PREPARED FOR: Leidos, ASC Centennial, CO			**BY:** Peter S. Soles **SENIOR MARINE CONSULTANT**
Glosten 1201 WESTERN AVENUE, SUITE 200 SEATTLE, WASHINGTON 98101-2953 T 206.624.7850 GLOSTEN.COM			**CHECKED:** Matthew A. Lankowski **SENIOR ENGINEER**
			APPROVED: Timothy S. Leach **PRINCIPAL-IN-CHARGE**
DOC: 19136-000-06	**REV:** -	**FILE:** 19136.01	**DATE:** 29 April 2021

Digitally Signed 03-May-2021

Reference

1. *Ice Class Selection Study for Palmer Replacement*, American Bureau of Shipping (ABS), Report No. HTEC-2020-4557330-1, 6 January 2020.

Executive Summary

This study was conducted to analyze the difference in potential operability of the ARV in ice-covered waters based on its Polar Class (PC) level of ice strengthening. The results of this study are intended to help NSF make an informed decision on the selection of PC3 or PC4 as the design standard for the vessel structure and propulsion train.

The goal of Polar Class selection is to establish the minimum strength of the vessel so that missions can be performed safely and confidently in the intended operational areas at the desired times of year. It is important to note, however, that ice class does not define operational capability in ice, which is dependent upon hull form, propulsor type, installed power, and the ice operating skills of the crew (Reference 1).

For this study, the difference in the potential operability between PC3 and PC4 vessels in Antarctic waters was characterized using the International Maritime Organization (IMO)-approved Polar Operational Limit Assessment Risk Indexing System (POLARIS). POLARIS is IMO guidance for operators to use for evaluating the risk of operating in different ice regimes. It provides a means to quantify the risk posed to the ship by ice conditions and the ship's assigned ice class (or lack thereof). POLARIS can be used for voyage planning purposes or navigational decision-making in real time. If an "acceptable" operating risk level can be defined, POLARIS can also be used for conducting an objective comparison between ice classes for a given operating area and season. A detailed background and description of the POLARIS system is provided in IMO Circular MSC.1-Circ.1519.

POLARIS assesses ice condition risk and quantifies it as a Risk Index Outcome (RIO) - where a lower RIO indicates greater risk than a higher RIO. RIO values are determined by the following calculation:

$$RIO = (C_1 \times RV_1) + (C_2 \times RV_2) + (C_3 \times RV_3) + (C_4 \times RV_4)$$

Where:

- $C_1 \ldots C_4$ – concentrations of ice types within ice regime
- $RV_1 \ldots RV_4$ – corresponding risk index values for a given vessel ice class

The Risk Values (*RV*s) are a function of ice type, ice class, and season of operation.

A RIO of zero (0) is defined as the pivotal point between "normal" and "elevated" levels of operational risk (see Table 1 below).

Table 1 POLARIS Risk Index Outcome (RIO) criteria (Reference 1)

RIO_{SHIP}	Ice classes PC1-PC7	Ice classes below PC 7 and ships not assigned an ice class	Color Code
20 ≤ RIO	Normal operation	Normal operation	
10 ≤ RIO < 20			
0 ≤ RIO < 10			
-10 ≤ RIO < 0	Elevated operational risk	Operation subject to special consideration	
-20 ≤ RIO < -10	Operation subject to special consideration		
-30 ≤ RIO < -20			

Generally recommended RIO levels for polar water operations are:

- RIO ≥ 10 for voyage planning purposes.
- RIO ≥ 0 while underway.

These RIO levels were used to evaluate the difference in potential operability in three geographic areas representing the types of locations containing ice in which the ARV is expected to perform its missions. The three representative Antarctic areas are:

- Pine Island Bay.
- Weddell Sea.
- Ross Sea.

The Pine Island Bay and Ross Sea geographic areas were divided into two discrete study areas to provide more accurate information about accessing and operating in these areas during certain times of the year. In total, five study areas were evaluated, covering the three broader geographic areas identified above.

Table 2 summarizes the results of the study. It was found that PC3 generally allows for significantly more potential operability in the study areas than PC4. For example, if the acceptable risk level for mission planning is RIO ≥ 10, the southern study area of Pine Island Bay would be potentially accessible 100% of the year if the ARV is PC3, but only 38% of the year if the ARV is PC4.

Table 2 Percent of the year acceptable risk levels not exceeded – PC3 versus PC4

	Pine Island Bay Southern Study Area	Pine Island Bay Northern Study Area	Ross Sea Western Study Area	Ross Sea Eastern Study Area	Weddell Sea Study Area
	Mission Planning: Acceptable RIO = 10				
PC3	100%	38%	100%	88%	33%
PC4	38%	0%	100%	31%	0%
	Underway: Acceptable RIO = 0				
PC3	100%	100%	100%	100%	100%
PC4	100%	44%	100%	94%	44%

Though it is clear that PC3 would offer a significant advantage in terms of being adequately strengthened for year-round operability in all five study areas, ice class, ultimately, is a balance between ice conditions, operational requirements, and cost (Reference 1).

Purpose

In early team discussions regarding the scope and purpose of this study, NSF expressed a desire to understand the operational implications of selecting PC3 vs. PC4 as the design ice class, in terms of being adequately ice strengthened to operate in key areas for conducting science missions. The purpose of this study was to provide NSF with data to aid an informed decision on this matter, for inclusion in the ARV Performance Specifications.

Methodology

Three geographic areas of interest near the Antarctic continent were identified for evaluation: Pine Island Bay (including Pine Island Glacier and the Thwaites Ice Tongue), the Weddell Sea, and the Ross Sea.

An exhaustive research effort on the availability of current and archived sea ice data for the three areas was carried out. Detailed data on the composition of ice regimes in each area would inform a comparative analysis of PC4 and PC3 classed vessels, in terms of their suitability for operation in these areas. The requisite data for such an analysis is percent concentration by ice type (also known as stage of development, SoD). However, accessing high quality SoD data for the Antarctic is not trivial. Research was conducted to identify and obtain high quality ice data, as found on World Meteorology Organization (WMO) Egg Codes or in SIGRID-3 shapefiles (code), which are used to generate published Antarctic ice charts.

ABS has developed a proprietary software program to read and process SIGRID shapefiles for supporting vessel ice classification studies and other purposes, called ABS-POLARIS, part of a larger suite of programs called ABS Polar Suite. ABS-POLARIS reads archived sea ice data shapefiles and converts the composition of the ice regimes, for a given area and date(s), into operating risk values or "Risk Index Outcomes" (RIOs) consistent with the IMO-approved methodology for assessing operational limitations in ice, called the Polar Operational Limit Assessment Risk Indexing System (POLARIS). A detailed background and description of the POLARIS system is provided in IMO Circular MSC.1-Circ.1519. This "extension" of POLARIS enables a systematic process that can be used to compare ice classes by calculating expected RIOs for a given date and location. For this study, the calculated RIOs are the average RIOs over five years of historical data. This process should not be taken as an indication of the actual ice going capability of a vessel. It merely provides a convenient means to evaluate the suitability of a particular ice class for a given area and season on an operational risk basis.

For calculation of RIOs, the ice class of the subject vessel must be designated in advance of running the software. Thus, ABS-POLARIS was run twice for all study areas defined - once for PC3 and once for PC4. From the results, a comparative analysis was then performed, using RIOs as an indicator of the vessel's structural suitability for operation in each area over the course of the year.

Three study areas were initially defined by NSF:

- Weddell Sea 0° to 90°W
- Pine Island Bay centered on 104.9°W, 74.65°S
- Ross Sea centered on 161.5°W, 77°S

The study areas were selected by ASC subject matter experts based on where the R/V *Nathaniel B. Palmer* (NBP) has operated previously and historically struggled or, in some cases, become beset. It was felt these areas would be illustrative of how a PC3 vessel could potentially improve access to areas of known scientific interest. Two of the areas noted above, Pine Island Bay and the Ross Sea, were ultimately each divided into two smaller study areas, which brought the total number of study areas to be analyzed to five (5). The reason for this was twofold:

1) The ABS-POLARIS software works by averaging RIOs within a selected study area or "polygon" for a given dataset (date), which means that variation in ice regimes occurring within the geographic boundaries of the study area and corresponding variability in navigational risk are not captured. Thus, selection of a geographically large study area will generally depict the area as having a uniform ice regime and operating risk level, when in fact there may be areas of significantly higher and lower operational risk. For this reason, the selection of smaller, more site-specific study areas is recommended by the ABS Harsh Environment Technology Center (HETC).

2) There are local ice anomalies occurring in or near both Pine Island Bay and the Ross Sea that warrant analysis of two discrete subareas for each. For Pine Island Bay, it was discovered that the area immediately to the north and west of the bay itself (effectively the seaward approach to Pine Island Bay) historically has ice regimes that would be considerably more challenging for a PC4 during the primary operating season than those within the confines of the bay. Similarly, for the Ross Sea, locally heavy ice formations in its eastern portion can sometimes prevent vessels from accessing the central Ross Sea and McMurdo Station. Thus, a second "eastern study area" was added to address this concern.

The final set of study areas selected for analysis are shown in Figure 1 below.

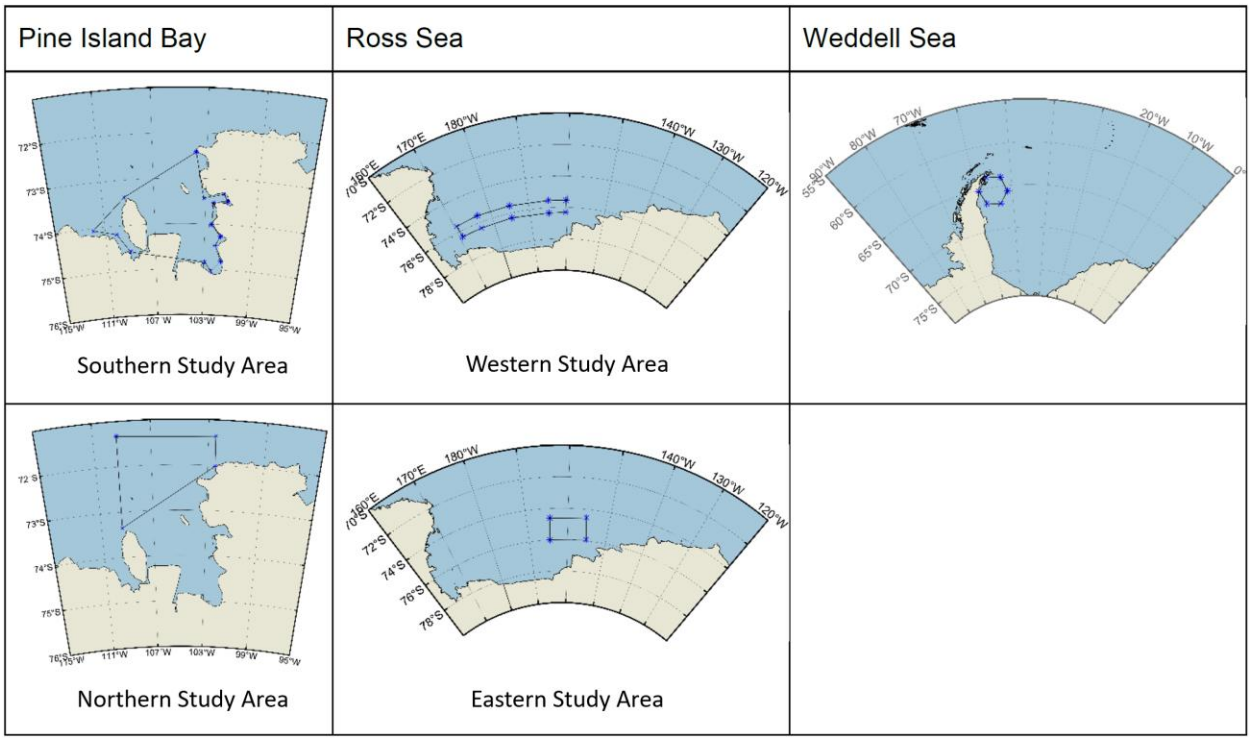

Figure 1 Study Areas projections and study areas

A final RIO for each study area was then calculated for each week of the calendar year, which was the average of all data points within the study area across five years of historical data. ABS-POLARIS was used to develop RIO plots and tables for PC3 and PC4 vessels for each week of the year for all five study areas. These plots are provided in Appendix A of Reference 1. RIOs versus time of year plots were regenerated for this report (see Findings section). These figures make it easy to visualize the benefit afforded by PC3, as compared to PC4, in terms of reduced operating risk over the course of the year within each of the study areas.

Findings

IMO guidance on use of the POLARIS methodology states a minimum RIO of zero (0) for planning purposes, but a different "acceptable RIO" for ice class comparison and, ultimately, ice class selection can be used (Reference 1). Once an acceptable RIO is selected, a practical operating window can be determined for each ice class and for each geographic area. The conclusions to be drawn regarding the operating benefits afforded by PC3 vs. PC4 are dependent on the RIO value that is determined to be "acceptable."

However, using the ABS-POLARIS averaging method, as described in the previous section, means that there are areas of higher and lower RIOs within any given study area. For this reason, using average RIOs as operational limits should be cautioned. For example, if the average RIO for a given study area and a specific date is zero (0), the study area is almost certain to have ice regimes within it that result in negative RIOs. Therefore, it may be speculative to select zero (0) as the "acceptable RIO" for planning purposes. By comparison, selecting a value higher than zero (0), reduces the probability of encountering low RIOs "in the field" that exceed the vessel's capacity (Reference 1).

For all five study areas considered in this report, there were no RIOs (prior to averaging) below the -10 to -20 RIO range; and the lowest study area *average* for a PC4 vessel was -10. This implies that, across all study areas and for both PC3 and PC4 vessels, the deviation between the study area average and the lowest actual RIO should be within 10. From this, the HETC suggests that selection of +10 as an "acceptable RIO" for planning or ice class selection would be considered reasonable, given that a polar classed vessel can operate in RIOs as low as -10 (at an "elevated" risk level).

Our assessment of the study results is that the designation of a "design RIO" of +10 indicates a recommended Polar Class of PC3 for the NBP replacement vessel (cost considerations aside), in order to ensure a low probability of disruption to science missions in and around the analyzed geographic areas.

In most conditions analyzed using ABS-POLARIS, it was shown that a PC3 ship offers a significantly greater range of viable operating dates. At the RIO = +10 level, across all five study areas, the total percent operability for a PC3 vessel is 72%, whereas it is only 34% for a PC4 vessel (Reference 1).

Table 3 below shows the percentage of the year within a correlating RIO "limit" for both PC3 and PC4 vessels for each study area.

Table 3 Percentage of the year within RIO limits

		Acceptable RIO					
		0	2	4	6	8	10
Pine Island Bay	PC3	100%	100%	100%	100%	100%	100%
Southern Study Area	PC4	100%	100%	92%	73%	52%	38%
Pine Island Bay	PC3	100%	100%	98%	73%	63%	38%
Northern Study Area	PC4	44%	29%	17%	6%	0%	0%
Ross Sea	PC3	100%	100%	100%	100%	100%	100%
Western Study Area	PC4	100%	100%	100%	100%	100%	100%
Ross Sea	PC3	100%	100%	100%	100%	100%	88%
Eastern Study Area	PC4	94%	67%	56%	48%	40%	31%
Weddell Sea	PC3	100%	75%	56%	52%	48%	33%
Study Area	PC4	44%	23%	2%	0%	0%	0%

Generally, in terms of extending the allowable operating season within the study areas, the results show that selection of PC3 would afford the most benefit for the Weddell Sea study area. Where a PC4 vessel can expect to plan for about 4 months of the year in this area, a PC3 vessel can effectively plan for year-round operation, with some expected tough conditions from May to August.

In Pine Island Bay proper, both PC3 and PC4 vessels are adequately ice-strengthened for "normal operation" year-round; but, importantly, the area immediately to the north of Pine Island Bay has more challenging ice conditions, historically, which could limit access to Pine Island Bay for a PC4 vessel from April to November.

For the Ross Sea, the data suggest that selection of PC3 would afford comparatively little operating benefit. Both PC3 and PC4 vessels are adequately ice strengthened for "normal operation" in this area year-round, except perhaps the month of October, during which a PC4 vessel may encounter ice conditions that result in negative RIOs. It is noted, however, that these conditions appear limited to the eastern portion of the Ross Sea study area (Eastern Study Area).

A summary of findings for each study area is provided below.

Pine Island Bay

For Pine Island Bay proper (southern study area), both PC3 and PC4 vessels are adequately ice-strengthened top operate year-round (RIO>=0); but the area immediately to the north of Pine Island Bay (northern study area) has more challenging ice conditions, historically, which could limit access to Pine Island Bay for a PC4 vessel from April to November.

Figure 2 below shows that, at an acceptable RIO level of +10, a PC4 vessel can be expected to operate 38% of the year in the Pine Island Bay southern study area, whereas a PC3 vessel can expect to operate 100% of the year at this level.

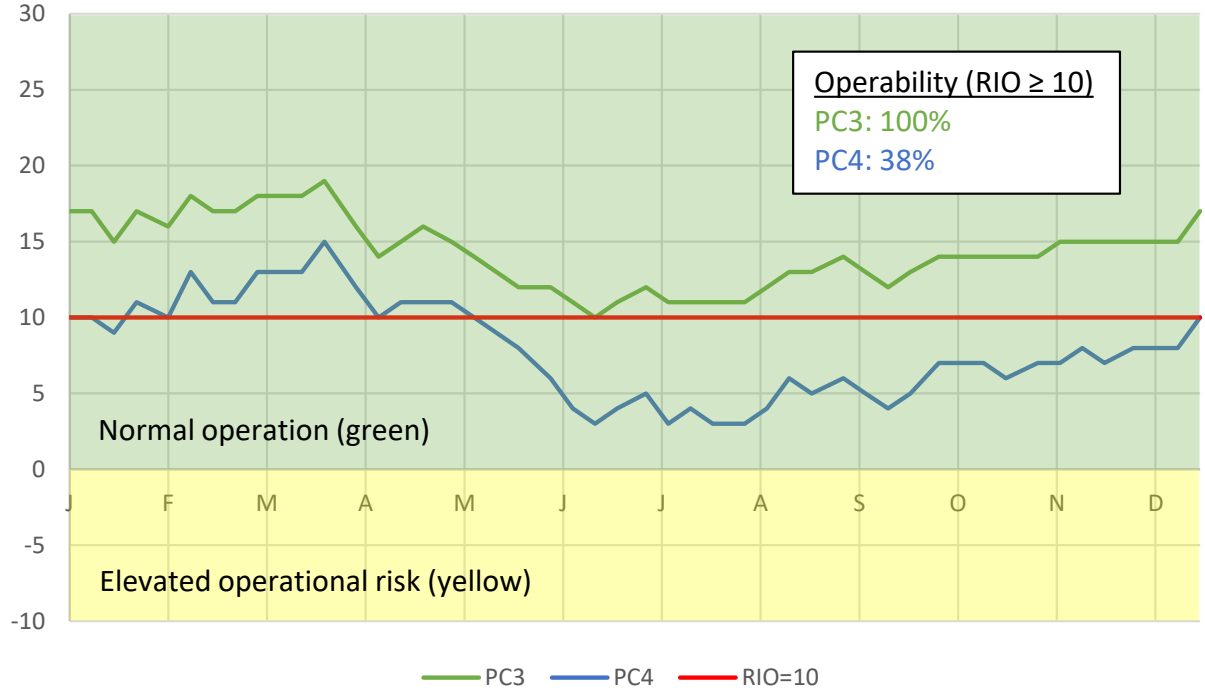

Figure 2 Pine Island Bay – southern study area

Figure 3 shows that, at an acceptable RIO level of +10, a PC4 vessel cannot be expected to operate any time of the year in the Pine Island Bay northern study area, whereas a PC3 vessel can expect to operate 38% of the year.

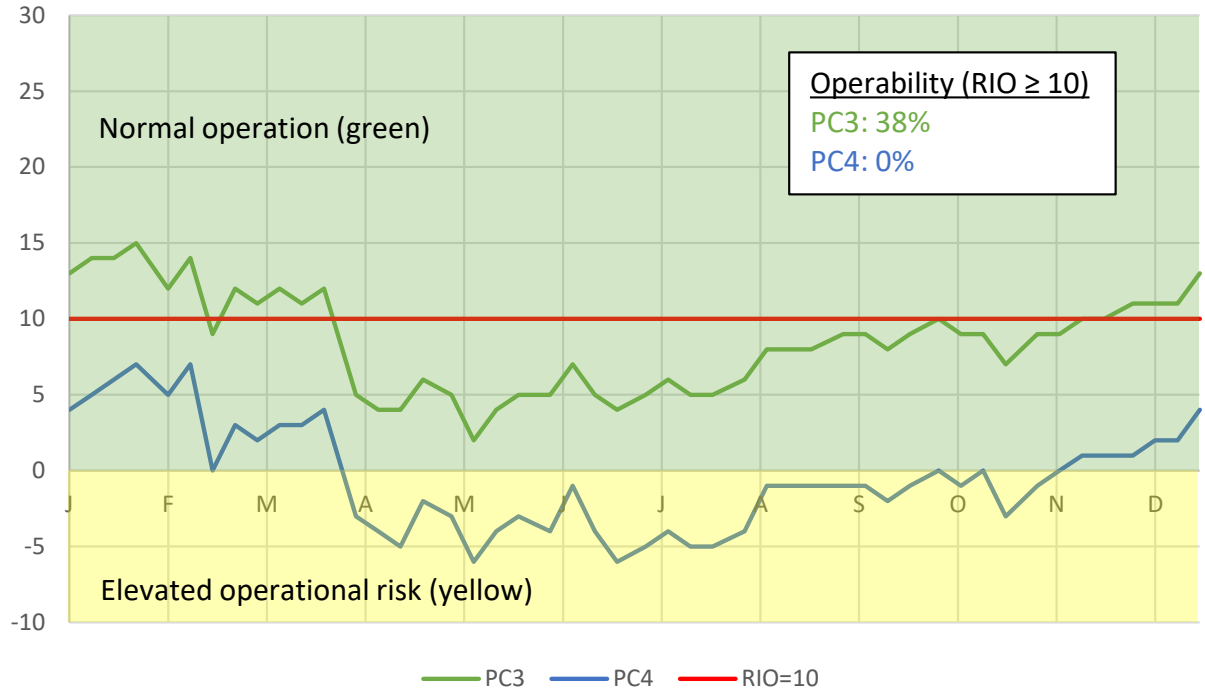

Figure 3 Pine Island Bay – northern study area

Ross Sea

The Ross Sea was shown to be potentially accessible for both PC3 and PC4 vessels year-round, except possibly the month of October, during which a PC4 vessel would likely encounter ice conditions resulting in negative RIOs, limited to the eastern portion of the study area.

Figure 4 shows that, at an acceptable RIO level of +10, a PC4 vessel can be expected to operate 100% of the year in the Ross Sea western study area. A PC3 vessel can also expect to operate 100% of the year at this level.

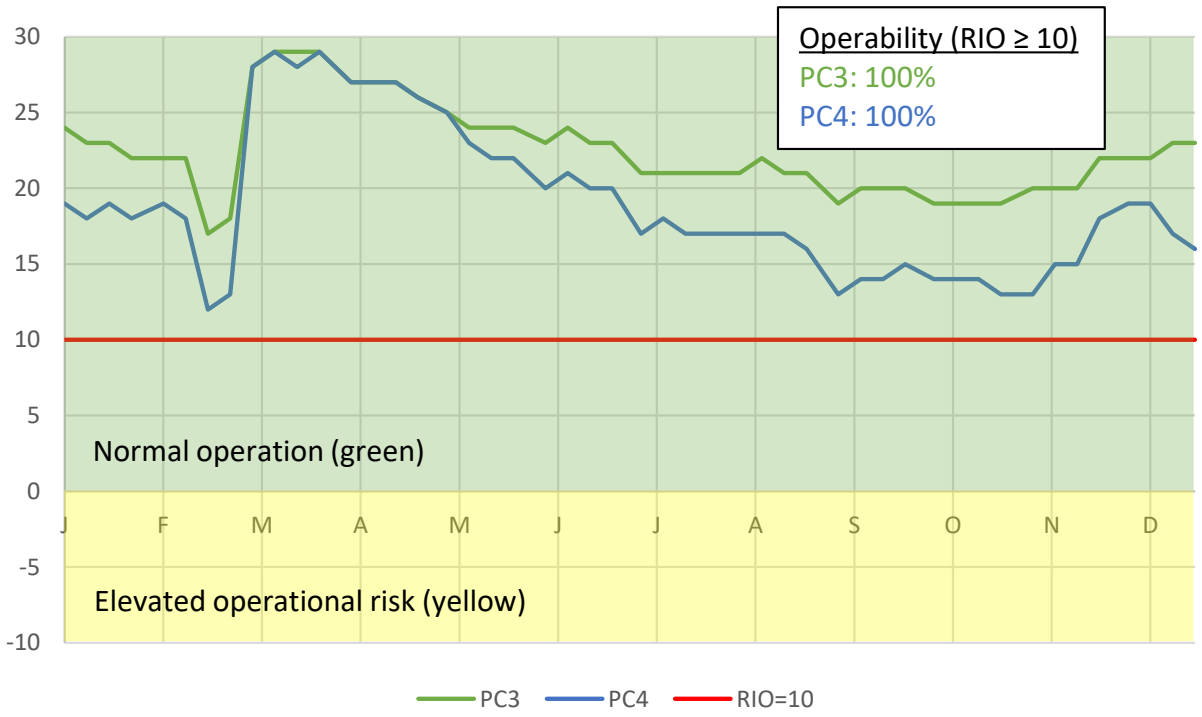

Figure 4 Ross Sea – Western Study Area

Figure 5 below shows that, at an acceptable RIO level of +10, a PC4 vessel can be expected to operate 31% of the year in the Ross Sea eastern study area, whereas a PC3 vessel can expect to operate 88% of the year at this level.

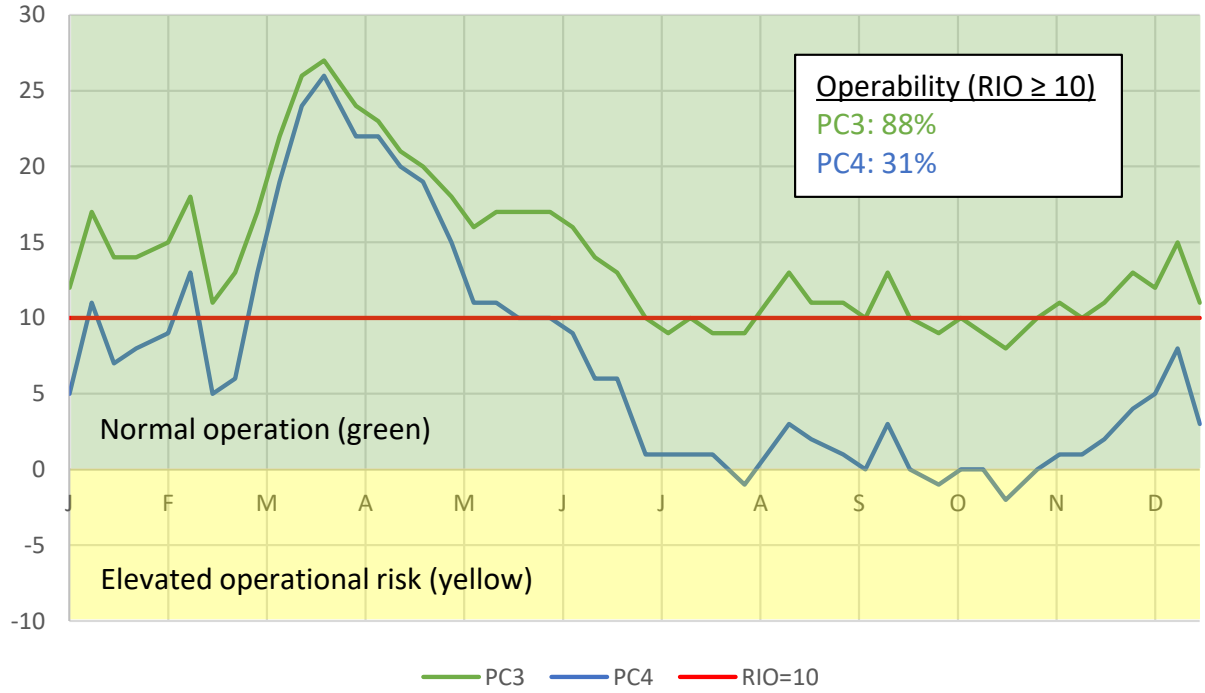

Figure 5 Ross Sea – Eastern Study Area

Weddell Sea

The benefit of selecting PC3 over PC4 is most pronounced for the Weddell Sea study area. Where a PC4 vessel can expect to plan for about 4 months of the year in this area, a PC3 vessel can effectively plan for year-round operation, with some expected tough conditions from May to August.

Figure 6 shows that, at an acceptable RIO level of +10, a PC4 vessel can be expected to operate 0% of the year in the Weddell Sea study area, whereas a PC3 vessel can expect to operate 33% of the year at this level.

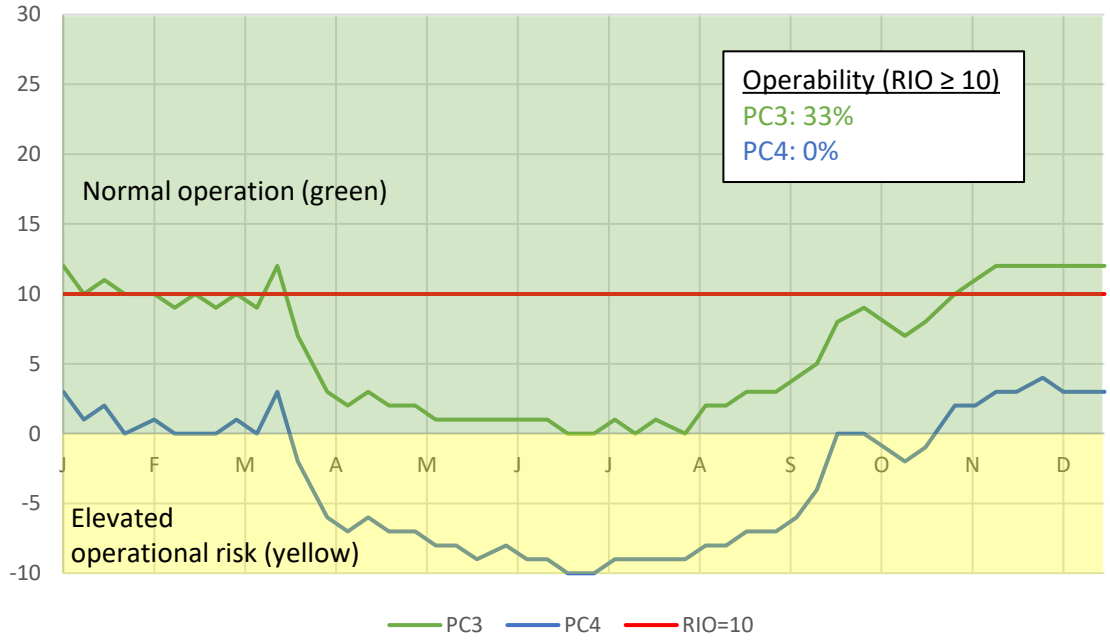

Figure 6 Weddell Sea Study Area

Assuming an "acceptable RIO" of +10 is adopted, selection of PC3 as the design ice class would afford a significant benefit in terms of being adequately ice-strengthened for year-round operation across the three primary study areas (Pine Island Bay, Ross Sea, and Weddell Sea). Therefore, in the interest of generally increasing operability and minimizing the probability of disruptions to science missions, it may be of interest to select PC3 as the design ice class. It should be noted, however, that the capital cost trade-off associated with such a decision, due to the heavier scantlings of PC3, would be significant and has not been estimated. Ultimately, ice class selection is a balance between ice conditions, operational requirements, and cost (Reference 1).

Specification Changes

Recommended Changes

ARV Performance Specifications Section 070.7 specifies ABS Ice Class PC4 as a minimum threshold, with PC3 as an objective. We recommend removing the threshold/objective format for this specification, and simply requiring PC3 or PC4 (see "Required Owner Decisions" below).

ARV Performance Specifications Section 522 requires seachests to be designed in accordance with PC3. This should match the overall vessel ABS Ice Class rating (PC3 or PC4).

Required Owner Decisions

The ARV Performance Specifications will require designation of either PC3 or PC4. A decision is needed from NSF as to which PC level to require.