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Impact of climate change on design and operation of Arctic ships and offshore units

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ABSTRACT

Arctic environmental parameters form the basis for the design and operation of ships and offshore platforms, and as the understanding of climate change evolves this knowledge needs to be reflected in the processes and methods that developing the environmental design basis.

This paper provides a review of the applicable Rules and Regulations for Arctic regions with focus on the environmental parameters impacted by climate change, such as air temperature, ice properties, wind, snow, and wave states, etc. Scenarios of parameter variations are presented and the applicability of probabilistic models for trend analysis and extreme events are discussed. The influence of environmental parameters on the evolution on design are discussed including the hull strength, steel grade, and stability, as well as operational parameters such as ship speed, crew procedures and maintenance.

The paper highlights the importance of a risk analysis approach to evaluate the impact of climate change on the design and operation of the ship and offshore platforms in the Arctic. For offshore platforms in ice, ISO 19906 recommends that probabilistic methods be used to determine ice actions. Such an approach can also be used to assess the effects of different climate change scenarios based on either temperature trends or future temperature assumptions. It is important to note that ice loads may reduce under various future climate change scenarios. Whether or not to take advantage of such potential reductions will be a key issue for future projects. The risk analysis approach could be helpful in this regard.

The analysis has shown that the climate change may have an optimistic influence on some design or operational parameters but others may have a negative influence on some of these parameters. It is clear that the issue is complex and requires in depth research, and that the industry needs to cooperate in further development as climate change plays an important role.

Keywords: Climate Change, Sea Ice, Ships, Offshore Structures, Design Criteria.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change, IPCC (2013), anticipates increasing natural impacts over the coming decades as the global temperature increases. For example, the global mean air temperature has risen 1^{0}C above pre-industrial levels and continues to increase. There is also clear evidence of climate change in environmental parameters such as sea temperature and in sea level rise.

The Arctic region is considered an area which is particularly affected by climate change, e.g. Rodrigues (2008) and details are given in Appendix A. As the understanding of climate change evolves this knowledge needs to be reflected in the processes and methods related to the environmental design basis of ships and offshore units. The implications for design and operations in Arctic regions are however not necessarily evident and are often not integrated into regulations and standards.

1.1. Impact of Climate Change on Design Approaches and Criterion

The safety regime of a ship or offshore unit is formed by a range of international and national requirements, for example as outlined by Riska et al. (2018) and Bridges et al. (2018). International requirements include the IMO Polar Code (2014), Arctic Council Guidelines (2009) and ISO Arctic standards (2010), whilst national requirements are those such as the Guide to the Northern Sea Route (2013) and Transport Canada Arctic Shipping Pollution Prevention Regulations (ASPPR 1989). Additional requirements are also contained in IACS Polar class rules and guidance (2016). These requirements provide a safety regime and incorporate factors of safety for structures and equipment provisions. In most cases, the environmental parameters may be explicitly expressed in the design equations or requirements, however a more difficult situation also arises when parameters affected by climate change are not openly stated.

During the typical design process meteorological, oceanographic and sea ice measurements are taken on site and supplemented by additional information such as satellite data and from climate models. This data is used to develop statistics describing the operating conditions and also extrapolated to determine extreme conditions, typically determined for 100 and 1000 years, ULS and ALS respectively. The ships and facilities are designed to withstand these conditions and build in safety margins around these to permit safe operations.

The approach of extrapolating data can however introduce uncertainties, see McKenna et al. (2014), for example, in estimating and extrapolating to the tails of the data. An example showing uncertainties using different curve fitting is shown in Figure 1. Statistical data methods such as Monte Carlo simulations, can improve this uncertainty but is reliant on the modelling input and relationships and require verification. Thus it is not always evident that the trends are clearly established.

The influence of climate change on the design is specifically noted in the international standard on Arctic offshore structures, ISO 19906, which notes that 'C*onsideration for such changes should be included in the design', (section 5.3.2).* The standard also refers to ISO 35106, Arctic operations: Metocean, ice, and seabed data. This provides similar provisions, including '*Design criteria should not be reduced based on projected climatic trends, (section 5.2.7).* However, they do not cover any specific requirements for how to include climate change in these criteria. Further, as many impacts of climate change are region, location and asset-type specific the level of adaptation is required and needs careful consideration. Criteria to be representative of the environment into which structures are placed. Changes in the statistical values of the parameters can impact the efficiency and robustness, the loading and structural integrity, as well as in the event chronology which can impact the cumulative responses and operating windows.

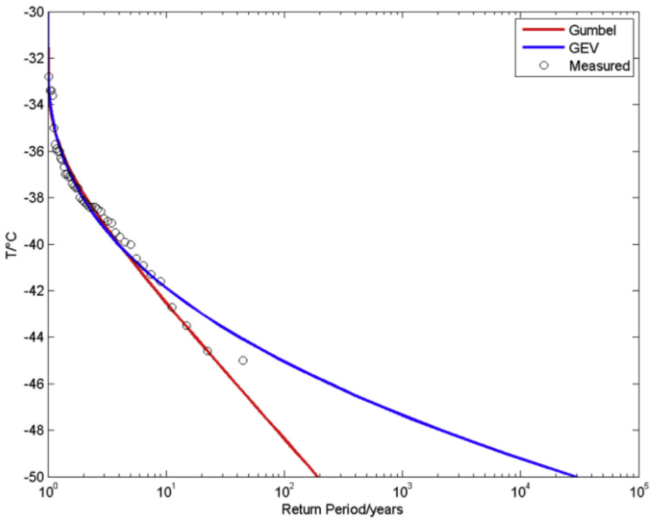

Figure 1. Extreme value analysis for air temperature data based on historical measurements taken Russian Arctic, from Bridges et al. (2018). The different curves fitted to the data illustrate a range of uncertainty.

1.2. Impact of Climate Change on Marine Operations

Many studies have been made on the potential changes and economic feasibility in Arctic shipping routes based on the observed low Arctic summer sea ice extent together with climate model projections, such as Liu and Kronbak (2010), Ho (2010), Hong (2011), Valsson and Ulfarsson (2011) and Smith and Stephenson (2013), to mention just a few. However it is important to note the summer sea-ice thickness information is crucial for seasonal Arctic shipping as noted by Melia et al. (2017). Further the opening of large areas of the Arctic Ocean previously covered by ice can result in wind and surface waves evolving and change in the Marginal Ice Zone (MIZ) illustrated by Aksenov et al. (2017). These changes can have an impact on the safe design of ships, for example the projected changes of wave climate is discussed by Bitner-Gregersen et al. (2018), albeit for the North Atlantic. In addition, increase in marine hazards resulting from the increasing mobility of sea ice is discussed by Barber et al. (2014) noting the ice features off the east coast of Newfoundland.

The impact of climate change on offshore units differ from that of shipping; and studies have consequently considered environmental variables, such as changes in ocean acidity, air and water temperature, precipitation patterns, sea level rise, and storm intensity. For example as discussed in coastal and marine regions impacts of climate change observed in North America by Burkett et al. (2011). Analysis of the impact on the Beaufort Sea, Environmental Canada (2013), also illustrates the following potential positive and negative effects:

"Key Positive Effects include:

- *longer operating seasons for seismic and drilling activities due to reduced ice cover and thickness*
- *earlier mobilization and later demobilization of vessels both to and from the Beaufort Sea as well as from overwintering anchorages and offshore areas*
- *reduced icebreaking requirements*

Key Negative effects include:

- *increased threats to drilling and production platforms due to increased ice velocities and the increased presence of glacial ice features*
- *larger wave heights may cause delays in ship support activities and seismic operations*
- *increased sea surface temperatures which may increase degradation of permafrost in coastal areas with implications for coastal oil and gas infrastructure*
- *reduced use of ice roads and ice spray islands in nearshore areas*

- *increased coastal areas affected by storm surge potentially affecting infrastructure"*

1.3 Purpose of study

The aim of this study is to investigate the change in environmental parameters that may influence the design and operations of Arctic ships and offshore structures. It is not intended to provide a definitive approach, but to raise awareness and disseminate knowledge related to the methodologies and approaches. In particular emphasis is given in the use of climate data in relation to quantifying the uncertainty. The paper highlights some of the understanding that the impact of climate change and the means for adaptation that can be used in developing a design basis and performing marine operations.

2. DETERMINATION OF CLIMATE TRENDS AND UNCERTAINTY

Climate change depends on a large number of parameters that may be classified in a first approximation into natural effects i.e. considered as independent of human action, and into anthropometric effects i.e. dependent on the human action.

2.1 Ice Extent

The Arctic Offshore Structures standard ISO 19906 specifies two limit states: ULS (Ultimate Limit State) and ALS (Accidental Limit State) with return periods of 10^2 and 10^4 years for ice action, respectively. There is also a suggestion how extensive the database from where the extrapolation is made should be (at least 30 years). Often the ice action is described by some environmental parameter like ice thickness or presence of ice – an example of the latter is given by the discussion in Norway of ice boundary in the Barents Sea. Much uncertainty is introduced if the database for prediction of the ULS or ALS values has a trend due to climate change. One of the most famous trends is given by the ice extent in the Arctic, see Fig. 2. This is used as an example in the following analysis.

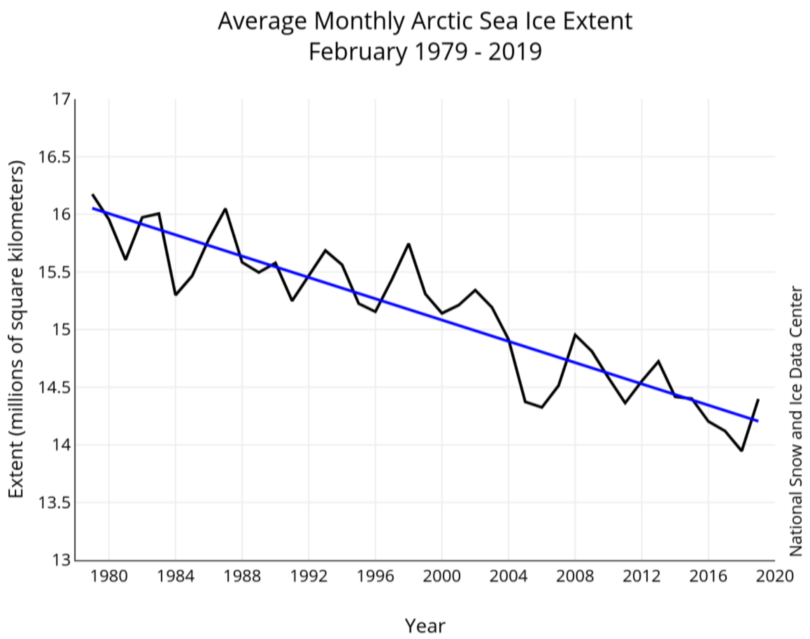

Fig. 2. The Arctic ice extent in February (http://nsidc.org/arcticseaicenews/, accessed 14.3.2019).

If the data has a trend, then the extrapolation to long return periods is not clear and contains some uncertainty. A direct extrapolation using the data in Fig. 2 is given in Fig 3. There the ice extent data is plotted versus the return period using the usual plotting position $P(A_m)=m/(N+1)$ where the data is an ordered sequence $\{A_m\}$, $m=1,\ldots,N$ and return period $T = 1/f \cdot 1/(1-P)$ (f frequency of data, here once per year). It is immediately clear that the extrapolation to ULS gives an ice extent of about $18 \cdot 10^6$ km^2. This does not, however, take into account the clear trend in the data.

The way around this question is to divide the data into two parts, the trend A_T and a stochastic variation around the trend A_S (here the design variable is termed A as the ice extent is used as an example, but this could be in principle any design variable). Then the total value is

$A = A_T + A_S$.

This naturally induces the question how to determine the trend and also, do we consider the trend as deterministic once we have worked it out. One way is to set the trend as linear as is done in Fig. 2. This is well and good for the years we have data but when extrapolating to life time or ALS/ULS return periods, the linear trend might deviate much from the actual trend.

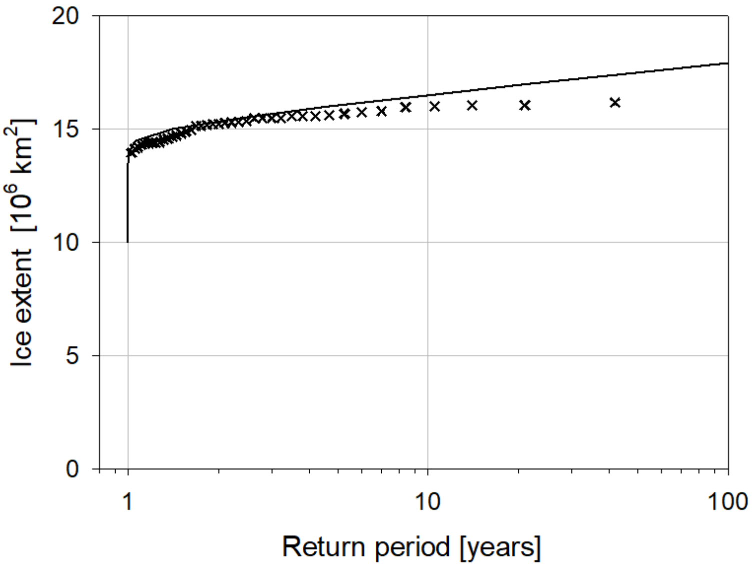

Fig. 3. The ice extent data plotted versus the return period together with the Gumbel 1 extreme value distribution fit.

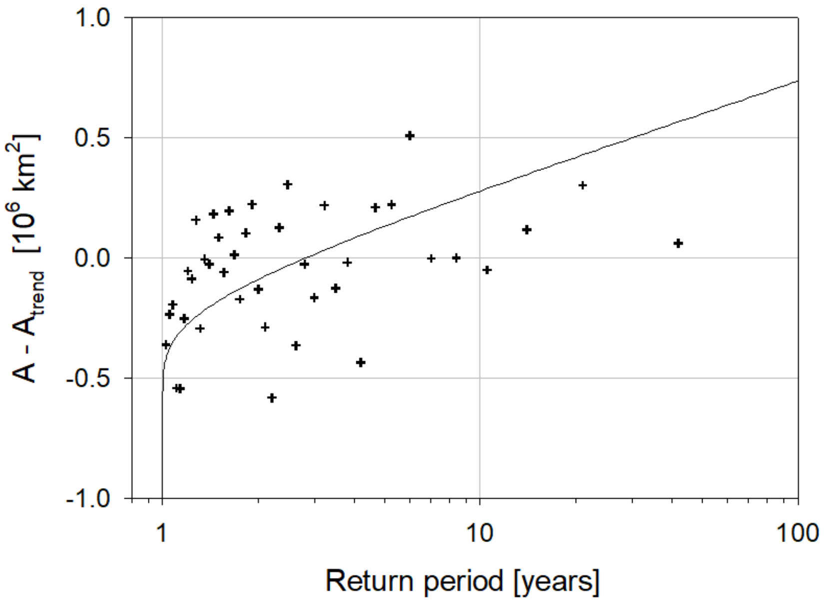

Fig. 4. A statistical plot of the ice extent data where a linear trend has been removed, plotted versus the return period. An extreme value distribution fit is also shown.

Anyway, a straightforward approach to ULS design ice extent would be to determine A_T with the lifetime of the structure (for example 25 years or 40 years into the future) and A_S using a return period of 100 years. A_S can be calculated by fitting a trend in values in Fig. 2 and then removing this trend. This is done using a linear trend and the resulting values are plotted in Fig. 4 where also the Gumbel 1 extreme value distribution is shown. The ULS value is about $0.7 \cdot 10^6$ km^2. Now the ULS design value would be (in this somewhat artificial example) $10.4 \cdot 10^6$ km^2 using 100 years from now for the trend – or $13.1 \cdot 10^6$ km^2 using just the lifetime of the project (40 years). It is seen that there is large difference in using the basic data or trend removed data. Uncertainty lies also in deciphering the trend. In the example here a linear trend to the whole database was used but some nonlinear trends could give better fit, or the fit for the trend could be done for part of the data. If some theoretical insight for the trend exists, then this could be used. The above analysis leaves anyway a large uncertainty for the value based on the trend. Perhaps the trend should also be considered as a statistical quantity – but in this formulation we have put all the statistics into the other part of the design quantity.

The above discussion on uncertainty concerning the trends in data due to climate change tries to highlight the problems the extrapolation to ULS/ALS values faces. Many designers (and also some ISO standards) consider that if there is a trend towards decreasing design values, this trend should not be taken into account. This leads to conservative designs but the problem still exists regarding how to use the present data as the trend makes the statistics (and especially the extrapolation to long return periods) uncertain.

2.2 Other Environmental Parameters

Natural parameters may be considered more or less predictable within acceptable uncertainty margins, whereas anthropic effects at least partly depend on political decision making. To handle the difficulty in predicting the results of political decision making, standard scenarios have been defined depending on the expected anthropic production of greenhouse gas corresponding to the resulting policies.

For example, concerning the air temperature, Document IPCC Climate Change 2013 The Physical Science Basis WG1 Chapter 14 table 14.1 page 1278 deals with regional temperatures and particularly the arctic is involved. Seasonal information is also provided indicating DJF (December, January, and February) and JJA (June, July, August). But local effects on air temperature, on the scale of an offshore field, remain to be established.

There is not always documentation, publications or research results to document the trend for each environmental parameter.

For some parameters, as water temperature, ice icebergs (number and size) or sea water level, the information to define a trend is available but needs to be more accurately analysed. For example, the evolution of wind in relationship with climate change is now very uncertain. This means in a first step that this uncertainty is to be evaluated carefully. This involves the global wind change, but also local wind change up to the scale of an offshore field.

Climate change may change the reliability of a marine structure for a structure designed according to a given set of rules. Structural design currently in BV Rules is based on a semi probabilistic format, involving a characteristic value, reference value for the design equation, and partial safety factor. Combining through the design equation the parameters with their characteristic values and partial safety factors fitted to obtain the requested safety factor allows us to obtain a design reaching the expected reliability.

Climate change leads to change the statistical approach to determine the probability law. To take into account climate change, the probabilistic model should involve time dependence for the stochastic parameters. Up to now, following the scientific documentation, the most investigated stochastic parameter is the temperature. Factors driving the temperature changes are shared into factors depending on the climate natural trend, and factors related to the human activity.

Factors depending on natural trends may be shared into periodic and non-periodic factors.

Some periodic factors are well identified (seasonal, or multi–years climate cycles, e.g. El Nino, North Atlantic Oscillation …)

The most critical issue is modeling of factors related to human activity, as on one hand the relationship between human activity and global climate temperature is not fully controlled, on the other hand the knowledge on the future human activity related to temperature is questionable as depending on political decision making and efficiency of these decisions. The easiest way to take into account effect of political decisions is to set up scenarios corresponding to decisions.

The number of climate scenarios available in the scientific documentations is limited as there are a cluster of decisions leading to the same mean target temperature change. Attributing a probability to each scenario is highly subjective. It is preferable to examine exhaustively all scenarios and set up a probabilistic model of above parameters within each scenario. After selection of the factors to be involved in the time correction, parameters are to be fitted to adjust the median. The residual scatter is then normalized such as the scatter is independent of time.

The scatter is then treated as a stationary process and as long as the sampling may be considered as a set of independent variables, the quantile corresponding to the Characteristic value may be determined. It is not obvious that the time dependent factors are following the same model for the mean value and the extreme values. This hypothesis is to be tested.

For example, the temperature probability law is to be expressed in the same format as the temperature probability law in the current analysis i.e. using an extreme value distribution. If no better approach is available, parameters of the extreme value law are to be corrected by adjusting the value corresponding to annual return period and hundred years return period with the temperature change due to climate.

The evaluation of the uncertainties regarding trends of environmental parameters shall be subject of additional studies in the future.

3. DESIGN CRITERIA FOR OFFSHORE FACILITIES

3.1. Current Practice

Offshore projects will usually have lifetimes of 20 – 40 years and are required to be designed for the extreme physical environmental effects which could occur during their lifetime. To achieve acceptable reliability, codes require design loads to be derived at a certain level of annual exceedance probability.

An annual exceedance of 10^{-2} is the first level to be assessed (the nominal the 100 year return period load) and this is combined with load and resistance factors and a “no-damage” limit state. Codes may also require the ALS to be checked at the 10^{-3} or 10^{-4} load level. For this load, the structure has to survive but can be significantly damaged (with no load factor).

Past practice in deriving these loads has been to look at contributing parameters and develop historical statistics for them (which are then combined into derivation of the design loads at certain probability levels). This approach essentially assumes that the future is the same as the past.

3.2. Accounting for trends and forecasts

Part of this study is focussed on how climate change may affect ice loads and whether any changes in the design approaches should be implemented. The motivation for the study is that there are observable trends in Arctic ice coverage as well as warming trends in Arctic temperatures which if continued would be expected reduce ice thickness and presence.

The study has reviewed reported trends in ice thickness, air temperatures, ice coverage and thickness. There is convincing evidence that Arctic ice areal coverage has diminished since 1980 especially the maximum summer extent (Areal reduction at about 15% per decade). Average thickness has also reduced, but this seems to be primarily due to less MY ice being present. Old MY ice (the really thick ice) has diminished from 16% in 1985 to about 0.9% in 2017 (The Arctic Report Card, 2017). It is this reduction of MY ice which leads to spectacular statements about the thinning of Arctic ice. For example Kwok and Rothrock (2009) examined submarine data from 1975 to 2000 as well as more recent satellite data up to 2008. The highest average Arctic pack ice thickness peaked at about 3.6m in 1980. It was thinner in the 70s and diminished to about 1.9m by 2008. This is a reduction of almost 50% and is often quoted and will be commented on again later.

On the other hand certain researchers who have focussed on ice thickness of specific ice features have seen little change (up to about 2016 anyway). Such data is illustrated in Figure 5 for Resolute in Canada.

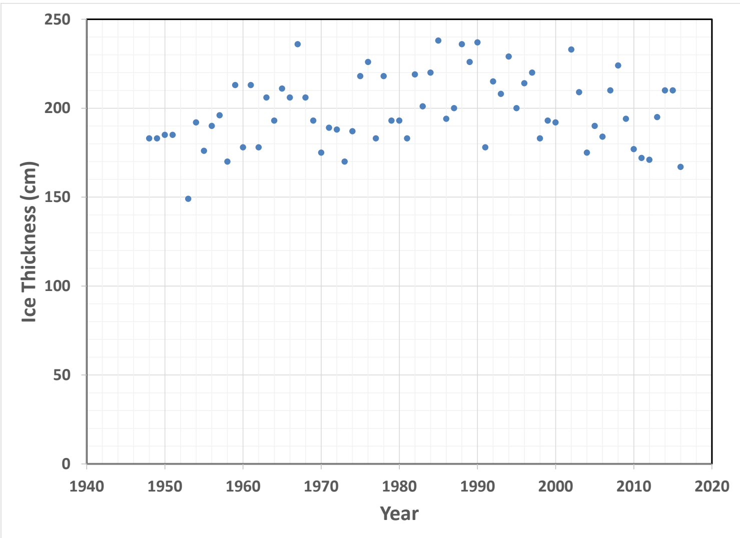

Figure 5: Measured maximum ice thickness 1948 to 2016 at Resolute, Canadian Arctic.

The study examined thickness data as well as accompanying temperature trends. Using established ice growth models based on air temperatures, sensitivities to various future warming were evaluated. For a typical Arctic location (Pond Inlet), and using historical data, the base-case 100 year ice thickness is 2.05m. Using adjusted freezing degree days based on a +2C warming, the 100 year thickness becomes 1.97m. Using a global +2C warming and assuming this leads to a +6C Arctic warming, gives a 100 year thickness of 1.83m.These reductions are not as much as one might expect and to some extent explain the real data shown in Figure 5 where trends seem to be within annual variability.

There are clearly uncertainties and difficulties in predicting future ice regimes, so ice loads and sensitivities have been developed for a number of potential scenarios and for various structure types and ice features.

3.3. Scenarios addressed

Three ice regimes were addressed in the study.

1) A region with only FY ice but severe ridges.
2) An Arctic region with MY ice
3) A temperate ice region (the Caspian Sea) with minimal ridges

Region 1) An Arctic region subject to only FY ice.

The base case values (pre-warming) were developed for 10^{-2} values for level ice and extreme ridges based on Pond Inlet (Canada) measurements and pre-warming temperatures. Two warming scenarios were developed; Scenario 1 is based on [1]CRUTEM temperature anomalies for Pond Inlet (giving about +2C warming); Scenario 2 is based on +2C global (+6C Arctic). Ice thickness change as in Figure 2 and also predictions for ridges were used as inputs to the ice loads calculated using current ISO (2010) methods on a 100m wide vertical structure; results are shown in Table 1.

Table 1: Typical Ice load design criteria sensitivities for level ice and FY ridges in the Arctic for two climate change scenarios

Load case (FY ice only)		Loads based on historical data 1960 - 1993	Loads based on Scenario 1: CRUTEM	Loads based on Scenario 2: Global +2C, Arctic +6C
Level Ice load (MN)		249	240	226
Ridge	Consolidated layer load (MN)	398	384	360
	Keel load MN)	44	41	37
	Total ridge load (MN)	442	425	397

The overall impression in looking at these results is that the changes in ice loads are not very significant. The changes are well within the range of load sensitivities which would be due to uncertainties in various input parameters and the ice load methodology itself.

Region 2: Arctic Region with MY Ice

Three “climate scenarios” were addressed
a) The percentage of MY ice stabilizes at the percentages noted above and loads compared to the “nominal 1985 loads”
b) All MY ice disappears and loads are due to FY ridges
c) The export of MY ice reverses and MY ice builds up again but at lower thicknesses based on a permanent increase in Arctic temperatures

Use was made of a prior study for the Beaufort Sea in which historical data had been used in a probabilistic model to derive the 10^{-2} loads for a 55 degree sloped cone in 40m of water (Thijssen et al, 2016). The base case load assuming the future would be the same as the past (ice data up to about 1985) was calculated at 995MN.

The outputs were then modified to address less MY ice as in scenario a) above. In this case the 10^{-2} load reduced to about 600MN.

Scenario b) also assumed a general global warming of +2C (Paris Accord) and that the Arctic would be three times warmer (+6C). Extreme FY ridges were synthesized for this warmer Arctic but were calculated to still be severe (e.g. A 10^{-2} ridge with a maximum average Consolidated Layer (CL) thickness of 4.4m and a keel 32m deep). This FY ridge load was estimated at up to about 430MN (depending on other inputs). So even without MY ice, a typical Arctic structure would experience significant loads

For Scenario c) use was made of deterministic calculations for MY ridge loads and assumed the design MY ridge reduced from 25m to 20m in the +6C warmer scenario. For this ridge the load was about 560MN.

These potential changes in MY loads from “the nominal -1985 levels” are significant. Mainly

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[1] CRUTEM is a dataset derived from air temperatures near to the land surface recorded at weather stations across all continents of Earth. It has been developed and maintained by the Climatic Research Unit **University of East Anglia,** since the early 1980s, with funding provided mostly by the US Department of Energy. It can be accessed via Google Earth

because of the trend to less MY ice which lowers the load for a given level of probability. The work also showed however that even if all MY disappears (no ice cover in the Summer), if the temperature anomaly is limited to +6C in the Arctic then loads from FY ridges can still be very significant for design. However mapping a way forward to make rational design choices is difficult because of the uncertainties relating to MY ice presence.

Region 3: Caspian Sea

For the Caspian Sea, use has been made of the extensive ice data gathering and probabilistic ice load modelling for the Kashagan Field (Jordaan et al, 2011). Within that modelling, sensitivities had been run for fewer FDDs (Freezing Degree Days) which drove the model. The base case had used data going back to 1901, so sensitivities had been run using the most recent 25 years of FDDs. These were also deemed compatible with the CRUTEM trends in temperature anomalies for Atyrau.

The base case 100 year load on a 100m structure at Kashagan East was derived as 78MN. Sensitivities were performed using more recent FDD data. Using the past 25years data the design load was reduced to about 60MN. On the other hand this was still using the same inputs for the length of ice moving past the structure annually. This would likely increase in a warmer world and the comparison with Kashagan West within the same study implied that more ice motion could increase the load by about 10MN. So the comparison would be more like 78MN reducing to 70MN. Not a big difference.

3.4. Ice Strength and Increased Ice Movement

Ice strength has been reviewed and it is concluded that for the few degrees of higher ice temperatures, the mid-winter ice strengths to be used in ice load models would not be significantly different.

Ice movements may be higher in a warming world. This tendency to more movement and possibly higher impact speeds may in certain scenarios actually increase the ice loads (As indicated in the Caspian case).

3.5. Discussion on ice load design criteria

Annual ice thickness measurements and predictions seem relatively insensitive to the warming trends to date. Therefore ice loads for platforms in first-year ice environments are not predicted to significantly reduce within the bounds of predicted temperature increases. In this study, reductions in 100 year loads in FY ice are about 10%. Ice season lengths will likely reduce but this does not affect the design ice loads.

The big change is in the Arctic basin where MY ice has reduced from about 16% in 1985 to 0.9% in 2017. This gives the spectacular reduction in average ice thickness often quoted for the Arctic and the reduction in Summer ice extent. The reduction in MY ice cannot be due to warming (in fact the thickness of MY ice, where stable in the channels of the Canadian Arctic Archipelago has not changed - at least up until about 2015). The mechanism for less MY ice seems to be one of ice export from the Arctic Basin. This still may be a climate change process, so the trend could continue and most expect that to be the case. Because of the reduction in MY ice occurrence, probabilistic ice load models give lower loads for Arctic structures. This study showed a reduction of the 100 year ice load on a structure designed for MY ice from about 995MN to 600MN due to the reduction from 16% to 0.9% MY ice presence. If the MY ice goes completely, the loads due to FY ice on the same platform are estimated to be 430MN – as significant load but also a significant reduction. This particular scenario has the most uncertainty.

The ice growth modelling used in this study although proven in a pre-warming world may need to be modified and recalibrated. Of concern is the effect of warmer water delaying freeze up (which has nominally been assumed not to change – although a sensitivity was done on this which resulted in a further small thickness reduction of a few percent).

Finally, probabilistic modelling should be used as the preferred tool to assess design ice loads at the required probability levels - as well as to conduct sensitivities.

4. RISK FRAMEWORK

As it was seen in the former chapters, the design and the operations of ships and offshore structures may be impacted by the climate change. At this level it is important to make the difference between environmental parameters on one hand and design and operational parameters on the other hand. The climate change, by modifying environmental parameters will influence both the design of new structures as well as the operations.

4.1 Environmental parameters

The environmental parameters impacted by the climate change are for example: air and water temperatures, ice interaction, sea states, wind, Polar lows, currents, sea level variation, additional snow and rain, increase of iceberg number and size…

As mentioned earlier in this article, the influence of climate change may be favourable or unfavourable on the design and operational parameters. For example, the reduction of ice may reduce the loads on the structures, but it may also lead to an increase in the force of currents.

4.2 Design parameters

The list of design parameters potentially impacted by climate change parameters include but are not limited to those in this section. They may be divided in different categories:

The hull scantling parameters categories includes: hull girder strength, Yielding/buckling extreme events, Fatigue loads, (repeated event), ultimate strength, stability, buoyancy, steel grades, hull strength against Ice, winterization, etc…

The hull and structure geometry parameters include for example: the draft & air gap of platforms, the design of forecastles, the mooring systems, and the design of the risers…

The parameters related to the soil data which are impacted by the mooring of floating platforms or the stability of the Gravity based platforms…

Each of these parameters may be impacted by changes in environment parameter.

4.3 Operational parameters

The operational assessment looks into each type of structure and its interaction with the environment.

Concerning the ship's operational parameters, the duration of operation (forward speed increased…), the speed reduction, the training and level of the crew can be considered.

Regarding the Offshore units, the operational parameters may include: the duration of operation, the ice management, the maintenance, the mooring system, the risers, the green water, the production…

The operational parameters may be influenced by the change of environment parameters.

4.4 Relation between environmental parameter and design parameter

Interaction assessment between the environmental parameter changes and design parameters is to be studied on a case by case basis, for each project and each Arctic area and condition. First the environmental and design conditions for each structure, such as location, and paths shall be analysed. The following table shows a relation between the 2 types of parameters.

Table 2: Matrix of Design Parameters versus Environmental Change parameters

Design Parameters	Environmental Change Parameters						
Hull Scantlings	Temperature	Ice efforts	Gas evaporation	Sea states	Wind Polar lows	Currents	Sea Level Variation
Hull Girder Strength		X		X			
Yielding/Buckling		X		X			
Fatigue		X		X			
Ultimate Strength		X		X			
Stability-Buoyancy		X	X	X			
Steel Grades	X						
Ice Class selection		X					
Cold notation selection	X				X		
Geometry							
Draft and Air Gap				X			X
Mooring				X	X	X	X
Gravity Based Platform				X	X	X	X
Soil							
Mooring				X	X	X	X
Gravity Based Platform				X	X	X	X

In this table all the environmental parameters impacted by the climate change are in the first line and a cross indicates which design parameter may be impacted.

This table constitutes a guideline for ship and offshore platform designers to carry out analyses of the impact Climate change may have on the structures.

4.5 Relation between environmental parameter and operational parameter

Afterwards, the operational parameters that are critical shall be assessed quantitatively in conjunction with the impact of the climate parameters.

Table 3: Matrix of Design Parameters versus Environmental Change parameters

Environmental Change Parameters	Operational parameters					
	Duration of Operation	Speed reduction	Production time	Ice Management	Maintenance	Mooring and Risers	Green water
Temperature				X	X		
Ice efforts		X	X	X		X	
Gas evaporation	X		X				
Sea states	X						X
Wind Polar lows	X			X	X		
Currents						X	X
Sea Level Variation							X
Number of Icebergs	X	X	X	X	X	X	
Increase snow				X	X		

Table 3, shows all the environmental parameters impacted by the climate change in the first column and a cross indicates which design parameters may be impacted.

This table constitutes a guideline for ship and offshore platform operators to carry out analyses of impact Climate change may have on the structures.

4.6 Risk analysis

Both design and operational parameters will vary from project to project, therefore an exhaustive list of design parameters is to be compiled along with the detailed list of operation parameters impacted by climate change effects. Once the list of parameters has been defined, a HAZID (Hazard Identification) and HAZOP (Hazard and Operability) study shall be performed in order to evaluate the risk. The HAZOP will identify the abnormalities in the environment and workplace operations, identifying the aspects where injury or loss of life could be encountered.

This allows to take the necessary measures to avoid these circumstances. HAZID, will be performed as early as possible in the design assessment process and it provides a qualitative analysis in order to determine the risk level.

The HAZID will be used to determine what Polar class shall be taken into consideration throughout the design and the HAZOP will be used to evaluate how the operational aspects can take place and minimize the risk either through the design or through the choice of route or location etc.

Once the above has been completed for the 3 Operational, Environmental and Design Parameters, the higher risk ranked items are to be identified and assessed as noted in the risk rank I and II respectively.

5. CONCLUSION

Trends have begun to form regarding the climate change effects throughout the world. Whether certain environmental parameters will increase or decrease through the years to come is not yet clearly determined. The goal, then, is to assess ways in which a designer can take the present data and foresee the possible impacts on offshore and marine structures. How the projected trends will truly play out is a question. Industry needs to cooperate as climate change brings an increasing uncertainty.

The study showed that ice loads for platforms in first-year ice environments are not predicted to significantly reduce. Conversely, if a climate trend could result in lower environmental forces, it is recommended to take the advantage of such trends only with a high level of confidence. Probabilistic modelling should be preferred tool to assess design ice loads.

As the Climate Change has become a reality and seems to be accelerating and progressing faster, it is recommended to take this evolution both at the design stage and for operation of Arctic structures, into account. For that, this risk analysis is a good means to address these risks.

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