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A risk-based approach to developing design temperatures for vessels operating in low temperature environments

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ABSTRACT

Increasing activities in the Arctic and Antarctic waters have drawn awareness of the risks of shipping in these regions. Winterization of vessels needs to be considered at the design stage to mitigate the risk of icing, freezing or other damages due to low temperature. The temperature that should be used for design and equipment procurement specification must be defined. Classification societies have proposed design temperatures such as the design service temperature (DST) and the minimum anticipated temperature (MAT). The DST is selected to be at the lowest mean daily average for the operational window and geographical location. However, there is very limited guidance provided to define the MAT. The lack of analytical tools that can be used to develop design temperatures still remains a problem.

This paper proposes a risk-based approach to estimate minimum anticipated temperature as design temperatures for vessels intended for service in cold regions such as the Arctic and Antarctic. Hourly air temperature data from climatology stations in these regions were obtained from the website of the National Climatic Data Center (NCDC) which is affiliated to the National Oceanic and Atmospheric Administration (NOAA). The criteria used to select the stations include the time span of available data for at least 20 years, availability of hourly data, and altitude of the station (close to sea level). The analysis procedure involves statistical analysis, consequence quantifications and risk calculations.

Results from a case study show that the proposed methodology can be reasonably applied. As the minimum anticipated temperature was obtained by looking at the smallest risk with corresponding larger return period or the smallest probability of occurrence. It is expected to have the smallest risk when the minimum anticipated is applied. In addition, an extreme low temperature contour map of the Arctic region has been developed which provides a quick and useful way to evaluate the temperature profile for voyage planning and winterization requirements. A plot of the ship's route on the extreme low temperature contour map will provide information on the magnitude and duration of the extreme temperatures encountered by the ship during the journey.

1. Introduction

Recent years have seen increasing activities in the high latitude regions of the world (Transport Canada, 2010; Environment and Natural Resources, 2012; Morse, 2012). The number of ice-classed vessels has dramatically increased with more frequent transportation in the cold regions, such as the Arctic, Northern Sea Routes, Northwest Passage, Eastern Baltic, Sakhalin, Snovhit and some places in the Antarctic (ABS, 2009). The harsh environment of these regions places additional challenges on the design and operation of these vessels. The low temperatures may affect functioning of vessel systems and consequently cause safety problems (Yang et al., 2013; ABS, 2009). Poorly developed design temperatures can cause catastrophic consequences if the system does not function reliably when the temperature is low. Therefore, it is important to define temperatures to verify that structures and systems are designed to the appropriate level for the intended service environment. Design temperature requirements may potentially affect operational limitations of vessel systems, material selection for structure and machinery, selection of equipment and testing regimes. For instance, material grades need to be selected based on design temperature, material class and thickness.

In this paper, the design temperature is the minimum anticipated temperature established based on measured data from the vicinity where the vessels will be operating. All vessel systems should be designed and manufactured to operate at this temperature. The most recognized definition of a design temperature is from the

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International Association of Classification Societies (IACS) Unified Requirement (UR) S6 for structural steel to be serviced at low temperature. IACS-UR-S6 requires that the design service temperature (DST) be selected as the lowest mean daily average temperature (LMDAT) for the operational window and geographical location. Use of the LMDAT as a design temperature has been widely accepted and practiced for many years. ABS (2010) requires that the DST be applied to the vessel structural material, e.g., the structural steel, and the minimum anticipated temperature (MAT) be used for machinery. The MAT can be defined by the designer, owner, or operator or taken as 20 °C lower than the DST. However, there is very limited guidance available to define the MAT rationally. In some circumstances, vessel systems may be exposed to the low temperature that occurs for only a few minutes. It may not be necessary to design or winterize the entire system using such a temperature because the duration of the cold occurrence could be too short to reduce safety levels. The development of design temperature as minimum anticipated temperature is a complicated problem and currently there is lack of effective tools that can be used.

Sulistiyono et al (2014) have proposed a new and more rational approach to estimate the MAT in a graphical format called the Temperature-Duration-Frequency graph or TDF graph. The new approach of estimating MAT using the TDF graph can statistically answer the chance of occurrence of extreme temperatures for a given duration. They provided the details of the development of TDF graphs and provided sample TDF graphs for selected weather stations in the Arctic region. The work presented herein is an extension of Sulistiyono et al (2014).

Safety must be prioritized when operating in remote and cold regions with limited resources and longer rescue time. To ensure safe operations, it is reasonable to develop minimum anticipated temperatures considering risk as a key factor. Risk analysis is helpful to reduce conflict between cost, schedule, and safety goals that manifest routinely in management decision-making (Faber, 2007). Goerlandt et al. (2015) have developed a risk-informed ship collision alert system in a real-time operational environment. Dong and Frangopol (2015) have used the life-cycle risk associated with flexural failure as one of the criteria to develop inspection and maintenance strategies of ship structures. A risk-based approach to winterization of vessels has been proposed and applied to a North Atlantic-based ferry design (Yang et al., 2013, 2015). This paper proposes a risk-based approach to estimate a minimum anticipated temperature whose value incorporates both the probability of a low temperature occurrence and the duration of its occurrence. Vessel systems will be designed and manufactured for service at this temperature specification. This paper is structured as follows. The next section will start with a brief discussion of the concept of risk followed by the proposed methodology. A demonstration of the proposed approach is then applied in a case study. Finally, conclusions are provided in the last section.

Authors wish to confirm that intention of this work is to provide a scientific basis for an alternative approach to establishing a temperature for a given operational period and location; it may be used to establish a value used as the Minimum Anticipated Temperature (T_{MAT} or MAT) as defined in the ABS *Guide for Vessels Operating in Low Temperature Environments* (ABS, 2010).

2. Proposed methodology

The concept of risk will first be discussed. Considering an activity with only one event with potential consequences C, the risk R is the probability P that this event will occur multiplied by C given the event occurs (Faber, 2007). In Pate (2007), probabilistic risk analysis (PRA) has been discussed in detail to include probabilities of conditional events characterized by several levels. The method proposed by Pate (2007) has inspired this study to estimate a risk based minimum anticipated temperature for Arctic and Antarctic Shipping and Offshore Operations with 3 levels of conditions: Probability of Occurrences, $P(O)$, Duration of Occurrences (D) and Probability of Exceedances, $P(E)$. In this study, risk is defined by the probability of loss due to the exceedance of the minimum anticipated, and therefore referring to the concept of risk and Eq. 1, risk is estimated using Eq. (1):

$$\text{Risk} = P(O) \times C \tag{1}$$

where the probability of occurrence, (i.e., the probability of the event that more extreme temperatures are encountered than the estimated extreme temperature for a given return period) can be calculated using Eq. (2):

$$P(O) = \frac{n}{N} \times \frac{1}{RP} \tag{2}$$

where n is the number of the times that more extreme temperatures are encountered than the estimated extreme temperature for a given return period; N is the total number of temperatures in the whole data set; and RP is the return period of the estimated extreme temperature (i.e., a recurrence interval of the extreme temperature).

And consequences, C can be estimated using Eq. (3), which represent the severity of the consequence through the duration of the extreme cold temperature occurrence:

$$C = D \times P(E) \tag{3}$$

where $P(E)$ is the annual exceeding probability (i.e., the inverse of the return period). A further explanation on the above equation is presented in *Step* 8.

Therefore, risk can be calculated using Eq. (4):

$$Risk = P(O) \times D \times P(E) \tag{4}$$

where D is duration of averaged temperatures and $P(E)$ is probability of exceedance which can be determined from a fitted distribution and a return period.

Next, the steps to be followed for the proposed risk-based approach to estimating minimum anticipated temperature will be discussed. The steps start from determining the route to be taken by the vessel to estimating the risk-based minimum anticipated temperature. Fig. 1 gives the flowchart of the proposed methodology. Each step is described in the following paragraphs.

Step 1: Determining the region of operation or route of vessel

It is important to determine the region of operation or the route to be taken by a vessel because every region or route might have a different climatic condition including the extreme low temperatures to be encountered. Cold environments with the presence of ice at times require special ship designs, navigation skills and winterization level and technology. Information about the region of operation or the route of a ship can be obtained from the owner of the ship or from ship route maps. Some well-known routes that have been voyaged by ships include the Northeastern Passage or the Northern Sea Routes, Northwestern Passage, the Arctic Bridge and along the Southern Ocean (Clarkson Research Service Ltd., 2013; Anonymous, 2010).

Step 2: Determine the period of operation in the harsh environment

Ships operating in the Polar Regions are most likely in the summer season when there is open water. The period of shipping operation is often obtained from the shipping schedules. While for ship design, the period of shipping operation can be obtained from the time series plot of temperature data for the year. Fig. 2 shows an

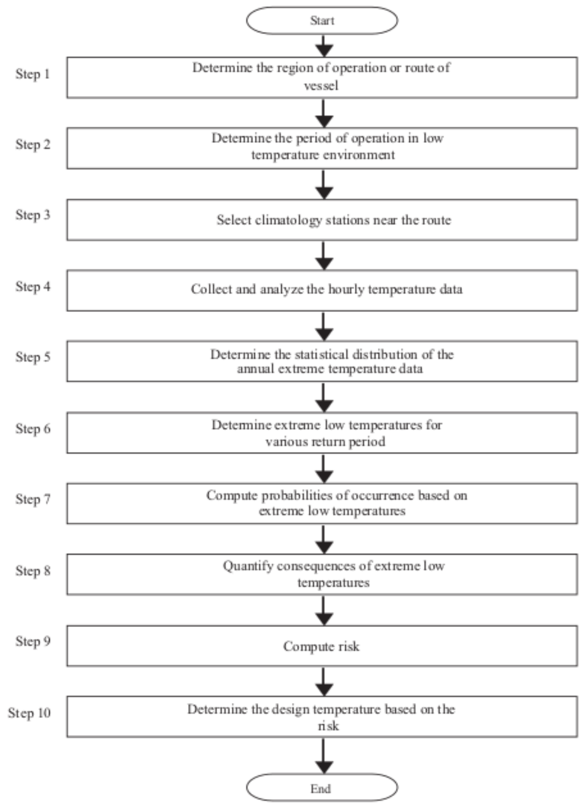

Fig. 1. The proposed methodology.

example of time series plot of the daily temperature data of Resolute Station through the year. It shows that summer temperatures in Resolute is approximately from June to September. Open water is expected to be during this period. However, it is to note that air temperature (as plotted below) does not necessarily tell if sea ice will be present or not.

Step 3 Selecting climatology stations near the route

The climatology stations near the route of the vessel need to be selected based on the length of available data (at least 20 years), availability of hourly data, and altitude of the station (close to the sea level). For example for ships traveling along the Northwestern Passage, the selected climatology stations in the vicinity of this route are shown in Table 1.

Step 4: Collection of hourly temperature data

The hourly air temperature data are acquired from the climatology stations selected in *Step* 3. These data can be obtained from the website of the National Climatic Data Center (NCDC) which is affiliated with the National Oceanic and Atmospheric Administration (NOAA). The hourly temperature data are then analyzed based on various durations: 1, 2, 3, 4, 6, 8, 12, 24, 32, 36, 40, 48, 56, 72, 96, 120, 144, and 168 consecutive hours. The method of moving average can be applied in this analysis to obtain the minimum values for each duration. This can be done by taking historical hourly temperature data for a reasonably long period, calculating average temperatures over specified durations as defined above (i.e., the intervals used to determine the moving average), and identifying minimum temperature for each year. The minimum values can then be noted for all available years. These minimum values are called the annual extreme low temperatures for the given duration. As data used in

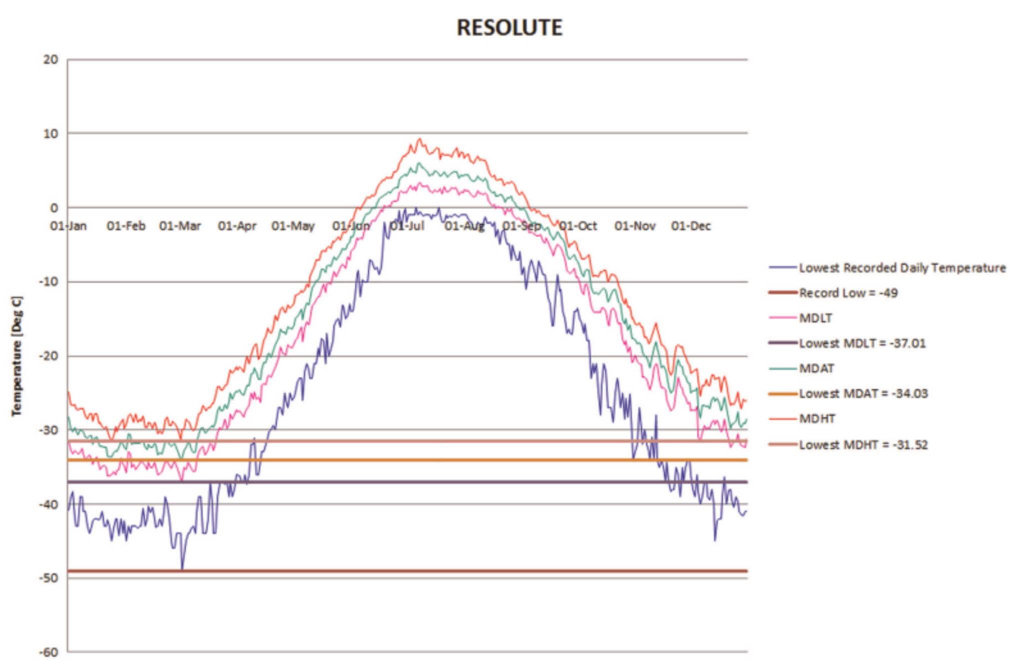

Fig. 2. Time Series plot of daily temperature data of Resolute Station. (MDLT- Mean Daily Low Temperature, MDAT- Mean Daily Average Temperature, MDHT- Mean Daily High Temperature).

this study ranged 20 years, therefore 20 data points of annual extreme low temperatures are available for the next step.

Step 5: Determination of statistical distribution of the annual extreme data

Several types of statistical distribution are then fitted to the temperature data for each duration from *Step* 4. Commonly used distributions such as the normal, lognormal, gamma, Weibull and extreme value can be tried. The goodness of fit can be judged statistically using a goodness-of-fit test such as the Anderson–Darling or Kolmogorov–Smirnov test (D'Agostino and Stephens, 1986). A significance level of 5% can be used to judge whether a distribution is acceptable. The parameters of the distribution can be obtained by the method of maximum likelihood. Standard software packages such as Minitab, or Statistical Package for the Social Sciences (SPSS) can be used to assist with this step.

Step 6: Determination of extreme low temperatures for various return periods

The extreme low temperatures are determined for each return periods (e.g., 2, 5, 10, 20, 50, and 100 years) and duration. These are estimated from the best probability distribution fitted to the data in *Step* 5. For each duration, this can be done by converting the return periods into probabilities of exceedance (e.g., 2 years to ½=0.5), and taking the temperatures corresponding to these probabilities from the best-fitted probability plot. An example is given in *Step* 6 of Section 3. The details can be found in Sulistiyono et al. (2014).

Step 7: Calculation of probabilities of occurrence based on extreme low temperatures

For each duration and return period, the estimated extreme low temperature is compared with the temperatures in the whole data set to obtain the number of times that more extreme temperatures are encountered than the estimated extreme temperature for the given return period. This number is n in Eq. (2). The probabilities of occurrence are calculated using Eq. (2).

Step 8: Quantification of consequences of extreme low temperatures

The duration of an extreme low temperature is used to quantify the severity of its consequence to a vessel system. A simple analogy may help to understand this concept. Consider a man who works outdoors where the temperature is very low. He should wear a jacket that would protect him from the extreme harsh environment. However, if this man is working outside without the jacket, his operation and himself would be adversely affected by the coldness. For a given low temperature, the severity of its consequence is dependent on the duration of the extreme cold temperature occurrence. For example, if the duration of an extreme low temperature (say -20 °C) is one hour and its return period is 2 years, the consequence can be calculated as: C (consequence)$=1\ \text{h} \times (1/2\text{year}) = 0.5$ h/year.

Step 9: Calculation of risks

Risks are obtained by combining the probability of exceedance and its associated consequence. Risk values need to be calculated for all defined durations and return periods. For example at a given location, a temperature of 0 °C has a probability of occurrence of 0.05.

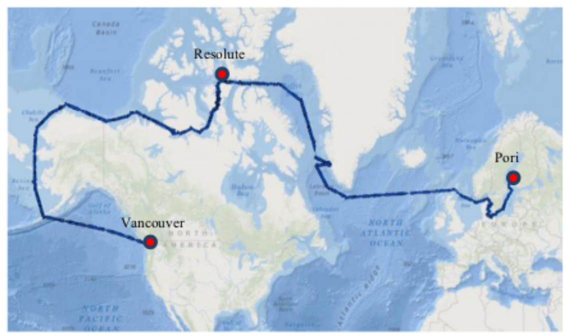

Image Source: www. exactearth.com

Fig. 3. Route of the Nordic Orion through the Northwest Passage.

Table 1
The selected climatology stations near the Northwestern passage.

No	Station	Last year in the date used	Country	Latitude (°)	Longitude (°)	Elevation (m)
1	MYS UELEN	2013	Russia	66.15	– 169.833	3
2	POINT HOPE AIRPORT	2013	USA	49.36	– 121.5	4
3	NOME	2013	USA	69.717	– 163	7.599
4	POINT LAY	2013	USA	71.283	– 156.782	4
5	BARROW/W POST-W.R	2013	USA	70.192	– 148.477	18.299
6	OLIKTOK POW 2	2013	USA	70.134	– 143.577	1.5
11	DEADHORSE	2013	USA	69.633	– 135.433	12
12	BARTER ISLAND	2013	USA	74.717	– 94.983	30
17	CYLDE AIRPORT	2013	Canada	74.033	– 57.817	40
20	CAPE DYER	2013	Canada	70.683	– 54.617	27
13	KUGLUKTUK	2013	Canada	76.233	– 119.333	12
14	REA POINT	2013	Canada	75.35	– 105.717	15
9	PELLY ISLAND	1999	Canada	70.5	– 149.883	4.9
10	MOULD BAY AIRPORT	2013	Canada	64.511	– 165.44	6.699
15	RESOLUTE CS	2013	Canada	74.717	– 94.983	30
16	PITUFFIK (THULE AB)	2013	Greenland	70.483	– 68.517	27
18	AASIAAT/EGEDESMIND	2013	Greenland	70.483	– 68.517	27
19	KITSISSUT/CAREY OE	2013	Greenland	76.633	– 73	11
21	KITSISSORSUIT/EDDE	2013	Greenland	67.783	– 53.967	12
22	KITSISSUT (ATTU)	2013	Greenland	76.633	– 73	11
23	ANGISOQ	2013	Greenland	74.033	– 57.817	40
25	NUUSSUAATAA/NUUSSU	2013	Greenland	64.132	– 21.933	61
24	REYKJAVIK	2013	Iceland	64.13	– 21.9	27

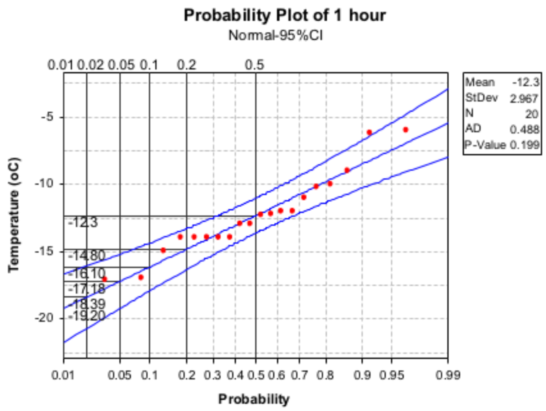

Fig. 4. The probability plot of extreme low temperatures of 1-h duration.

Table 2
Extreme low temperatures (°C) for various durations and return periods.

Duration (h)	Probability of exceedance					
	50%	20%	10%	5%	2%	1%
1	−12.30	−14.80	−16.10	−17.18	−18.39	−19.20
6	−11.55	−14.07	−15.38	−16.46	−17.68	−18.50
12	−10.96	−13.55	−14.91	−16.02	−17.28	−18.12
24	−10.03	−12.50	−13.80	−14.87	−16.07	−16.88
48	−9.03	−11.55	−12.87	−13.96	−15.18	−16.00
72	−8.48	−11.09	−12.46	−13.59	−14.86	−15.70
96	−8.02	−10.58	−11.93	−13.03	−14.28	−15.11
120	−7.61	−10.12	−11.43	−12.52	−13.74	−14.55
144	−7.23	−9.67	−10.95	−12.00	−13.19	−13.98
168	−6.83	−9.15	−10.36	−11.36	−12.49	−13.24

Table 3
Probability of occurrence at various durations and return periods.

Duration (h)	Probability of exceedance					
	50%	**20%**	**10%**	**5%**	**2%**	**1%**
1	1.56%	0.38%	0.03%	0.00%	0.00%	0.00%
6	2.67%	0.43%	0.10%	0.00%	0.00%	0.00%
12	3.39%	0.56%	0.14%	0.00%	0.00%	0.00%
24	5.04%	1.01%	0.27%	0.00%	0.00%	0.00%
48	6.17%	1.77%	0.27%	0.00%	0.00%	0.00%
72	6.40%	1.53%	0.45%	0.00%	0.00%	0.00%
96	6.75%	2.17%	0.56%	0.00%	0.00%	0.00%
120	7.06%	1.96%	0.83%	0.00%	0.00%	0.00%
144	7.25%	1.59%	0.70%	0.00%	0.00%	0.00%
168	9.17%	1.45%	0.54%	0.10%	0.00%	0.00%

Temperature 0 °C might cause a consequence with a severity of 0.5 h/year. Thus, the risk can be estimated as $0.05 \times 0.5 = 0.025$ h/year.

Step 10: Determination of a minimum anticipated temperature *based on the risk*

An acceptable risk level (e.g., 10^{-3} h/year) needs to be defined by the operators. Based on this level, acceptable risk values can be identified. For each acceptable value, there is an associated extreme low temperature. A minimum anticipated temperature is selected as the extreme low temperature with the smallest return period. Because it may be too conservative and unnecessary to design vessel systems based on a low temperature that only occurs at a very long period (e.g., once in 100 years).

3. Case study

The applicability of the proposed methodology can be demonstrated using a case study. Consider the trip of the vessel the Nordic Orion from Vancouver, Canada (September 06th, 2013) to Pori, Finland (October 07th, 2013). Fig. 3 shows the route.

Fig. 3 shows that the Nordic Orion sailed through the Northwestern Passage. The length of Northwest Passage is about 900 miles (1450 km) (Rosenberg, 2014). Each step of the proposed methodology is now applied.

Step 1: Determining the region of operation or route of vessel

As shown in Fig. 3, the region of operation of the Nordic Orion was in the Arctic Ocean. The ship sailed through the Northwest passage.

Step 2: Determine the period of operation in the harsh environment

As the ship sailed from September 06th, 2013 to October 07th, 2013, the period of operation in the North Pole was mostly in September.

Step 3: Selecting climatology stations near the route

The climatology stations in the vicinity of the Northwest Passage were given previously in Table 1. The data from Resolute Station will be used to demonstrate the next few steps. This station met all the criteria for station selection.

Step 4 Collection of hourly temperature data

The hourly temperature data was downloaded from the website of the National Climatic Data Center (NCDC) which is affiliated

Table 4
The consequences with respect to defined durations and return periods.

Duration (h)	Probability of exceedance					
	50%	**20%**	**10%**	**5%**	**2%**	**1%**
1	5.00E-01	2.00E-01	1.00E-01	5.00E-02	2.00E-02	1.00E-02
6	3.00E+00	1.20E+00	6.00E-01	3.00E-01	1.20E-01	6.00E-02
12	6.00E+00	2.40E+00	1.20E+00	6.00E-01	2.40E-01	1.20E-01
24	1.20E+01	4.80E+00	2.40E+00	1.20E+00	4.80E-01	2.40E-01
48	2.40E+01	9.60E+00	4.80E+00	2.40E+00	9.60E-01	4.80E-01
72	3.60E+01	1.44E+01	7.20E+00	3.60E+00	1.44E+00	7.20E-01
96	4.80E+01	1.92E+01	9.60E+00	4.80E+00	1.92E+00	9.60E-01
120	6.00E+01	2.40E+01	1.20E+01	6.00E+00	2.40E+00	1.20E+00
144	7.20E+01	2.88E+01	1.44E+01	7.20E+00	2.88E+00	1.44E+00
168	8.40E+01	3.36E+01	1.68E+01	8.40E+00	3.36E+00	1.68E+00

with the National Oceanic and Atmospheric Administration (NOAA). Hourly temperatures are available from 1947 to 2013 but only the last 20 years of data were used. The hourly temperature data were processed based on various durations: 1, 6, 12, 24, 48, 72, 96, 120, 144, and 168 consecutive hours.

Step 5: Determination of statistical distribution of the annual extreme data

Considering the 1-h duration extreme low temperature data as an example, the distribution that best fits the data is the normal distribution. This is confirmed by the Anderson–Darling goodness-of-fit test, which gave a p-value of 0.199 (>0.05). Fig. 3 shows the normal probability plot of the fitted data. The best-fitted distributions of other durations can be obtained through the same process.

Step 6: Determination of extreme low temperatures for various durations and return periods

Fig. 4 shows extreme low temperatures estimated for six selected return period: 2 years (½=50%), 5 years (20%), 10 years (10%), 20 years (5%), 50 years (2%), and 100 years (1%); which are −12.3, −14.8, −16.1, −17.2, −18.4, and −19.2, respectively. The same procedure was used for the nine other durations: 6, 12, 24, 48, 72, 96, 120, 144, and 168 h. The results are summarized in Table 2.

Table 5
Risks for given extreme low temperatures with respect to defined durations and return periods.

Duration (h)	Probability of occurrence					
	50%	20%	10%	5%	2%	1%
1	0.008	0.001	0.000*	0.000	0.000	0.000
6	0.080	0.005	0.001	0.000	0.000	0.000
12	0.203	0.014	0.002	0.000	0.000	0.000
24	0.605	0.048	0.007	0.000	0.000	0.000
48	1.481	0.170	0.013	0.000	0.000	0.000
72	2.304	0.220	0.032	0.000	0.000	0.000
96	3.240	0.416	0.054	0.000	0.000	0.000
120	4.236	0.471	0.100	0.000	0.000	0.000
144	5.220	0.457	0.101	0.000	0.000	0.000
168	7.703	0.486	0.091	0.008	0.000	0.000

Step 7: Calculation of probabilities of occurrence based on extreme low temperatures

The percentages of times that the temperatures of various durations are lower than the extreme low temperatures in Table 2 are obtained by comparing the temperatures in Table 2 with the corresponding historical temperature data. The results reflect the probabilities of occurrence and are shown in Table 3.

Step 8: Quantification of consequences of extreme low temperatures

Consequences are then calculated based on Table 3 and the results are shown in Table 4.

Step 9: Calculation of risks

Risks are calculated using Eq. (4) and presented in Table 5.

Step 10 Determination of a minimum anticipated temperature based on the risk

In Table 5, the lowest risk is about 0. The risk value shown with an asterisk (*) is the lowest risk and the shortest return period (i.e., the largest probability of exceedance). The estimated extreme temperature corresponding to cell in Table 2 was selected as the minimum anticipated temperature (design temperature). From Table 2, the design extreme low temperature is −16.10 °C.

4. Development of a contour map of extreme low temperatures

Applying the same procedure to all climatology stations along the route, an extreme low temperature contour map can be developed as shown in Fig. 5. Surfer 12 (http://www.goldensoftware.com/products/surfer) was used to draw this contour map. The trip of the Nordic

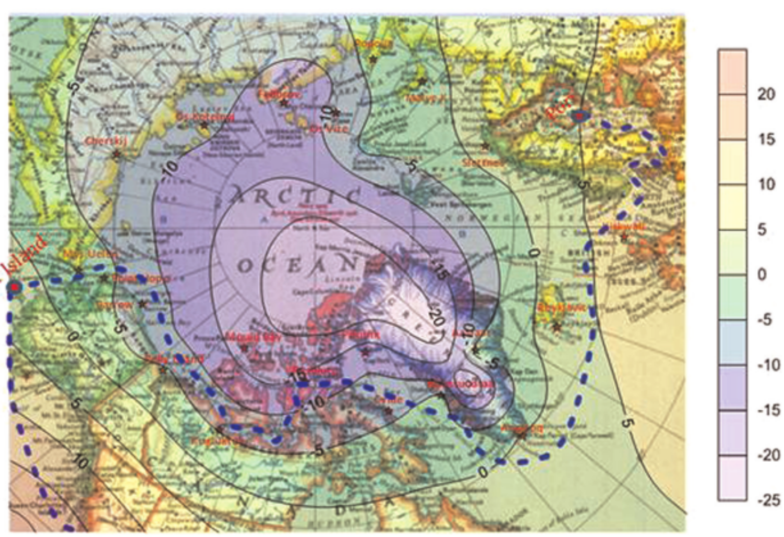

Fig. 5. Extreme Low Temperature Map of Northern Hemisphere for September. (For interpretation of the references to color in this figure,the reader is referred to the web version of this article).

Orion can be marked on the map. It is shown as a blue dashed line in Fig. 5.

Fig. 5 shows that a half of the Nordic Orion's route (15 days) was through regions with the extreme low temperatures that can go below -5 °C. The lowest temperature is approximately -16 °C. For this temperature condition, the ship most probably needs to be winterized during the first half of the route for all devices to work properly. When the ambient temperature goes below the operational temperature of an exposed system, measures to ensure continued functionality need to be taken. Fig. 5 shows that almost half of the Nordic Orion's route is in a region where temperatures are expected to be below 0 °C. Based on the contour map the crew of the Nordic Orion had to start considering low temperature operations before Nunivak Island. A vessel not intended or prepared for low temperature operations would have had difficulty with this voyage.

5. Conclusions

To ensure safe operations in cold and harsh environments with limited infrastructures, vessel systems must be properly designed. An appropriate design temperature is key to the design of such a vessel intended for service in cold regions. Although some classification societies have required DST and MAT be used as design temperatures for low temperature operations. Now as Polar Code been adopted with a definition of polar service temperature, it could be used as a tool for minimum anticipated temperature. This paper proposed a risk-based approach to the development of minimum anticipated temperature. Based on long-term hourly temperature data, extreme low temperatures for defined durations and return periods can be determined. Risks associated with these extreme low temperatures are quantified. Then a minimum anticipated temperature is selected as the extreme low temperature with an acceptable risk value and the shortest return period. The proposed approach was validated through a real-world case.

This study has developed a methodology for the development of minimum anticipated temperatures for vessels intended for service in cold regions using a risk-based approach. The procedures involve statistical analysis, consequence quantifications, and risk calculations. The minimum anticipated temperature was obtained through identifying the lowest risk with corresponding smallest return period. Therefore, it is expected to have the smallest risk when the minimum anticipated temperature is applied.

From the case study, the result shows that the proposed methodology can be reasonably applied. The development of extreme low temperature contour map is also a very useful tool to evaluate whether the ship needs winterization or not during the trip, as the plot of ship's route on the extreme low temperature contour map is clearly seen. From the map, the coldest temperature and the length of extreme low temperature encountered by the ship can be clearly identified.

Disclaimer

The views expressed herein are those of the authors and are not to be construed as official views of ABS. The proposed approach is a new concept it is not meant to question existing DST or MAT in the ABS guidelines for low temperature operations.

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