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FREQUENCY OF SEA ICE AND ICEBERGS AT SKRUGARD – BARENTS SEA

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ABSTRACT

As the developments of oil and gas fields in the Norwegian part of the Barents Sea grows Northwards, there is an increasing risk for interactions between offshore structures and sea ice or icebergs As a part of the Skrugard development, specific studies have been carried out to estimate frequency of occurrence of sea ice and icebergs at the Skrugard location. The frequency of sea ice was found by extrapolation of ice charts while the frequency of iceberg encounters was found by drift model simulations. It was found that sea ice with a concentration of 1/10 or more will occur statistically with a recurrence period of once per 2400 years. The encounter frequency of icebergs within a 100 m diameter circle centered at Skrugard was found to be $2.6 \cdot 10^{-5}$encounters per year.

INTRODUCTION

The Skrugard field is an oil field discovered in the Norwegian part of the Barents Sea in 2011 (Figure 1). Prior to concept selection, the probability for interactions between at structure at the site and sea ice as well as the probability of impacts between structure and icebergs needed to be quantified. This paper describes the work done in order estimate these probabilities.

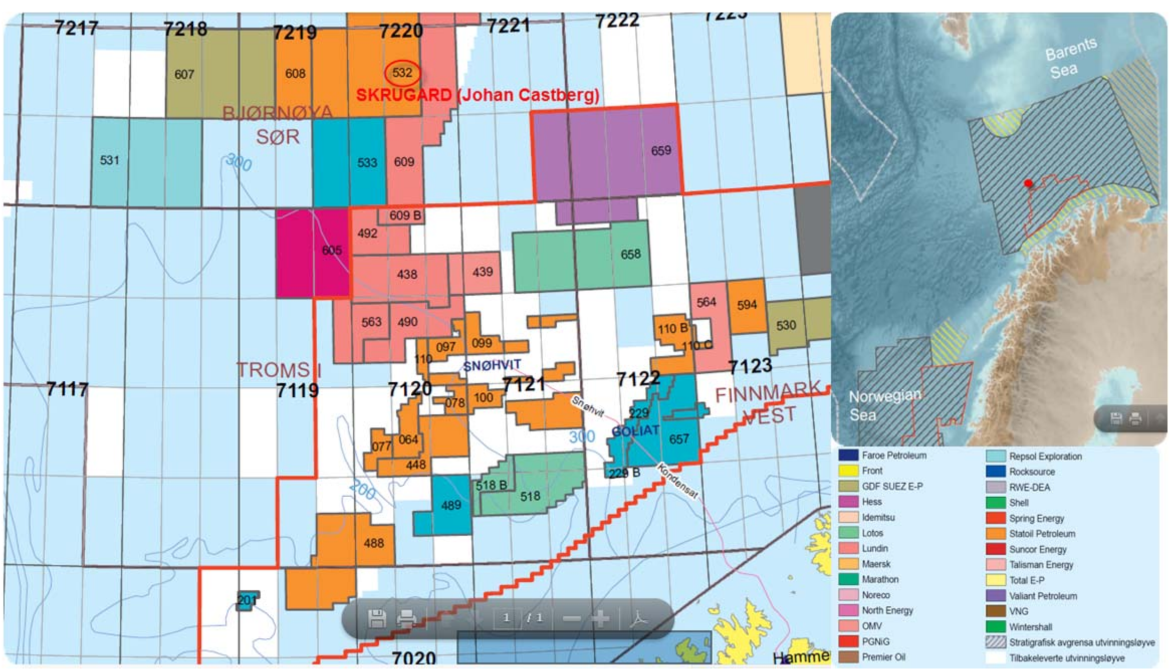

Figure 1. Location of the Skrugard field in the Barents Sea

ICEBERG ENCOUNTER FREQUENCY

Atlas of Arctic Icebergs (Abramov, 1996)

The Atlas of Arctic Icebergs is a summary of existing data on iceberg distribution in the Arctic Seas and is a very good first source for evaluations of iceberg presence. The main sources for the Atlas are ice charts of aerial surveys. 96% of the iceberg data was obtained from ice reconnaissance flights while about 4% are from shipboard observations. A minor portion of observations (0.1%) were obtained either by satellite observations or observations at coastal polar stations. Within the period 1950-1993 there were in average about 25 flights per year in the Barents Sea. The number of flights over the Barents Sea varied with seasonality with a peak usually in September. The maximum zone of survey along the aircraft route was reported to be no more than 15-20 nautical miles even with good visibility.

Abramov (1996) plotted all recorded iceberg observations for particular months into appropriate cells of regular 100x100 km mesh. The total numbers of icebergs were added for each cell and for each period of time. Based on the multi-year series of observation data, the maximum and mean values for icebergs within each cell were plotted on charts. The occurrence probability of icebergs was estimated by the relationship:

$$P = 100 \cdot \frac{m}{n} \tag{1}$$

where P is the probability of occurrence (in %), m is the number of years when icebergs occurred in the given cell and n the total numbers of observations for the given cell. Based on these probability estimates, Abramov (1996), developed contour lines with constant annual probability of iceberg occurrence (Figure 2). The estimated annual probability of an iceberg in a 100 x 100 km cell in the Skrugard region is approximately 0.01 meaning one iceberg intrusion within the cell in a 100 year period.

Abramov (1996) did also present occurrence probabilities for different iceberg shapes. Based on the flight information about 67% of all observed icebergs in the Barents Sea were Bergy Bits (sail in the range 1-5 m, length in the range 5-15 m), about 9% where Growlers (sail less than 1 m) while about 24% of the observations were of icebergs larger than Bergy Bits and with different shapes.

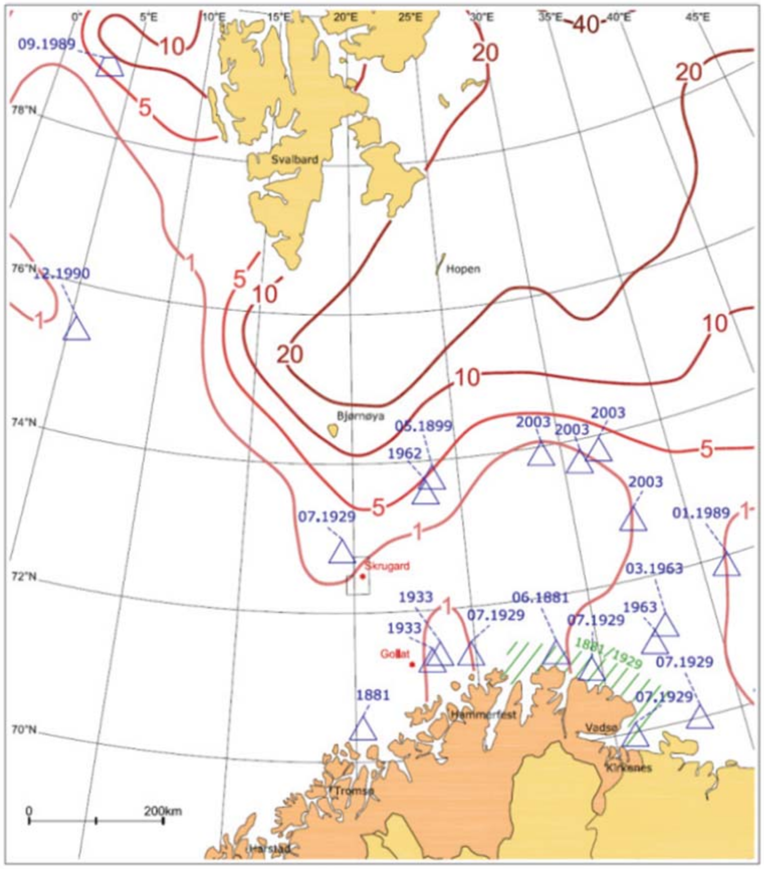

Figure 2. Iceberg occurrence in the Barents Sea. The contour lines are the annual probability (%) of occurrence of icebergs in a 100 x 100 km cell. Triangles and shaded areas are abnormal observations of icebergs. The map is prepared by Multiconsult based on figures in Abramov (1996).

Iceberg drift modelling

When considering concepts for the Skrugard field, the expected annual number of impacts between an iceberg and a structure need to be estimated. Further, if the frequency of impacts is sufficiently high the actions from impacting icebergs will also need to be assessed in order to evaluate the probability of structural failure. In order to be applicable for all sorts of concepts, the encounter rate within areas of different sizes is useful. There are different ways of calculating encounter rates whereof the “swept area approach” developed by Fuglem et al. (1996) is most recognized. Eik and Gudmestad (2010) highlighted the need to know the iceberg residence time within an area in order to estimate the average areal density of icebergs and presented an alternative approach by using iceberg drift simulations for encounter estimates. In the present work, an iceberg drift model for the Barents Sea has been applied in order to estimate iceberg residence time within a 100 x 100 km are centered at Skrugard.

The iceberg drift model and quality of simulated drift trajectories was presented by Eik (2009a). Despite some obvious weaknesses due to limitations in oceanographic models, the iceberg drift model is still found adequate for encounter estimates; the general ocean circulation is assumed to be described properly, tidal variations are included and wind and wave forcing is well described. The iceberg drift model incorporates current, wind and wave hindcast data covering the entire Barents Sea within the period 1987 to 1992. The historical iceberg drift of an observed iceberg may be calculated by solving Newtons second law where the wind, wave and current forces need to be balanced by iceberg mass and acceleration. Details can be found in Eik (2009a).

A Monte Carlo simulation was performed in order to estimate how long time icebergs would tend to stay within a 100x100 km cell around Skrugard. Icebergs were simulated by first pulling a random number from the iceberg length distribution. Secondly an observation date was pulled out randomly within the period 01.01.1987-31.12.1992. Thereafter, an artificial observation position was pulled out randomly along the borders around the 100x100 km cell. Since icebergs are expected to approach into the cell mainly from the North, 75% of all the icebergs were distributed randomly along the Northern border of the cell. 20% of the icebergs were distributed randomly along the Eastern border, 4% along the Western border and 1% along the Southern border. Reason for this is the assumption that the main source of icebergs into the region are the glaciers at Frans Josef Land and the second source are glaciers on the Northern part of Novaya Zemlya. Some icebergs may also come from Svalbard if they escape the shallow fjord areas at the East coast. Once distributed with size, time and location, drift simulations were started and would continue until the iceberg would leave the 100 x 100 km cell or be completely deteriorated (i.e. length less than 1 m). The time from start till end of simulations were recorded and used as a basis for estimate on residence time.

An iceberg waterline length distribution taking into account the high number of bergy bits was applied in the simulations. In accordance to the distribution more than 65% of the icebergs are Bergy Bits ($15\,m \leq l \leq 30\,m$) while the remaining 35% are longer. This is somewhat conservative compared to the information provided by Abramov (1996) on iceberg size distributions.

The iceberg widths where assumed to be 2/3 of the waterline length while the sail height was assumed to be 1/7 of the iceberg draft.

In total, 10 000 icebergs were generated and simulated. Amongst these only 4139 entered into the cell while the remaining would drift away from the cell. Reason for this is that both waves and currents would tend to move the icebergs towards East-NorthEast most of the time. Amongst the iceberg entering into the cell 3586 icebergs were simulated until they left the cell while 553 simulations were stopped because the icebergs were fully deteriorated. The deterioration in this part of the Barents Sea is expected to be significant due to the combination of warm incoming water from the Gulf stream combined with relatively high waves. Information on the deterioration contributions in the iceberg drift model is given in Eik (2009b).

Estimation of iceberg encounters at Skrugard

The “swept area approach” presented by Fuglem et al. (1996) has been applied in order to estimate the iceberg encounter rate in circles with diameters of 100 m , 300 m and 500 m centered at Skrugard (72.48°N, 20.32°E)

In brief, this approach is based on an iceberg areal density estimate. The encounter probability for all iceberg lengths in all environmental conditions is then summed up. The encounter probability for one single iceberg is calculated from the ratio between the area swept by the iceberg and the total area considered when calculating the areal density estimate of icebergs:

$$p_e = \frac{(w_i + w_s) \cdot v_i . \Delta t}{A} \tag{2}$$

where p_e is the probability of collision during time Δt. w_i is the iceberg width, w_s is the structure width[1], v_i is the mean iceberg drift speed and A is the regional area through which the iceberg is transiting. The total annual expected number of iceberg encounters (η_e) is expressed by (Fuglem et al., 1996):

$$\eta_e = \rho_a \cdot (w_s + \overline{w}_i) \cdot \overline{v}_i \cdot T \tag{3}$$

where ρ_a is the average areal density of icebergs per year (number of icebergs per unit area), $\overline{w}_i$ is the mean iceberg length, $\overline{v}_i$ is the mean iceberg drift speed and T is the number of seconds per year. It should be noted that the iceberg length is conservatively chosen to represent the swept iceberg width.

From observations of icebergs in the Barents Sea based on several sources, the mean iceberg waterline length, $\overline{w}_i$, is estimated to 48 m. Based on iceberg drift observations during the IDAP campaign in the Barents Sea (Spring, 1994), the average drift speed was found to be 0.19 m/s while the average drift speed from simulated icebergs in this work was as high as 0.44 m/s. Reason for the very high drift velocities in the simulations is explained by the relatively severe wave climate in the Skrugard region. The higher of these two has been applied in the estimates of iceberg encounters since this correspond to the estimated residence time. It should however be noted that this also will include some conservatism. This is caused by using a constant wave coefficient in the simulations. The large portion of Bergy Bits will not be able to reflect much of the incoming waves and will thus not experience the large net drift indicated by the calculations.

With respect to the average areal density of icebergs per year, ρ_a, this is calculated as follows:

$$\rho_a = \rho \cdot R \cdot p \tag{4}$$

where ρ is the crude areal density (not averaged over time), R is the iceberg residence time within the cell and p is the annual probability of occurrence. In accordance to Abramov (1996), the annual probability of an iceberg per 100 x 100 km^2 is 1/100. Given that an iceberg is within the cell, the areal iceberg density is at least $\frac{1}{10\,000\,km^2}$. Considering the uncertainties regarding the iceberg detections and the high probability of not being able to detect Bergy Bit from the reconnaissance flights, it has however been found rational to assume that for each iceberg detected two minor icebergs were missed. The areal iceberg density, ρ, is thus estimated to $3 \cdot 10^{-4}\frac{icebergs}{km^2}$. From the iceberg drift simulation the average residence time was found to be 37 hours. Since we are assuming 3 icebergs totally within the cell in a 100 year period we get:

$$\rho_a = \frac{3}{100 \cdot 100 \cdot 10^6} \cdot \frac{37}{365 \cdot 24} \cdot \frac{1}{100} = 1.2671 \cdot 10^{-14} \text{ icebergs per m}^2 \text{ at any time} \tag{5}$$

[1] In the present work, this is the same as the circle diameter considered. Different structures with different shapes and drafts has not been considered.

Consequently, the annual number of icebergs encountered is:

$$\eta_e = 1.2671 \cdot 10^{-14} \cdot (w_s + 48) \cdot 0.44 \cdot 365 \cdot 24 \cdot 3600 \text{ encounters per year} \quad (6)$$

Table 1 shows the estimated annual encounter frequency for circular areas with different size. It must however be emphasized that there are significant uncertainties related to these estimates. The numbers represent a "best estimate" while in reality the encounter frequency may very well be of an order higher or lower, i.e. in the range between 10^{-3} to 10^{-5} per year (for a 500 m wide circle). Projects are encouraged to seek robustness when considering specific platform concepts in the Arctic. Operational mitigations such as disconnection capabilities or active iceberg management may be considered. Ideally, the encounter frequencies can be reduced about 80% if a proper iceberg management system is in place (Eik and Gudmestad, 2010.

Table 1. Annual iceberg encounter frequency at Skrugard.

Diameter of area considered	w_s=100 m	w_s=300 m	w_s=500 m
Iceberg encounters per year	$2.6 \cdot 10^{-5}$	$6.1 \cdot 10^{-5}$	$9.6 \cdot 10^{-5}$

EXTREME AND ABNORMAL SEA ICE EXTENSION

In order to know whether sea ice needs to be taken into account in design considerations for Skrugard, the sea ice extension corresponding to extreme and abnormal events have been estimated. With extreme, it means the extension that is exceeded once during a 100-year period while abnormal means the extension exceeded one time during a 10 000 year period. The distance from the ice edge to Skrugard during these events have been estimated.

Ice charts

Sea-ice charts for the period 1967 to 2012 have been analyzed. Charts for the period 1967-2002 are gathered from the "ACSYS Historical Ice Chart Archive (1553-2002)" (ACSYS, 2003). Charts for the period January 2003-March 2005 and January 2006–October 2012 have been received from Istjenesten (Ice Service) at met.no, Tromsø.

The files (shapefiles) have been gridded and converted from GIS data format to ascii text files prior to analysis. The resulting gridded files have a 0.14° x 0.14° resolution.

Spatial extrapolation of ice charts

The following describes the steps performed in the analysis:

1. All sea-ice with concentration exceeding 10% is counted as ice. Any sea-ice with less concentration is not detected and hence not classified in the ice charts.
2. The southernmost position, north of 71°, of sea-ice in each year, for each longitude between 10°E to 30 °E, with a 0.14° step, is registered as the annual maximum extension. The annual maximum extension may consist of longitudinal maxima taken from different charts (times) within each year. This means in practice that the annual maximum ice extent may not have been observed as an ice border at any time, but is a constructed annual maximum.

3. A matrix consisting of the annual maximum extent given as the latitude (°N) for the period 1967-2012 is then created.
4. The annual maxima are redefined as distance to 90°N, so that higher values indicate larger extent.
5. A Gumbel distribution is then fitted to these values for each longitude between 10°E to 30 °E, with a 0.14° step. For each longitude the values with annual probability of exceedance of 10^{-1}, 10^{-2} and 10^{-4} is registered.
6. The extreme values are then defined back to latitude (°N).
7. Prior to plotting, the extreme extents are smoothed using a running average. The resulting extents have approximate 30 km resolution.

The resulting contours along constant values for extent exceedance are shown in Figure 3 together with maximum ice extensions for each individual year within the period 1967-2012. It can be seen that Skrugard is about 55 km to the North of the ice extension exceeded once per 10 000 years. By applying the Gumbel distribution[2] valid for the same longitude as Skrugard (20.32°E), it is possible to read the frequency of sea ice at the site. It was found that approximate statistical recurrence period of sea ice is 2400 years.

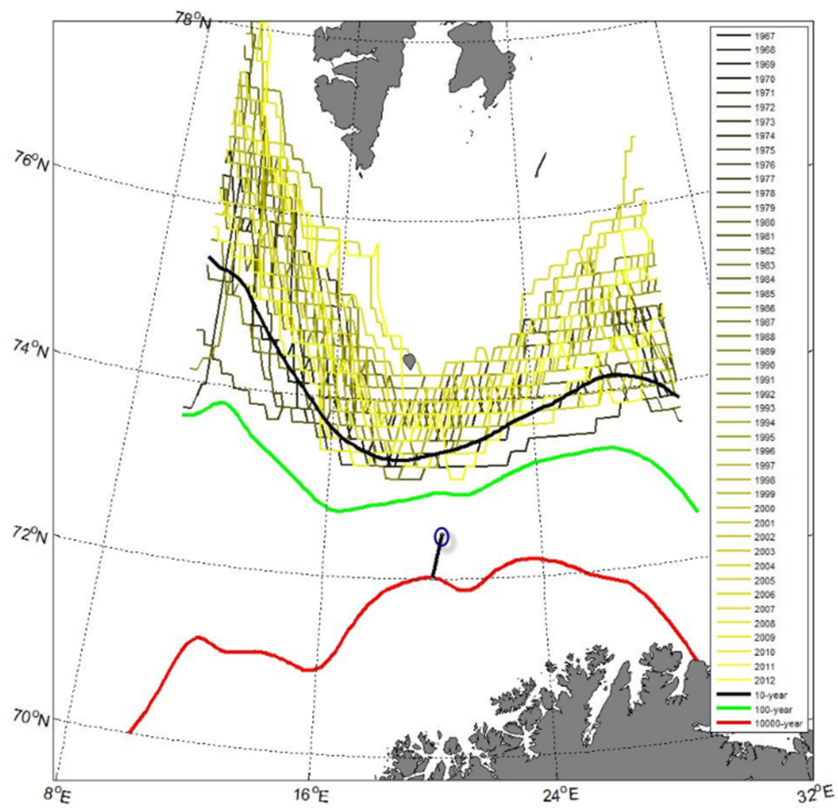

Figure 3. Limits of sea ice extent in the western Barents Sea with annual probability of exceedance of 10^{-1}, 10^{-2} and 10^{-4}. The Skrugard location is marked with a blue circle. A black line shows the shortest distance to the ice edge in an abnormal ice extension event (i.e. 10 000 year maximum). The maximum ice extension in individual years is shown with thin yellow and black lines.

[2] Gumbel parameters: Scale=0.18; Location=16.12 [°]

Discussion and results – sea ice frequency

It should be emphasized that the suggested approach is based entirely on a statistical treatment of existing ice data. In order to get sea ice as far south as Skrugard there need to be persistent Northerly winds for a longer period or alternatively, the amount of warm incoming water from the Gulfstream need to be reduced. Generally, the warm water being fed into the Barents Sea will act as a buffer impeding the ice to form in the region and even to drift into the region. This is only partly taken into account when extrapolating the ice charts and thus the maximum 100 year and 10 000 year extensions can be considered as conservative estimates.

Considering the uncertainties related to extrapolation of ice edges, precautions should be made when applying 10^{-4} estimates on sea ice frequency. The borders shown in represent a "best estimate" thus the estimated 10^{-4} border can potentially be reached with a frequency in the range 10^{-3} to 10^{-5} per year. Projects are encouraged to seek robustness when considering specific platform concepts and their ability to resist ice actions.

SUMMARY

The frequency of sea ice and icebergs at the Skrugard field has been estimated.

The expected iceberg residence time for icebergs in a 100 x 100 km cell at Skrugard was estimated to 37 h by use of a numerical iceberg drift model. The associated iceberg drift speed was estimated to 44 cm/s. The high velocity is explained by the relatively severe wave conditions in the region. The encounter frequency within a 100 m diameter circle is estimated to $2.6 \cdot 10^{-5}$ [encounters/year].

The frequency of sea ice as far South as Skrugard is, based on extrapolation of ice charts, estimated to once per 2400 years. In an abnormal ice extension event, the ice edge will be approximately 55 km to the South of Skrugard.

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