed areas of go/no-go ice conditions.

The result was an ice categorization product that was both process and output. Management saw none of the complexities of the development steps, just the clean result. This allowed operations people to focus more time ensuring safe and efficient operations and less interpreting a multitude of ice information sources. And while this process relied heavily on the experience of the ice management personnel, the result was well worth the extra effort invested.

TGS' multi-year operations in North-East Greenland wrapped up in the fall of 2016 and were by all measures, an outstanding achievement in one of the most challenging ice regimes in the world. The ice categorization process described herein was clearly part in achieving that success!

KEY WORDS: IceCat; Ice Categorization; Ice Charting; Polar Code; Greenland

INTRODUCTION

NE Greenland is one of the few remaining challenging areas for in-ice operations in Arctic regions and our plans would eventually take us into the most difficult areas within this region.

From 2006 to 2009, TGS-NOPEC Geophysical Company acquired 2D seismic data in NE Greenland on an as-able basis using an Akademik Class 2D seismic vessel, Shatskiy, and a small chase boat, Kvitbjorn. Both vessels had a light ice class rating which was sufficient for operations in open water and the occasional stray piece of small ice.

Ice information to support the project during this period came from public domain ice charts from various national ice services that cover the area of NE Greenland. The vessels acquiring seismic data simply used the charts to locate areas of open water and to follow along ice edges, something that large scale ice charts based on satellite imagery are very useful for.

The program to this point worked well enough until the need for seismic data from more challenging ice areas drove the requirement for a more formal ice management program that would provide higher resolution ice data to make better informed decisions. While the quality of public domain charts was good, the scale of these charts was insufficient to provide the small-scale ice information detail required to support seismic data collection in harsh areas.

It was knowing these limitations that saw us reintroduce ground-truthing, using ship borne and helicopter visual ice reconnaissance, and eventually (2016) even drone (UAV) data input. The ice management program would therefore require the ability to collect needed ice information on a frequent basis and augment it with satellite data of a higher-resolution than that used for public domain ice charts. This plan would necessitate the use of an ice reconnaissance helicopter and an ice management vessel capable of handling flight operations.

THE CHALLENGE

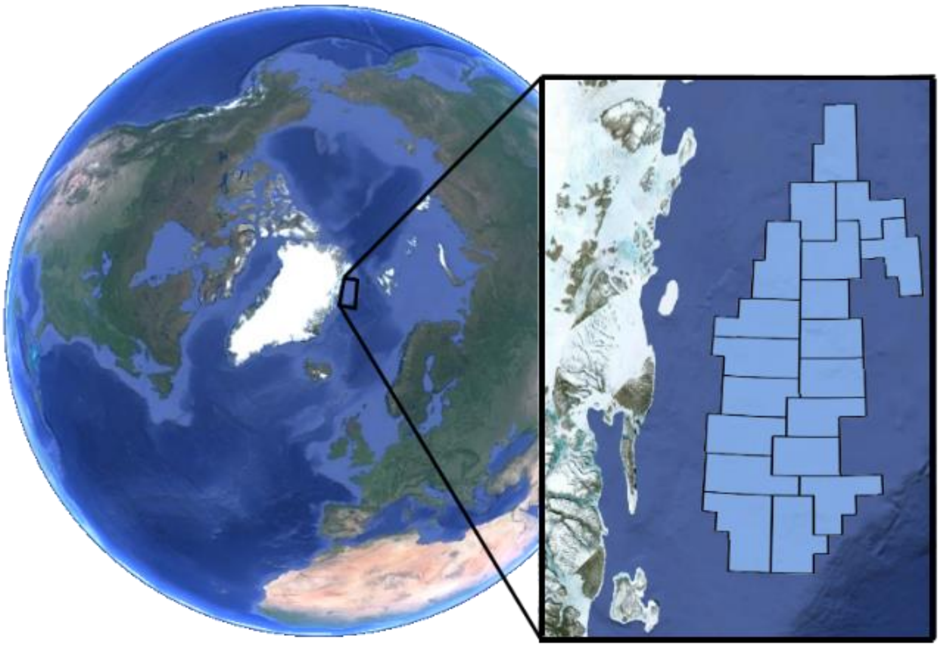

Figure 1. The area of interest (AOI) for the seismic acquisition program in NE Greenland is in one of the most ice-hostile regions of the Arctic. The AOI is divided into subsets called blocks. These blocks are leased by various oil exploration companies for seismic evaluation and possible future development.

Figure 2. (2016) Otso (icebreaker) leading Lazarev (seismic vessel) through heavy ice in the western extremes of the AOI, close to the NE Greenland coast. The six year program used the icebreaker Fennica in 2011 and 2014, the anchor handling ice breaker Balder Viking in 2012-13 and Otso in 2015-16. Lazarev replaced Shatskiy for the 2016 season.

The ice management program commenced with the 2011 summer season using the Finnish icebreaker Fennica, a 116m icebreaker with 15MW of power from 2 Aquamaster propulsion units. An A-Star helicopter was brought along for ice reconnaissance. Dedicated weather forecasting was added and the program launched northwards in late August of 2011. Initial ice charts from various ice services sources had shown a large percentage of multi-year ice existed throughout the block region AOI. As well, satellite imagery showed some areas of ice that could be open to interpretation. The first plan upon arrival at the southern ice edge was to ground truth the AOI using the helicopter and then bring in Fennica to test areas identified from the imagery and the heli-recce, to confirm what they were.

Figure 3. (2014) From 400m above, Fennica clearing the way for Shatskiy through light ice conditions. Note the clear wake aft of Fennica created by her powerful azimuth thrusters.

The format for the collection of seismic data was to have the lead icebreaker clear the way for the seismic vessel that followed just 200m behind, all while navigating carefully along the desired line of acquisition within a defined geographical region of interest or block. The acquisition line must be followed exactly, with little room for deviation, so knowing the exact ice conditions along the line was key. As well, the acquisition speed was just 4.5 knots and the 7km streamer must be kept moving forward or it will sink. When the streamer sinks, it triggers hydro-static floats that would bring it back to the surface, a surface often covered by ice. This occurrence would likely result in the total loss of the equipment and was something to be avoided at all costs. Further complicating these challenges was knowing what extreme ice features might be to the left or right of track out as far as 1km. This was because the streamer, following at a nominal depth of 15m was highly influenced by the unpredictable currents of NE Greenland. These currents would push the streamer left or right of track and potentially into the path of an extreme ice feature. If such an ice feature had a keel depth greater than 15m, the streamer would impact it causing damage and potential total loss. With currents playing such a strong role in moving the streamer off center it wasn’t always the ice in front of the lead vessel that you had to worry about, but ice to the sides of the intended track out to several hundred meters. With often poor visibilities in snow and fog, this was a major challenge, even with shipborne radar in use.

And finally, the 4.5 knot acquisition speed is not best for an ice breaker that likes to break ice at 6-8 knots. There were several occasions when we would hit 100m floes but wouldn’t break them due to our low speed and instead push them in front of the icebreaker. This floe would then impact a similar floe and so on until such time as we may have been pushing several of these small floes together, eventually slowing the ice breaker. We coined the phrase floe stacking where pushing one floe was fine but several stacked up together became problematic.

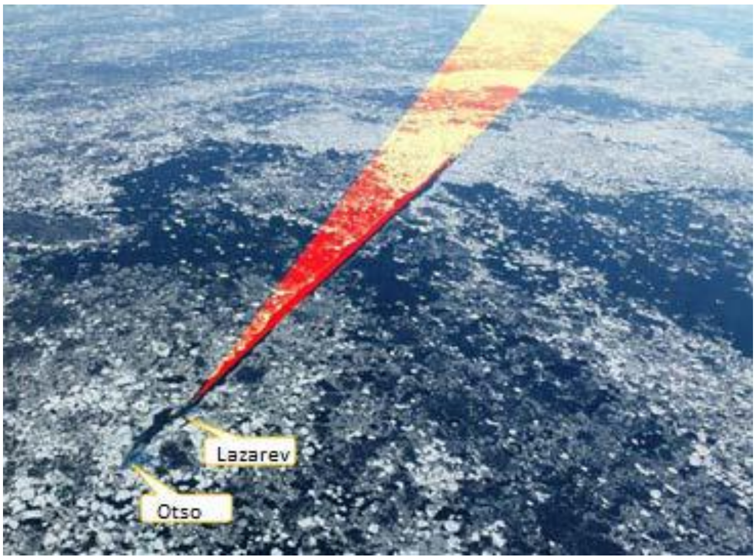

Figure 4. Otso (icebreaker) leads Lazarev (seismic vessel) through mixed ice conditions in NE Greenland. The black line shows the track that has been travelled while the red/yellow shading shows the potential offset of the seismic streamer should currents displace (in this concept example) the streamer to the right of track.

Figure 5. An extreme ice feature seen noted on a heli-recce. This is a small-medium (220m) size first-year floe with embedded heavy ridge elements having keel drafts estimated to be in excess of 15m. This ice feature would be a major challenge if encountered along a seismic line.

Our standard ice management technique was to bump floes off the track then flush them clear of the wake, something we intuitively termed “Bump & Flush”. But for extreme ice features like icebergs and multi-year ridge remnants, something common during the 2016 program, we added “Avoidance” to our ice management techniques. If a track deviation was small enough we would simply avoid the ice feature ahead and then return to track once the streamer was clear of all possible danger. Through the six years of the program, “Wake Management” was coined as a term to capture the microscale level of ice management required to do the work we needed to do.

THE ICE MANAGEMENT PLAN

All of these challenges resulted in us acquiring as much data as we could to support our decision making. We developed an environmental database containing weather, sea conditions and ice data as well as vessel-in-ice performance characteristics. We acquired multiple daily satellite images which were managed by our ArcGIS based system that merged imagery with seismic planning and ship movements. We added high resolution dedicated weather forecasting and flew countless ice reconnaissance missions with a dedicated helicopter to look along planned lines to ensure they were clear or failing that, identify options if the original planned lines were ice covered. We used all available data to drive our understanding of drift patterns and then applied this to forecasting ice conditions along planned seismic lines.

With all the data at hand, it was possible to make informed operational decisions safely and efficiently. **What was lacking however was our ability to inform the shore based operations management about ice conditions now and what was expected in the next 24-48 hours.** They shared in most other data but for ice information they were still referencing broad scale public domain ice charts. The scale for these charts for NE Greenland considers vast areas of up to 300nm in a north to south orientation while we needed to consider ice conditions on a granular scale as small as 30nm. The public domain ice charts were coalesced from various satellite data and issued daily. We had access to the same base image data but the challenge for our operations was that currents moved ice about in random patterns that made satellite imagery older than 6 hours of academic interest only. Using the latest imagery and pre-flying lines planned for acquisition gave us a 6-7-hour look-ahead based on the vessel speeds of 4.5 knots.

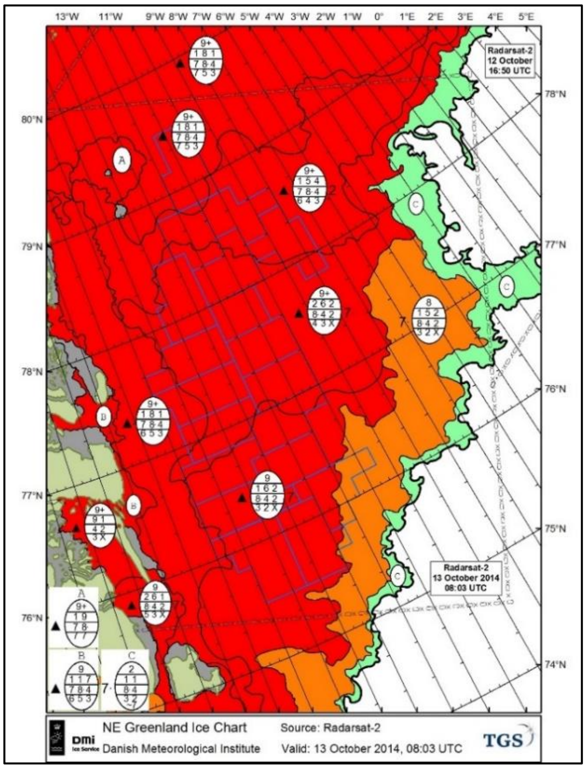

Figure 6. An example ice chart from the Danish national ice service (DMI) using the WMO color scheme for Ice Concentration

For example, at one juncture, we were getting questions from shore as to why we were focused on a certain area while onboard we were wondering why shore based operations wanted us to go to some other area. We were simply looking at different sources of ice information.

Intuitively, the chart on the right appears to indicate the possibility of penetrating the ice edge by 2-15nm but no further (at the boundary of red). The actual possibility for ice edge penetration is much greater if you consider the egg code classifications for the various ice boundaries.

Another example of where the color-coding doesn’t intuitively help is a situation where 9+/10ths of Nilas would be color coded as red while 3/10ths of multi-year ice would be color coded as green. For this project we would easily be able to operate in 9+/10ths of Nilas (red) but not 3/10ths of multi-year (green).

With the shipboard ice management team using local knowledge and the shoreside offices using the broad scale ice charts from various ice services, it wasn’t long before we knew we needed a product that suited both offshore and onshore operations.

The shoreside office used color coded WMO chart formats (Figure 7 Left) showing ice concentration by color. In one example, the office saw us working in a southern area and wanted us to move north to acquire seismic data in an area shown in yellow, or just 4-6/10ths of ice. This was an important area to acquire data from and given the short summer season, it was important to go there as soon as it was clear enough. The red color had recently changed to yellow as ice conditions eased and melted. But what changed was that the first-year ice melted leaving only multi-year & second-year ice remaining. This ice was impossible to work in for seismic acquisition but the change in colors from red to yellow had suggested a major improvement had taken place as far as the office was concerned.

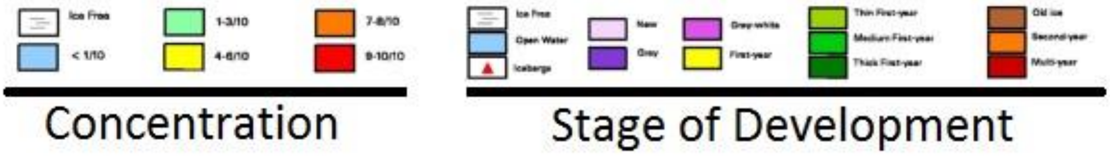

Figure 7. WMO Color code for Ice Concentration and Stage of Development

And this is where the second major challenge came in to play and the subject of this paper … How to capture all this high-resolution and verified ice conditions data in a form readily understood by marine and seismic operations, both onboard the ice breaker, the accompanying seismic vessel and shoreside management?

THE DEVELOPMENT OF ICECAT 1-2-3

With challenged bandwidth aboard the icebreakers, due to our far northern location, we knew we had to keep any product developed to be simple to reproduce and that answered the obvious question “Where can we work and for how long?”. We originally experimented with a QuickLook format. The QuickLook came from the Dome Petroleum/Canadian Beaufort Sea days in the early 1980s and was a simple sketch taken from the latest airborne reconnaissance data and faxed to vessels offshore. It showed the current ice conditions in terms of ice edges, concentration boundaries and composition. What we needed was to take things one step further and identify areas where lines of acquisition were possible and what trends were occurring in terms of ice clearing in one area versus another.

The request from shoreside management was to produce a simple ice chart showing where we could work and where we couldn’t and make it as intuitive as possible. This meant no egg codes and no underlying imagery that might require interpretation. It must show where it was possible to work for the pairing of the icebreaker being used and the seismic vessel it would escort.

We already knew the exact ice conditions based on our ground truthing efforts and this was aided by higher resolution imagery as well as understanding the limitations of our vessel pairing based on the ice trials we undertook. This then allowed us to develop a custom ice chart based simply on observed ice conditions, the most recent satellite data and the capabilities of the vessels involved. This saw the development of an operations-focused ice chart based simply on categorizing known ice conditions relevant to the operational limitations of the vessels involved.

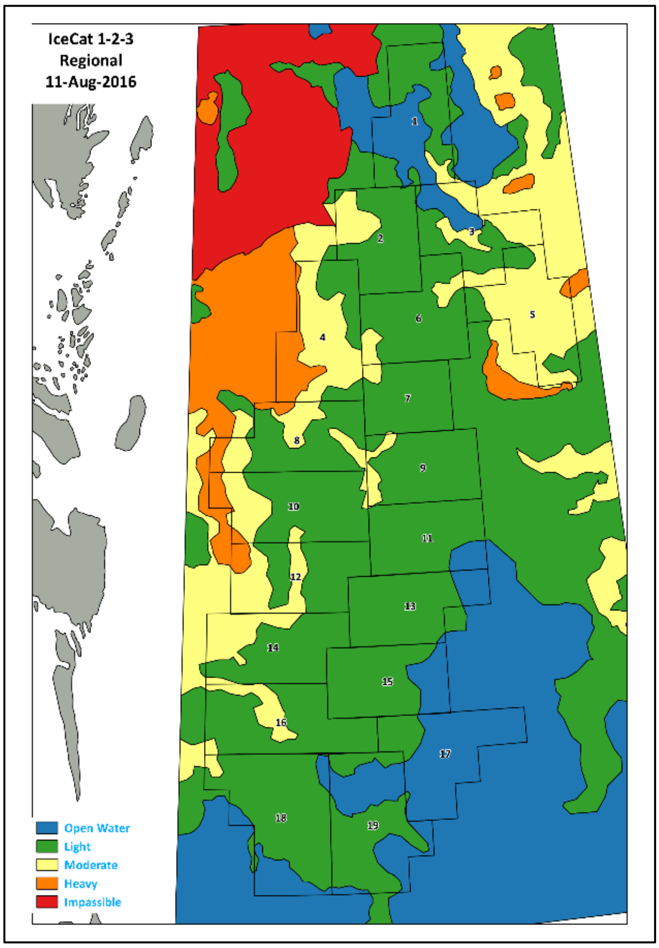

Figure 8. An IceCat 1-2-3 product covering the entire AOI. Note Greenland coastline to west shown in gray.

Thus, the IceCat 1-2-3 product came into being. IceCat for ice categorization and 1-2-3 to symbolize the simplicity of interpretation. Using the universal stop light analogy where green is go, yellow is cautionary and red is danger, we added a few more categories based on our experience. Blue was readily understood to mean ice free or open water with no challenge to vessels, and orange was added for heavy ice conditions, one category higher than moderate (yellow) but not yet impassable (red).

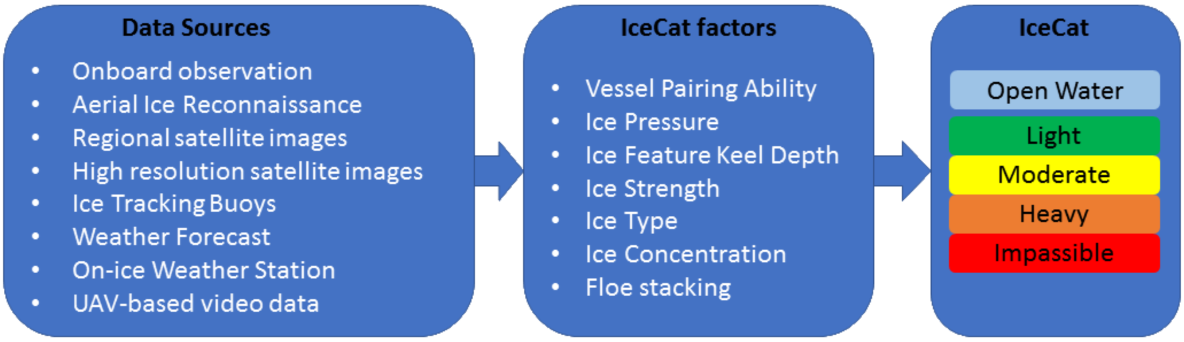

Figure 9. The data flow from input sources to factors considered in making an IceCat 1-2-3 chart to finally determine the appropriate color coding for the area of ice being investigated.

The chart covered the entire AOI and immediately showed where we could work (Blue through Orange) and where we couldn't (Red). A day to day comparison showed the trends in ice movement and decay/development.

Most importantly, and a key strength of this product was that it took the onus for chart interpretation from the end user (shoreside management & marine operations) and placed it solely with the ice management team onboard the icebreaker. Everything the ice team knew about the area ice was coalesced from various data sources, referenced to relevant IceCat factors such as vessel pairing, ice pressure, ice features, etc., and rendered into a colored chart called an IceCat 1-2-3. It was a daily snapshot of ice conditions that showed both line options as well as areas where seismic acquisition could be managed easier than other areas. The IceCat 1-2-3 didn't so much as embolden shoreside management to get involved in managing line choices as much as allow them to understand why we worked in areas where we did.

The IceCat 1-2-3 continued to develop through the six-year period of operations and improve with the addition of more and better data inputs.

For example, the 2015 season saw us 3D imaging some extreme ice features to calculate mass and then potentially infer danger to our operation. In 2016, we increased the resolution of our weather forecasting capabilities eventually adding a portable weather station to a grounded berg along the coastline due west of our AOI. This provided early warning of adverse weather and further strengthened the quality of our weather models and resultant forecast output. We started using ice tracking buoys that provided an accurate position every 30 minutes. We used these devices to track immediate threats by deploying and redeploying them on hazardous ice features, sometimes several redeployments per day when conditions were challenging.

Once we started to produce the IceCat 1-2-3 chart on a daily basis it became possible to monitor trends in ice cover changes. Our working area of interest was divided into many block areas that provided easy boundaries to use when investigating amounts and types of ice within each block and how the makeup of each block or region was changing. By clipping the boundaries either by block or region and using the inherent capabilities of the GIS-based IceCat 1-2-3 system, we could see if ice conditions were trending towards easier or more difficult. This provided TGS with the ability to monitor what trends were occurring and shift planning to more important areas as required. We had used a similar technique with our Caspian ice operations in previous years, so it made sense to port the technique for use in our NE Greenland operations.

THE ICECAT 1-2-3 SOFTWARE AND DATABASE

The IceCat 1-2-3 product is prepared within a GIS environment using Python plugins developed by the onboard ice management team. After gathering knowledge of current ice conditions from all available data sources, areas with different ice conditions were separated by lines and then converted to color-coded polygons using the IceCat 1-2-3 scheme.

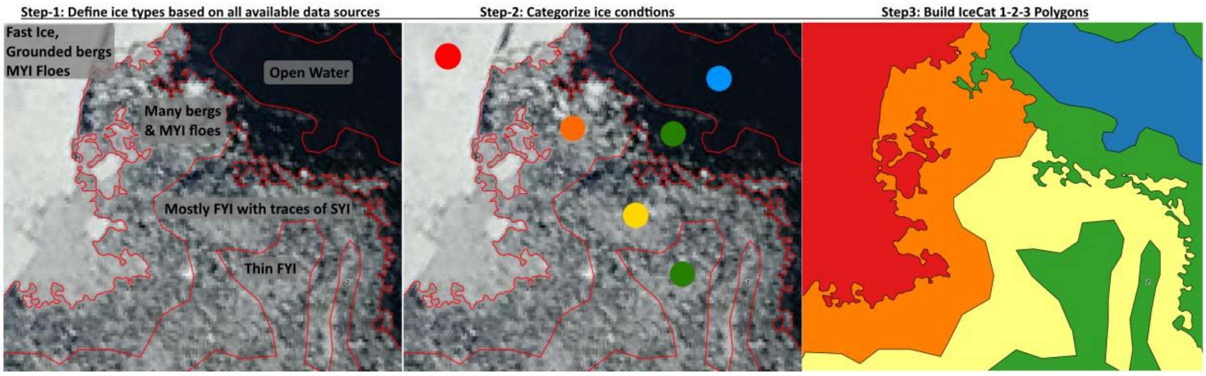

Figure 10. IceCat 1-2-3 product preparation steps.

These polygons were stored in the geo-spatial database, which allowed us to use the product for both operational (Figure 11) and post-seasonal analysis (Figure 12)

Block	OW	Light	Moderate	Heavy	Impassible
1	0.0%	65.3%	28.1%	6.7%	0.0%
2	0.0%	49.7%	27.5%	22.8%	0.0%
3	0.0%	64.7%	9.9%	19.4%	6.0%
4	0.0%	88.4%	5.5%	6.1%	0.0%
5	0.0%	18.9%	50.5%	22.1%	8.5%
6	0.0%	94.6%	2.7%	2.7%	0.0%
7	9.7%	86.2%	4.1%	0.0%	0.0%
8	12.3%	69.0%	10.4%	8.2%	0.1%
9	62.0%	33.9%	4.1%	0.0%	0.0%
10	83.6%	15.2%	0.0%	1.2%	0.0%
11	98.9%	1.1%	0.0%	0.0%	0.0%
12	94.0%	4.7%	1.3%	0.0%	0.0%
13	81.5%	18.5%	0.0%	0.0%	0.0%
14	85.2%	12.0%	2.8%	0.0%	0.0%
15	44.8%	51.7%	3.5%	0.0%	0.0%
16	100.0%	0.0%	0.0%	0.0%	0.0%
17	34.3%	56.3%	9.4%	0.0%	0.0%
18	98.5%	1.5%	0.0%	0.0%	0.0%
19	89.9%	10.1%	0.0%	0.0%	0.0%
All	49.8%	37.0%	8.0%	4.4%	0.7%

Data source: Radarsat-2
12 Oct 2015, 07:47 UTC

Statistical Summary

Current 12-Oct-2015:
Open Water: 7.4% (-2.7%)
Light: 17.8% (-11.0%)
Moderate: 17.5% (-2.1%)
Heavy: 51.3% (+14.2%)
Impassible: 6.0% (+1.5%)

Previous 11-Oct-2015:
Open Water: 10.1%
Light: 28.8%
Moderate: 19.6%
Heavy: 37.1%
Impassible: 4.5%

Conditions are:
Deteriorating

Data source: Radarsat-2
11 Oct 2015, 08:16 UTC

Statistical Summary

Current 11-Oct-2015:
Open Water: 10.1% (-2.6%)
Light: 28.8% (-2.4%)
Moderate: 19.6% (-7.0%)
Heavy: 37.1% (+9.9%)
Impassible: 4.5% (+2.2%)

Previous 10-Oct-2015:
Open Water: 12.7%
Light: 31.2%
Moderate: 26.6%
Heavy: 27.2%
Impassible: 2.3%

Conditions are:
Deteriorating

Figure 11. Example of statistics calculated for ice conditions occurring for 12 October 2015 for all blocks (left) and the comparison statistics calculated for ice conditions occurring for 11 October 2015, from two subsequent IceCat 1-2-3 charts covering all blocks (right). The timing of choice for this example covers the period where freeze-up is commencing with new ice forming throughout the AOI.

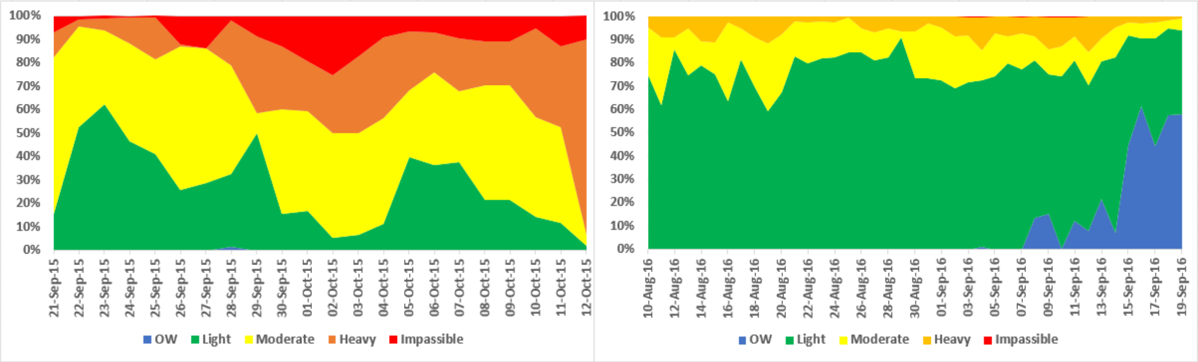

Figure 12. Seasonal comparison of the same license block for seasons 2015 (left) versus 2016 (right). 2015 showed substantially heavier (Orange) and impassable (Red) ice conditions in 2015 compared to the most recent season, 2016. This is in line with a generally observed trend of less heavy ice being noted throughout the AOI from project start in 2011 until project end in 2016.

Although the IceCat 1-2-3 database contains data for just six years, compared to decades of WMO ice chart databases, the recent rapid climate shift now taking place may make the 50-year data set less relevant for planning purposes. As well, and a key observation, is that ice chart interpretations made now are built from higher resolution imagery and much better data sources that were available even 10 years ago.

PORTABILITY OF THE ICECAT 1-2-3

The IceCat 1-2-3 can be ported to other geographic locations where a higher resolution of ice data may be required to drive specific operational or environmental reporting requirements. Such operations might include offshore oil exploration programs using floating or bottom founded rigs or even ice islands. It also shows promise for providing information on smaller or contained geographic areas such as the Great Lakes, Caspian Sea, navigable straits or even poorly sheltered harbors or transit routes in areas such as the northern sea routes. It would certainly work in areas like the southern Beaufort Sea, Chukchi Sea and along the Alaskan coast.

But there are challenges … the sheer volume of data required to produce the best IceCat 1-2-3 means that all inputs must be available in a timely fashion and that communications with all input sources such as satellite imagery be available via high-bandwidth.

It is very likely that in the not too distant future, clusters of satellites will provide frequent, high-resolution ice data imagery. Forecast weather models will continue to improve and the use of drones (UAVs) equipped with both optical and nano-SAR instrumentation requiring fast and reliable data streams will become standard. Upward-looking sonars deployed in arrays and connected via acoustic or fiber-optic networks will give early warning of heavy ice floes with substantial ridge element concentrations of encroaching the AOI. Real-time current meter data, from instruments deployed in wide areas at various depths will drive ice drift models with a much higher degree of accuracy than is available now.

To produce the best IceCat 1-2-3, all personnel involved must be very experienced and capable in ice management, marine operations, meteorology, oceanography, technically capable and have direct knowledge of the capabilities and limitations of the vessels or structure being supported as well as the skills of the personnel operating such vessels or structures.

And while quantifying vessel operations personnel and vessel capability is difficult to ascertain without a major time and testing investment, it is possible and is already being done to a limited degree. There is already a real push to qualify vessel management skills in ice. As well, through the use of the Polar Code, there is now a real effort to quantify a vessel's capability in ice.

That leaves just ground truthing missing from the mix of ingredients. Higher and higher resolution imagery will help but a standardized requirement for vessels to report ice conditions would certainly help. This is currently handled within National Coast Guard Fleets, ice breaker fleets, ferry services, the military and within other companies routinely operating in ice but a standardized reporting would help for vessels that follow. Weather reporting has been handled like this for many years by ships transiting the world's oceans so why not ice reporting? Airline pilots routinely report current turbulence for aircraft following behind so this is quite possible to handle with come cooperation and leadership.

All of this could lead to an ice chart, similar to an IceCat 1-2-3 product and specific to a vessel, its personnel and their geographic surroundings, being issued coincident with a change in any major input such as weather forecast, availability of newer ice imagery, other vessel's ice report, etc. Telling vessels where they can and can't go using an intuitive product put together by a capable ice service could increase safety of all operations carried out in remote Arctic water.

CONCLUSIONS

Having honed this product/service over several years in operational practice it is easy to see its possibilities for use with the new IMO Polar Code, where the code for each vessel would allow an IceCat 1-2-3 to be tailored for each vessels capability (polar code) based on ice conditions occurring in the planned area of operations. For multiple vessels intending to navigate through an area of ice, the IceCat 1-2-3 product would reflect the enhanced capabilities or limitations such as would occur when the vessel in question is being accompanied by a Polar 10 icebreaker (enhanced capability) or if the vessel in question picks up a barge for towing (degraded capability).

While this IceCat product is a large departure from traditional WMO egg code ice charts, it may be that adopting a simple product such as an IceCat 1-2-3 would allow all Arctic stakeholders from villagers to regulatory authorities and the public in general, to appreciate the ice challenges faced by vessels transiting through their waters, without the need for specialized knowledge.

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