On the Estimation of the Distribution of Massive Marine Ice Features Derived from Moored Upward Looking Sonar Instruments

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ABSTRACT.

Using year-long, continuous measurements from modern upward looking sonar (ULS) data sets, potentially hazardous marine ice features can be identified and compiled as to their statistical distribution and frequency of occurrence. Previously, the focus of the analysis of these moored sonar data sets has been on identification of potential marine ice hazards in the form of the deepest ice keels, which extend to 20 m or greater along with occurrences of rubbled/hummocky ice features with horizontal scales of up to a few to several hundred metres.. A more robust, geometrical characterization of potentially hazardous marine ice features is presented in this paper to identify episodes of continuous ice draft measurements exceeding a threshold value, for which the cross-sectional area of the ice draft and horizontal ice distance is computed, using a user-selectable minimum threshold value (e.g. 1.2 or 2.0 m). Based on several hundred or thousands of individual features identified, the maximum and average values of the cross-sectional area are computed. Using an assumed statistical approach for the horizontal geometry of the individual ice features, the total volume of these large marine ice episodes, can be estimated as the product of the cross-sectional area and the single measured width, with over 1,000 features each year exceeding the median value of 82,000 metric tonnes for a 2.0 m minimum ice draft, being realized in the mooring data sets north of Fram Strait off northeast Greenland. The numbers of massive ice features exceeding nearly the same median value is much reduced at about 160 in the Canadian Beaufort Sea.

KEY WORDS: Arctic, polar, sea-ice, sonars, ice keels, icebergs, hummocks

INTRODUCTION

Upward-looking sonar (ULS) instruments have become the primary source of data for high resolution and long duration measurements of sea ice drafts to support engineering requirements for oil and gas exploration projects in Arctic and other ice-infested areas. The data sets provide typical accuracies of 0.05 m for ice draft on a continuous year-long basis; these data attributes allow detailed characterization of keel shapes and other ice features (Fissel et al., 2008a).

ULS instruments, in the form of ASL's Ice Profiler, have the data capacity for unattended operation for continuous measurement periods of two years, with three year operations possible under some circumstances. When combined with a companion Acoustic Doppler Current Profiler (ADCP) to measure ice velocities, the combined data sets provide horizontal resolution of 1 m or better. The combined ice thicknesses and ice velocities, measured along thousands of kilometers of ice which typically move over each moored ice profiler location, provide important data for establishing metocean design criteria related to oil and gas operations in areas with seasonal or year-round ice cover.

The early versions of ULS instruments for sea ice measurements were developed in the early 1990s (Melling et al., 1995) for scientific studies of Arctic sea ice. In 1996, the first ULS sea ice oil and gas application was conducted in the Sakhalin exploration area using the ASL Ice Profiler through a Joint Industry Program funded by Exxon Neftegas and Sakhalin Energy Investment Co. Since then, hundreds of year-long ULS deployments for oil and gas applications have been conducted with these instruments in the ice infested areas of the northern and southern hemispheres.

The capabilities of the instruments for detailed and accurate representation of the thousands of kilometers of sea ice passing over the moored ULS measurement sites are well established. The processing and analysis of these very large data sets are routinely undertaken using an extensive library of purpose designed software.

For oil and gas engineering requirements there is a particular need for the detection and characterization of potentially hazardous sea ice features which can be derived from these very large ULS data sets. Previously, the focus of the analysis to identify potential marine ice hazards has been on the deepest ice keels, which typically extend to 20 m or greater. Typically hundreds to a few thousand ice keels are measured each year using a threshold level of 8 m ice draft. Other types of potentially hazardous marine ice for which algorithms have been developed are rubbled/hummocky ice and multi-year ice.

In this paper, we present a more robust and unified geometrical characterization of potentially hazardous marine ice features to identify episodes of continuous ice draft measurements exceeding a threshold value, for which the cross-sectional area of the ice draft and horizontal ice distance is computed. The advantages of this characterization, dubbed massive ice features, are presented by comparison with the previous results. Differences by Arctic region in the numbers and other statistics of massive ice features are also presented.

UPWARD LOOKING SONAR INSTRUMENTS

Instruments

The upward looking sonar instrumentation, consisting of the Ice Profiler Sonar (IPS) and the Acoustic Doppler Current Profiler (ADCP) are designed to be deployed 25 to 60 m below the air water interface from sea floor based moorings (Fig. 1) or, in shallower water, from bottom-mounted platforms. The instrument operates by emitting and detecting surface returns from frequent short pulses (pings) of acoustic energy concentrated in narrow beams (less than 2°). Precise measurements of the delay times between ping emission and reception were converted into ranges separating the instrument's transducer and the ice undersurface. Contemporary data from the instrument's on-board pressure sensor were then combined with atmospheric surface pressure data and estimates of the mean sound speed in the upper water column (obtained from data collected during absences of ice above the instrument) to derive estimates of ice draft from each emitted ping.

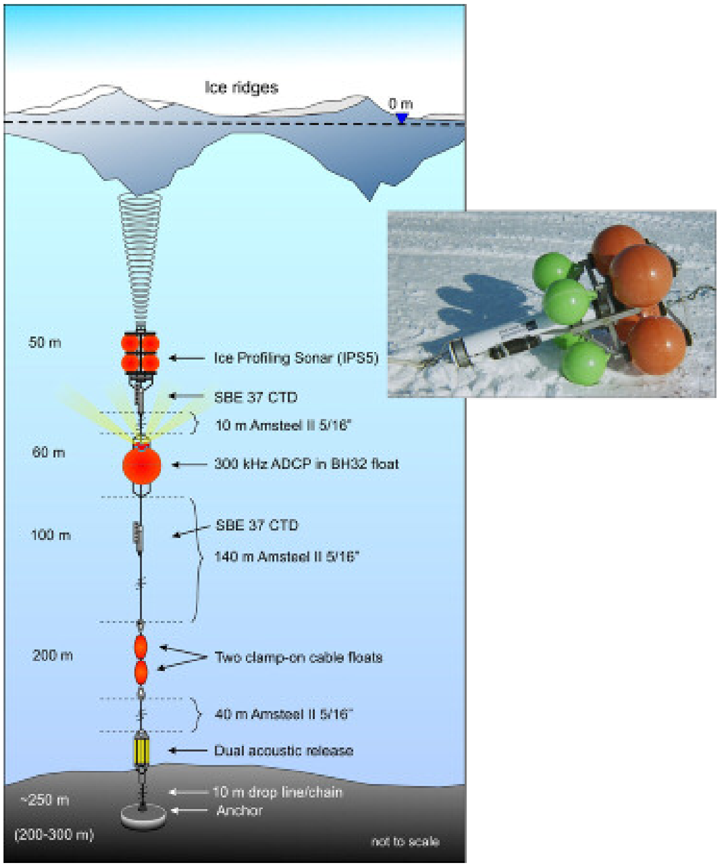

Figure 1. A typical deployment arrangement of an ice profiler and ADCP ice velocity measuring instruments on a single subsurface mooring. In shallow waters the Ice Profiler and ADCP are operated from separate moorings located within 100 m of one another.

Ice Draft Data

When IPS instruments, and the adjacent upward-looking ADCP (Acoustic Doppler Current Profiler) instruments (Fig. 1) with capabilities measuring ice drift velocity, the obtained data are used to construct two dimensional cross-sections of the ice cover moving over the instruments (Fig. 2), designated as quasi-spatial profiles (or ice distance series). With careful processing these products depict detailed variations in the depth of the lower ice surface with a horizontal resolution of about 1 m and an accuracy in the vertical of 5-10 cm. Keys to the utility of the technique are its on-board data storage capacity and capabilities for reliable long term un-attended operation in the hostile environments usually associated with ice covered waters. Until recently, principal users of this technology have been polar ocean scientists with interests and concerns regarding climate change (Fissel et al., 2008b) and, increasingly, international oil and gas producers with deployments throughout the Arctic Ocean and in sub-polar seas (Fig. 3)

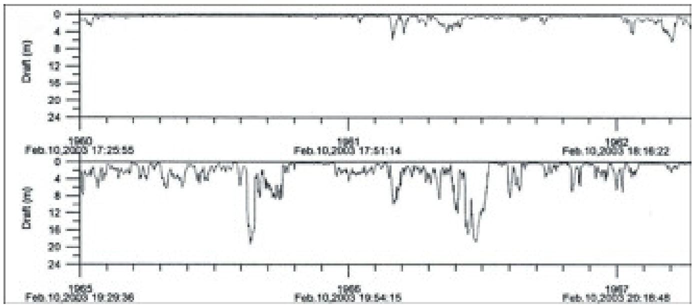

Figure 2. A quasi-spatial profile of an ice cover produced by combining time series draft and ice speed data to produce a product equivalent to the profile of the ice undersurface along a line traced out by all points on the ice which move over the ice profiler instrument during the measurement period. The abscissa is in kilometers, annotated with time of observation.

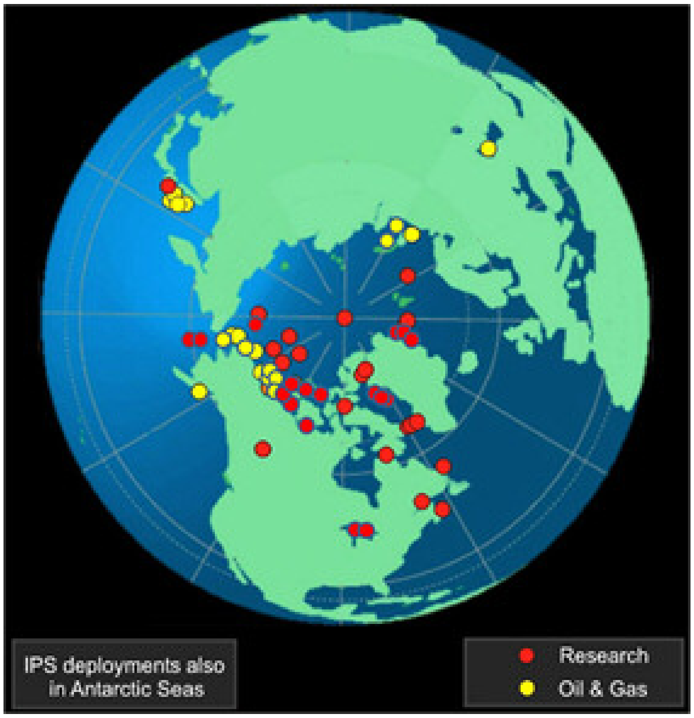

Figure 3. Areas of marine moored ice profiler deployments in the Northern Hemisphere from 1996 to the present. Note that some measurement areas are on major rivers and lakes.

METHODOLOGY

Large Individual Ice Keels

Each large ice keel in the spatial or distance ice data sets is identified from special scanning software applied to the 1.0 meter resolution ice draft spatial series. The algorithm used in identifying large individual ice keels follows the methods described in Vaudrey (1987) as Criterion A. This criterion includes user-selected parameters of: a threshold value of the maximum ice draft value that each ice keel must exceed (Start Threshold, values of 5, 8 or 11 m are often used) which starts the search; and the Rayleigh criterion (α= 0.5) and a lower End Threshold (typically set at 2m) which together determine the end of the large ice keel. Overlapping big keels can also result from the backward search of the next successive keel when a keel with a very large maximum draft value is followed by a keel with a lesser maximum draft value, as long as both exceed the specified Start Threshold value. An example of a combined ice keel feature which includes two originally individual ice keels with some overlap is presented in Fig. 4. More details on the method for identifying large ice keels are available in Fissel et al. (2012).

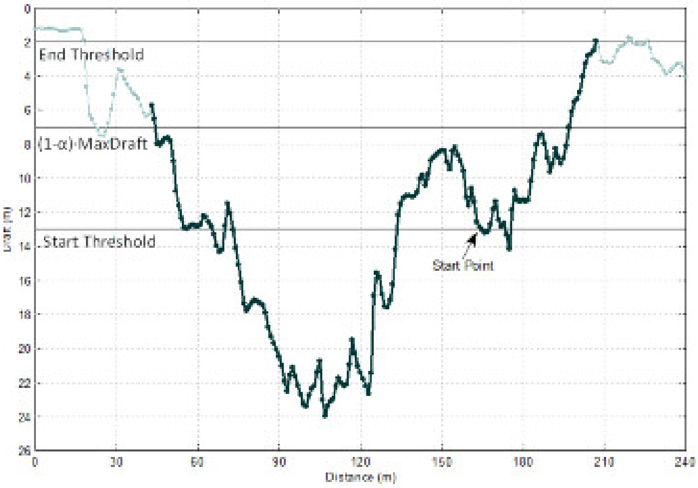

Figure 4. An example of a large keel feature extending from the Start Point beyond the feature shown in Fig. 4, which had some overlap with the preceding keel, resulting in a combined ice keel feature.

Hummocky Ice Features

Hummocky (sometimes referred as ice rubble fields) sea ice represents a different type of deformation of first year sea ice from the large ice keel features described above (sometimes referred to as pressure ridges). Distinctions between hummocky and large ice keels are based on the underlying deformation mechanism for each ice type: hummocky ice originated primarily from compressive events which force adjacent floes to ride up or slide over each other while ridged ice tends to arise from more drastic events in which smaller ice pieces are crushed and turned so that their original planes are oriented well off the vertical direction to produce combined deformed ice features which are larger in the vertical dimension and have distinct sides.

Automated methods for detecting hummocky ice were derived from analysis of several ice profiler sonar (IPS) data sets from the Canadian Beaufort Sea as described in Fissel et al. (2012). The spatial ice draft series were examined for continuous segments of hummocky ice, initially identified by satisfying four criteria:

1. The minimum draft is no lower than 1m
2. The segment maintains this minimum draft for at least 100m in distance
3. The 50th percentile draft is at least 2.5 m
4. The segments are free of any keels already identified in the 8m large keel database.

Based on the segment identified through these criteria, a method based on statistical parameters was developed to automatically classify likely episodes of hummocky ice. An example of an ice feature classified as hummocky ice is shown in Fig. 5.

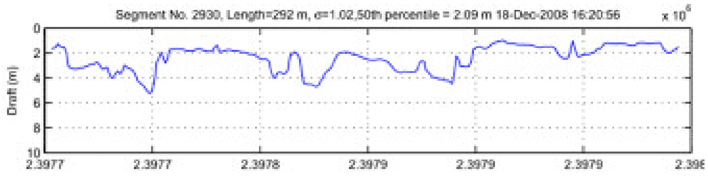

Figure 5. An example of a hummocky ice feature as detected with the algorithm described in Fissel et al. (2012).

The orientation of the deformed ice feature relative to the direction of draft can result in quite different results in terms of the classification of the ice feature characterization type. For example, if the orientation of an ice ridge is normal to the drift, as would generally be expected, the underlying ice feature will generally be seen as a large keel. In the less likely event that the orientation of the ice ridge is parallel to the drift of the ice floe drift, and the ridge feature travels over the ULS mooring, which is not as likely, then the ice feature may be classified as hummocky ice.

Cross-Sectional Areas of Continuous Ice Exceeding a Threshold (Massive Ice Features)

A more robust, geometrical characterization of potentially hazardous marine ice features is presented to identify episodes of continuous ice draft measurements exceeding a threshold value, for which the cross-sectional area of the ice draft and horizontal ice distance is computed. A reasonable ice draft threshold would be the value of undeformed thick first year (1.2 m), at which considerable ice loads can be supported. For comparison purposes and to test the sensitivity of the results to the draft threshold value, the computations were also made for a draft threshold of 2.0 m. The cross-sectional area values for qualifying ice episodes are then compiled from year-long measurements and those episodes with a cross-sectional area exceeding 250 m^2 and a width exceeding 100 m are included in a database along with the mean and maximum ice drafts and the horizontal width values.

RESULTS

Massive Ice Features

Selected spatial series of year-long ice drafts measured at 1 m horizontal resolution were analysed. These data sets included: two locations in the Canadian Beaufort Sea over two consecutive years of 2009-2011 (water depths of approximately 650 m); two data sets from Fram Strait for the year 2008-2009 (sites F13 and F14); and at one site in the Chukchi Sea for 2011-2012 (45 m water depth). The measurement locations are shown in Fig. 6.A database was assembled of data segments having consecutive ice draft values exceeding the draft threshold levels of 1.2 and 2.0 m along with the minimum values for cross-sectional area (250 m^2) and width (100 m). For each data segment, the cross-sectional area was computed along with the width (or distance spanned by the segment) and the mean and maximum ice draft values. Examples of these ice draft segments, or massive ice features are shown in Fig. 7.

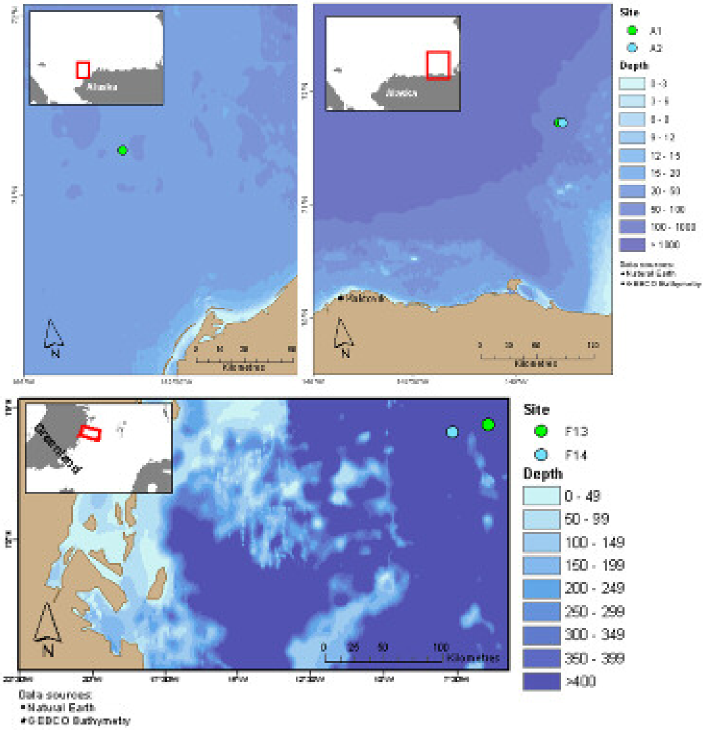

Figure 6: The locations of the measurements sites in the Chukchi Sea (upper left), the Canadian Beaufort Sea (two sites – upper right) and the Fram Strait (lower panel).

A statistical summary of the results for each measurement area and each ice draft threshold are provided in Table 1. The total number of massive ice features has much different values by region with over 7,000 features per site-year in the Fram Strait vs. 1,184 each site-year in the Canadian Beaufort Sea and 2,638 in the Chukchi Sea region for the 1.2 m draft threshold value. For the larger 2.0 m threshold, the differences are also large: 2,724 each year for the Fram Strait area vs. 265 per site-year for the Canadian Beaufort Sea and 931 for the Chukchi Sea.

For the draft threshold of 1.2 m, the mean and maximum ice drafts exhibit much less regional variability with average values of 2.8 – 3.1 m and 5.0 – 5.8 m for the draft thresholds of 1.2 and 2.0 m, respectively. Similarly, the cross-sectional areas are quite consistent among the regions ranging from 775 - 976 m^2 with relatively small changes according to ice draft threshold. The mean width values are also similar among the regions, although the use of the larger draft threshold of 2.0 m results in a reduction of the range of mean width values to 153 – 168 m vs. 272 – 333 m for the 1.2 m ice draft threshold.

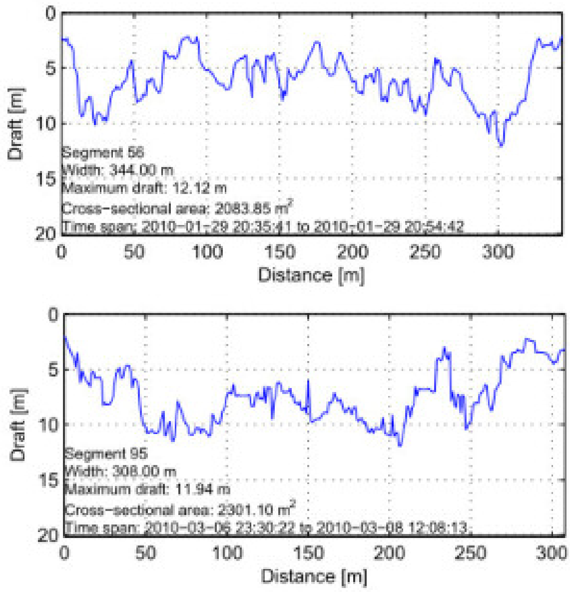

Figure 7: Examples of two massive ice draft features, from the Canadian Beaufort Sea data sets.

Table 1: Statistics for all data segments of consecutive ice drafts exceeding the 1.2 or 2.0 m threshold value. Note that the areas, widths, drafts are presented as the averages per site-year while the number of features are given for all data sets available in each area

Draft threshold [m]	Area	# site-years	Total # massive ice features	Cross-sectional area [m^2]			Width [m]			Draft [m]	
				Mean	Min	Max	Mean	Min	Max	Mean	Max
1.2	Beaufort Sea: Average	4	4736	775	250	9259	272	100	5271	2.8	24.7
	Fram Strait: Average	2	14614	982	250	28640	333	100	9651	2.9	26.0
	Chukchi Sea	1	2638	976	251	11073	317	100	3134	3.1	26.4
2.0	Beaufort Sea: Average	4	1058	877	262	5394	153	100	973	5.8	24.7
	Fram Strait: Average	2	5448	850	251	11140	168	100	1682	5.0	24.4
	Chukchi Sea	1	931	894	264	6309	156	100	798	5.7	26.4

The maximum values of both cross-sectional area and the width are much greater than the mean values which is due to a frequency distribution having an extended tail over which the largest values occur much less frequently than the mean or typical values. This very large range in the frequency distribution of the cross-sectional area and width parameters can be seen in Fig. 8 and Fig. 9. The distributions show that the most occurrences occur at the threshold value level with a continuous decline in the frequency of occurrences as the values increase. The one exception to this is for the cross-sectional area parameter for ice drafts exceeding 2.0 m where the most probable values occur at about 500 m^2 which is well above the threshold level of 250 m^2. This appears to be associated with the minimum width threshold of 100 m which restricts the occurrences of areas less than 500 m^2 due to the typical mean ice drafts of about 5 m for this larger ice draft threshold level.

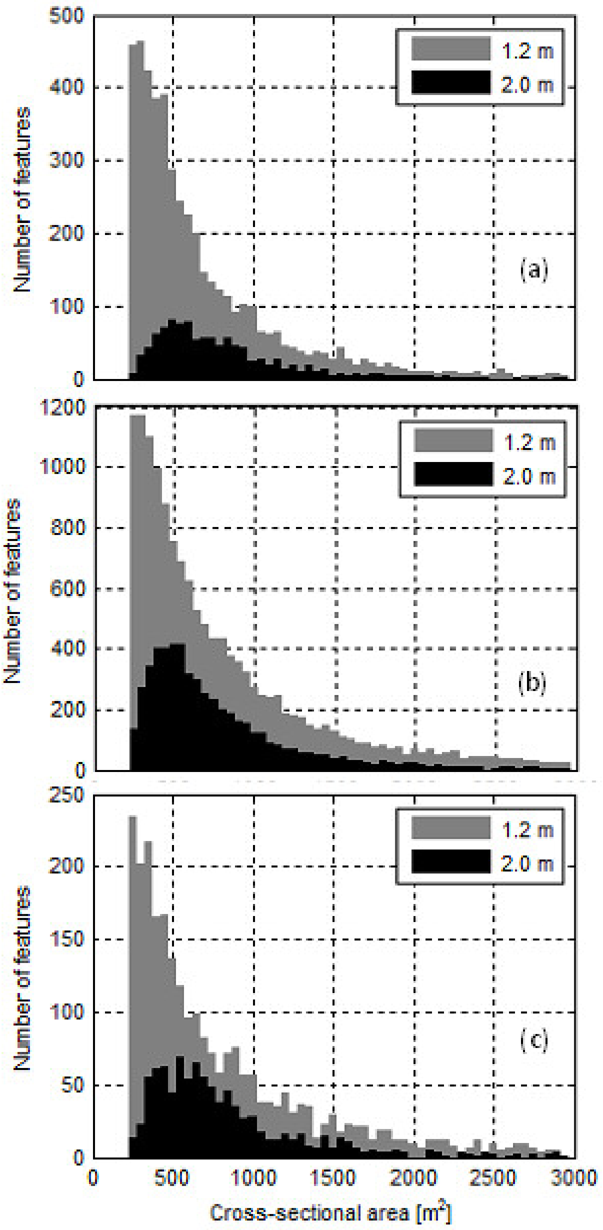

Figure 8: Histograms of cross-sectional area for massive ice features identified using a draft threshold of 1.2 and 2.0 m in the (a) Beaufort Sea, (b) Fram Strait and (c) Chukchi Sea. The histograms are limited to values of 3,000 while the largest values (9,259, 28,640 and 11,073 for (a), (b) and (c) respectively) occur very rarely and are not plotted.

The occurrences of massive ice features varies on seasonal and shorter time scales as can be seen in the plot of the total cross-sectional area of all massive ice features occurring each week at the two measurement sites in Fram Strait (Fig. 10). Massive ice features are most commonly found in winter and the late fall period with reduced numbers in the spring and summer; however, even larger variations occur from week to week.

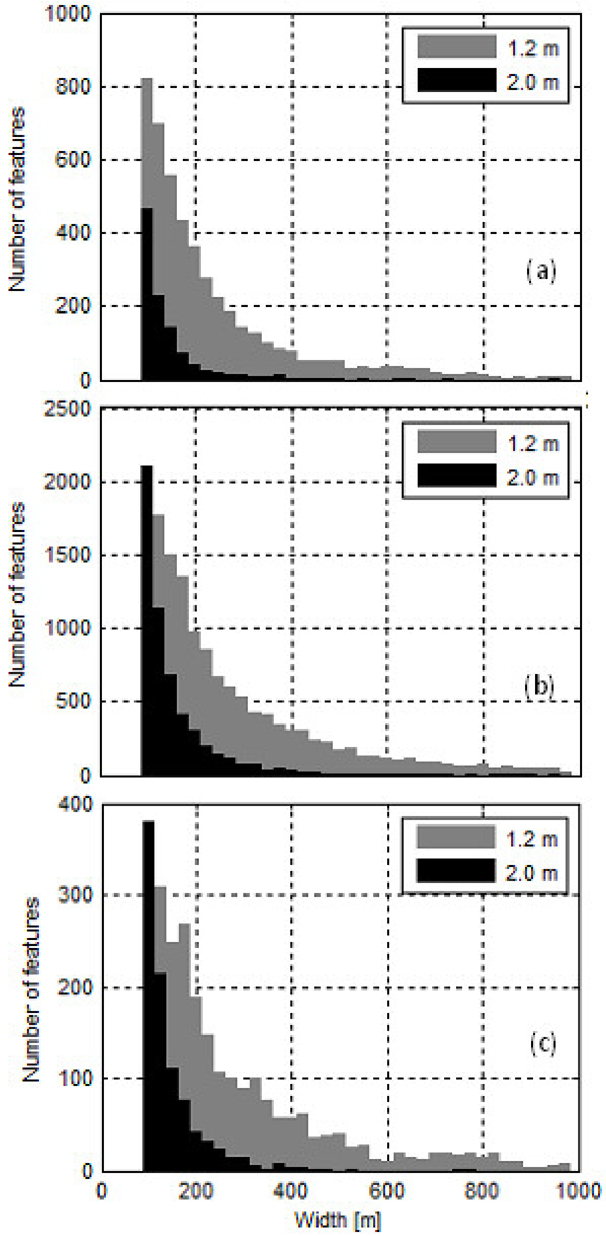

Figure 9: Histograms of the width parameter for massive ice features identified using a draft threshold of 1.2 and 2.0 m in the (a) Beaufort Sea, (b) Fram Strait and (c) Chukchi Sea. Note that the histograms are limited to values of 1,000 while the largest values range from 5,271 (a), 3,134 (b) to 9,651 (c).

Comparisons of Massive Ice Features with Large Individual Ice Keels and Rubbled / Hummocky Ice Features

A comparison of the number of massive ice features, as defined in this study, with the number of very deep individual keels and hummocky ice features (as presented in Fissel et al. (2012)) is instructive. Very large individual ice keels exceeding a maximum value of 8 m have many occurrences per site year: 699 in the Canadian Beaufort Sea, 3000 in the Chukchi Sea and 3,376 in Fram Strait. However, these large individual ice keel features typically have widths of less than 100 m and typical and maximum cross-sectional areas of 400 and 1,000 m^2, respectively.

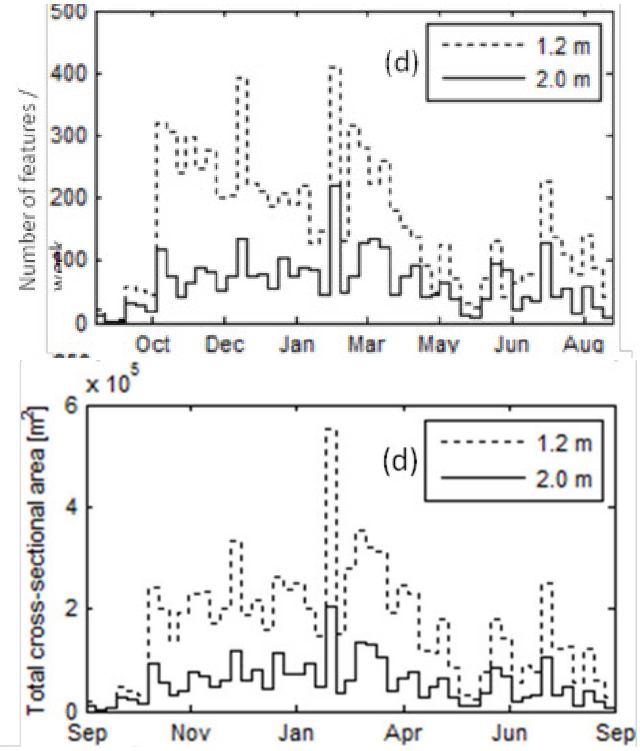

Figure 10: The number of occurrences and total cross-sectional area in m^2 of massive ice features at site (d) F14 in Fram Strait.

Because of the 100 m minimum width threshold value used, the massive ice features are largely additional to those of the large individual ice keel features. The massive ice features occur more frequently and typically have much larger cross-sectional areas than individual ice keel features.

For hummocky and rubbled ice features, which are detected after the removal of the 8 m ice individual ice keels, the total number of hummocky ice segments is smaller in number than the individual large ice keels. As an example of this, comparative numbers are provided for the numbers of very large keels, hummocky and massive ice features per year for the Fram Strait region in Table 2.

Table 2: The number per year and typical width characteristic of different ice feature types computed from the Fram Strait data sets.

Fram Strait				
Ice Feature Types	Ice draft (m)	Min. width (m)	Number/year	Avg. Width (m)
Large Keels	maximum > 8 m	-	3,376	38
Hummocky Ice	1.0 m min.	100	1,111	368
Massive Ice Features	2.0 m min.	100	2,724	168

There were many more large keels in Fram Strait (Fissel et al., 2012) than hummocky ice features (3376 vs. 1111 per year). However, the width of these rubbled/hummocky ice features is much larger corresponding to an average width of each segment of 368 m in Fram Strait vs. 38 m for the large individual ice keels. Overall, the cross-sectional areas of the rubbled/hummocky ice features are larger than that of individual ice keels with typical values of 800 m^2 vs. 400 m^2, respectively.

The massive ice features include many of the rubbled / hummocky ice features given that rubbled/hummocky ice has a minimum draft of 1 m and a minimum width of 100 m vs. 1.2 or 2.0 m and the same 100 minimum width for massive ice features. However, the quantities of the massive ice features is much larger than those of rubbled/hummocky ice: for example in the Fram Strait area the numbers of massive ice features per year are 7,307 and 2,724 for 1.2 and 2.0 m draft thresholds vs. 1,111 data segments per year for rubbled/hummocky ice.

As discussed by Fissel et al. (2012) there is overlap in the sea ice feature algorithm for characterizing large individual ice keels and rubbled/hummocky ice which reduces the numbers of rubbled/hummocky ice features due to the interspersed large individual keels. Giving the capabilities demonstrated by the massive ice feature characterization and its comparative simplicity vs. the rubbled/hummocky algorithm, the plan going forward is to use the massive ice feature algorithm in place of the rubbled/hummocky ice algorithm while continuing to use the individual large ice keel algorithm. The latter algorithm will be limited to a maximum distance of an appropriate width relative to the very deepest ice keels present. For example if the deepest ice draft is 30 m, an appropriate upper limit of width for the individual ice keel algorithm could be selected as 100 m which provides for a width to depth aspect ratio of 3.3. The minimum width parameter for the massive ice keels would then use 100 m as a lower bound with a minimum cross-sectional area parameter to be set to avoid any gaps in identifying important ice features between the two algorithms.

Estimations of Total Volumes and Mass Derived from the Massive Ice Keel Database

It is useful to extend the characterization of potentially hazardous marine ice features beyond computation of cross-sectional areas to estimation of the volume and mass of ice features, at least in a statistical sense. One approach to doing this is to map the horizontal areas of the ice features from use of ancillary high satellite data sets, such as the all-weather Radarsat-2 image scenes (Ersahin et al., 2014). However, given the realities of orbit repeat cycles and budgets, it will not be possible to obtain full temporal coverage of the hundreds or thousands of ice features passing over ULS mooring sites.

An alternative approach is to extend the ULS derived cross-sectional area, ice draft and widths of ice features as presented in this paper to a statistical estimation of the distribution of volumes and ice masses of many ice features.

Based on information available about the shapes and orientations of marine ice floes derived from satellite and airborne image data sets for first year (Toyota et al., 2006) and multi-year ice (Hudson, 1987), sea ice floes have irregular shapes that are generally close to a length to width aspect ratio. The ratio of the maximum floe dimension to the minimum floe dimension is approximately 1.2 – 2.2 for both first year and old sea ice types. If the track of the ice floe traversing the mooring site is along the larger (smaller) dimension, the width value will overestimate (underestimate) the actual ice floe dimension by a mid-range factor of 1.23 (0.79) in linear dimension or 1.51 (0.62) in areal dimension. Although individual ice floe widths can be misrepresented, this effect will be much reduced when considering the statistical distribution of many ice floes, assuming that the orientation of the maximum ice floe dimension relative to the track orientation is random in nature.

There is also an effect of the measured width of ice floe features which pass over the sonar mooring off the centre point of the ice floe, which tends to reduce the observed width from the actual maximum floe dimension. Geometrical computations of this effect on circular or square shaped ice floes indicate a bias toward reduced values for the measured to actual dimensions of the ice floes of approximately 0.8 in length or 0.64 in area. Overall, the effect of the deriving volume estimates from a single measured width available from the ULS data sets appears to be a random variation in the horizontal dimension of the ice floe by a factor of 1.7 on average for individual floe features, with a smaller potential bias in area of 0.8, resulting in an underestimate of ice volume and mass by this factor.

Given the above reasoning, no adjustment will be made to the measured width values in estimating the ice volume and mass for an ensemble of many ice features. The total volume of these large marine ice features using the 2.0 m ice draft threshold, yields estimated median volume values of 0.09 x 10^6 m^3 for both the Canadian Beaufort Sea and the Fram Strait region. The distributions of the computed ice volumes for all identified massive ice features are presented in Fig. 10.

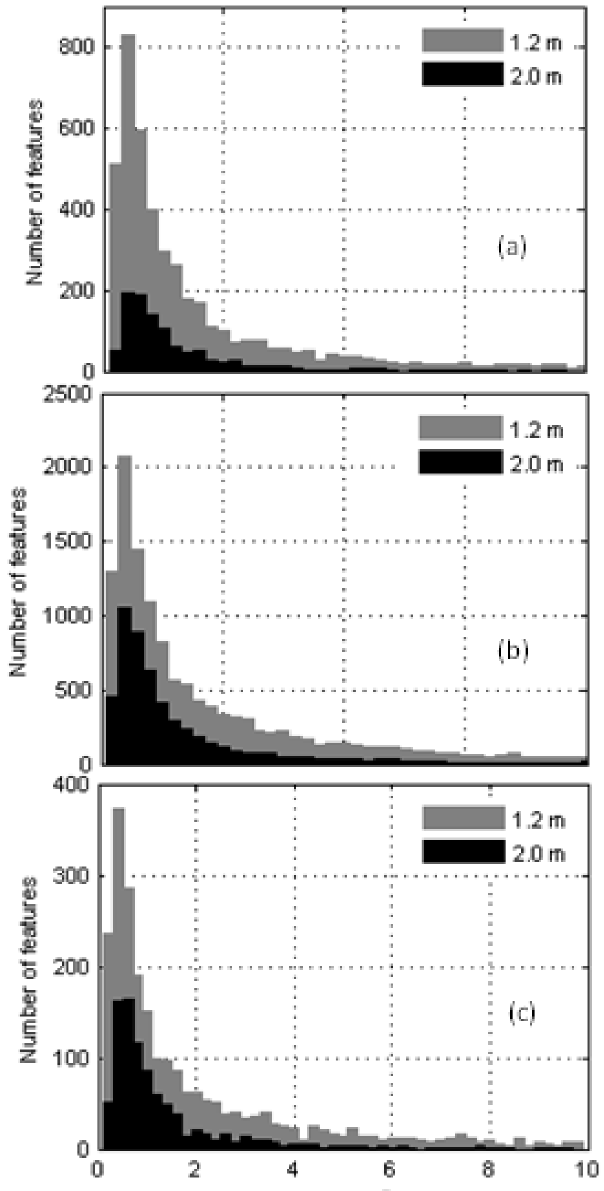

Figure 10: Histograms of the estimated volume in m^3 for massive ice features identified using a draft threshold of 1.2 and 2.0 m in the (a) Beaufort Sea, (b) Fram Strait and (c) Chukchi Sea. The histograms are limited to values of 1 million m^3 while the actual largest volumes, although very infrequent, can be considerably larger than 1 million m^3 (as discussed in the text).

The largest volumes of massive ice features, while more prone to uncertainties, are instructive to consider. For massive ice features with volumes exceeding 2.0 x 10^6 m^3 there are: five in the Chukchi Sea in 1 year of data (up to 4.8 x 10^6 m^3); six in the Canadian Beaufort Sea in 3.5 site-years of data (up to 5.20 x 10^6 $m^{3);}$ and 51 in Fram Strait over two site-years of data (up to 13.5 x 10^6 m^3). After allowing for the density of sea ice being approximately 900 kg/m^3 and the possibility of voids in the deeper portions of large ice keels, these identified episodes of massive marine ice features have estimated masses of typically 0.081 million metric tonnes which maximum values of up to 4.3 million metric tonnes in the Chukchi Sea, 4.7 million metric tonnes in the Canadian Beaufort Sea and up to 12.2 million metric tonnes in the Fram Strait region. Using the lower ice draft threshold value of 1.2 m, results in even more large ice volume and ice mass values with maximum levels of well over 100 million metric tonnes.

CONCLUSIONS AND RECOMMENDATIONS

A more robust, geometrical characterization of potentially hazardous marine ice features is presented in this paper to identify episodes of continuous ice draft measurements exceeding a threshold value, for which the cross-sectional area of the ice draft and horizontal ice distance is computed, using a user-selectable minimum threshold value (e.g. 1.2 or 2.0 m) along with selected minimum values for cross-sectional area (250 m^2) and width (100 m). Based on many year-long ULS data sets obtained at measurement sites spanning the Arctic Ocean, the maximum and average values of the cross-sectional area, or massive ice features are computed. The numbers of individual massive ice keel features identified per year total 7,000 features per year in the Fram Strait vs. just under 1,400 each year in the Canadian Beaufort Sea and 2,638 in the Chukchi Sea region for the 1.2 m draft threshold value. For the larger 2.0 m threshold, the differences are also large: 2,724 each year for the Fram Strait area vs. 350 each year for the Canadian Beaufort Sea and 931 for the Chukchi Sea. The large numbers of ice features detected with this algorithm provide very robust statistics.

Using an assumed statistical approach for the horizontal geometry of the individual ice features, the total volume of these large marine ice episodes, can be estimated as the product of the cross-sectional area and the single measured width, with thousands of features exceeding 81,000 metric tonnes for a 2.0 minimum ice draft, being realized in typical moored ULS data sets. The maximum estimated mass is 12.2 million metric tonnes in the heavy pack ice exiting the Arctic Ocean in Fram Strait for a 2.0 minimum ice draft and much larger (> 100 million metric tonnes) for a 1.2 m minimum ice draft.

Giving the capabilities demonstrated by the massive ice feature characterization and its comparative simplicity vs. the rubbled/hummocky algorithm previously developed, the going forward plan is to use the massive ice feature algorithm in place of the rubbled/hummocky ice algorithm while continuing to use the individual large ice keel algorithm with a selectable maximum ice draft threshold, probably 8 m for most areas in the Arctic, and a maximum width value of 100 m. The minimum width parameter for the massive ice keels would then use 100 m as a lower bound with a minimum cross-sectional area parameter to be set to avoid any gaps in identifying important ice features between the two algorithms.

This combined approach would be the basis for the identification and characterization of potentially hazardous marine ice features. Two other types of marine ice of special interest are floating glacial ice features consisting of icebergs and ice islands, as well as old or multi-year ice. Work is underway to develop better characterizations of these ice feature types from ULS distance series of ice drafts. These ice features would be captured within the individual ice keel (small to moderate glacial ice) and massive ice feature (very large glacial ice and old/ multi-year ice) categories with special additional algorithms under development at present to identify and characterize these subsets of potentially hazardous ice features.

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