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Survival in the Canadian Arctic: Recommended Clothing and Equipment to Survive Exposure

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Abstract

The reduction in sea ice in the Arctic has produced new routes for shipping, thereby increasing the amount of marine traffic that can transit through the area. Additionally, the Arctic has become a popular destination for cruise ships some of which are increasingly large capacity ships that are operating a great distance from search and rescue assets and other assistance. If a marine accident were to occur in the Arctic and people became exposed to the elements then the clothing they could use may not provide sufficient thermal protection while waiting for rescue.

This paper contains the results from two studies. The first measured the amount of thermal protection provided by various clothing ensembles that could be used in a mass Arctic evacuation, which were then used to calculate predicted survival time (PST). The second study evaluated the length of time a person may be exposed to the environment if they were forced to abandon a vessel or installation at one of eight different locations in the Arctic. These exposure times are based on the range of times search and rescue assets would take to reach the individual. The results from these two previous studies were combined to provide recommendations for clothing ensembles for different locations in the Canadian Arctic while awaiting rescue.

The estimated exposure time while awaiting rescue varied considerably, ranging from a minimum of 14 hours to a maximum of 261 hours.

In certain conditions, the thermal protection provided by eight of the ten clothing ensembles tested was sufficient to delay death from hypothermia. However, it should be noted that if PST is greater than 36 hours then factors other than hypothermia are likely to result in death (e.g. drowning or dehydration). The majority of the ensembles did not provide a sufficient level of thermal protection to prevent death from hypothermia in less than 36 hours when wetted and exposed to wind.

It is concluded that certain clothing ensembles that could be used during a marine accident in the Arctic would not provide sufficient thermal protection to survive exposure to the environment while awaiting rescue. This finding is particularly important given the relatively recent increase in marine traffic through the Arctic and the subsequent increase in the likelihood of a marine accident that may require abandonment and result in direct exposure to the environment.

Introduction

The reduction of sea ice in the Canadian Arctic has resulted in the creation of new transit routes through what was once a previously inaccessible area. These routes could have significant advantages for marine operations as they allow vessels to navigate through Arctic waters, a much shorter link between the northern waters of the Atlantic and Pacific Ocean than is afforded by more traditional routes such as the Panama Canal. These shorter marine voyages could result in significant financial savings for shipping companies which makes transiting through the Canadian Arctic a very appealing endeavour.

In addition to the shipping industry, the decline in sea ice in the Arctic has benefitted both the adventure tourism and cruise line industries as previously inaccessible regions are now “open for business”. The exploration of the Arctic through adventure tourisms and cruise ship voyages has become a very popular activity, resulting in large increases of both marine traffic and people in this area. In August of 2016, the Crystal Serenity cruise ship is scheduled to transit through the Canadian Arctic carrying 1600 people (CBC, 2016). It has been suggested that if the Crystal Serenity were to become compromised and a mass rescue were to take place, such a scenario would “break” the current Canadian search and rescue (SAR) network due to the sheer number of people needing assistance in a remote location (CBC, 2016).

If the people on board a cruise ship such of this size had to abandon the vessel in the Arctic they would need to rely on life saving appliances (LSA) to protect them from the harsh environments while they await rescue. These LSA could include equipment such as protective clothing, immersion suits, liferafts, and lifeboats. LSA are always required by a variety of standards, both national and international, to achieve a certain minimum level of performance to ensure that they provide a sufficient level of protection for the people using them. For example, the International Maritime Organization (IMO) LSA code (2010 edition) states that an insulated immersion suit should prevent a person from experiencing a 2°C drop in deep body temperature when they are immersed in calm, circulating 2°C water for up to six hours. This prescriptive criteria creates a knowledge gap as to how this immersion suit will perform when it is used in harsher environments than simply “calm, circulating water”. Previous work by Power and colleagues has shown that the addition of wind and waves can cause a significant increase in heat loss from an insulated immersion suit when compared to immersions in calm water, resulting in reduced predicted survival times (Power et al., 2015). When the environment in which LSA will be utilized is not considered (and expected performance is based on tests conducted in calm, circulating water) one has what Tipton referred to as “surprisingly poor performance in a real accident” (Tipton, 1995).

The consideration of environmental conditions with respect to LSA performance is even more critical when marine accidents occur in norther regions. Due to its remote nature, lack of infrastructure and harsh weather the Arctic is an extremely challenging environment in which to operate safely. This is largely because all equipment must perform at a higher level of performance than what is considered adequate at lower latitudes. In other words, if people wish to survive in the Arctic, then they will need LSA that can protect them from extreme temperatures, for a longer period of time then what may be expected in other regions.

Some consideration has been given to the unique challenges in the Arctic by IMO via the drafting of the Polar Code which was developed to help increase the safety of SOLAS certified ships operating in polar waters (IMO, 2015). The Polar Code provides some recommendations on LSA that should be used during operations in the Arctic by suggesting additional equipment be provided to people to help protect them from the environment.

Therefore, in order to operate safely and confidently in the Arctic, two important research questions must be answered with respect to LSA:

1. How long can people expect to be exposed to the environment following an accident in the Arctic (i.e. how long will it take SAR assets to reach their location)?
2. Will the clothing ensembles people wear following the accident provide a sufficient amount of protection throughout the expected exposure time (i.e. will they survive until SAR assets reach their location)?

Establishing the estimated exposure time provides a baseline for the minimum length of time clothing ensembles must be required to keep individuals alive until rescue arrives. Once this length of time has been estimated, then various clothing ensembles can be tested to see if they meet this baseline. The National Research Council of Canada (NRC) conducted two separate studies to address these questions in order to establish the baseline level of performance and what clothing ensembles can meet it.

Methods

Study 1 was designed to evaluate the estimated length of time a person could be exposed to the Arctic environment while they wait for rescue (Kennedy et al., 2013). Study 2 measured the thermal insulation provided by a variety of clothing ensembles that could be used to provide protection following a marine accident in the north (Power and Monk, 2012). Those insulation values were then used in a predictive model to estimate the amount of time a given ensemble could allow an individual to survive before succumbing to hypothermia.

Study 1.

Based on current and prospective marine traffic, eight different locations in the Canadian Arctic were chosen as potential areas where an accident could occur (Figure 1).

Figure 1. Locations used to estimate exposure time in the Canadian Arctic.

Canadian SAR subject matter experts (SME), both marine and air, were sent surveys that asked them to consider their responses to a theoretical emergency scenario at each of the eight locations. The details of the scenarios were limited in an attempt to generalize the results to a larger number of emergency events. The SME were asked to consider and quantify the potential impact that a large number of factors could have on the length of time it would take for a search and rescue resource to reach each of the highlighted locations. These factors included: distance from shore; wind and waves; temperature; precipitation; visibility; ice conditions; type of resource tasked (primary or secondary SAR asset); physical state of resource (fuel tank full or low); communication capabilities; physical state of evacuees (injured or not injured); bathymetry accuracy; level of experience of the Captain and crew; training of ranking officer and crew; quality of environmental forecasting models. The primary air assets are located at five set locations across Canada. In the case of an emergency event, air assets would be tasked based on their proximity to the event and their availability, amongst other factors. The location of primary marine resources can change throughout the year based on vessel duties. The scenario selected for consideration in this study assumed that the emergency event occurred in August. One reason for selecting this month is that there would be a higher primary marine SAR resource presence in the Canadian Arctic at this time.

The Canadian SAR SME completed the surveys and returned them to the research team so that the results could be compiled and analyzed. The researchers ranked each of the factors based on the survey responses and used these rankings, along with the SME responses, to create a range of estimated times an individual may be exposed to the Arctic environment while awaiting rescue. Initially, the times for each of the eight locations were calculated separately for marine and air resources to demonstrate the differences between potential exposure times. At each location low and high exposure time values were indicated. The ‘low’ time was representative of a scenario in which all factors were at an optimal level in terms of their effect on exposure time. In contrast, the ‘high’ time represented a scenario in which all factors were at a ‘worst case’ level. For example, an optimal level for the factor “level of experience of captain and crew” would be a very high level of training since this case would likely lead to shorter exposure times. Once these times were calculated, a follow up workshop was held at NRC where the SME were invited to participate and provide feedback on the results. In addition, the workshop allowed for a full review of survey questions and responses to ensure that there was no confusion with questions that could have skewed the calculated exposure time values. Feedback from this workshop was used to adjust the exposure time calculations to ensure they were representative of marine and air resource capabilities that were available at that time.

Study 2.

The insulation value of ten separate clothing ensembles were measured in different environmental conditions using a Thermal Instrumented Manikin (TIM) (Sweeney and Potter, 2010; Power-Macdonald et al., 2012). Insulation values were measured in clo[1] and a description of each clothing ensemble is given in Appendix 1. The environmental conditions were: immersed up to the neck in water; dry ensemble with no wind; dry ensemble with wind (7 $m \cdot s^{-1}$); wet (one minute immersion; followed by five minute drip dry in air) ensemble with no wind; and wet ensemble with wind.

The insulation values for each of the ensembles across all the different environmental conditions were used to generate predicted survival time (PST) using a modified version of the Cold Exposure Survival Model (CESM) (Power and Monk, 2012). The CESM is a predictive modelling program used by Canadian SAR to determine the length of a time a person can survive until they perish from hypothermia. PSTs were generated for two separate conditions: immersions in 0°C water and in -15°C

[1] One clo is equivalent to the amount of insulation required to keep a seat person comfortable in 21°C air at 50% relative humidity, and air movement of 0.1 $m \cdot s^{-1}$ (Golden and Tipton, 2002).

air. Survival times were generated for an 60 – 70 year old female population since they would represent the "worst case" scenario as PST decreases with age (Keefe and Tikuisis, 2008). If an individual is able to survive hypothermia past 36 hours, then factors other than hypothermia are more likely to result in death (e.g. predation from wildlife or drowning) (Keefe and Tikuisis, 2008). PSTs for certain ensembles (e.g. MAJAID #2a) were not generated for immersions and wetted conditions as it is not reasonable to expect that someone would be in a sleeping bag in the water.

The results from Studies 1 and 2 were then combined to determine if the clothing ensembles tested would provide a sufficient level of protection from hypothermia for the estimated amount of time a person may be exposed to the harsh Arctic environment while waiting for SAR.

Results

Study 1.

The range of estimated exposure times based on SAR SME responses are given in Table 1 and Figure 2.

Table 1. Exposure time ranges based on marine and air resources.

Resource Type	Exposure Time(hours)	Location							
		1	2	3	4	5	6	7	8
Air	Low Value	27	24	23	16	14	13	15	13
	High Value	49	45	42	31	27	25	28	26
Marine	Low Value	48	28	14	14	48	14	36	24
	High Value	237	261	48	24	131	75	140	43

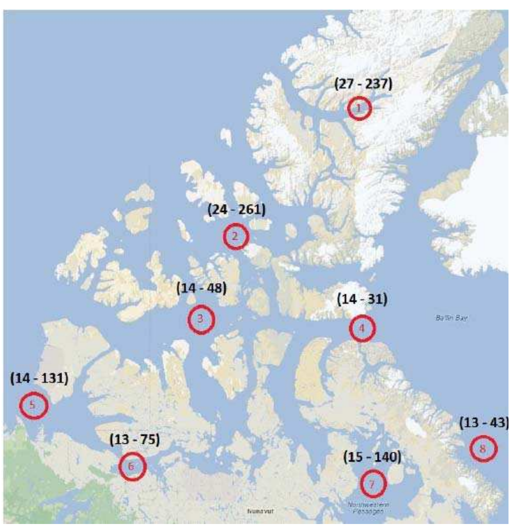

Figure 2. Merged exposure time ranges (based on all Canadian resources).

The lowest reported estimated exposure time is 13 hours (air-based SAR response at locations 6 and 8) which can be considered the minimum amount of time one can be expected to be exposed to the Arctic environment.

Generally for the low range values, air-based SAR resources had a much faster response time than marine-based ones (Table 1); the exceptions being locations 3 and 4. For the high range values, the marine-based SAR resources were always greater than the air-based ones with the exception of location 4.

The largest range in estimated response times were observed in the marine-based resources with the largest range being 233 hours for location 2, and the smallest being 10 hours at location 4. By comparison the ranges in estimated response times for the air-based resources were generally lower. The largest range of response times for the air-based resources was 22 hours at location 1; the lowest range was 12 hours at location 6.

SAR SME reported that estimated marine exposure times are highly influenced by the presence (or absence) of Canadian Coast Guard (CCG) vessels operating in the area. During the operational season, marine-based assets would already be operating in Arctic areas, thereby allowing for much shorter response times compared to other times of the year where they would be stationed in lower latitudes. Air-based resources were much more consistent in their times since they are based at the same locations throughout the year. .

Study 2.

When immersed up to the neck in 0°C water, none of the ensembles generated a PST of greater than 7 hours. The highest reported value was 6.2 hours for the Abandonment Wear #2 ensemble.

The PST for each ensemble in -15°C air across all conditions are given in Figure 3.

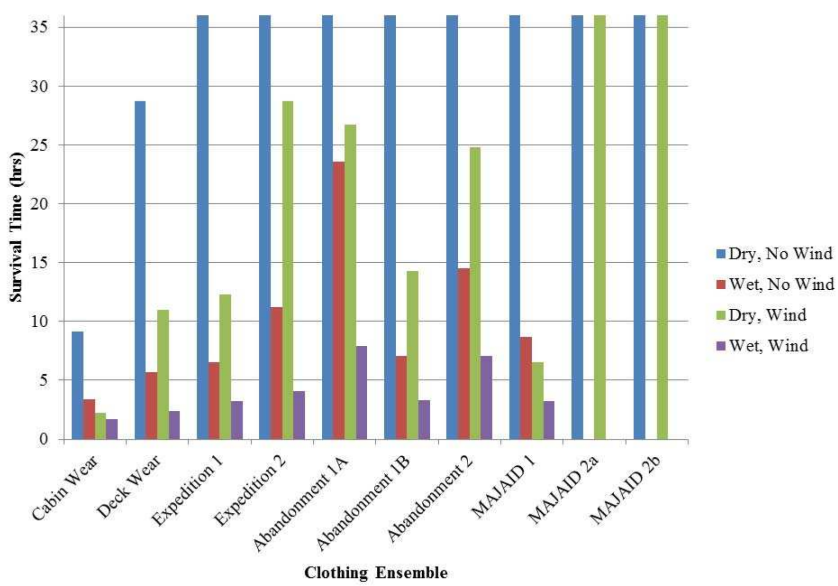

Figure 3: Predicted survival times (hrs) for 50th percentile 60 – 70 year old females for all clothing ensembles in varying conditions in -15°C air.

When dry and with no wind present, eight of the ten ensembles provided a sufficient amount of thermal protection to generate PSTs greater than 36 hours (Figure 3). When the ensembles were subjected to wind, but still dry, only two of ten provided enough thermal protection to generate PSTs greater than 36 hours. For the eight ensembles that were wetted, with no wind present, the highest PST was 23.6 hours. Wetting the same eight ensembles with wind blowing over them resulted in a maximum PST of 7.9 hours.

For reporting purposes, the middle value in the range of estimated exposure times for each location were used to determine if each clothing ensemble would provide a sufficient level of protection to allow the person to survive cold exposure until help arrived. The results for marine responses are given in Table 2; air responses are given in Table 3.

Table 2: Predicted survival time (PST; hours) for each ensemble compared to estimated marine exposure time (hours) for each location.

		Location Number and Estimated Exposure Time (hours)							
		1	2	3	4	5	6	7	8
Ensemble	PST (hours)	142.5	144.5	31	19	89.5	44.5	88	33.5
Cabin Wear		Survive Estimated Exposure Time? (Y = Yes; N = No)							
Dry, No Wind	9.1	N	N	N	N	N	N	N	N
Wet, No Wind	3.4	N	N	N	N	N	N	N	N
Dry, Wind	2.2	N	N	N	N	N	N	N	N
Wet, Wind	1.7	N	N	N	N	N	N	N	N
Deck Wear									
Dry, No Wind	28.7	N	N	N	Y	N	N	N	N
Wet, No Wind	5.7	N	N	N	N	N	N	N	N
Dry, Wind	11	N	N	N	N	N	N	N	N
Wet, Wind	2.4	N	N	N	N	N	N	N	N
Expedition 1									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	6.5	N	N	N	N	N	N	N	N
Dry, Wind	12.3	N	N	N	N	N	N	N	N
Wet, Wind	3.2	N	N	N	N	N	N	N	N
Expedition 2									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	11.2	N	N	N	N	N	N	N	N
Dry, Wind	28.7	N	N	N	Y	N	N	N	N
Wet, Wind	4.1	N	N	N	N	N	N	N	N
Abandonment 1A									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	23.6	N	N	N	Y	N	N	N	N
Dry, Wind	26.7	N	N	N	Y	N	N	N	N
Wet, Wind	7.9	N	N	N	N	N	N	N	N
Abandonment 1B									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	7.1	N	N	N	N	N	N	N	N
Dry, Wind	14.3	N	N	N	N	N	N	N	N
Wet, Wind	3.3	N	N	N	N	N	N	N	N

Abandonment 2									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	14.5	N	N	N	N	N	N	N	N
Dry, Wind	24.8	N	N	N	Y	N	N	N	N
Wet, Wind	7.1	N	N	N	N	N	N	N	N
MAJAID 1									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	8.7	N	N	N	N	N	N	N	N
Dry, Wind	6.5	N	N	N	N	N	N	N	N
Wet, Wind	3.2	N	N	N	N	N	N	N	N
MAJAID 2A									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Dry, Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
MAJAID 2B									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Dry, Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y

Table 3: Predicted survival time (PST; hours) for each ensemble compared to estimated air exposure time (hours) for each location.

		Location Number and Estimated Exposure Time (hours)							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ensemble	**PST (hours)**	38	34.5	32.5	23.5	20.5	19	21.5	19.5
Cabin Wear		**Survive Estimated Exposure Time? (Y = Yes; N = No)**							
Dry, No Wind	9.1	N	N	N	N	N	N	N	N
Wet, No Wind	3.4	N	N	N	N	N	N	N	N
Dry, Wind	2.2	N	N	N	N	N	N	N	N
Wet, Wind	1.7	N	N	N	N	N	N	N	N
Deck Wear									
Dry, No Wind	28.7	N	N	N	Y	Y	Y	Y	Y
Wet, No Wind	5.7	N	N	N	N	N	N	N	N
Dry, Wind	11	N	N	N	N	N	N	N	N
Wet, Wind	2.4	N	N	N	N	N	N	N	N
Expedition 1									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	6.5	N	N	N	N	N	N	N	N
Dry, Wind	12.3	N	N	N	N	N	N	N	N
Wet, Wind	3.2	N	N	N	N	N	N	N	N
Expedition 2									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	11.2	N	N	N	N	N	N	N	N
Dry, Wind	28.7	N	N	N	Y	Y	Y	Y	Y
Wet, Wind	4.1	N	N	N	N	N	N	N	N
Abandonment 1A									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	23.6	N	N	N	Y	N	N	N	N

Dry, Wind	26.7	N	N	N	Y	Y	Y	Y	Y
Wet, Wind	7.9	N	N	N	N	N	N	N	N
Abandonment 1B									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	7.1	N	N	N	N	N	N	N	N
Dry, Wind	14.3	N	N	N	N	N	N	N	N
Wet, Wind	3.3	N	N	N	N	N	N	N	N
Abandonment 2									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	14.5	N	N	N	N	N	N	N	N
Dry, Wind	24.8	N	N	N	Y	Y	Y	Y	Y
Wet, Wind	7.1	N	N	N	N	N	N	N	N
MAJAID 1									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Wet, No Wind	8.7	N	N	N	N	N	N	N	N
Dry, Wind	6.5	N	N	N	N	N	N	N	N
Wet, Wind	3.2	N	N	N	N	N	N	N	N
MAJAID 2A									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Dry, Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
MAJAID 2B									
Dry, No Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y
Dry, Wind	>36	Y	Y	Y	Y	Y	Y	Y	Y

Limitations

The estimated exposure times reported in Study 1 can vary over a large range which may make it difficult to choose a realistic value to represent how long SAR assets will take to reach a given location. The subject matter experts surveyed in Study 1 reported that many factors can influence how long it takes SAR assets to reach an area. Therefore, though it is possible that the low time estimate could occur, the potential for all factors being at an optimal level during a marine accident is low. Conversely, it is also unlikely that all factors occur at a "worst case" level during a marine accident and thus it is unlikely for the exposure time to be as large as the "high" time estimate. As such, in this study, we chose to use a value in the middle of the estimated ranges as a compromise between the best and worst scenarios. However, it should be cautioned, that planning for higher exposure time values may increase survivability by providing a buffer against unforeseen delays.

It is noted here that Study 1 did not account for new infrastructure that could be developed if a significant increase in vessel traffic or resource development requiring marine support was to occur. Such new infrastructure could be equipped with SAR tools and equipment, potentially reducing exposure time due to closer tasking locations.

All PSTs generated in Study 2 by the CESM are for 60 – 70 year old females which represents a demographic that would have the lowest times compared to others. If individuals who are not part of this demographic are awaiting rescue in the Arctic then it likely that their PST will be higher than what was reported hereother demographics would most likely survive in the Arctic with the clothing and equipment we recommended.

Also, the PSTs were calculated assuming an air temperature of -15°C; a value that can be much colder than the average temperature at the surveyed locations during certain points of the year. This again represents a value chosen as a compromise between the extreme ranges of temperature that locations in the Arctic can experience throughout the year. While it is unlikely that people may be working or travelling in the Arctic during the coldest months of the year, basing our results on -15°C has created an additional factor of safety in the recommendations. For example, if the ambient air temperature is higher than -15°C during a marine accident then the individuals involved would have higher PSTs than what was reported thereby increasing their likelihood of surviving hypothermia while awaiting rescue.

Discussion

The findings from Study 1 suggest that the estimated exposure time for a given location in the Arctic is highly dependent on a variety of factors which results in a wide range of values. The range of times for air SAR responses were smaller compared to those reported for marine assets. The largest range of values for air SAR responses was at location 1, on Ellesmere Island, where the difference between the low and high estimate was 38 hours; for marine SAR responses at the same location the difference was 142 hours.

Comparing the low value estimates for exposure time between air and marine assets shows that for the majority of the locations the latter response is higher; with locations 3 and 4 being the exceptions (Table 1). These exceptions can be attributed to the likely position of marine assets relative to these locations since during certain times of the year they may be operating in close proximity.For locations 1, 2, 6, 7, and 8 the marine low value estimates for exposure time are between 1.08 – 2.4 times greater than the air values. This means that for these locations it would take a marine SAR resource approximately 1.08 – 2.4 times longer to arrive on scene and affect a rescue for the considered scenario. The marine low value estimates for location 5, near Banks Island, was 3.4 times greater than the air values which can be attributed to the fact that even in the most optimal conditions, marine assets would not be operating in the area, under current scenarios, and would still require time to transit to this location. The only two occurrences where marine low value estimates were smaller than those for air were at locations 3 and 4. This can also be attributed to the position of marine assets relative to these locations since during certain times of the year they may be operating in close proximity.

A much larger range of times is observed when comparing the marine high value estimates to the air values (Table 2). The only occurrence of a marine high value estimate being less than those for air is at location 4. At locations 3 and 8 the marine high value estimates are 1.14 and 1.65 times higher than their respective air values which is comparable to the differences in their low value estimates. For all other locations the marine high value estimates are much greater than the air values; with some marine estimates being 5.8 times larger than air estimates (Location 2).

The large differences between the low and high value estimates for both air and marine times speak to the number of factors that influence SAR responses to an Arctic incident according to the subject matter experts. While it may be convenient to take the low value estimates reported in Table 1 as a possible SAR response time to various locations, this would be an unrealistic approach to take. As reported by the experts surveyed in Study 1, the best case scenario for each of the factors described would have to occur (no inclement weather; no ice coverage; assets operating near the incident, etc.) in order to obtain the low value estimates which is a highly unlikely scenario. A more pragmatic and plausible approach would be to expect average response times to fall somewhere between the middle and high values.

Another important factor that must be considered when assessing air and marine response times to an Arctic incident is the number of people who need to be rescued. A Cormorant helicopter is only capable of holding 18 people (Kennedy et al., 2013). While this may be sufficient for small shipping vessels transiting through Arctic waters, it could not accommodate all of those on board larger vessels such as cruise ships. If a large-capacity cruise shipwas to become incapacitated and require SAR assistance for everyone on board, typical air assets alone would not be sufficient for the rescue due to the sheer number of evacuees. As a result, the marine response times may be more appropriate to consider when dealing with a SAR incident involving a large number of evacuees.

While the evacuees are awaiting SAR in the Arctic, they will need to rely on warm clothing to protect them from the environment so that they do not succumb to hypothermia. The results from Study 2 suggest that while the majority of the ensembles do offer a sufficient amount of thermal insulation to protect from hypothermia in -15°C air (> 36 hours PST), many of them are highly susceptible to the effects of wind and wetting (Figure 3). Given that all ensembles provided such low PSTs when immersed relative to estimated exposure time, it can be surmised that if people were in the water they would perish long before SAR assets arrived.

The only ensembles that were found to be unable to provide a sufficient level of thermal insulation to generate PST greater than 36 hours when dry and in still air (Figure 3) were Cabin Wear and Deck Wear; the other eight were able to do so. When these eight ensembles were exposed to wind, they all produced a PST less than 36 hours with the exception of MAJAID 2A and MAJAID 2B. Notably, these two specific ensembles included sleeping bags that proved effective in preventing the wind from causing a drop in thermal insulation that would have resulted in a PST of less than 36 hours.

Wetting the ensembles (except MAJAID 2A and MAJAID 2B) caused them to generate a lower PST compared to exposing them to wind alone (Figure 3). Given that the thermal conductivity of water is 23 times greater than that of air it is not surprising to see that wetting the ensembles had a greater effect than wind blowing over them. It should be noted that all the ensembles were immersed up to the neck in water prior to measuring their thermal insulation which allowed water to ingress underneath the outer layers of clothing and saturate that which was underneath. It could be argued that in a rescue scenario some of the ensembles would include a waterproof outerlayer (e.g. Abandonment 1A) that would offer some protection against the underclothing becoming saturated; however, this assumes that an individual was completely dry before donning the waterproof outerlayer and did not become accidentally immersed prior to doing so. It also presumes that their clothing did not become wet from sweat, rain or ocean spray.

As expected, the trials that involved both wetting the clothing and blowing wind over the ensembles resulted in the lowest PST compared to all other conditions (Figure 3). Wetting the clothing in the presence of wind resulted in significant reductions in PSTs with the highest value being only 7.9 hours for the Abandonment 1A ensemble.

The results from Study 2 suggest that the majority of the ensembles tested are capable of providing a sufficient amount of thermal insulation to protect from hypothermia, but only under the most ideal conditions: completely dry and with no wind. During a marine accident in the Arctic it would likely be unrealistic to expect all personnel to remain dry and not experience the effects of wind blowing past them. Therefore, it may be more advantageous to rely on training to help mitigate these factors and ensure that clothing remains warm enough to provide protection from hypothermia. For example, objects such as tents and inflated liferafts can be used to help keep evacuees out of the wind and precipitation while they await rescue. This would require personnel to be trained in such survival techniques and for them to be cognizant of the fact that relying on clothing alone may not be sufficient to protect them from hypothermia in the Arctic.

The results from Studies 1 and 2 can be combined to provide recommendations on what clothing should be carried on board vessels to ensure that evacuees can survive until SAR assistance arrives (Tables 2 and 3). These recommendations are geared towards the cruise industry, for example, and do not take into account industrial or federal requirements, such as immersion or survival suits that companies or agencies may already require for standard Arctic operation abandonment procedures. Under the most ideal conditions (completely dry; no wind) all ensembles except Cabin Wear and Deck Wear would provide a sufficient amount of thermal insulation at every location to allow evacuees to survive hypothermia until air SAR assets reach them (Table 2). As discussed, relying on ideal conditions to survive is not recommended; therefore it should be assumed that at the very least, wind is blowing through the area. When wind is added to locations 1-3, none of the ensembles provided a sufficient amount of thermal protection to survive hypothermia until air SAR assets arrive except MAJAID 2A and MAJAID 2B. For locations 4-8 with wind present, the Expedition 2, Abandonment 1a and Abandonment 2 ensembles provided sufficient protection from hypothermia until air SAR assets arrived. Wetting the ensembles resulted in none of them providing a sufficient amount of protection from hypothermia except for the Abandonment 1A ensemble at location 4, but only by a very small amount.

Similar to the air SAR response times, the clothing ensembles followed a similar trend in protection for the marine SAR responses (Table 3). All ensembles (expect Cabin Wear and Deck Wear) provided a sufficient level of protection under ideal conditions at all locations. The presence of wind, but still dry, resulted in most ensembles not providing enough thermal protection at all locations while waiting for marine assets except for MAJAID 2A and MAJAID 2B; these two ensembles were sufficient for all locations with wind. Three ensembles provided enough protection at location 4: Expedition 2, Abandonment 1A and Abandonment 2. Similar to the results observed with the air exposure times, the Abandonment 1A ensemble was the only one that, when wetted, could provide a sufficient level of protection at location 4. When exposed to wind and wetting none of the ensembles provided enough protection at any of the locations to prevent death from hypothermia while waiting for marine assets.

The results from both studies indicate that clothing ensembles consisting of those similar to what were used in Cabin Wear and Deck Wear would be insufficient to survive the estimated exposure time in the Arctic. In order to ensure survival from hypothermia in the Arctic, an individual should be wearing clothing equivalent to the Expedition 1 ensemble. However, these ensembles must be kept dry and not exposed to wind in order to provide the sufficient amount of protection from hypothermia while waiting for rescue. Wetting the ensembles results in none of them providing a sufficient amount of protection at any location, and the presence of wind (while dry) reduces the likelihood of survival to only a select few locations. The addition of a sleeping bag provides enough protection from the wind for some ensembles to prevent death from hypothermia at all of the locations.

The IMO Polar Code offers some clothing equipment suggestions for use by people travelling through the Arctic. Specifically, it suggests that “protective clothing” consisting of a hat, gloves, socks, and face and neck protection be used along with a thermal protective aid (IMO, 2015); an ensemble that would be roughly equivalent to Abandonment 1A. It also suggests the use of shelters such as tents, thermal protective aids, sleeping bags, and foam sleeping mats. Based on the results from the two studies, these recommendations *should* be enough to ensure protection from hypothermia while waiting for rescue. Unfortunately, the use of the word “suggested” in the Polar Code indicates that it is not mandatory that this equipment be carried on board every vessel operating in the Arctic. Additionally, “protective clothing” is a vague, subjective term that does not convey a specific level of performance. This creates a potential scenario where the interpretation of the Polar Code, for the ships it applies to, could result in an individual opting for what they would consider to be "protective clothing" while in actual fact it only offers the same level of thermal protection equivalent to that of the Deck Wear ensemble tested. Moreover, since it is only suggested that tents and sleeping bags be carried on board a vessel, there is no requirement for the operators to do so which may lead to them choosing not to bring this equipment. Given the results from the studies detailed in this paper, it is recommended that clothing equivalent to at least the Expedition Wear 1 ensemble should be worn by people working and traveling in the Arctic if not already required to do so. Additionally, equipment such as a tent or a liferaft should also be required so that these individuals are protected from the wind and their clothing becoming wet.

Conclusions

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If a marine accident were to occur in the Canadian Arctic that required SAR assets to respond, evacuees may be exposed to the harsh environment for many hours; and possibly days. In order to prevent death from hypothermia the evacuees should be wearing clothing equivalent to, and ideally greater than, that which makes up the Expedition 1 ensemble and as well as take shelter in a tent or inflated liferaft to protect themselves from the environment. It is recommended that the clothing recommendations in the IMO Polar Code should be more specific and that the suggested equipment actually be mandatory for the ships the code applies to. Since marine traffic is continually increasing in the Canadian Arctic, this is an issue that is becoming more relevant and posing greater risk.

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Appendix 1 – Clothing Ensemble Descriptions

Ensemble	Description
Cabin Wear	Denver Hayes JMC61001 denim jeans; Cherokee 100% cotton long sleeve flannel shirt; 90% cotton socks (9% nylon + 1% Lycra Spandex); Denver Hayes 100% cotton boxer shorts; Dakota Style #MDNS308NST leather shoes.
Deck Wear	Cabin Wear plus : Stanfield's long underwear (long sleeve shirt [6623] and pants [6602]); Helly Hansen soft pile jacket and pants; Helly Hansen compass jacket (AJ301) and pants (U310); Wind River toque (style 47-2694HH with fleece lining), Wind River mittens (style 71-9-85905).
Expedition Wear #1	Deck Wear plus: wool socks and Baffin Industrial ASTM 2413-05 Polar proven -40°C with five layer liner.
Expedition Wear #2	Expedition Wear #1 except: Helly Hansen compass jacket and pants replaced by Mustang Survival MS195 HX Integrity Suit (XL).
Abandonment Wear 1a	Deck Wear plus: Helly Hansen P2000 Passenger Suit/Thermal Protective Aid; SOLAS life vest (Lalizas 70169 BV) (gloves replaced by fleece mittens because TPA has gloves); wool socks.
Abandonment Wear 1b	Deck Wear plus : Mustang Survival Coverall (once only suit) Anti-exposure model MSD685; SOLAS life vest (Lalizas 70169 BV) (gloves replaced by fleece mittens because TPA has gloves); wool socks.
Abandonment Wear 2	Deck Wear with wool socks minus footwear plus Mustang SOLAS immersion suit, SOLAS life vest (Lalizas 70169 BV) (gloves replaced by fleece mittens because immersion suit has gloves); wool socks.
MAJAID #1	Cabin Wear without Dakota Shoes; parka; pants; mittens; toque; boots.
MAJAID #2a	MAJAID #1 ensemble inside down filled casualty bag.
MAJAID #2b	MAJAID #1 ensemble inside synthetic filled causality bag.