# Appendix A

# Metocean & Ice Data

# A.0 METOCEAN & ICE DATA

Appendix A contains metocean and ice information which was collected as part of this study. This information was considered and used in identifying analogue areas and assessments of technology. For convenience of collection and presentation the information has been captured in tabular format – there are 13 tables in total. General table formats and parameters were selected to focus and aid in subsequent information collection.

A significant search for metocean and ice information was conducted. Some examples of information sources researched include reports, journals, papers, texts, and presentations. The reader should note, however, that in some cases certain information was not able to be found (e.g. ridge dimensions or frequencies). If possible in such cases, a description or related parameter was typically provided to aid in characterizing the environment. In addition, notes/comments, and in some instances direct quotations from source(s) were provided for context and/or for further explanation. For convenience, the information is adequately referenced so that the reader may obtain the sources if further basis or background is sought.

Where possible, metocean and ice information was obtained for specific areas of development or exploration. For example, information for the Alaska OCS study areas (the Beaufort, Bering, and Chukchi Seas) was collected for particular locations and water depths, where available. Collection of information for analogue areas was carried out in the same manner. For example, Barents Sea information collection focused on the *Shtokman* field area. In absence of specific information, general sea/regional metocean and ice values were collected.

Table A-1: Beaufort Sea Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 10.4 (-12)[a] | Annual average temp. |
| Temp – Min, °F (°C) | -59.8 (-51)[a] | |
| Temp – Max, °F (°C) | 86 (30)[b] | |
| Winds – average, kt (m/s) | 11.5 / 10.2 (5.9 / 5.2)[a] | Deadhorse / Barter & Barrow (annual mean winds) |
| Winds – 10 year, kt (m/s) | 47.9 / 69 (24.6 / 35.5)[b] | Pt. Barrow / Barter (no value found for Oliktok) |
| Winds – 100 year, kt (m/s) | 70.3 / 76.8 / 97.9 (36.2 / 39.5 / 50.4)[b,c] | Pt. Barrow / Oliktok Pt. / Barter |
| Gust over 3 seconds, kt (m/s) | n/f | Highest and most frequent gusting winds occur in Sept. – Nov.[a] |
| Prev. Wind – Winter | WSW[a] | ~December – March (Deadhorse) |
| Prev. Wind – Summer | ENE[a] | ~Rest of year (Deadhorse) |
| Waves – yearly average Hs, ft (m) | 7.6 (2.3)[a] | Easterly storm (data from *Northstar* EIS for Seal Island area (approx. 11m water depth)) |
| Waves – 10 year extreme Hs, ft (m) | 10.8 (3.3)[a] | Westerly storm (data from *Northstar* EIS for Seal Island area (approx. 11m water depth)) |
| Waves – 100 year extreme Hs, ft (m) | 19.9 (6.1)[a] | Westerly storm (data from *Northstar* EIS for Seal Island area (approx. 11m water depth)) |
| Waves – period (sec) | 7.0 / 8.3 / 10.9[a] | Associated periods (1/10/100-yr waves) |
| Max. Current top/bottom, ft/s (cm/s) | ~3.8 / 1.6 – 3.3 (~115[c] / 50-100)[d,*] | *Below the surface waters, near shelf break, a narrow current moves to the east @ up to 50-100 cm/s (daily means)[d] |
| Storm surge tide, ft (m) | 1.1 (0.34)/ 4.1 (1.2)[a]<br><br>3.0 (0.9)/ 6.5 (2)[a] | - Annual / 100-yr Seal Island<br><br>- Common / Occasional along coast |
| **Other Metocean Information Findings** | - Suggested maximum wave height for Beaufort Sea is 12m[e] | |
| **Ice** | | |
| Typical duration | 9-10 months per year[a] | Polar pack ice can be brought into the area by winds during summer. |
| Typical Months of cover | >5/10ths coverage (begin Nov to mid-May)[f] | - 10/10 cover in mid-winter |
| Ice thickness, ft (cm) | 5.9 – 6.6 / 9.8 – 16.4 (180 – 200 / 300 – 500)[h] | First-year (undeformed) / multi-year |
| Old ice max. concentration/season | 3/10ths[g] | Mean concentration of multi-year ice between Barrow & Harrison Bay[g].<br><br>Note: After severe winters, multi-year concentration along the coast (near Point Barrow) can approach 100% throughout summer[f]. |
| Old ice 5 year extreme concentration | 4/5ths[g] | 10-yr return period for multi-year ice between Barrow & Harrison Bay |

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| Max ridged area/season | 3-7 / km[g] | Ridging is most severe between 20 – 80 km from the coast and usually increases from east-west[g]<br><br>"Grounded ridges first form just outside the Barrier islands in ~8-15 meters of water; by late winter they may extend beyond the 20-m isobath"[c]. |
| 5 yr max ridged area/season (%) | 10[b] | |
| Mean max ridge height/season, ft (m) | 3.3 – 6.6 (1 – 2)[h] | "The height of most ridges appears to be about 1 – 2 meters; ridge heights up to 6.4 meters have been observed" |
| Total ridge thickness, ft (m) | Suggested ridge sail-to-keel ratios: first-year 1:4.5; multi-year 1:3.3[h] | Shear zone ridge observations (in 1976) [g]<br>- Avg. draft = 12.2 m<br>- Max. draft = 28.8 m<br><br>- Polar pack ridges with mean drafts of 11.8 m and max. drafts of 31.1 meters have been observed[g] |
| Floe Sizes, miles (km) | 0.3 – 6.2 (0.5 – 10)[h] | "Undeformed ice floes with diameters greater than 500 meters occupy about 60% of the pack-ice zone; some floes may have diameters up to 10 kilometers"[h].<br><br>- Typical floes near-shore have diameters ranging up to 1 km[f] |
| Ice movement/Velocity, ft/s (m/s) | 0.3 – 3.3 (0.1 – 1.0)[f] | - General movement rate range<br><br>- The long-term direction of ice movement is from east to west in response to the Beaufort Gyre (5-10 cm/s)[h]<br><br>- Maximum reported landfast ice movement rates = 10-50m/hr[f] |
| Icebergs mean size above water | 1km x few m high[b] | Stamukhi[b]<br><br>- Probability of structure (in Canadian Beaufort Sea) being struck by an ice island is 0.001 (1000-yr event)[f] |
| Icebergs max size above water | 40 x 4km x 10m high[b] | Stamukhi grounded in 20m waters off Oliktok Point. |
| Fast ice – extent, miles (km) | 5 / 50 (8 / 80) | Barrow / Harrison Bay[l]<br><br>- Land fast ice zone is essentially defined by Stamukhi which occur at the 20-m isobath (extending about 25 – 50km from shore)[f] |
| Fast ice – thickness, ft (cm) | 6.6 (200)[c] | (By late winter and is frozen to the seabed out to 2 meters) |
| **Other Ice Information Findings** | - The transition zone, where intense ridging and shear occurs, generally lies between approx. 20 – 60 km from shore in water depths of 20 - 100m[f]<br>- Ridging typically occurs in the shear/transition zone, but can also occur in the floating fast ice zone[a]<br>- "Occasional westerly winds during ice-free summer can bring ice floes from the polar pack to shore or inside the barrier islands"[a] | |
| **Other Findings** | Typical Design Loads (for structure in 30m water depth)[j]<br>100-yr ice load = 100,000 tonnes<br>Design wave load = 35,000 tonnes | |

Note: n/f = Not Found / Available

[a] US Army Corps of Engineers (1999)
[b] Source: CANATEC Associates International Ltd.
[c] MMS (2002)
[d] MMS (2007c)
[e] Fitzpatrick, 1994
[f] Sanderson (1988)
[g] Cammaert and Muggeridge (1988)
[h] MMS (2003)
[i] Brower et al. (1988)
[j] Kennedy et al. (1994)

Table A-2: Chukchi Sea Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 0 to -22 / 32 to 45[a] (-18 to -30 / 2 to 5) | Winter / summer mean temperature ranges |
| Temp – Min, °F (°C) | -56.2 (-49)[b,c,d,e] | |
| Temp – Max, °F (°C) | 80.6 (27)[c] | |
| Winds – average, kt (m/s) | 5.8 – 9.7 (3 - 5)[a] | "Moderate winds of 3-5 m/s much of the year" |
| Winds – 10 year, kt (m/s) | 41 (21)[e] | 6-hr wind duration; ~10m above sea level |
| Winds – 100 year, kt (m/s) | 62 (32)[e] | 6-hr wind duration; ~10m above sea level |
| Gust over 3 seconds, kt (m/s) | ~71 (~37)[e] / 106 (~55)[e] | For 10 / 100-yr return periods; ~10m above sea level |
| Prev. Wind – Winter | 'Northerly'[a] | NE (in eastern sea); NW (in western sea) |
| Prev. Wind – Summer | NE-SW[b] | NE is mean direction for all months except July (SW) |
| Waves – yearly average Hs, ft (m) | <4.9 / <8.2 (<1.5 / <2.5)[b] | 'Typical' values summer / fall[b] |
| Waves – 10 year extreme Hs, ft (m) | 20.0 (6.1)[e] | For water depths >= 140ft (~43m) |
| Waves – 100 year extreme Hs, ft (m) | 29 (8.8)[e] | For water depths >= 140ft (~43m) |
| Waves – period (sec) | 12.2 / 10.2[e] | 100-yr / 10-yr Significant waves |
| Max. Current top/bottom, ft/s (cm/s) | 5 / 2.3 (152[d,*] / 70[e]) | 100-yr return period conditions; 140ft (~43m) water depth[e]<br><br>*Extreme current conditions = 200cm/s[d] |
| Storm surge tide, ft (m) | 9.8 (3)[d]<br>10.8 (3.3)[f]<br>6.9 (2.1)[e]<br>15.4 (4.7)[e] | Storm surge data points found:<br>1) At Point Lay<br>2) Near Wainwright, water depth 37 m<br>3) 100-yr total rise offshore (in 43m water depth)<br>4) Shoreline water depth |
| **Other Metocean Information Findings** | "The most severe surges, often accompanied by high waves, occur during September & October when storm frequencies are highest and open water exists."[f] | |
| **Ice** | | |
| Typical duration | 7 – 10 months[a] | Annual Arctic pack ice coverage of Chukchi shelf |
| Typical Months of cover | Generally min. extent in Sept & max. in March[a] | - 80% ice-free @ height of summer (mid-Sept.)[a]<br>- Nov-May: 97% sea ice coverage[b] |
| Ice thickness, ft (cm) | 3.9 – 4.9 / 9.8 – 16.4 (120 – 150* / 300 – 500)[a] | Historical thicknesses of first-year floes / multi-year floes |
| Old ice max. concentration/season | 9+/10ths (@72 – 73°N)[g] | Extent of polar pack ice (>= 5/10th multi-year ice concentration) edge is usually at 71°N, although in extreme years it can extend to 69°N. |
| Old ice 5 yr extreme concentration (%) | 20 / 80[h] | 10-yr return south / north multi-year ice concentration. |

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| Max ridged area/season | 60 to 90%[d]<br><br>3-10 ridges/km[h] | "In Chukchi, the region of most intense ridging occurs in water depths of 15-40 m; moderate ridging extends seaward and shoreward of these regions."[a] |
| Mean max ridge height/season, ft (m) | 5.2 (1.6)[h] | - Mean ridge sail heights of up to 1.6m peak in the vicinity of the 30 m contour[h]<br>- Pressure ridges are found with sail heights of 5 to 6 meters[f]<br>- Ridge height of 38ft (11.6m) recorded between 70°N-72°N[g]<br>- Additional ridge height distribution data can be found in Wilson et al. (1982) (noted below) |
| 1st year ridge thickness (m) | - | - Extreme first-year ridges can reach 18-20ft (5.5-6.1m) in height[g] |
| Max. multi-year ridge thickness, ft (m) | > 90 (> 27)[g] | "Thicknesses in excess of 90ft (~27m) will be associated with multi-year pressure ridges." |
| Flow size (km) | See Below | - "Large flows with diameters ranging from 0.5 to 10 km have been observed in 30-40-m isobaths between Cape Lisburne and Barrow."[c]<br><br>- Information on Chukchi Sea flow size distributions found in INTEC (1991), as noted below. |
| Ice movement / Velocity, kt (cm/s) | Avg. ice speed: 0.2 – 0.4 (~10 - 20)[g]<br><br>Peak velocities: > 3 (154) | - Ice motion in the Chukchi is very dynamic[g]<br>- Pack ice in N. Chukchi generally moves in westerly direction due to Beaufort Gyre, while in the S. Chukchi movement is generally north or NW[a]<br>- Ice can move 10-20 km/day; anecdotal reports of ice movements up to 6 knots[f] |
| Icebergs mean size above water | - | Floebergs & ice islands (islands range up to 1,000 sq.km or more with thicknesses up to 60m)[a] |
| Icebergs max size above water | - | Floebergs & ice islands (islands range up to 1,000 sq.km or more with thicknesses up to 60m)[a] |
| Fast ice – extent, miles (km) | 18.6 (30)[d] | 50 km in large bays; 3 km at headlands[d] |
| Fast ice – thickness, ft (cm) | 5.9 – 7.9 / 2 – 3.9 (180 – 240 / 60 – 120)[c]<br><br>5.5+/-3.3 (167+/-100)[a] | North / South (of Icy Cape)[c]<br><br>Near Pt. Barrow[a] |

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| **Other Ice Information Findings** | MMS (2007b)<br>- See Figure IIIA-13 for max. ice free water in Chukchi Sea<br><br>MMS (1990b)<br>- 20m shore pile-up observed @ Icy Cape<br>- Rafted ice thickness in vicinity of pressure ridges: 2-4 times sheet thickness<br>- Figure III-A-9: Areas of ridging & Pack-ice movement<br><br>INTEC (1991)<br>- Predominantly first-year ice South of 71N; trace to moderate concentrations of multi-year ice have been encountered in the vicinity of Cape Lisburne.<br>- Deformed ice predominates over level ice; the majority of deformed ice area will be comprised of rubble fields with typical elevations of less then 1.5ft (~0.46m) and a maximum solid thickness of 4-6ft (0.6-1.8m); Total ice thickness including soft unconsolidated ice will typically be double the solid ice thickness (i.e. 8-12ft (1.2-3.6m)).<br>- Ridge keel-to-sail ratio (derived from limited data) 3.6:1; for Northern Chukchi (based on Beaufort Sea profiles from CRREL researchers) 4.5:1 is more representative.<br>- Flow size distributions provided in Figures 20, 21, 22<br>- Ridge height distribution data provided in Figure 40<br><br>Wilson et al. (1982)<br>Table 3-6: Extrapolated pressure ridge characteristics & frequency |

[a] MMS (2007b)
[b] MMS (2007c)
[c] MMS (1990b)
[d] Source: CANATEC Associates International Ltd
[e] INTEC (1986)
[f] Wilson et al. (1982)
[g] INTEC (1991)
[h] Cammaert and Muggeridge (1988)

Table A-3: Norton Basin Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 5 / 51.8 (-15 / 11)[a] | - Average mean temperatures @ Nome for Coldest/Warmest month. |
| Temp – Min, °F (°C) | -50 (-46)[b] | |
| Temp – Max, °F (°C) | 80 (27)[b] | |
| Winds – average, kt (m/s) | 70 (36)[c] | In winter: "velocities exceeding 70 kts (110km/h) have been recorded" |
| Winds – 10 year, kt (m/s) | 84 (43)[c] | Maximum sustained wind |
| Winds – 100 year, kt (m/s) | 110 (57)[c] | Maximum sustained wind |
| Gust over 3 seconds (kt) | n/f | |
| Prev. Wind – Winter | N-NE[c] | |
| Prev. Wind – Summer | S[c] | |
| Waves – yearly average Hs, ft (m) | 17 (5.2)[b] | |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | 29 (8.8)[b]<br>37 (11.3)[b] | For water depths of:<br>- 30ft (9.1m)<br>- 50 - 70ft (15.3 - 21.3m)<br>(wave heights based on storm sea levels - i.e. accounts for surge) |
| Waves – period (sec) | 10 / 14[b] | Periods associated with 10 / 100-yr waves |
| Max. Current top/bottom, ft/s (cm/s) | 4.9 / 3.3 (150 / 100)[b] | 100-yr max currents |
| Storm surge tide, ft (m) | 13 / 12 / 9[b]<br>(4.0 / 3.7 / 2.7) | 100-yr total rise for water depths of 30 / 50 / 70 (9.1 / 15.3 / 21.3)[b]<br><br>- Note that storm surge can reach extremes of 7-8m (e.g. 1975 Nome)[c] |
| **Other Metocean Information Findings** | - Current scour has been reported in two main areas of Norton Sound (see Figure 3.1-3.2 of MMS (2007c)) | |
| **Ice** | | |
| Typical Months of cover | ~October-June[c] | - Freeze-up in shallow coastal bays can begin as early as September or as late as November.<br><br>- During Winter, ice cover is essentially 100% |
| Ice thickness, ft (cm) | 4.9 (150)[c] | - First-year ice is dominant form of ice in Norton Basin<br>- Rafted floes of 2-3m thick |
| Old ice max. concentration/season | - | Multi-year ice rarely present & concentrations are negligible[d]. |

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| Max. ridged area/season | commonly occur ~5/km[d] | First-year ridges are a common feature in the Bering Sea (though generally smaller than in the Chukchi owing to the smaller deformed ice thickness from which they are formed)[d]<br><br>- Observations of 8-10 ridge/mile (>3ft) have been recorded[e] |
| Mean max. ridge height/season, ft (m) | 11.2 (3.4)[f] | "Preliminary design data"; insufficient data is available to provide max ridge sizes for specific return periods. |
| Total Ridge thickness/ season, ft (m) | 55.1 (16.8)[f] | Consolidated portion = 7.0 meters ("preliminary design data"; insufficient data is available to provide max ridge sizes for specific return periods.)[f]<br><br>- 'Greatest' grounded rubble piles: 65ft (19.8m)[b] |
| Flow size | 500m to several km's[d] | North of St. Lawrence Island |
| Ice movement / Velocity, kt (cm/s) | 0.2 - 0.4<br>(10 - 20)[e]<br><br>2.0 (100)[e]<br><br>3.0 (150)[e] | Avg. ice speed in Northern Bering Sea<br><br>"Likely to occur in any one year"<br><br>"Extreme ice speeds", "theoretically reasonable for north Bering" |
| Icebergs mean size above water | n/f | |
| Icebergs max. size above water | n/f | |
| Fast ice – extent (km) | - | - "In the shallow waters off the Yukon delta, the shorefast ice zone extends up to 40 km offshore."[c] |
| Fast ice – thickness (cm) | n/f | |
| **Other Ice Information Findings** | - Shore fast ice generally reaches its maximum extent by February; it is generally contained within the 20-m isobath and extends furthest offshore in southern Norton Sound where the water is shallower (refer to Figure 2.7 & 2.8 of MMS (1985)).<br>- In the northern Bering Sea, the shorefast ice edge is generally located inside the 20-m isobath.[c]<br>- "Ice pileup along the Yukon delta shorefast ice front creates areas of pressure ridging along the shear zone."[c] | |

Note: n/f = Not Found / Available

[a] MMS (2007c)
[b] Fluor Engineers Inc (1982)
[c] MMS (1985)
[d] Sanderson (1988)
[e] INTEC (1991)
[f] Cammaert and Muggeridge (1988)

Table A-4: Navarin Basin Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 35 (1.7) / 51 (10.6)[a] | "Southern Bering Sea" offshore mean monthly temperatures - February / August |
| Temp – Min, °F (°C) | -22 (-30)[a] | Lowest from 25 years of ship observations (general Bering Sea value) |
| Temp – Max, °F (°C) | 71 (21.7)[a] | Highest from 25 years of ship observations (general Bering Sea value) |
| Winds – average, kt (m/s) | 13 (6.7) to 16 (8.2)[a] | Annual average wind speed (general Bering Sea values) |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | 112 (57.8)[a] | Design Basis Value (Max. winds (1-minute avg.))<br>Sensitivity range upper/lower: ~104 (53) / 121 (62) (in mph: 120-140) |
| Gust over 3 seconds, kt (m/s) | n/f | |
| Prev. Wind – Winter | N-NE[a] | "Predominant" wind directions Oct. – May (general value) |
| Prev. Wind – Summer | SW-SE[a] | "Predominant" wind directions June – Sept. (general value) |
| Waves – yearly average Hs, ft (m) | *32 (9.8)[a] | 'Expected' maximum annual wave height approximately 60 ft (18.3 m) (general value)<br><br>*Hs calculated based on factor of 1.87 |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | 43 (13.0)[a] | Design Basis Value (based on 80 ft (24.4 m) max wave) Hs=Max/1.87<br>- Sensitivity range: 70 ft (21.3 m) / 85 ft (25.9 m) |
| Waves – period (sec) | 14[a] | Design Basis Value<br>- Sensitivity range: 13 / 15 s |
| Max Current top/bottom, ft/s (cm/s) | 4 (122) / 0 (0)[a] | Design Basis Values<br>- Sensitivity range: Top 0 (0) / 5 ft/s (152 cm/s); Bottom 0 (0) / 1 ft/s (30 cm/s) |
| Storm surge tide, ft (m) | 5 (1.5)[a] | Design Basis Value<br>- Sensitivity range: 4 ft (1.2 m) / 7 ft (2.1 m) |
| **Other Metocean Information Findings** | | |
| **Ice** | | |
| Typical duration | ~ 8 months of the year[a] | |
| Typical Months of cover | mid-October to mid-June[a] | - Navarin is near the "Southern limit of the sea ice coverage; and therefore, open water exists in these areas for ~ 8 months of the year (with mid-June to mid-Oct. nearly ice free)."<br>- Ice cover is usually less then 8/10ths |

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| Ice thickness, ft (cm) | 4 (120)[a] | Design Basis Value<br>- Sensitivity range: 2 ft (61 cm) / 5 ft (152 cm)<br><br>- Rafted ice (consolidated) floe thickness: 8 ft (244 cm)<br>Design Basis Value<br>- Sensitivity range: 6 ft (183 cm) / 9 ft (274 cm) |
| Old ice max. concentration/season | -[a,b] | "Negligible"; some isolated floes have been observed north of 60°N but are "extremely rare."[e] |
| Max. ridged area/season | 8 ridges/mile (<2ft)[b]<br><br>~9 ridges/mile (< 3ft)[b]<br>2-4 (>3ft)[b] | - Observed in South Bering 56°N-60°N<br><br>- Observed in South-central Bering 60°N-62°N |
| Mean max. ridge height/season, ft (m) | 4.6 (1.4)[c]<br><br>7 (2.1)[b]<br><br>8.0 (2.4) -12 (3.7)[b] | - "Preliminary design data"; insufficient data is available to provide max ridge sizes for specific return periods.[c]<br><br>- Maximum sail height observed below 60°N[b]<br><br>- Max. sail heights observed in northern Navarin basin and more northerly (60°N and 62°N)[b] |
| Total Ridge thickness/ season, ft (m) | 19.7 (6)<br><br>51.6 (15.7)* | Annual mean ridge thickness[d]<br><br>Max. total ridge thickness (*based on average sail-to-keel ratio of 1:3.3 & max. ridge height observed (noted above)[b])<br><br>- See also Figures 36 & 37 INTEC (1991), as noted below |
| Flow size, miles (km) | < 0.3 (< 0.5)[e] | Typical south of St. Lawrence Island |
| Ice movement / Velocity, miles/day (ft/s) [cm/s] | 10 (0.6) [19] /<br>20 (1.2) [37][a] | - Typical long term motions / max. velocities<br><br>'Ice Slam' velocity = 12 ft/s (3.7m/s) Design Basis Value<br>- Sensitivity range: 10ft (3.0 m) / 20ft (6.1m)<br>("Wave-ice interaction may be the controlling design premises for local loading on Bering Sea Platforms"[a]) |
| Icebergs mean size above water | n/f | |
| Icebergs max. size above water | n/f | |
| Fast ice – extent (km) | n/f | |
| Fast ice – thickness (cm) | n/f | |

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| **Other Ice Information Findings** | - The Eastern Bering Sea is covered in winter by sea ice; the maximum extent is approximately the same as the shelf extent[f]<br>- Sea ice occurs every year in the Navarin Basin[a]<br>- Ice concentrations do not start to increase until January[b] and the maximum extent occurs between Feb.-Mar.[f,b]<br>- "Significant ice loads may also occur from single year unconsolidated ridges in Northern Navarin Basin."[a]<br>- "Ice in Navarin basin is very dynamic, but is not well documented."[a]<br>- The ice edge in the Southern Bering is a marginal ice zone and is characterized by broken and rafted floes and is strongly influenced by wind.[b]<br><br>INTEC (1991)<br>- Figure 36 & 37 **-** Average Ridge characteristics and sail/keel probabilities<br><br>**NOTE:** 'Design Basis Value' indicates parameter(s) which have been selected from the PMB Systems Engineering et al. (1983) design basis conditions; sensitivity (upper & lower) values are "intended to bracket plausible design conditions".[a] |

Note: n/f = Not Found / Available

[a] PMB Systems Engineering et al. (1983)
[b] INTEC (1991)
[c] Cammaert and Muggeridge (1988)
[d] Source: CANATEC Associates International Ltd.
[e] Sanderson (1988)
[f] MMS (2007c)

Table A-5: St. George Basin Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 35 (1.7) / 51 (10.6)[a] | "Southern Bering Sea" offshore mean monthly temperatures - February / August |
| Temp – Min, °F (°C) | -22 (-30)[a] | Lowest from 25 years of ship observations (general Bering Sea value ) |
| Temp – Max, °F (°C) | 86 (30)[b] | |
| Winds – average, kt (m/s) | 13 (6.7) to 16 (8.2)[a] | Annual average wind speed (general Bering Sea value) |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | 112 (57.8)[a] | Design Basis Value (Maximum winds 1-min. avg.)<br>Sensitivity range upper/lower: ~104 kt (53 m/s) / 121 kt (62 m/s) |
| Gust over 3 sec, kt (m/s) | n/f | |
| Prev. Wind – Winter | N-NE[a] | "Predominant" wind directions Oct.-May (general value) |
| Prev. Wind – Summer | SW-SE[a] | "Predominant" wind directions June-Sept. (general value) |
| Waves – yearly average Hs, ft (m) | *32 (9.8)[a] | 'Expected' maximum annual wave height approximately 60 ft (18.3 m) (general value)<br><br>*calculated based on factor of 1.87 |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | 45 (13.9)[a] | Design Basis Value (based on 85 ft (25.9 m) max wave); Hs=Max/1.87<br>- Max. wave height sensitivity range: 75 ft (22.9 m) / 90 ft (27.4 m) |
| Waves – period (sec) | 15[a] | Design Basis Value<br>- Sensitivity range: 14 / 17 sec. |
| Max Current top/bottom, ft/s (cm/s) | 4 (122) / 0 (0)[a] | Design Basis Values<br>- Sensitivity range: Top 0 (0) / 5 ft/s (152 cm/s); Bottom 0 (0) / 1 ft/s (30 cm/s) |
| Storm surge tide, ft (m) | 7 (2.1)[a] | Design Basis Value<br>- Sensitivity range: 5.5 ft (1.7 m) / 8.5 ft (2.6 m) |
| **Other Metocean Information Findings** | | |
| **Ice** | | |
| Typical duration | ~ 8 months of the year[a] | |
| Typical Months of cover | mid-October to mid-June[a] | - St. George is near the "Southern limit of the sea ice coverage; and therefore, open water exists in these areas for ~ 8 months of the year (with mid-June to mid-Oct. nearly ice free)."[a]<br>- Ice cover is usually less then 8/10ths[d] |
| Ice thickness, ft (cm) | 2 (60)[a] | Design Basis Value<br>- Sensitivity range: 2 ft (60 cm) / 4 ft (122 cm)<br>- Rafted (consolidated) floe thickness: 6 ft (183 cm)<br>Design Basis Value - Sensitivity range: 4 ft (122 cm) / 7 ft (213 cm) |

| | | |
|---|---|---|
| Old ice max. concentration/season | -[a] | |
| Max ridged area/season | 8 ridges/mile (<2 ft)[d] | - South Bering (56°N-60°N) |
| Mean max ridge height/season, ft (m) | < 3.3 (< 1)[b] / 7 (2.1)* | *Max sail height observed below 60°N |
| Total Ridge Thickness, ft (m) | 14.8 (4.5)[b] | Annual mean ridge thickness<br>- see also Figures 36 & 37 INTEC (1991) as noted below |
| Flow size, miles (km) | < 0.3 (< 0.5) in diameter[c] | Typical south of St. Lawrence Island |
| Ice movement / Velocity, miles/day (ft/s) [cm/s] | 10 (0.6) [19] / 20 (1.2) [37][a] | - Typical long term motions / maximum velocities<br><br>'Ice Slam' velocity = 12 ft/s (3.7m/s) Design Basis Value<br>- Sensitivity range: 10 ft (3.0 m) / 20 ft (6.1m)<br>("Wave-ice interaction may be the controlling design premises for local loading on Bering Sea Platforms"[a]). |
| Icebergs mean size above water | n/f | |
| Icebergs max size above water | n/f | |
| Fast ice – extent (km) | n/f | |
| Fast ice – thickness (cm) | n/f | |
| **Other Ice Information Findings** | - The Eastern Bering Sea is covered in winter by sea ice; the maximum extent is approximately the same as the shelf extent.[e]<br>- St. George Basin ice conditions are generally less severe then that of the Navarin Basin[a]<br>- Ice does not occur every year in St. George Basin.[a]<br>- "Primary ice features in St. George Basin & North Aleutian Basin include sheet ice, broken ice, rubble piles, and first-year pressure ridges; scattered drift ice is also characteristic of SE St. George Basin and SW North Aleutian shelf areas."[a]<br>- Ice concentrations do not start to increase until January[d] and the maximum extent occurs between Feb.-Mar.[d,e]<br>- The ice edge in the Southern Bering is a marginal ice zone and is characterized by broken and rafted floes and is strongly influenced by wind.[d]<br><br>INTEC (1991)<br>- Figure 36 & 37 **-** Average Ridge characteristics and sail/keel probabilities.<br><br>**NOTE:** 'Design Basis Value' indicates parameter(s) which have been selected from the PMB Systems Engineering et al. (1983) design basis conditions; sensitivity (upper & lower) values are "intended to bracket plausible design conditions."[a] | |

Note: n/f = Not Found / Available

[a] PMB Systems Engineering et al. (1983)
[b] CANATEC Associates International Ltd.
[c] Sanderson (1988)
[d] INTEC (1991)
[e] MMS (2007c)

Table A-6: North Aleutian Basin Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 35 (1.7) / 51 (10.6)[a] | "Southern Bering Sea" offshore mean monthly temperatures - February / August |
| Temp – Min, °F (°C) | -22 (-30)[a,b] | Lowest from 25 years of ship observations (general Bering Sea value ) |
| Temp – Max, °F (°C) | 86 (30)[b] | |
| Winds – average, kt (m/s) | 11-20 (5.7-10.3)[c] | Range of mean monthly winds (June-July to November) |
| Winds – 10 year, kt (m/s) | 81 (41.7)[c] | 1-min. avg. wind |
| Winds – 100 year, kt (m/s) | 106 (54.6)[c] | 1-min. avg. wind |
| Gust over 3 seconds, kt (m/s) | n/f | |
| Prev. Wind – Winter | N[c] | |
| Prev. Wind – Summer | S[c] | |
| Waves – yearly average Hs, ft (m) | 26 (7.9)[c] | |
| Waves – 10 year extreme Hs, ft (m) | 32 (9.8)[c] | |
| Waves – 100 year extreme Hs, ft (m) | 38 (11.6)[c] | |
| Waves – period (sec) | 10.5 / 11 / 14[c] | 1-yr / 10-yr / 100-yr |
| Max Current top/bottom, ft/s (cm/s) | 5 (152) / 2 (61)[a] | Surface currents<br><br>- "Tidal current can reach as high 4 knots (~200cm/s)"[c] |
| Storm surge tide, ft (m) | 8 (2.4)[c] | 100-yr (total rise)<br><br>Nearshore storm surge can reach 4 - 6ft (i.e. total rise can equal 12ft or greater based on an average tide range of 6 ft) |
| **Other Metocean Information Findings** | | |
| **Ice** | | |
| Typical duration | ~ 8 months of the year[a] | |
| Typical Months of cover | mid-October to mid-June[a] | - North Aleutian Basin is near the "Southern limit of the sea ice coverage; and therefore, open water exists in these areas for ~ 8 months of the year (with mid-June to mid-Oct. nearly ice free)"[a]<br>- Coverage in the northern part of the lease sale area is on average 50%[c] |
| Ice thickness, ft (cm) | 2 (61)[c] | Design Basis Value<br>- Sensitivity range: 1 ft (30 cm) / 4 ft (122 cm)[a]<br>- Rafted (consolidated) floe thickness: 6 ft (183 cm)[a]<br>Design Basis Value<br>- Sensitivity range: 4 ft (122 cm) / 7 ft (213 cm)[a] |
| Old ice max. concentration/season | -[a] | |

| | | |
|---|---|---|
| Max ridged area/season | 8 ridges/mile (< 2ft)[d] | - South Bering (56°N-60°N) |
| Mean max ridge height/season, ft (m) | < 3.3 (< 1)[e] / 7 (2.1)[d] | Maximum sail height observed below 60°N |
| Total Ridge thickness/ season, ft (m) | 14.8 (4.5)[e] | Annual mean ridge thickness[e]<br><br>- See also Figures 36 & 37 INTEC (1991) as noted below |
| Flow size, miles | Generally < 1/4 mile dia.[c] | Area coverage with floes range from 10%-40% |
| Ice movement / Velocity, miles/day (ft/s) [cm/s] | 10 (0.6) [19] / 20 (1.2) [37][a] | - Typical long term motions / max. velocities<br>- 'Ice Slam' velocity = 12 ft/s (3.7m/s)<br><br>Design Basis Value<br>- Sensitivity range: 10ft (3.0 m) / 20ft (6.1m)<br>("Wave-ice interaction may be the controlling design premises for local loading on Bering Sea Platforms"[a]) |
| Icebergs mean size above water | n/f | |
| Icebergs max size above water | n/f | |
| Fast ice – extent, miles, miles (km) | n/f | |
| Fast ice – thickness, ft (cm) | n/f | |
| **Other Ice Information Findings** | - The Eastern Bering Sea is covered in winter by sea ice; the maximum extent is approximately the same as the shelf extent.[f]<br>- North Aleutian Basin ice conditions are generally less severe then that of the Navarin Basin[a]<br>- Ice does not occur every year in St. George Basin & North Aleutian Basin[a]<br>- Ice concentrations do not start to increase until January[d] and the maximum extent occurs between Feb.-Mar.[d,f]<br>- "Primary ice features in St. George Basin & North Aleutian Basin include sheet ice, broken ice, rubble piles, and first-year pressure ridges; scattered drift ice is also characteristic of SE St. George Basin and SW North Aleutian shelf areas."[a]<br>- The ice edge in the Southern Bering is a marginal ice zone and is characterized by broken and rafted floes and is strongly influenced by wind.[d]<br><br>INTEC (1991)<br>- Figure 36 & 37 **-** Average Ridge characteristics and sail/keel probabilities<br><br>**NOTE:** 'Design Basis Value' indicates parameter(s) which have been selected from the PMB Systems Engineering et al. (1983) design basis conditions; sensitivity (upper & lower) values are "intended to bracket plausible design conditions." [a] | |

Note: n/f = Not Found / Available

[a] PMB Systems Engineering et al. (1983)
[b] Source: CANATEC Associates International Ltd.
[c] Brian Watt Associates (1985)
[d] INTEC (1991)
[e] Source: CANATEC Associates International Ltd.
[f] MMS (2007c)

Table A-7: Cook Inlet Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 54 - 66 (12 - 19) / 12 (-11)[a] | Range of daily temperatures for Anchorage, July (warmest month) / Mean night time lows for Anchorage during January |
| Temp – Min, °F (°C) | -29 (-34) / -45 (-43)[a] | Anchorage / Kenai |
| Temp – Max, °F (°C) | 81 (27) / 86 (30)[a] | Anchorage / Kenai |
| Winds – average, kt (m/s) | 5.8 - 7.6 (3.0 - 3.9) / 10.3 - 16.5 (5.3 - 8.5)[a] | Anchorage: Mean monthly / mean monthly max. range (note that May - June have strongest winds) |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | n/f | Maximum wind recorded (1973) 31.9 m/s[a] |
| Gust over 3 seconds, kt (m/s) | n/f | |
| Prev. Wind – Winter | NE[b] | "Predominant" direction |
| Prev. Wind – Summer | NE[b] | "Predominant" direction |
| Waves – yearly average Hs, ft (m) | n/f | |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | n/f | |
| Waves – period (sec) | n/f | |
| Max Current top / bottom, ft/s (m/s) | > 6.6 [3.3 – 4.9] (>2 [1.0 - 1.5])[a] | General Maximum Tidal Currents: Upper Cook Inlet [Lower Cook Inlet]<br>- Note that 'Spring Tides' of up to 4.1 m/s can occur near constrictions such as between the Forelands (narrowest point in Cook Inlet)) |
| Storm surge tide, ft (m) | n/f | Mean tidal range: North Foreland = 5.58 m; Kenai River = 5.39 m ( note that during 'Spring Tides', mean tidal range can increase by 1.5m (i.e. ~7.0 m))[a] |
| **Other Metocean Information Findings** | Waves over 10ft (3m) are seldomly observed in Cook Inlet.[c] | |
| **Ice** | | |
| Typical Months of Cover | ~ Late Nov. - Early Apr. (10% ice concentration in Upper Inlet)[a] | - Sea ice is seasonal in Cook Inlet and typically begins forming in October, however significant coverage does not occur until late November.<br>- Sea ice concentration ranges from open (1/10th) to close pack (7/10th to 8/10ths).<br>- March is the peak of ice extent/concentration (see Mulherin et al. (2001)) |
| Ice thickness, ft (cm) | 1.6 – 6.6 (50 – 200)[a] | - Mean ice thickness lies in the 'thin first-year' category (30cm - 70cm thick) - see Mulherin et al. (2001)<br>- Rafted ice can occur |

| | | |
|---|---|---|
| Old ice max. concentration/season | - | - Multi-year ice is not present in Cook Inlet, however, "a significant portion of Cook Inlet's ice is freshwater ice that forms in the rivers and estuaries"[a]. Estuarine ice is "significantly" stronger than first-year ice[a]<br>- At spring break-up "a considerable amount of river ice, pieces of which can sometimes be 2 m thick, is discharged into the Inlet."[a] |
| Max. ridged area/season | n/f | |
| Mean max. ridge height/season (m) | n/f | |
| Total ridge thickness, ft (m) | 19.7 (6)[a] | "Pressure ridges have been reported to be as thick as 6 m."[a] |
| Floe Sizes, miles (km) | > 0.3 (> 0.5)[a] | "Floes in the Inlet can be classified as "big" (greater than 500 m across, with 400-m-wide floes being common."[a] |
| Ice movement/Velocity | n/f | |
| Icebergs mean size above water, ft (m) | - | '- Stamukhi have been reported up to 40 ft (12.2 m) thick.[a] Typical stamukha have been described as 15 ft (4.6 m) high and 20 ft (6.1 m) in diameter.[a] |
| Icebergs max. size above water | - | |
| Fast ice – extent, miles (km) | n/f | |
| Fast ice – thickness, ft (m) | up to ~1.6 (~0.5)[a] | |
| **Other Ice Information Findings** | - Cook Inlet Sea ice consists of pack ice, Shorefast ice, Stamukhi, and Estuarine and river ice.<br>- Tide driven ice presents the greatest danger to structures and navigation.[a]<br>- Stamukha can be freed by tidal action and get caught up in pack ice.[a] | |

Note: n/f = Not Found / Available

[a] Mulherin et al. (2001)
[b] MMS (2007c)
[c] MMS (2002)

Table A-8: Offshore Sakhalin Island Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 10 (-12)[a] | Winter / summer |
| Temp – Min, °F (°C) | -38 (-39)[b] | Recommended LAST (lowest anticipated service temp.) for structures (-35°C for production equipment) |
| Temp – Max, °F (°C) | -22 (30)[b] | Recommended HAST (highest anticipated service temp.) for structures |
| Winds – average, kt (m/s) | 7.6 – 8.6 (3.9 – 4.4)[a] | Annual average coastal wind speeds |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | n/f | |
| Gust over 3 seconds, kt (m/s) | n/f | |
| Prev. Wind – Winter | W & NW[b] | |
| Prev. Wind – Summer | S & SE[b] | |
| Waves – yearly average Hs, ft (m) | 13.1 (4.0)[c] | |
| Waves – 10 year extreme Hs, ft (m) | 23.6 (7.2)[b] | |
| Waves – 100 year extreme Hs, ft (m) | 32.2 (9.8)[b] | |
| Waves – period (sec) | 12.5 / 14.6[b] | 10 / 100-yr wave periods |
| Max Current top/bottom, ft/s (cm/s) | 4.9 / 4.3 (150 / 130)[a] | |
| Storm surge tide, ft (m) | 3.31 / 3.84 (1.01 / 1.17)[b] | 25 / 100-year occurrences |
| **Other Metocean Information Findings** | - "Maximum wind speeds of 4 to 7 m/s from the north and northwest are experienced during winter, with peak winds of 37 to 40 m/s."[a]<br>- In the region of the PA field, the strongest wind recorded over a 47-year period (1938-1984) was 40 m/s.[b]<br>- Characteristic wave height is higher then 2.5 m 30% of the time in November, and 53% in December (during the ice free period).[b] | |
| **Ice** | | |
| Typical Months of cover | ~December to June[b] | Based on PA Field |
| Ice thickness, ft (cm) | 3.9 – 4.6 / 5.2 – 5.6 (120 – 140 / 160 – 170)[b] | Typical / Design or Extreme level ice sheet<br>- Design or Extreme rafted ice thickness = 350 – 400cm)[b] |
| Old ice max. concentration/season | - | No multi-year present |
| Max ridged area/season | (5-7 / km) / (0.3 – 0.5 / km)[b] | Typical frequency of All (sail > 1m) / High Hummocks (sail 2.7 – 2.9m)[b] |
| Mean max ridge height/season, ft (m) | 4.6 – 5.9 / 8.9 – 9.5 (1.4 – 1.8 / 2.7 – 2.9)[b] | Typical Hummock sail height ranges (All / High)<br>- Design or Extreme Hummock sail height = 5.5 – 6.0m[b] |

| | | |
|---|---|---|
| Total ridge thickness, ft (m) | 27.6 – 38.7 / 48.2 – 52.2<br>(8.4 – 11.8 / 14.7 – 15.9)[b] | Typical Hummock thickness ranges (All / High)<br><br>- Design or Extreme Hummock thickness = 27.5 – 30.0m[b] |
| Floe Sizes | n/f | |
| Ice movement/Velocity, ft/s (m/s) | 1.6 – 2.0 / 4.9 – 5.6<br>(0.5 – 0.6 / 1.5 – 1.7)[b] | Typical / Design or Extreme ice velocity ranges |
| Icebergs mean size above water, ft (m) | n/f | |
| Icebergs max size above water, ft (m) | n/f | |
| Fast ice – extent, miles (km) | 1.2 – 2.5 / 5 – 6.2<br>(2 – 4 / 8 – 10)[b] | Typical / Design or Extreme extent ranges |
| Fast ice – thickness, ft (cm) | 3.3 (100)[c] | Estimate |
| **Other Ice Information Findings** | - Sea ice in this region is dynamic and basically in continual motion due to tides, currents, and wind.[a]<br>- Peak ice coverage occurs from March – April.[a]<br>- Typical and maximum hummock ridge widths are, 65 – 85 m and 100 – 130 m, respectively.[b]<br>- Hummock consolidated ridge parts range from 2.8 – 3.1 m[b] | |

Note: n/f = Not Found / Available

[a] SEIC (2003)
[b] Truskov (1999)
[c] Source: CANATEC Associates International Ltd.

Table A-9: Barents Sea Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 14 to 5 (-10 to -15)[a] | Winter |
| Temp – Min, °F (°C) | -31 (< -35)[b] | *Shtokman* |
| Temp – Max, °F (°C) | 73 (23)[c] | |
| Winds – average, kt (m/s) | 11. 7 – 19.4 (6.0 - 10.0)[d] | Central Barents |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | n/f | |
| Gust over 3 seconds, kt (m/s) | n/f | |
| Prev. Wind – Winter | SW[e] | |
| Prev. Wind – Summer | SW[e] | |
| Waves – yearly average Hs, ft (m) | n/f | |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | 41.0 (12.5)[d] | Central Barents |
| Waves – period (sec) | n/f | |
| Max. Current top/bottom, ft/s (cm/s) | 4.8 (146)[e] | Summary current for *Shtokman* |
| Storm surge tide, ft (m) | n/f | 1% extreme tide level range (cm): -86 to 107[e] |
| **Other Metocean Information Findings** | - 50-year return gust speed is 40 m/s.[d]<br>- Maximum winds (2-minute duration): 106 kt (54.5 m/s)[c]<br>- Of the Eurasian seas, the Barents has the highest and most developed wind-driven waves.[e]<br>- During winter, waves may reach a maximum height of 10-11m in the central Barents Sea when steady westerly winds are experienced.[f]<br>- 0.1% wave height of 23.7 m for *Shtokman* field area.[e] | |
| **Ice** | | |
| Typical Months of cover | April - May | - At the *Shtokman* field, sea ice occurrence is approximately 1 out of 3 years.[b]<br>- Sea ice concentrations of 70-80%[e] |
| Ice thickness, ft (cm) | 3.3 – 5.9 / 9.8 – 16.4 (100 - 180 / 300 - 500) | Level undeformed first-year ice / multi-year ice thickness[d]<br><br>- Although multi-year ice can be encountered, Barents sea ice is predominately first-year ice[d] |
| Old ice max. concentration/season | n/f | |
| Max ridged area/season | n/f | |
| Mean max ridge height/season, ft (m) | 9.8 (3) | Sail heights up to 3 m (1%) and keel depths up to 12 m (1%) in vicinity of *Shtokman*.[e] |
| Total ridge thickness, ft (m) | 49 (15) | |

| | | |
|---|---|---|
| Floe Sizes, miles (km) | 0.9 / 6.2 (1.4 / 10) | Average / 1% floe size for *Shtokman*[e] |
| Ice movement/Velocity, ft/s (cm/s) | 3.6 (110) | *Shtokman*[e] |
| Icebergs mean size above water, ft (m) | 210x151x36 (64x46x11)[c] | LxWxH |
| Icebergs max size above water, ft (m) | 574x125x285 (175x38x87)[c] | LxWxH |
| Fast ice – extent, miles (km) | - | |
| Fast ice – thickness, ft (cm) | - | |
| **Other Ice Information Findings** | - Sea ice in the Barents reaches its maximum southerly extent in March and is at a minimum in September.[d]<br>- The Barents Sea is part of an Arctic seasonal ice zone and therefore experiences high inter-annual variations of sea ice incursion.[d]<br>- Typical ice features encountered are level ice, ridges, ice bergs, and bergy-bits[b].<br>- Percentage of hummocked ice in vicinity of *Shtokman* = 60%[e]<br>- Iceberg parameters for *Shtokman* field[e]:<br>Draught: 100-120m / Mass: 105-106 t / Speed: 0.3-1.0 m/s.<br>- The occurrence of an iceberg within collision range of platform located in the *Shtokman* field would be approximately 1 in 20 years.[b]<br>- Some additional sea ice information can be found in Appendix D. | |

Note: n/f = Not Found / Available

[a] Mulherin et al. (1996)
[b] Karlsen (2006)
[c] Source: CANATEC Associates International Ltd.
[d] Løset et al. (1999)
[e] The Ministry of Natural Resources of the Russian Federation (1998)
[f] Nikiforov et al. (2005)

Table A-10: Pechora Sea Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 22 (-5.6)[a] | |
| Temp – Min, °F (°C) | -54 (-48)[a,b] | |
| Temp – Max, °F (°C) | 90 (32)[a,b] | |
| Winds – average, kt (m/s) | n/f | |
| Winds – 10 year, kt (m/s) | 31.0 (15.9)[a] | |
| Winds – 100 year, kt (m/s) | n/f | |
| Gust over 3 seconds, kt (m/s) | 95 (49) [a] | |
| Prev. Wind – Winter | SW[a] | |
| Prev. Wind – Summer | NE[a] | |
| Waves – yearly average Hs, ft (m) | 10.8 (3.3)[a] | 1-year return wave height |
| Waves – 10 year extreme Hs, ft (m) | 13.1 (4.0)[a] | |
| Waves – 100 year extreme Hs, ft (m) | 16.1 (4.9)[b] | |
| Waves – period (sec) | 8.2[a] | 1/10-year wave period |
| Max Current top/bottom, ft/s (cm/s) | 0.04 (1.23)[a] | |
| Storm surge tide, ft (m) | 7.28 (2.22)[a] | 1/100-year extreme sea level increase |
| **Other Metocean Information Findings** | - Wave Height (0.1% Probability) = 9.0 – 10.0m[a] | |
| **Ice** | | |
| Typical Months of cover | November - May[a] | Onset of ice formation – complete disappearance<br>- Average duration of ice-covered season = 213 days. |
| Ice thickness, ft (cm) | 2.6 (80)[a,b] | Maximum thickness = 145cm |
| Old ice max. concentration/season | None[c] | - Typical Pechora Sea regional site parameter.[c]<br><br>- Inflow of ice "from the Kara Sea is insignificant."[a] |
| Max. ridged area/season | 8 ridges/km[d] | Frequency of occurrence |
| Mean max. ridge height/season, ft (m) | 4.6 (1.4)[d] | |
| Total ridge thickness, ft (m) | 16.7 – 31.5 (5.1 - 9.6)[d] | Average thickness of consolidated layer = 2.9m |
| Floe Sizes, miles (km) | 0.9 (1.4)[a] | Average ice field size<br>- Maximum ice field size 10.9 (17.5) |
| Ice movement/Velocity, ft/s (cm/s) | 1 – 4.7 (30 - 142)[d] | Total drift speed |
| Icebergs mean size above water, ft (m) | 210 x151x36 (64x46x11)[a] | LxWxH |

| | | |
|---|---|---|
| Icebergs max. size above water, ft (m) | 591x525x98 (180x160x30)[a] | LxWxH |
| Fast ice – extent, miles (km) | 1.9 – 9.3 (3 – 15)[a] | Extents is typically to the 25m isobath[e] |
| Fast ice – thickness, ft (cm) | 3.6 (110)[a] | Average thickness |
| **Other Ice Information Findings** | - Percentage of hummocks in area = 60-90%; Hummocks range in mass from 47 - 130 x$10^3$ tons[a].<br>- Based on one hundred years of observations (1888-1991) 11 icebergs have been sited in the southeastern Barents Sea.[a]<br>- Some additional sea ice information can be found in Appendix D. | |

Note: n/f = Not Found / Available

[a] Nikiforov et al. (2005)
[b] Source: CANATEC Associates International Ltd.
[c] Kennedy et al. (1994)
[d] The Ministry of Natural Resources of the Russian Federation (1998)
[e] Sanderson (1988)

Table A-11: Canadian East Coast (Grand Banks) Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 32 / 57.9 (0 / 14.4)[a] | January / August |
| Temp – Min, °F (°C) | 0.9 (-17.3)[b] | |
| Temp – Max, °F (°C) | 79.7 (26.5)[b] | |
| Winds – average, kt (m/s) | 16.5 (8.5)[a] | Annual mean |
| Winds – 10 year, kt (m/s) | 54.0 (27.8)[a] | (Based on 1-hour mean winds) |
| Winds – 100 year, kt (m/s) | 60.6 (31.2)[a] | (Based on 1-hour mean winds) |
| Gust over 3 seconds, kt (m/s) | 81.1 (41.7)[a] | 100-year (calculated using hourly mean wind and a factor of 1.34) |
| Prev. Wind – Winter | Westerly & Southwesterly[a] | |
| Prev. Wind – Summer | Westerly & Southwesterly[a] | |
| Waves – yearly average Hs, ft (m) | 8.9 (2.7)[a] | Annual mean |
| Waves – 10 year extreme Hs, ft (m) | 43.6 (13.3)[a] | |
| Waves – 100 year extreme Hs, ft (m) | 51.2 (15.6)[a] | |
| Waves – period (sec) | 15.1 / 16.2[a] | Associated spectral peak period for 10/100-year Hs |
| Max Current top/bottom, ft/s (cm/s) | 2.3 / 1.3 (70 / 40)[c] | |
| Storm surge tide, ft (m) | +2.4 / -2.6 (+0.73 / -0.79) | 1/100-year[d] |
| **Other Metocean Information Findings** | | |
| **Ice** | | |
| Typical Months of cover | February & March | Sea ice is present a mean of approximately 4 weeks per year, and a maximum and extreme of 7 weeks and 11 weeks, respectively[e]. |
| Ice thickness, ft (cm) | 3.3 (100) | Maximum undeformed thickness[e]<br><br>- Extreme undeformed thickness = 200cm[e] |
| Old ice max. concentration/season | n/f | Multi-year ice, which has drifted south from Labrador, can also be encountered.[b] |
| Max. ridged area/season | n/f | |
| Mean max. ridge height/season, ft (m) | n/f | |
| Total ridge thickness, ft (m) | n/f | |
| Floe Sizes, ft (m) | < 98 (< 30) | Mean (Maximum = 60m; Extreme = 100m)[e] |
| Ice movement/Velocity, ft/s (m/s) | 0.8 (0.25) | Mean (Maximum = 0.6m/s; Extreme = 1.0m/s)[e] |

| | | |
|---|---|---|
| Icebergs mean size above water, ft (m) | 407+/-203 x 289+/-144 x 85+/-46 x 253+/-105 (124+/-62 x 88+/-44 x 26+/-14 x 77+/-32)[f] | Mean overall dimensions (LxWxHxD) of icebergs in the vicinity of *Hibernia*. |
| Icebergs max. size above water, ft (m) | n/f | |
| Fast ice – extent, miles (km) | n/f | |
| Fast ice – thickness, ft (cm) | n/f | |
| **Other Ice Information Findings** | - Grand Banks field developments are located on the edge of a marginal ice zone.<br>- Sea ice concentrations (%) range from: 50 (mean) / 90 (max) / 100 (extreme)[e]<br>- Maximum southerly extent of the ice edge typically occurs by the end-February to mid-March. Ice near the ice edge is predominantly made up of grey-white and first-year ice.[c]<br><br>- Iceberg mass distribution (tonnes):<br>300,000 (mean) / 2.2 Million (maximum) / 9 Million (extreme)[e]<br>- Drift speeds (m/s) of icebergs: 0.3 (mean) / 1.3 (maximum) / 1.8 (extreme)[e]<br><br>- In recent years, several ice island fragments have crossed the NE Grand Banks area. Ice islands are characterized by surface areas of up to 250,000 $m^2$, but typically have shallow drafts less then 70m.[e] | |

Note: n/f = Not Found / Available

[a] LGL Limited (2007)
[b] Husky (2001a)
[c] Jacques Whitford (2006)
[d] CNLOPB (1997)
[e] LGL Limited (2005)
[f] CANATEC Consultants Ltd. et al. (1999)

Table A-12: Labrador Sea Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | 28 / 54 (-2 / 12)[a] | Winter / Summer |
| Temp – Min, °F (°C) | -9 (-23)[a] | Winter |
| Temp – Max, °F (°C) | 82 (28)[a] | Summer |
| Winds – average, kt (m/s) | 44.7 (23)[a] | Winter |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | 169 (87)[a] | Winter |
| Gust over 3 seconds, kt (m/s) | 262 (135)[a] | Winter |
| Prev. Wind – Winter | W & NW[a] | |
| Prev. Wind – Summer | E & S[a] | |
| Waves – yearly average Hs, ft (m) | 3.3 – 4.9 (1.0 – 1.5)[a] | |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | - | 19.9 m maximum (not significant) wave from hindcast[a] |
| Waves – period (sec) | 13[a] | Maximum value |
| Max Current top/bottom, ft/s (cm/s) | - | General current direction is due south as a result of the Labrador Current (which flows at approximately 40 cm/s).[b] |
| Storm surge tide, ft (m) | n/f | |
| **Other Metocean Information Findings** | - Tidal range: 0.9 to 2.7 m[a]<br>- From October to March mean wind speed is 55 km/hr (30 knot) while from April to September the mean speed is 37 km/hr (20 knots)[a].<br>- Maximum wind speeds observed in Dec., Jan., Feb.[a] | |
| **Ice** | | |
| Typical Months of cover | ~December - July[b] | - Ice-bound January to May with a swath of ice reaching about 250 – 400 km offshore.<br>- Normal ice concentration during winter = 70-100% |
| Ice thickness, ft (cm) | 4.9 (150)[a] | |
| Old ice max. concentration/season | 10%[a] | - Normal old ice thickness (total): 6 to 9 m[a] |
| Max ridged area/season | n/f | |
| Mean max ridge height/season (m) | n/f | |
| Total ridge thickness (m) | n/f | |
| Floe Sizes | n/f | |
| Ice movement/Velocity, ft/s (m/s) | 0.5 – 0.8 (0.15 – 0.25)[a] | Average ice drift speed (Max. ice drift speed = 0.8m/s) |

| | | |
|---|---|---|
| Icebergs mean size above water, ft (m) | 502+/-240 x 381+/-187 x 115+/-59 x 302+/-118 (153+/-73 x 116+/-57 x 35+/-18 x 92+/-36) | Mean iceberg dimensions (LxWxHxD)[c] |
| Icebergs max size above water, ft (m) | 1805 / 738 (550 / 225)[a] | Maximum iceberg length / draft |
| Fast ice – extent (km) | n/f | |
| Fast ice – thickness, ft (cm) | 4.9 (150)[a] | |
| **Other Ice Information Findings** | - Ice cover consists of a narrow strip of landfast Ice, a wide swath of mobile pack Ice, and a zone of broken Ice floes at the eastern edge dispersed by wave action[a].<br>- Mean iceberg mass 500 kilotonnes[a]. | |

Note: n/f = Not Found / Available

[a] Source: CANATEC Associates International Ltd.
[b] Canning & Pitt Associates, Inc. (2007)
[c] CANATEC Consultants Ltd. et al. (1999)

Table A-13: Offshore West Greenland* Metocean & Ice Data

| Parameter | Value | Notes/Comments |
|---|---|---|
| **Metocean** | | |
| Temp – Mean, °F (°C) | < 50 (< 10)[a] | Year round |
| Temp – Min, °F (°C) | n/f | February is coldest month[a] |
| Temp – Max, °F (°C) | n/f | August is warmest month[a] |
| Winds – average, kt (m/s) | 10 – 12 (5 – 6)[a] | North of 65°N |
| Winds – 10 year, kt (m/s) | n/f | |
| Winds – 100 year, kt (m/s) | n/f | |
| Gust over 3 seconds, kt (m/s) | n/f | |
| Prev. Wind – Winter | Northerly[a] | |
| Prev. Wind – Summer | Southerly[a] | Small predominance |
| Waves – yearly average Hs, ft (m) | n/f | |
| Waves – 10 year extreme Hs, ft (m) | n/f | |
| Waves – 100 year extreme Hs, ft (m) | n/f | |
| Waves – period (sec) | n/f | |
| Max. Current top/bottom, ft/s (cm/s) | n/f | "Currents are generally weak 0.3 ft/s (< 10cm/s)."[a] |
| Storm surge tide, ft (m) | n/f | |
| **Other Metocean Information Findings** | - Gale force winds (above 26.8 ft/s (13.8 m/s)) occur < 5% in winter and <1% in summer.[a]<br>- Most severe waves occur November – March.[a]<br>- Wave data indicates[b] that less then 1% of significant waves ($H_s$) exceed 8.7 ft (4.5m).<br>- For Asiaat at Spring tide the difference in sea level = 4.9 ft (2.5 m).[a] | |
| **Ice** | | |
| Typical Months of cover | ~mid-June to mid-November | - With the exception of a flaw lead, which often forms near the Greenland coast, Davis Strait is normally ice covered north of 65°N during the winter and spring; the flaw lead can reach as far north as 67°N.[a] |
| Ice thickness, ft (cm) | 1.6 – 3 (50 – 90) | Approximate maximum thickness of first-year ice within about 62 miles (100km) from the Greenland coast (at the end of freeze-up - March/April).[a]<br><br>- In central Davis Strait, medium (~2.3 - 3.9ft (70 - 120cm)) and thick (~3.9 - 6.6ft (120 - 200cm)) First-year ice dominates (with a general thickness of 3.3 ft (100cm)).[a] |
| Old ice max. concentration/season | up to 3/10ths | In central Davis Strait[a]<br>- "Small amounts of multi-year ice" drift into western portion of Disko West Area, but do not typically reach Greenland shores.[a] |
| Max. ridged area/season | n/f | |

| | | |
|---|---|---|
| Mean max. ridge height/season, ft (m) | n/f | |
| Total ridge thickness, ft (m) | n/f | |
| Floe Sizes, mile (km) | 0.6 (1) | Dominant floe size[c]<br><br>- Near the ice edge (marginal zone) floe sizes are reduced to <328ft (100m)[c] |
| Ice movement/Velocity, ft/s (cm/s) | n/f | |
| Icebergs mean size above water, ft (m) | n/f | Based on observations[a]:<br>- Disko Bay icebergs range in mass from 5 - 11 million tons<br>- Mean drafts (North of 66°N) = 262 - 410ft (80 - 125m) |
| Icebergs max. size above water, ft (m) | n/f | Based on observations[a]:<br>- Maximum mass of Disko Bay iceberg = 32 million tons<br>- Maximum draft (North of 66°N) = 614ft (187m) |
| Fast ice – extent, mile (km) | n/f | |
| Fast ice – thickness, ft (cm) | n/f | |
| **Other Ice Information Findings** | - First-year ice is the predominant sea ice type present in Davis Strait - both drift and fast ice are found in this area.[c]<br>- Floes can range up to ~6.2 miles (10km).[c]<br>- "South of 65 - 67°N sea ice-free areas dominate throughout the year."[c]<br>- South of 66°N iceberg masses have been observed to generally range between 0.3 and 0.7 million tons, with a maximum of 2.8 million tons; "mean draft was 164 - 230ft (50 - 70m) and maximum draft was 410ft (125m)."[a]<br>- Disko Bay is a source of thousands of iceberg each year.[a] | |

*Information gathering for this table was primarily focused on the Disko West Area.
Note: n/f = Not Found / Available

[a] Danish Meteorological Institute (2004)
[b] Mineral Resources Administration for Greenland (1998)
[c] Mosbech et al. (2007)