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Estimation and Validation of Floe Size Distribution from Upward Looking Sonars

Todd Mudge; Keath Borg; Kaan Ersahin; Ed Ross; Dawn Sadowy; Jessy Barrette; Nikola Milutinovic. ASL Environmental Sciences Inc., Victoria, BC, Canada.

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Problem

Can a single beam inverted echo sounder measure ice floe diameter? For an individual floe, yes but imaging is required. How about a distribution of floes?

The Study Area

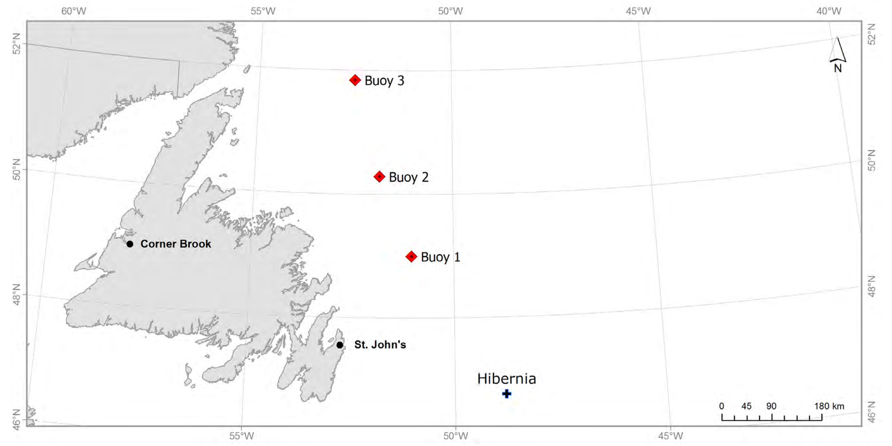

Figure 1: Locations for Statoil Canada's Upward Looking Sonar (ULS) moorings off the coast of Newfoundland that were deployed from 23 April 2015 to 11 June 2016.

- Statoil Canada, ArcticNet, the Research & Development Corporation of Newfoundland and Labrador (RDC) and Husky Energy partnered in an offshore research expedition
- The marginal ice zone off NE Newfoundland
- The Labrador Current carries ice down the coast
- Northeast winds push ice to the west, increasing ice concentrations
- Storms, including hurricanes, develop large waves and enlarge marginal ice zones.

Floes with Collocated Data

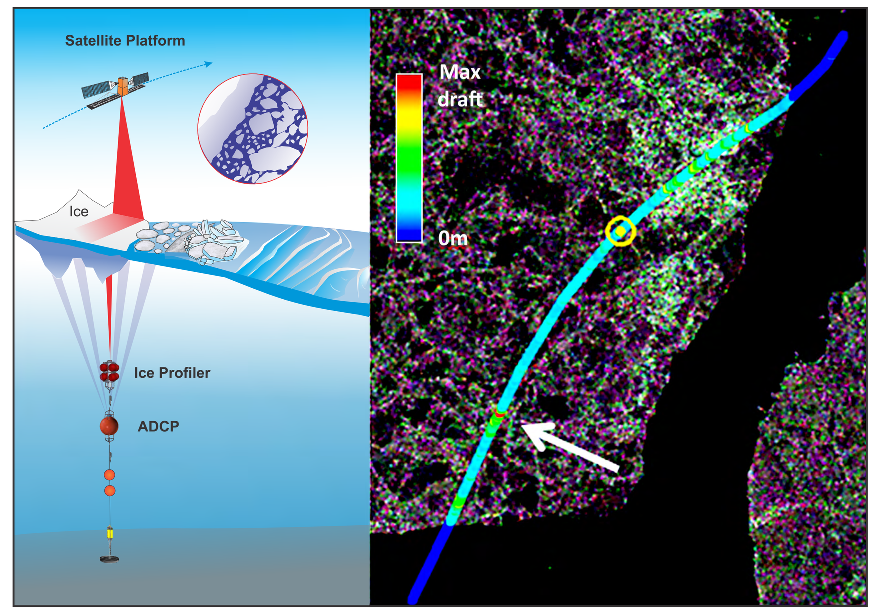

Figure 2: Left: A typical ULS mooring configuration. Right: Fusion of RADARSAT and ULS data (Ersahin et al, 2015). The RADARSAT image is an RGB colour composite of three polarizations. The ULS track is colour coded by ice draft.

- The ULS identifies where the track first encounters a floe and where it re-enters open water: the ULS Distance Made Good (ULS/DMG)
- We can collate floes in ULS and satellite data
- Can we use only ULS data to characterize ice floes?

Linear Path to Area Estimates

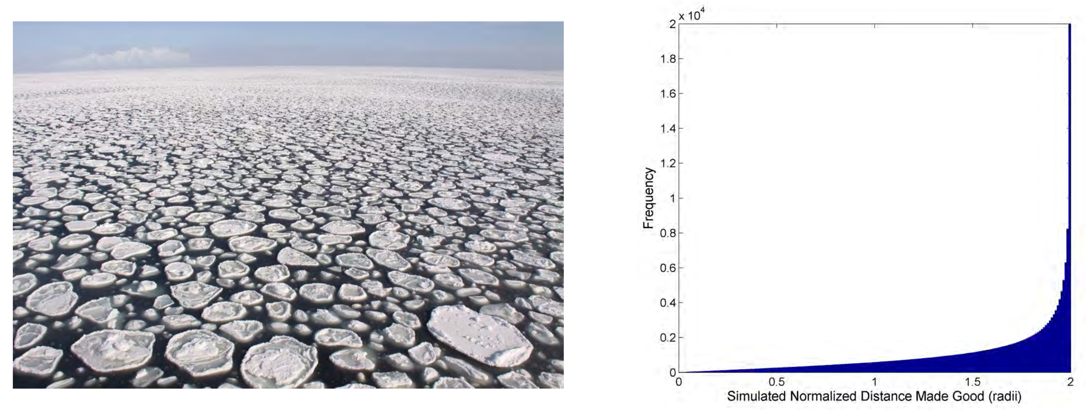

Figure 3: Left: Pancake Ice observed by Kenneth Mankoff (Mankoff, 2016) in Drake Passage on 23 September, 2009. Note the near-circular shape of the floes. Right: The simulated distribution of normalized distance made good ULS tracks (ULS/DMG) for 2 million identically sized circular floes.

- Can the bulk statistics of the ULS /DMG under a population of floes of similar size distributions provide information about the floe sizes?
- We first consider circular floes – similar to pancake ice (Figure 3)
- Simulating $2x10^6$ tracks assuming drift along the Y-axis and the X location of intersection is uniformly distributed
- The mean DMG=1.57 r, the median DMG=1.73 r, r being the simulated floe radius.

Figure 4: Left: RADARSAT image from the Beaufort Sea that illustrates some natural floe shapes. Below: The image provides a mask for one ice floe (ID 407).

- A similar simulation was done using 10 floes from a 50 m resolution RADARSAT image (Table 1)
- The mean ULS/DMG was 0.55 ± 2.5% of the max. floe length (value reported by CIS)
- The mean ULS/DMG was 1.43 ± 2.2% times the equivalent radius.

Table 1: Ice floe size statistics. Ratio 1 = Mean DMG/ sqrt(Area/π). Ratio 2 = Mean DMG/ Max Length.

Floe ID	Area (km^2)	sqrt(Area/π) (km)	Max Length (km)	Mean DMG (km)	Ratio 1	Ratio 2
20	2.45	0.883	2.02	1.29	146%	64%
30	0.78	0.499	1.27	0.75	149%	58%
44	23.74	2.749	7.27	3.89	141%	53%
60	3.03	0.982	2.48	1.44	147%	58%
61	1.33	0.651	1.64	1.01	154%	61%
240	3.09	0.992	2.96	1.33	134%	45%
247	28.45	3.009	8.70	4.23	141%	49%
259	5.58	1.333	3.92	1.83	137%	47%
407	37.38	3.449	7.69	5.07	147%	66%
486	115.01	6.050	18.29	7.97	132%	44%
				Mean	143%	55%
				Std Error	2.2%	2.5%

Application (April 12-17, 2016 at Buoy 3)

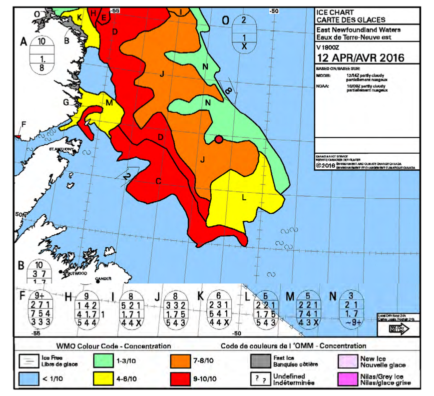

Figure 5: Canadian Ice Service Chart for the region on April 12th, 2016 (CIS, 2016b). The Buoy 3 mooring is denoted by the red dot with the black outline.

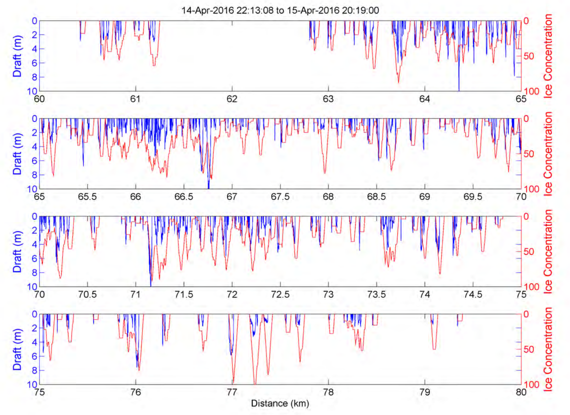

Figure 6: Ice draft spatial series at 1 m resolution (blue). Ice concentration over a 50 m window (red). The CIS identify ice patches with concentrations of 9+ tenths (~9+ in egg code N) similar to that observed by the ULS.

- 1088 ice floes were manually identified by an experienced ice scientist
- The ice concentration and drift speeds derived from the ULS spatial series were similar to that reported by CIS (Table 2).

Table 2: Tabulation of the daily ice concentration and net ice displacement in nautical miles.

Date	ULS Ice Concentration (%)	ULS Daily Ice Drift (nm)	CIS Daily Ice Drift (nm)
April 12, 2016	11.5	10	8
April 13, 2016	5.4	17	8
April 14, 2016	11.9	10	5
April 15, 2016	18.9	10	8
April 16, 2016	11.0	9	8
April 17, 2016	6.1	7	10
April 12-17, 2016	10.7	11	8

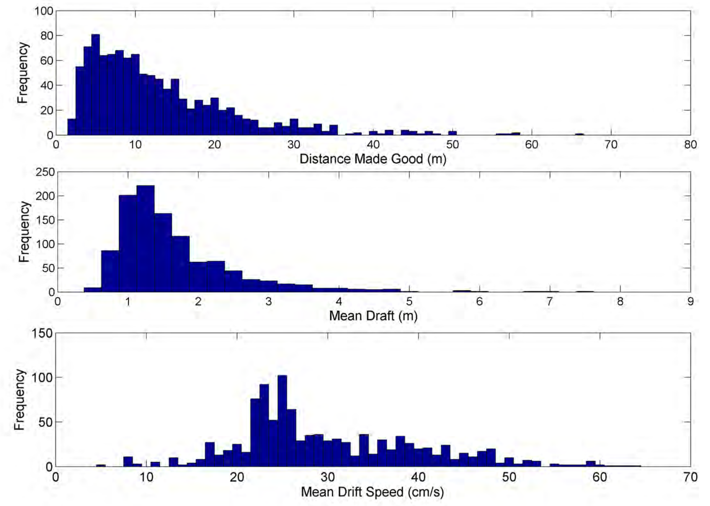

Figure 7: Histogram of the distances made good across the ice floes (top). Histogram of the mean measured draft (middle). Histogram of the mean drift speed (bottom).

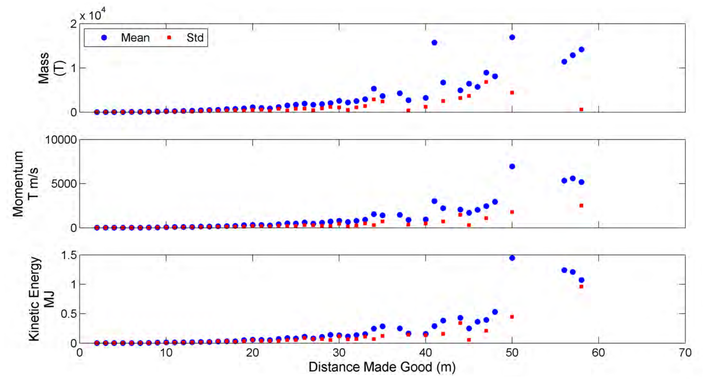

Figure 8: Mass (top), momentum (middle) and kinetic energy (bottom) versus Distance Made Good.

- The 1.57 scaling factor was used to obtain an equivalent radius/diameter
- The mean equivalent radius, draft, and density of 1000 kg m^3 was used to calculate mean momentum and kinetic energy for each size category
- The largest kinetic energy was ~1.5 MJ for a mass of ~ 17 kT
- This and other large features may be due to glacial ice or floebergs.

Conclusions

- ULS derived ice concentration and ice drift are similar to those reported by CIS
- A method has been developed to estimate the statistics of floe sizes from moored ULS for floes < 100 m width
- The mean ULS/DMG is approximately 80% of the equivalent diameter (based on simulations with circular floes or actual floes)
- The methodology appears to be working for a case study where the floes tended to be < 10 m width.

Further Work

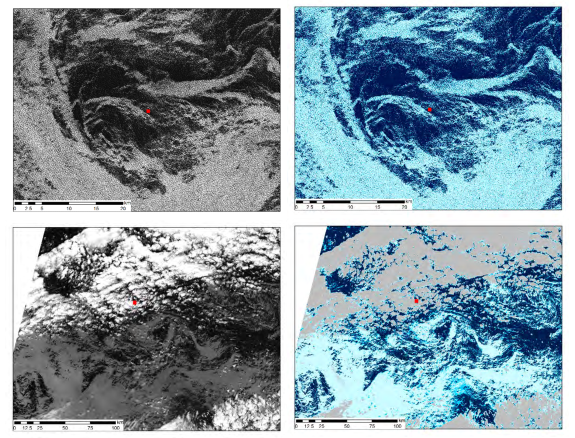

Figure 9: Top Left: Grey-scale Sentinel-1a RADAR image. April 13, 2016. Resolution 10 m^2.
Top Right: Same image as top left in false colour.

Bottom Left: Grey-scale image Landsat 8 SWIR. April 20, 2016. Resolution: 30 m^2.
Bottom Right: Same images as bottom left in false colour.

Right hand images open water = dark blue ; Ice/Water mix = medium blue; ice = light blue.

Red dot denotes Buoy 3.

- Direct comparison of ULS derived floe sizes with coincident or near-coincident satellite/airborne data. Figure 9 shows filament shaped ice patches from imagery collected around the period of interest.
- Analysis of more ULS data, particularly during periods with large waves when ice identification is challenging
- Investigate whether spectra help to resolve the concentration and patchiness

Acknowledgements

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