ARCTIC RESPONSE TECHNOLOGY
OIL SPILL PREPAREDNESS

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INITIAL TESTS COMPARING SEA ICE AND ARTIFICIAL ICE

ABSTRACT

Initial experiments have been performed comparing natural ice with artificial ice. The objective was to investigate if polyethylene blocks (PE-blocks) behave similar to natural ice, and with that replace natural ice in the planned dispersant and mineral fines efficiency testing. These experiments have also been used to test the protocol for in situ weathering and dispersant application, and as inter tank comparison between SINTEF and SL Ross. The findings from the initial tests demonstrated that there was a very good correlation between the tests performed in the SINTEF and SL Ross flumes. Both the weathering degree and the dispersant efficiency were in the same range.

Replacing PE blocks with natural ice did not influence the weathering or the dispersant efficiency. However, the PE blocks behaved differently than the ice in the flume, especially at high energy and prop wash conditions. This is probably due to different surface properties of the PE blocks compared to ice, and that the PE blocks have a slightly higher density than the ice.

Based on the experience and observations during the initial tests, SINTEF and SL Ross recommend that further tests should be performed using ice, and not PE blocks.

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1 INTRODUCTION

As a first phase of Task 2 of the project "Dispersant testing under realistic conditions", a calibration between the three flumes at CEDRE, SINTEF and SL Ross were conducted. Dispersant effectiveness testing of one oil-dispersant combination was performed using the pre-weathered Norwegian crude oil Grane and Corexit 9500 at three different energy conditions (low, medium, high). The results have shown that there was a very good correlation between the dispersant efficiency in all three flumes, especially at low and high energy levels (Faksness et al., 2013).

Initial experiments have been performed comparing natural ice with artificial ice (polyethylene blocks). The objective was to investigate if PE-blocks behave similar to natural ice to determine if PE-blocks could be used to replace natural ice in the dispersant and mineral fines efficiency testing planned in this project. These experiments have also been used to test the protocol for in situ weathering and dispersant application, and as inter tank comparison between SINTEF and SL Ross. The protocol was prepared after discussions during a project team meeting in Trondheim September 9-10, 2014, where SL Ross, Cedre, and SINTEF participated. OGP was represented by Tim Nedwed, ExxonMobil.

2 MATERIALS AND METHODS

2.1 Oil and dispersant

It was planned to use the Norwegian crude Grane in the initial testing, but due to delivery problems at the terminal, another Norwegian crude oil, Troll Blend, was used instead. SINTEF received 17 Jerry cans with Troll Blend Crude from Statoil September 22, 2014. The Troll oil is usually a naphthenic oil, as shown in the GC chromatogram given in Figure 2.1, but the Troll Blend received is more paraffinic than expected (Figure 2.2). Troll Blend is a mix of Troll C and Fram oil (Figure 2.3), which is transported in the same pipeline to the Mongstad terminal onshore. The mix ratio of the two oils is not known.

Table 2.1 compares density and viscosity of the two batches of Troll crude, and indicates that the naphthenic Troll crude has a slightly higher density than Troll Blend. Evaporative loss in residues from artificial weathering in the laboratory (simple one-step distillation) of Fram and Troll B is given in Table 2.2 (Andreassen and Sørheim, 2013).

Corexit 9500 (DOR 1:20) was used as dispersant in all experiments.

Table 2.1 Density and viscosity of Troll Blend, Troll B, and Fram. Viscosity is measured at 2°C for Troll Blend and Troll B, and at 5°C from Fram.

SINTEF ID	Oil	Density (g/mL)	Viscosity (cP), 10^{-1}	Comment
2014-0335	Troll Blend	0.854	38	OGP JIP 2014
2009-0702	Troll	0.892	48	SINTEF Oil in ice JIP 2009
2012-0340	Fram	0.850	213	Andreassen and Sørheim (2013)

Table 2.2 Evaporative loss (in vol %) in residues from artificial weathering in the laboratory (from Andeassen and Sørheim, 2013)

Oil	150°C+	200°C+	250°C+
Troll B	8 %	15 %	24 %
Fram	13 %	22 %	33 %

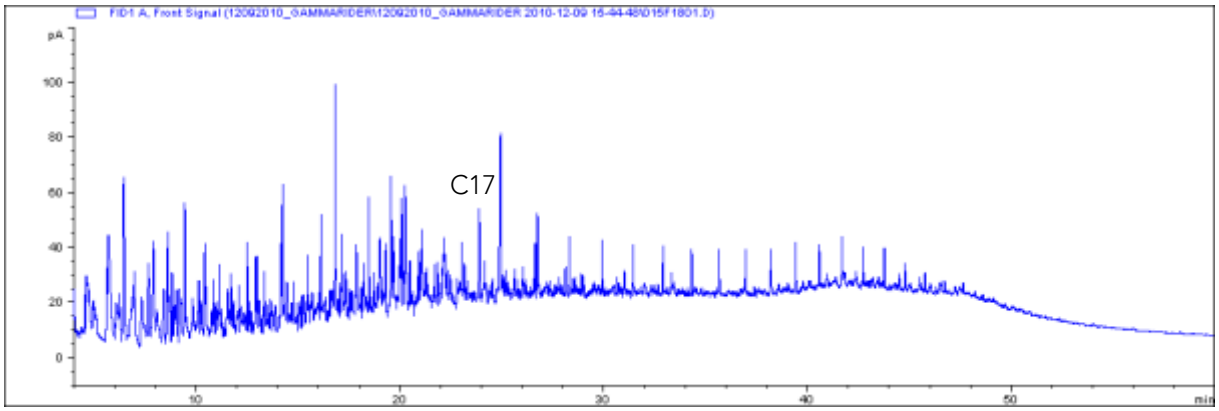

Figure 2.1 Troll crude used in the field experiment in the SINTEF oil in ice JIP in 2009 (SINTEF ID 2009-0702) (analyzed under other GC conditions)

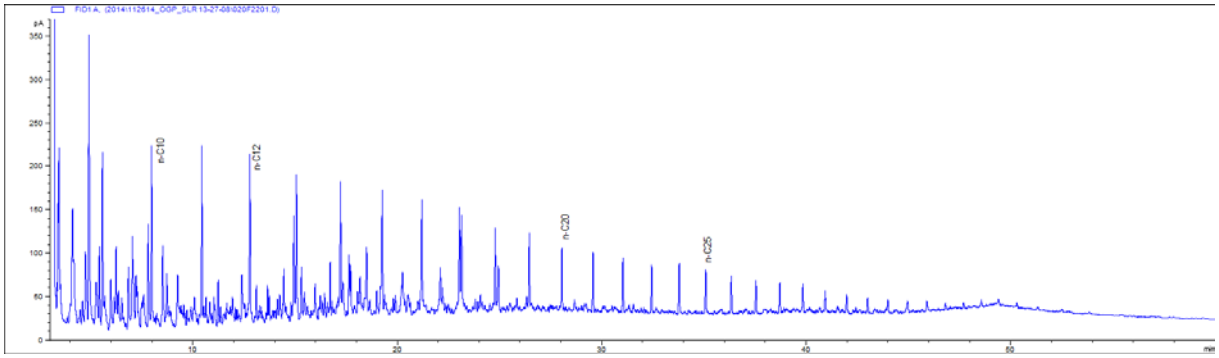

Figure 2.2 Troll Blend crude, received in September 2014 and used in the OGP Arctic oil spill response technology JIP (SINTEF ID 2014-0335)

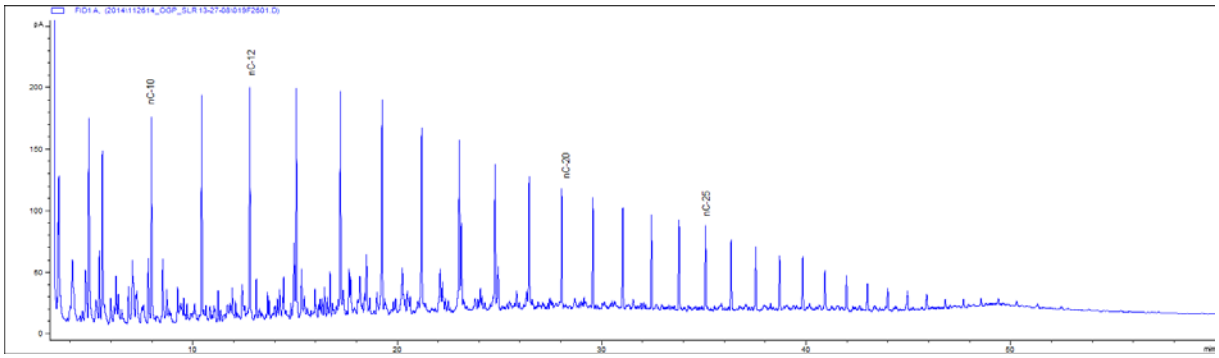

Figure 2.3 GC chromatogram of Fram crude oil from SINTEFs oil data base, received in 2012 (SINTEF ID: 2012-0340)

2.2 Test tank preparation

More detailed descriptions of the flumes and their settings are given in detail in the report from the test tank inter-calibration (Faksness et al., 2014).

A sketch of the flume is shown in Figure 2.4. The containment area for oil weathering was located on the opposite side of the wave maker, between position C and D. Key figures and settings for the flumes are given in Table 2.3. The sun simulator was not turned on during the experiments.

Approximately 4.8 m^3 of seawater is circulated in the 10 meter long flumes. The SINTEF flume is located in a temperature controlled room (0°C – 20°C). The SL Ross tank sides and surface are insulated to maintain the water and air temperature during the testing. The water in both flumes is cooled by a refrigeration system connected to a cooling coil placed in the tank water. Two fans placed in a covered wind tunnel allow for control of the wind speed.

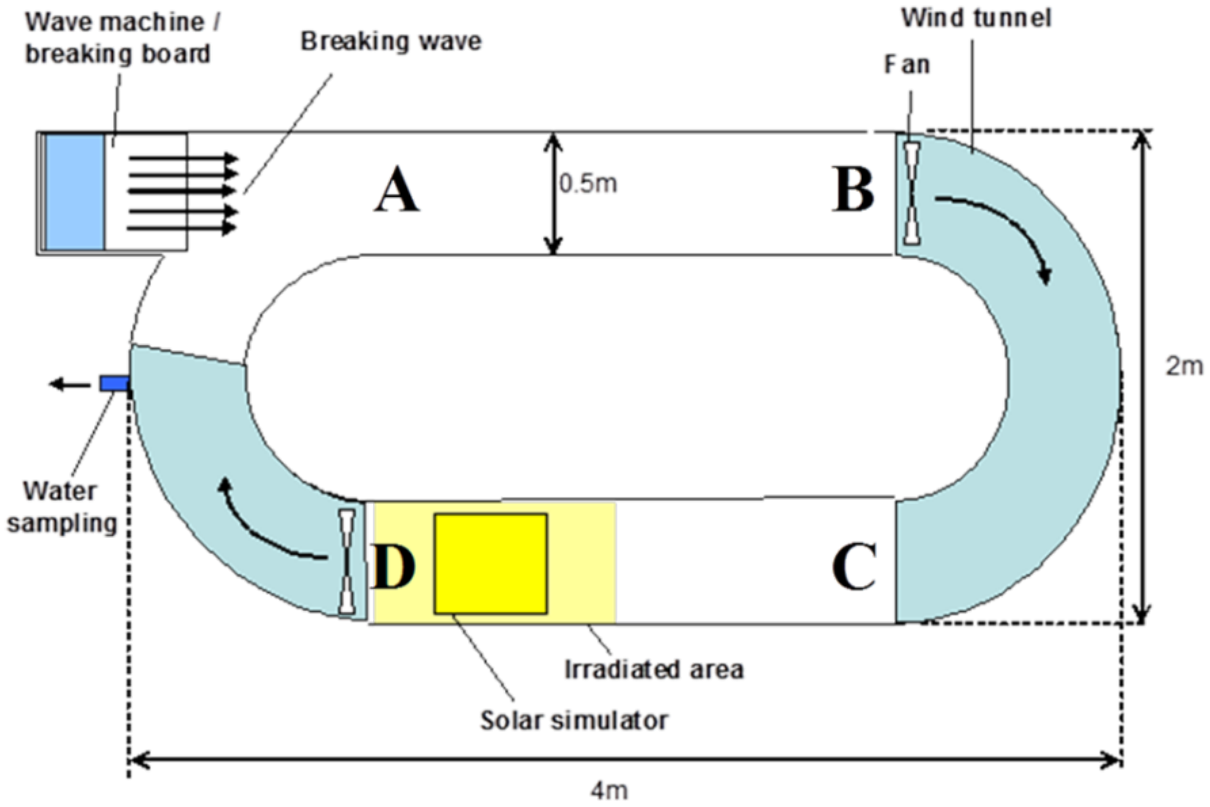

Figure 2.4 Sketch of the SINTEF and SL Ross flume

Table 2.3 Key figures for the flumes (yellow: To be checked)

Temperature water	-2 to 0 °C
Flume (circulation) length inner wall	10,2 m
Flume (circulation) length outer wall	16,6 m
Flume height	1,5 m
Flume width	0,5 m
Water depth	1 m
Water volume	4800 L
Surface area in flume	4.36 m^2
Containment area for oil and dispersant application	1 m^2
Dispersant applicator	Wagner 450
Nozzle size applicator (25% efficiency)	0,5 mm
Oil volume	1 L
Dispersant to oil ratio (DOR)	1:20
Particle size analyzer	LISST*
Low energy settings	
Frequency wave maker	24 rpm
Amplitude wave maker	12 cm
High energy settings	
Frequency wave maker	30 rpm
Amplitude wave maker	16 cm
Wind speed (reversed wind containment area)	1.2 m/s
Propeller	MinnKota Endura 30

**LISST: Laser In-Situ Scattering and Transmissiometry (Sequoia Scientific, Inc.)*

The LISST was located on the opposite side of the wave generator (before position C, outside the containment area). The water samples were collected using a Siphon system placed next to the LISST at 50 cm depth. The propeller used in the prop wash energy addition was placed in the centre of the flume before positon B at 22 cm depth and pointed upwards (second position from vertical on the transom mount).

Natural ice was prepared using 0.5% salinity water. Low density poly-ethylene blocks (PE-blocks) were used as artificial ice. The PE-blocks were cut from moisture resistant LDPE Polyethylene sheets and rods (McMaster-Carr Supply Co, Aurora OH, US) by SL Ross. Size distribution of artificial and natural ice is given in Table 2.4. Only squares were prepared from ice, no circular shapes.

The ice concentration in the experiments was calculated to be approximately 80%. Natural ice was replenished in the containment area during the weathering time to maintain the ice concentration.

Table 2.4 Size distribution of PE-blocks and ice in the SINTEF/SL Ross flumes. Note that the number of pieces in the containment area is included in the total flume numbers.

		80 % ice			
Total flume area (4.36 m^2)		PE-blocks		Natural ice	
	Size (m)	Number	Area (m^2)	Number	Area (m^2)
Squares	0.2 x 0.2	10	0.40	16	0.64
	0.1 x 0.1	78	0.78	141	1.41
	0.05 x 0.05	263	0.66	536	1.34
Circles (diameter)	0.2	14	0.44	None	
	0.1	75	0.59	None	
	0.05	264	0.52	None	
Containment area (1.0 m^2)					
Squares	0.2 x 0.2	6	0.24	6	0.24
	0.1 x 0.1	31	0.31	31	0.31
	0.05 x 0.05	76	0.19	76	0.19
Circles (diameter)	0.2	None		None	
	0.1	None		None	
	0.05	None		None	

2.3 In situ weathering of the oil in the flume

The following protocol was employed:

- Booms/barriers were placed across the tank width in the straight sides opposite wave generator (between C and D on the sketch).
- Ice or PE-blocks were added in the confinement area (Size distribution and numbers given in Table 2.4)
- Fresh oil (1 L) was applied between the ice floes (Figure 2.5A).
- The wind direction was reversed (opposite of the swells) during the weathering period to limit the downwind drifting (herding) of oil within the confinement area.
- The oil was allowed to weather for 18 hours (Figure 2.5B) with air flow (wind speed of approximately 1.2 m/s) and low energy wave action (settings given in Table 2.3).
- The fan and waves were turned off prior to oil sampling.
- Oil samples for physical/chemical analysis of the weathered oil were collected prior to dispersant application
- Surface oil samples to estimate weathering stage prior to dispersant application
    - Viscosity (5 mL), measured at 2 °C and shear rate $10s^{-1}$ as a minimum (method in Appendix A)
        - Water content (40 mL), add emulsion breaker (method in Appendix A)
        - Density (on broken emulsion, only in first test)
        - Evaporative loss (2 mL) – GC/FID analysis

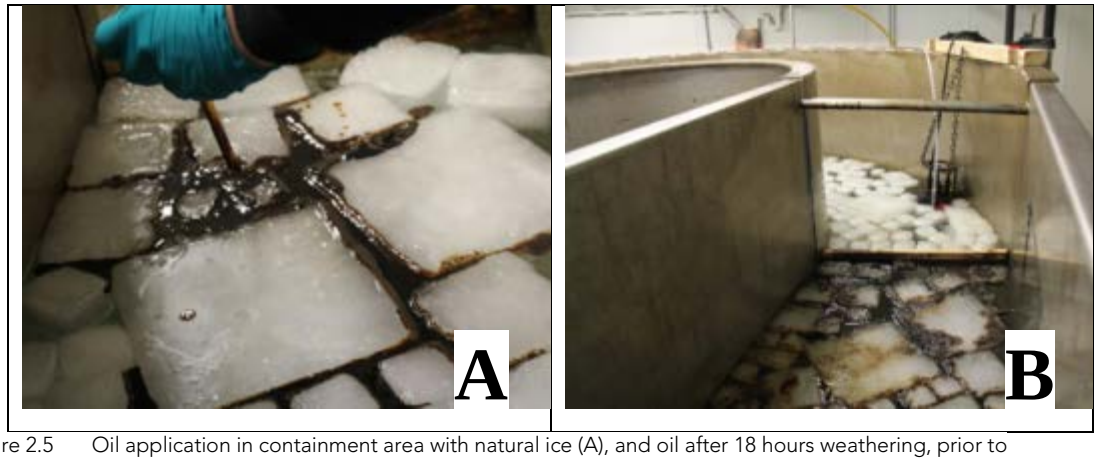

Figure 2.5 Oil application in containment area with natural ice (A), and oil after 18 hours weathering, prior to dispersant application with the LISST in position (B).

2.4 Dispersant application

The following protocol was employed (see photos in Figure 2.6)

- Prior to dispersant application:
    - Waves and wind were turned off
    - Ice or PE-blocks were placed in the non-contained surface area with the same ice concentration as in containment.
    - On line monitoring of particle size distribution and oil concentration by LISST were performed during the entire dispersant testing
- Dispersant (Corexit 9500) was applied on the oil in the contained area
- Barriers were removed to allow free movement of oil and ice in tank
- Waves and wind with the same direction as the waves was turned on one minute after the application of dispersant was finished
- Low energy waves were applied for 30 minutes
- The wave energy was increased to the high level and run for an additional 30 min.
- Waves were turned off prior to the prop mixing which lasted for an additional 5 minutes (8 minutes at SL Ross)
- Water grab samples were collected at the end of each energy conditions
- All three energy levels have been included in all tests, using the fixed times given above.

The experiments performed are described in Table 2.5.

Table 2.5 Testing of dispersant efficiency comparing sea ice and artificial ice.

Oil	Weathering	Dispersant	DOR	Ice coverage	Salinity	# Tests
Troll Blend	18 hrs in tank	Corexit 9500	1:20	80 % sea ice	~35 ppt	6*
Troll Blend	18 hrs in tank	Corexit 9500	1:20	80 % PE blocks	~35 ppt	6*

**Triplicate tests at SL Ross and SINTEF*

Figure 2.6 Dispersant application (A), removing barriers after 18 hours of oil weathering (B); Positioning of propeller (C); Water samples from experiment with natural ice (D).

2.5 Measurements of dispersant effectiveness

To quantify the dispersant effectiveness, both SINTEF and SL Ross have good experience with the use of the combination of LISST and water sampling to measure oil droplet size and oil concentration in the water column. The oil concentration in water samples were determined by liquid-liquid extraction with dichloromethane followed by colorimetric analysis of concentration using a response curve for a weathered crude oil (methods described in Appendix A).

3 RESULTS AND DISCUSSION

SL Ross and SINTEF agree that the protocol developed for in situ weathering of the oil in the flume, dispersant application, and the dispersant testing worked well.

Surface oil was sampled after approximately 18 hours of weathering. GC chromatograms of the oils are shown in Figure 3.1, and the oil properties are given in Table B 1 (Appendix B). The viscosity measurements and the GC chromatograms indicate that the evaporative loss was similar in all experiments independently of applying ice or PE.

However, since the Troll Blend is a mixture of Troll and Fram with varying content of the two oils, a very rough estimate of the evaporative loss during weathering was done based on the GC chromatograms and the evaporative loss in the laboratory weathered residues (Table 2.2). The chromatogram of the fresh Troll Blend suggests that the crude is dominated by the paraffinic Fram oil, but density indicate that the crude is a mixture of Troll and Fram. The properties in the surface sampled oil seem to be more similar to Troll than to Fram (Table 2.1). Here it is assumed that there was a 1:1 mix of the two oils (not confirmed by Statoil). The evaporative loss seems to be in the range of approximately 170 °C+ to 200 °C+.

The content of oil in the water grab samples are shown in Figure 3.2 and given in Table B 2 (Appendix B). There was no significant difference observed in the experiments using PE-blocks compared to ice, and the results indicate that applying prop wash after the high energy exposure did not increase the dispersant efficiency. The experiments performed at SINTEF and SL Ross correlated well.

Dispersant efficiency was calculated based on the oil concentration measured in the water grab samples with an adjustment for estimated evaporative loss (Figure 3.3 and Table B 2). There was no difference observed in the experiments using PE-blocks compared to ice. The estimated dispersant efficiency with natural ice after exposure to high energy in the flume tests performed at SINTEF and SL Ross was similar, with an average dispersant efficiency of 55±9% and 54±4%, respective. The dispersant efficiency in the SINTEF flume using PE blocks was slightly higher than in the SL Ross flume at high energy. After prop wash, the dispersant efficiency in the SINTEF flume was similar to high energy exposure, while it was somewhat lower in the SL Ross flume.

However, the findings in the initial tests demonstrate that there is a very good correlation between the tests performed in the SINTEF and SL Ross flumes, as also concluded in the inter tank calibration (Faksness et al., 2013). Both the weathering degree and the dispersant efficiency were in the same range.

The SL Ross LISST data indicates smaller drops were generated in the testes where PE-blocks were used. The average volume median drop size (VMD) for the natural ice tests was about 47 microns whereas the average VMD fro the PE blocks tests was about 18 microns. LISST data from SINTEF shows the same trend with smaller drops generated in the tests where PE-blocks were used. As the treatment LISST data is done differently at SINTEF and SL Ross, the d50s in the SINTEF experiments are higher. The same method for treating the data will be applied in the next phase of the project.

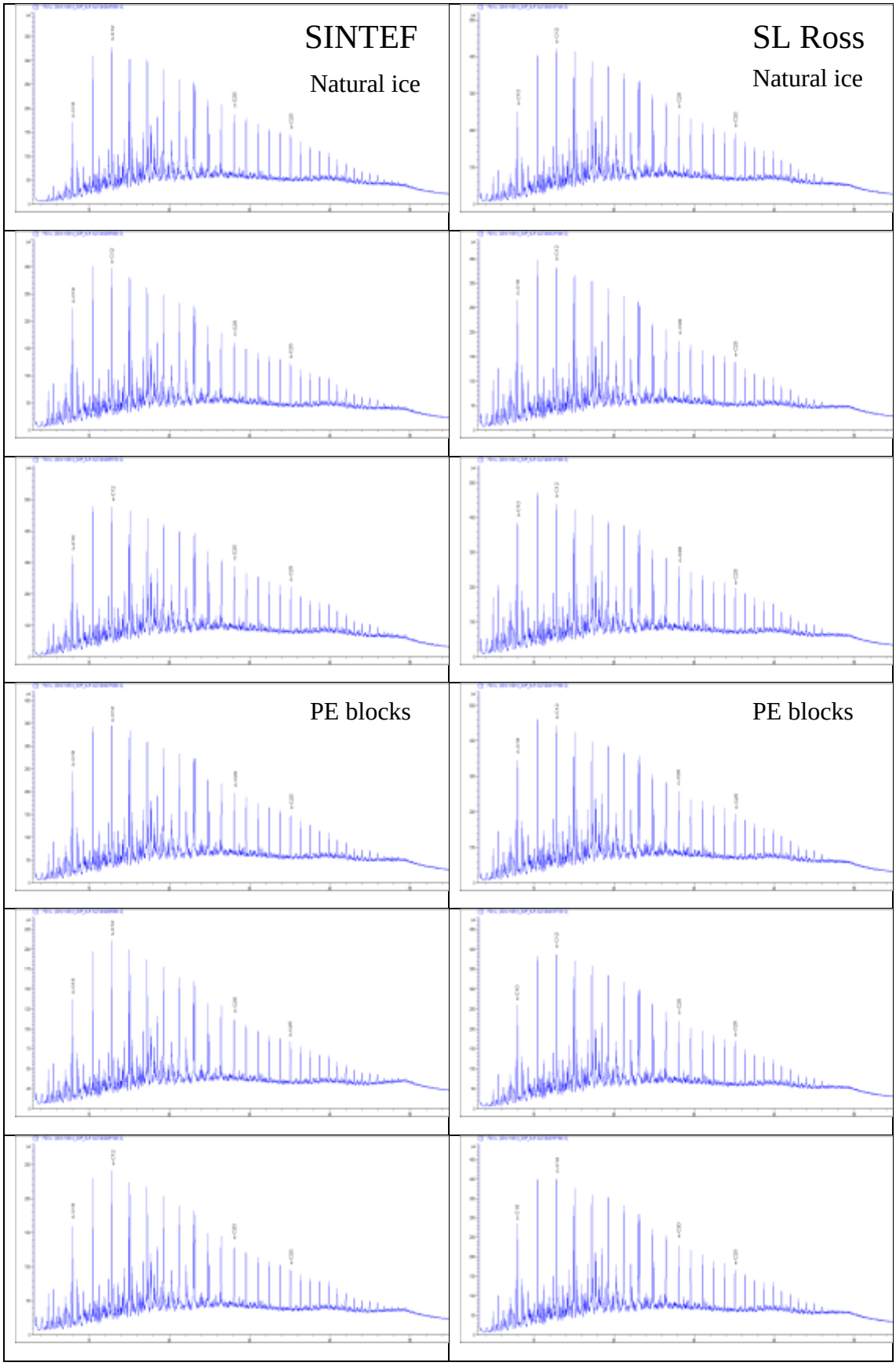
SINTEF
Natural ice
SL Ross
Natural ice
PE blocks
PE blocks

Figure 3.1 GC chromatograms of oils weathered for 18 hours collected prior to dispersant testing. Left chromatograms are from the SINTEF experiments, and the right chromatograms are from the SL Ross experiments. The three upper are with natural ice, and the three lower with PE-blocks.

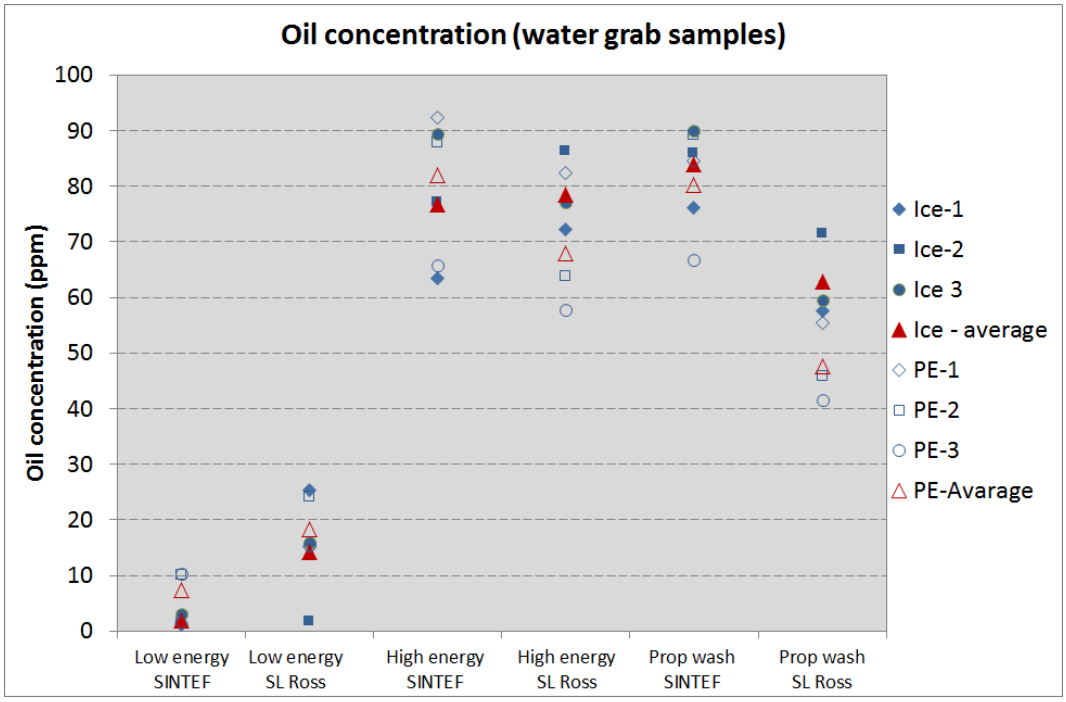

Figure 3.2 Oil concentrations (in mg/L) measured in water grab samples after the different energy exposure. Comparing the use of natural ice and PE-blocks at SINTEF and SL Ross.

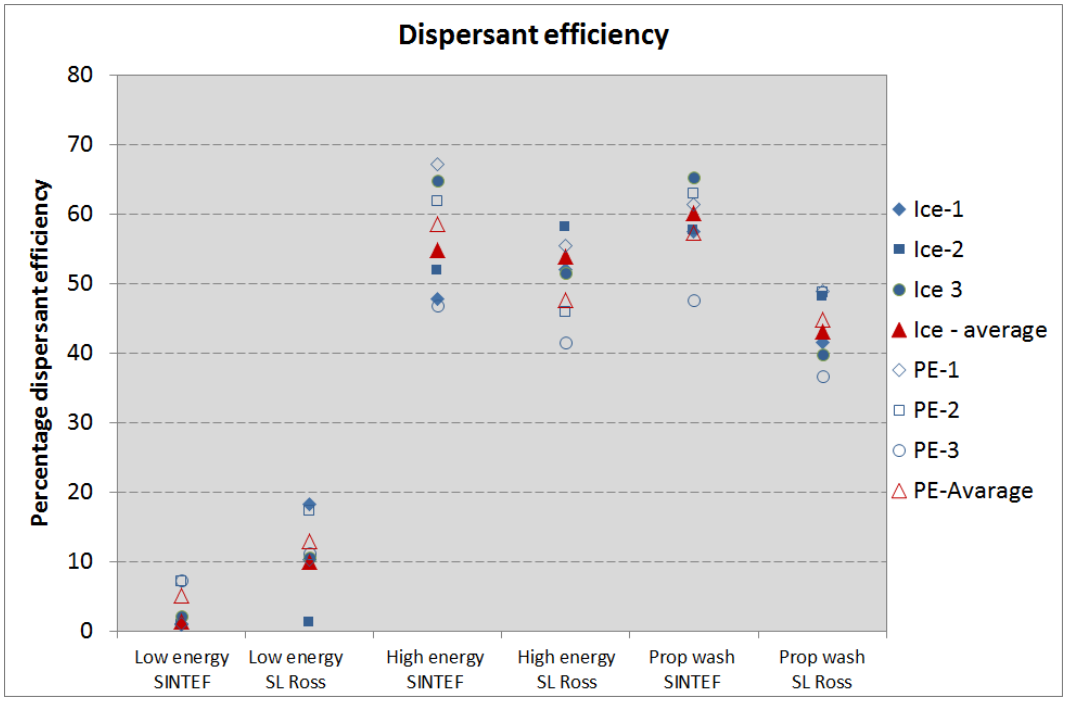

Figure 3.3 Dispersant efficiency (in percentage) estimated based on oil concentration in water grab samples from UV measurements, corrected for evaporative loss. Comparing the use of natural ice and PE-blocks at SINTEF and SL Ross.

However, it was observed that the PE-blocks behaved different than the natural ice in the flume, especially when exposed to high energy and prop wash: The smallest blocks stick to the flume wall, and in general the PE-blocks had a higher tendency to stick on top of each other after exposed to the waves. Therefore, at least two people had to "help" the PE-blocks to circulate at high energy and prop wash. The different behaviour of PE blocks is probably due to different surface properties on the PE blocks compared to natural ice, and that the PE blocks have a slightly higher density than the ice. The photos in Figure 3.4 illustrate the different behaviour of PE blocks and natural ice showing that even thought the ice blocks also become more packed after the wave exposure; they seem to float up and get better distribution than the PE blocks that ended up in several layers of blocks after the wave exposure.

Figure 3.4 Test tank experiments at high energy: PE blocks in upper photos, and natural ice in the lower photos.

4 RECOMMENDATIONS

Replacing PE blocks with natural ice did not influence the weathering or the dispersant efficiency. However, the PE blocks behaved differently than the ice in the flume, especially at high energy and prop wash. The different behaviour of PE blocks is probably due to different surface properties on the PE blocks compared to the ice, and that the PE blocks have a slightly higher density than the ice.

Based on the experience and observations during the initial tests, SINTEF and SL Ross recommend that further tests should be performed using ice and not PE blocks.

5 REFERENCES

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Faksness, L.G., R. Belore, and F. Merlin (2014). Test tank inter-calibration for dispersant efficiency.

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Mikkelsen O.A., T.G. Milligan, P.S. Hill, R.J. Chant, C.F. Jago, S.E. Jones, V. Krivtsov, and G. Mitchelson-Jacob (2008). The influence of schlieren and in situ optical measurements used for particle characterization. Limnol. Ocenaogr. 6: 133-143.

APPENDIX A OIL PROPERTY MEASUREMENTS

Viscosity measurements

Viscosity is measured with plate-plate (50mm) on a Physica rheometer at experiment temperature (2 °C) and with increasing shear rate. Shear rates used are 1, 5, 10, 50, 100, 200, 400 and 1000 s^{-1}. It is important to measure the viscosity as soon as possible after sampling – preferably within a few minutes - as the emulsion might not be stable.

Measurement of water content

Water content is measured by breaking the emulsion using emulsion breaker - Alcopol 60. Transfer 30-35 ml of the sample to a 40 mL cylindrical sampling glass and add 15 drops of Alcopol using a syringe or pipette. Shake well and place at 50°C (if the emulsion does not break the temperature can be increased to 60°C). Shake again after a few hours. Let the sample separate at least until the next morning and measure the height of the water and of the oil (water-height *100 / total-height = percentage of water in the sample.

The oil will have some residual water (0.5 – 2%). This is not so important in regards to the water-content, but will make the density-measurements a little higher. Measure the "broken" oil using a Karl Fischer Titrator and subtract the waters contribution from the density values.

Extraction of water samples

The water level of the flask containing the water sample is marked. The water sample is then transferred to a separatory funnel. 3x20 ml of technical grade DCM is used to rinse out the flask and is transferred to the separatory funnel. The flask is left in the fume hood until the next day allowing DCM to evaporate. The separatory funnel is shaken for 2 minutes and the extract is transferred to an erlenmeyer flask. This is repeated with ca. 40 ml of DCM and shaking for 2 minutes, then ca. 25 ml of DCM and shaking for 1 minute, giving a total of 3 shifts. The amount of DCM used varies with the oil concentration, the aim being extracts with absorbance 0.2-0.8 at 410 nm.

To remove water, sodium sulfate is added to the extracts as a drying agent. The erlenmeyer flasks containing the extracts are swirled and left for minimum 1 hour to allow the sodium sulfate to absorb the water. The extracts are then filtered, through glass wool and sodium sulfate, into graduated flasks. Absorbance of the extracts is measured at 410 nm using a spectrophotometer. The original sample flasks are filled with water to the sample level mark. This water is then transferred to a graduated cylinder for measurement of the sample volume.

Measurement of oil concentration in water samples

A standard curve for absorbance (410 nm) vs oil concentration is plotted using 3 samples of known oil concentration, with absorbance within 0.2-0.8 Abs. The oil concentration of the water sample is then calculated using the measured absorbance, the standard curve, the extract volume and the volume of the water sample.

Example:

((Absorbance * Extract volume (ml)) / (Slope of standard curve (ml/mg) * Sample volume (ml))) *1000 = ppm

If the oils weathered state (150+, 200+, 250+) is not known, a plot must first be made of slopes from the known residues vs density. Density measurement of the oil at the same time point as the water sample is then used to determine the weathered state and the correct slope to be used in calculation of the oil concentration of the water sample.

APPENDIX B PHYSICAL PROPERTIES OF THE OIL AND DISPERSANT EFFICIENCY

Table B 1 Physical properties of Troll Blend crude, and the in situ weathered oils samples prior to dispersant application at SL Ross and SINTEF.

	SL Ross			SINTEF		
	Viscosity (0°C) cP (100 s^{-1})	Water content %	Density (15°C) g/mL	Viscosity (2°C) cP (100 s^{-1})	Water content %	Density (15°C) g/mL
Troll Blend crude				26		0,854
Natural ice	299	5,0	0,892	567*	21	0,895
Natural ice	193	ND	0,890	200	NM	
Natural ice	206	ND	0,891	289	NM	
PE blocks	300	2,4	0,893	308*	22	0,893
PE blocks	302	9,5	0,893	232	NM	
PE blocks	220	ND	0,892	243	NM	

** Viscosity measured at shear rate 10 using a field viscosity meter; ND: Not detected; NM; Not measured*

Table B 2 Oil concentration in water (from UV measurements) and estimated dispersant efficiency of weathered oil. Estimated evaporative loss is based on the GC chromatograms of Fram (Appendix C).

SINTEF			Oil in water from UV (ppm)			Dispersant efficiency (%)		
Ice	Applied oil (g)	Estimated evap loss (wt%)	Low energy	High energy	Prop wash	Low energy	High energy	Prop wash
Natural ice	815	22	1	63	76	0,8	48	57
Natural ice	851	16	1	77	86	1,0	52	58
Natural ice	808	18	3	90	90	2,2	65	65
PE blocks	805	18	1	92	85	1,1	67	61
PE blocks	811	16	10	88	89	7,2*	62	63
PE blocks	802	16	10	66	67	7,3*	47	48

** some oil left on the PE-blocks after previous experiments*

SL Ross			Oil in water from UV (ppm)			Dispersant efficiency (%)		
Ice	Applied oil (g)	Estimated evap loss (wt%)	Low energy	High energy	Prop wash	Low energy	High energy	Prop wash
Natural ice	850	20	25	72	58	18	52	41
Natural ice	846	14	2	86	71	1,1	58	48
Natural ice	853	14	16	77	60	11	52	40
PE blocks	848	14	15	82	73	10	55	49
PE blocks	852	20	24	64	68	17	46	49
PE blocks	851	20	16	58	51	11	42	37

APPENDIX C GC CHROMATOGRAMS OF FRESH AND WEATHERED RESIDUES OF FRAM CRUDE

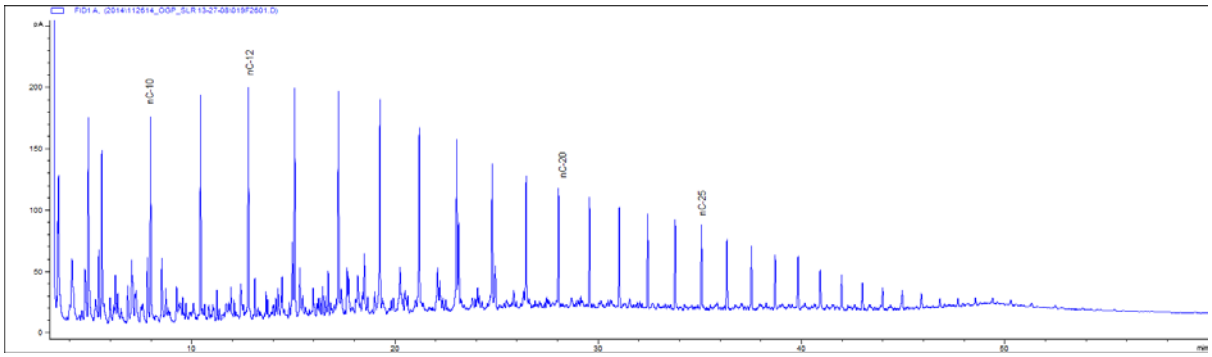


Figure C 1 Fram fresh oil (dissolved in DCM, SINTEF ID 2013-0340)

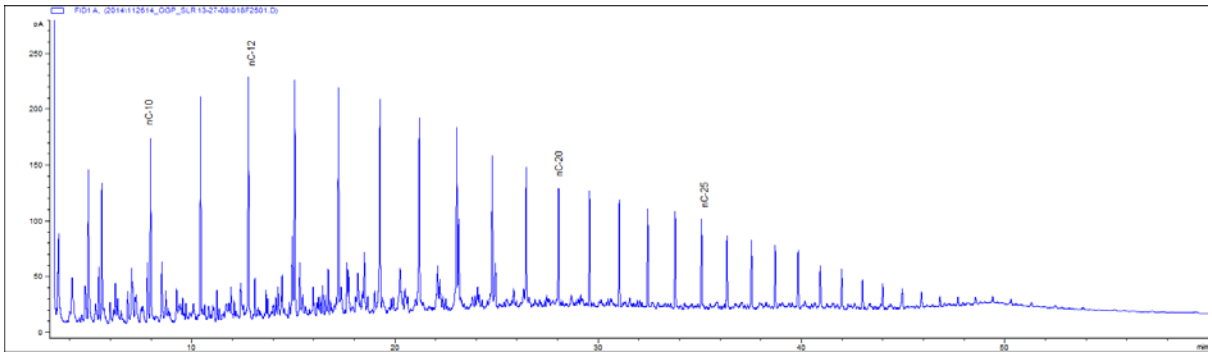


Figure C 2 Fram 150°C+ (evaporative loss of 13% (according to Andreassen and Sørheim, 2013))

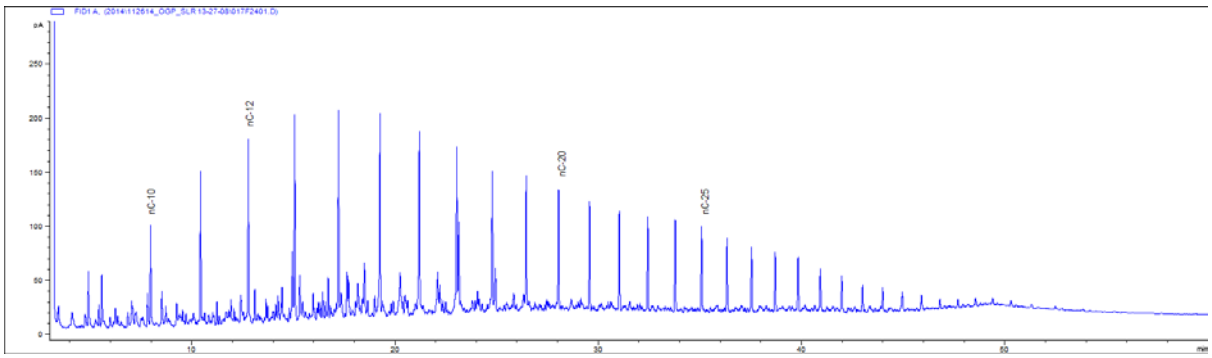


Figure C 3 Fram 200°C+ (evaporative loss of 22%)

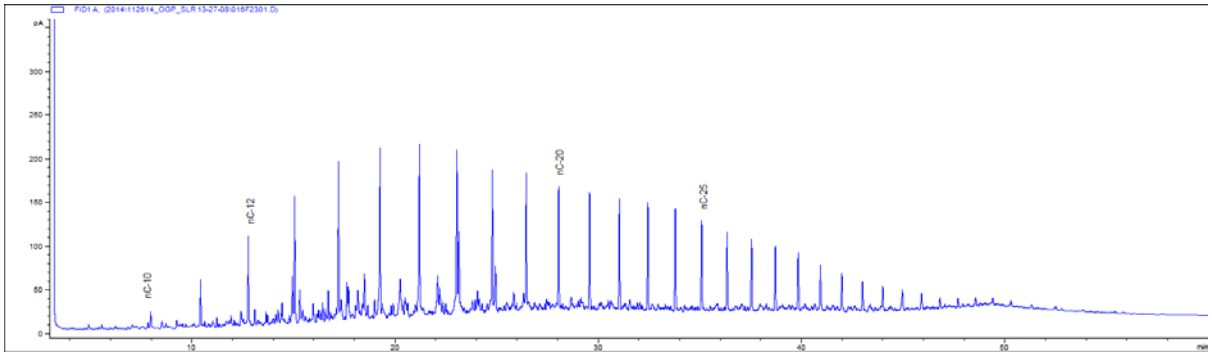


Figure C 4 Fram 250°C+ (evaporative loss of 33%)

APPENDIX D SUMMARY OF THE RESULTS FROM SL ROSS

Notes to SINTEF in e-mail from November 25, 2014.

Table D 1 shows the physical properties of the oil taken after the 18 hour weathering period in the meso-scale flume in the SL Ross tests.

Table D 1 Weathered Oil Property Data and LISST Oil Concentration Estimates

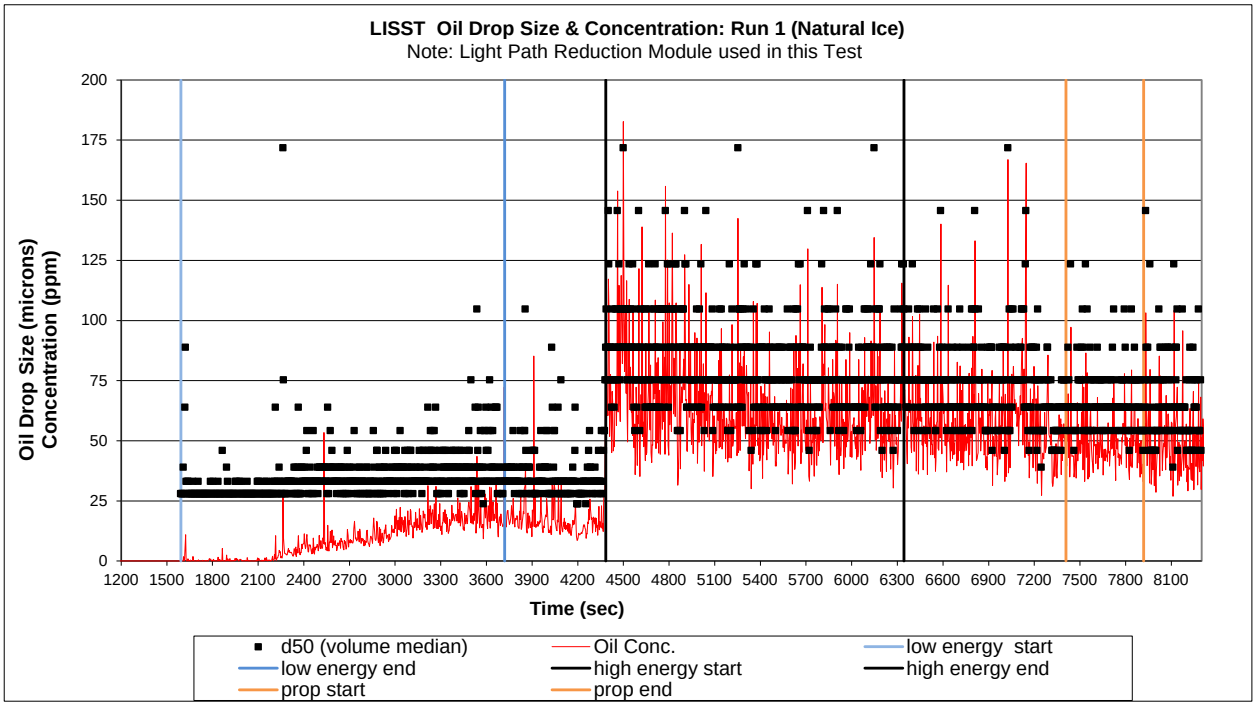
Sample id	Initial Oil Mass spilled g	Ice Type	Density (g/cc)				Viscosity cP	Water Content	LISST Peak Conc. (ppm)		
			0°C	10°C	20°C	15°C	0°C 100 s^{-1}	%	low	high	prop
1	850.0	natural	0.903	0.894	0.889	0.892	299	5	15-20	55-85	55-85
2	846.2	PE	0.903	0.896	0.889	0.893	300	2.4	10-15	70-75	70-75
3	853.0	natural	0.902	0.894	0.885	0.890	193	0	5-10	60-65	60-65
4	847.5	PE	0.904	0.896	0.890	0.893	302	9.5	10-20	50-55	50-55
5	852.1	natural	0.904	0.893	0.888	0.891	206	0	10-15	60-65	60-65
6	851.0	PE	0.905	0.895	0.888	0.892	220	0	10-15	70-75	65-70

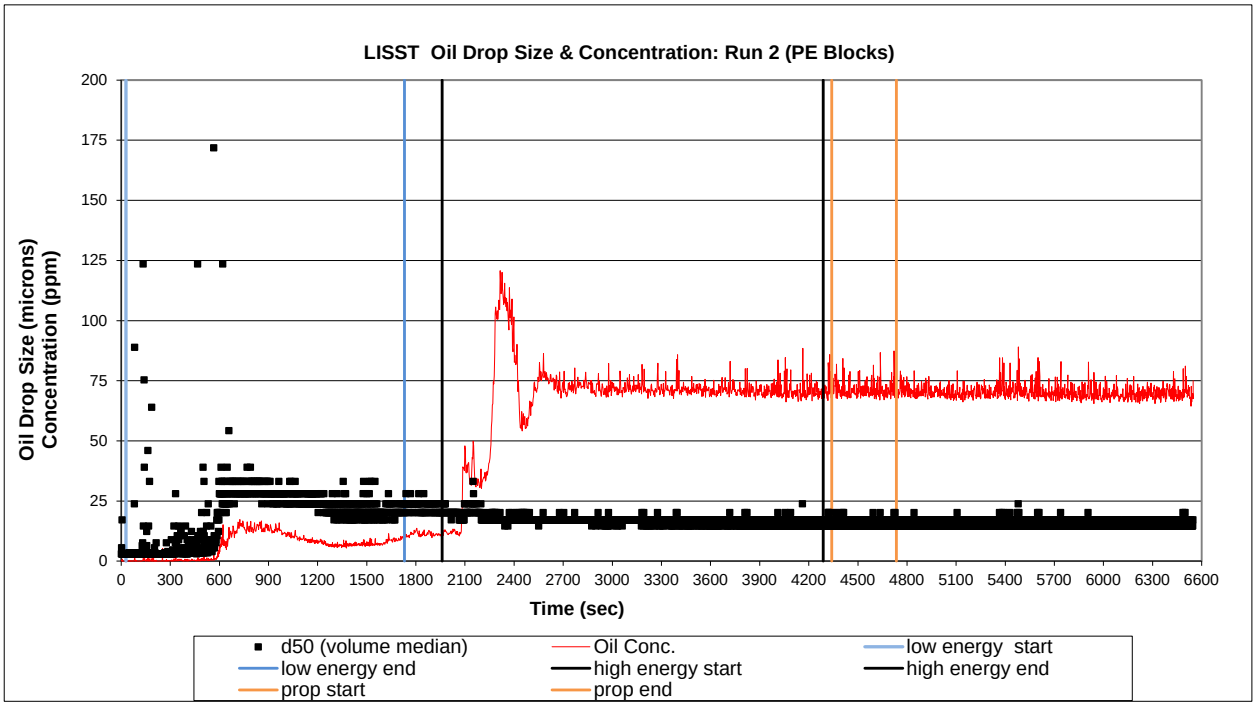
Note: the water content values may not be accurate due to the sampling procedure used. Oil was collected from the surface by passing a metal blade through the oil water interface, allowing the liquid that adhered to the blade to drip for a few seconds and then collecting the remaining 'drippings' in the vial for water content determination. The vial was allowed to sit for an hour or so for basic water and oil separation and any water present in the vial after this short settling period was not considered in the final water content of the sample. Alcopol was then added to the sample and the sample was heated to 50 °C for a minimum of 24 hours. The height of the oil and water were then measured to determine the water content. The visible appearance of the oil at the end of the weathering periods was very similar for all 6 tests. It is likely that for the samples where higher water content is identified that the water in the vials was due to the initial collection of free water during the sampling rather than oil that had been in the form of small droplets in a water-in-oil emulsion.

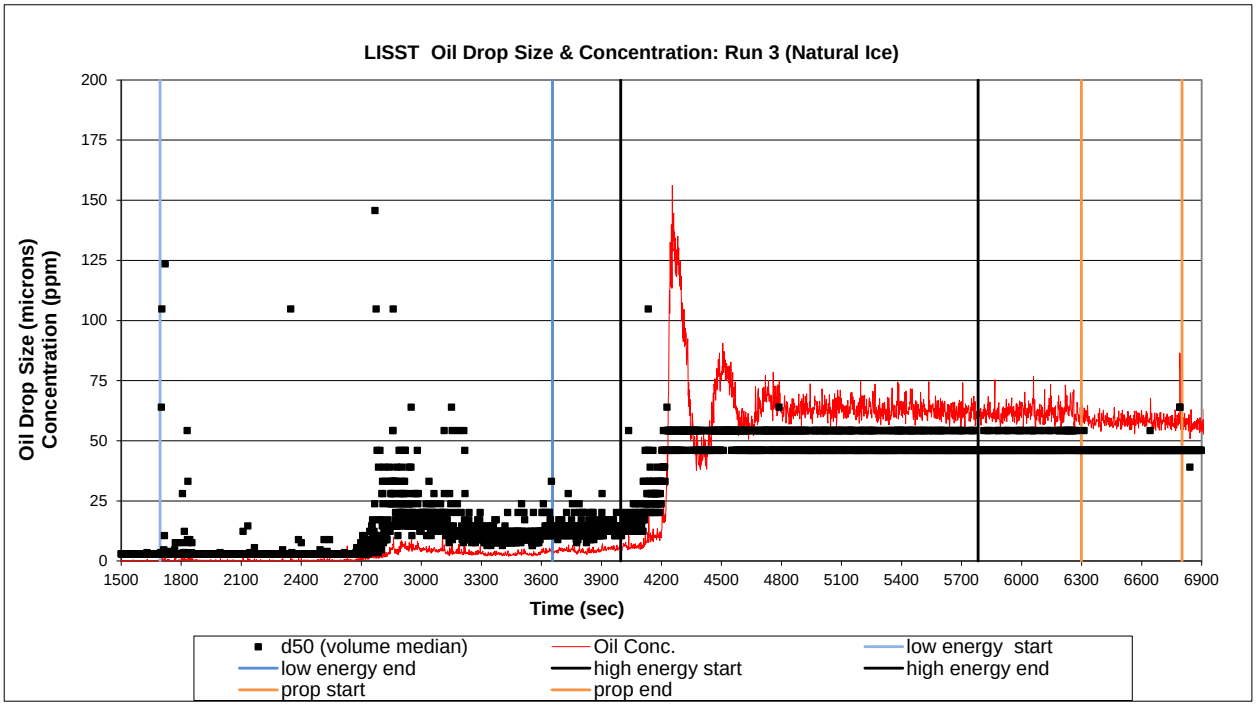
The densities were taken on the oils that were treated with Alcopol and heated to break any emulsions.

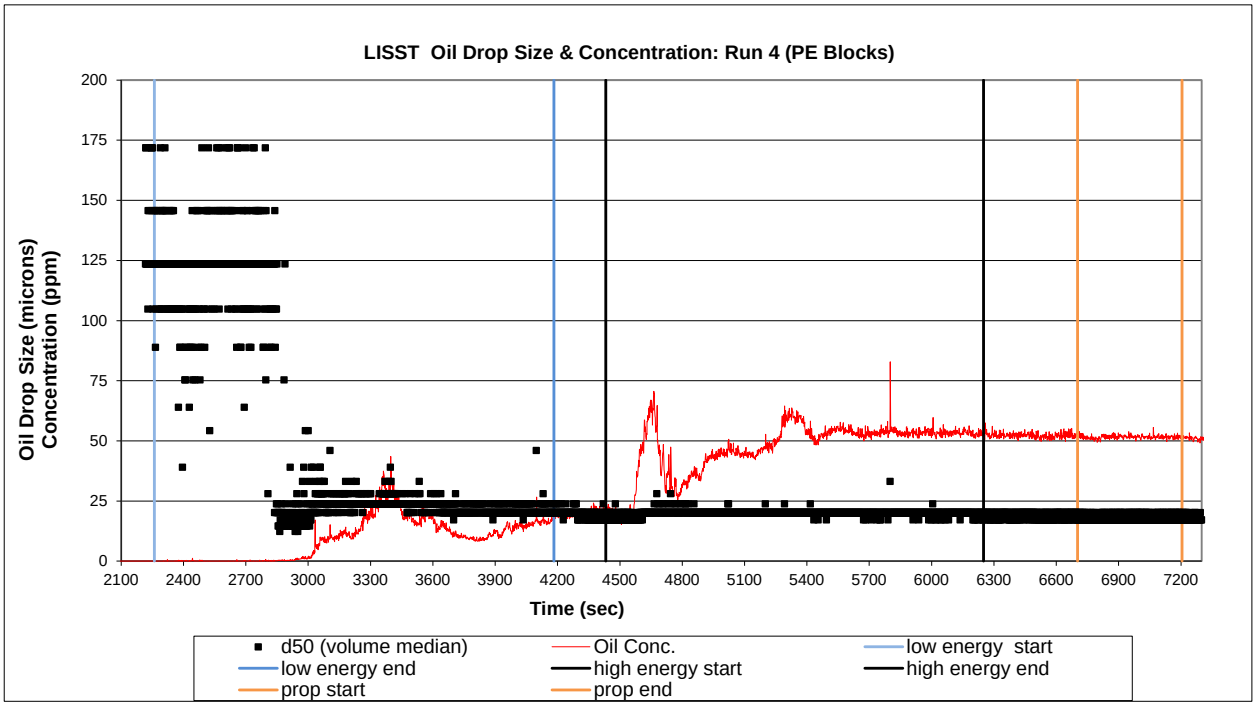
The viscosities were taken on separate oil samples that were not treated in any way after collection from the surface of the tank after the 18 hr weathering period.

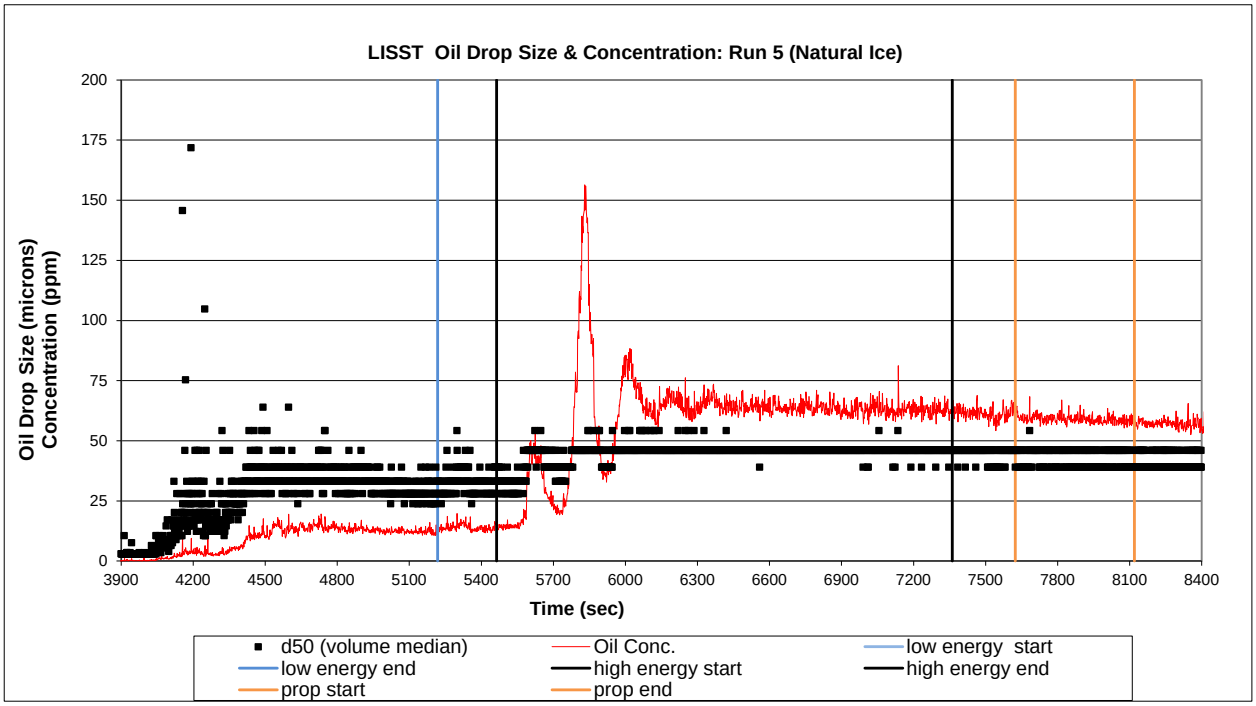
The LISST had a light path reduction module (LPRM) in place for test #1 only. The oil concentration results by the LISST for tests 2 through 6 seem more consistent than those taken with the LPRM in place. The results in the table are preliminary estimates of oil concentrations at the end of each energy cycle. Graphs of oil concentration vs time follow that show the progression of oil concentration over time and the oil drop size distributions. Volume median drop diameters are shown on the plots. The scale on the left is used for both oil concentrations in ppm and oil drop size in microns. It would appear at first look that the PE blocks resulted in smaller oil drops. Alternately, there may have been small ice crystals in the water that increased the size of the particle distribution measured in the natural ice tests. Unfortunately, we didn't look at any of the water samples under a microscope to see if this was the case, and we are not certain that this would have been helpful as any ice crystals would likely melt on the slide prior to viewing.

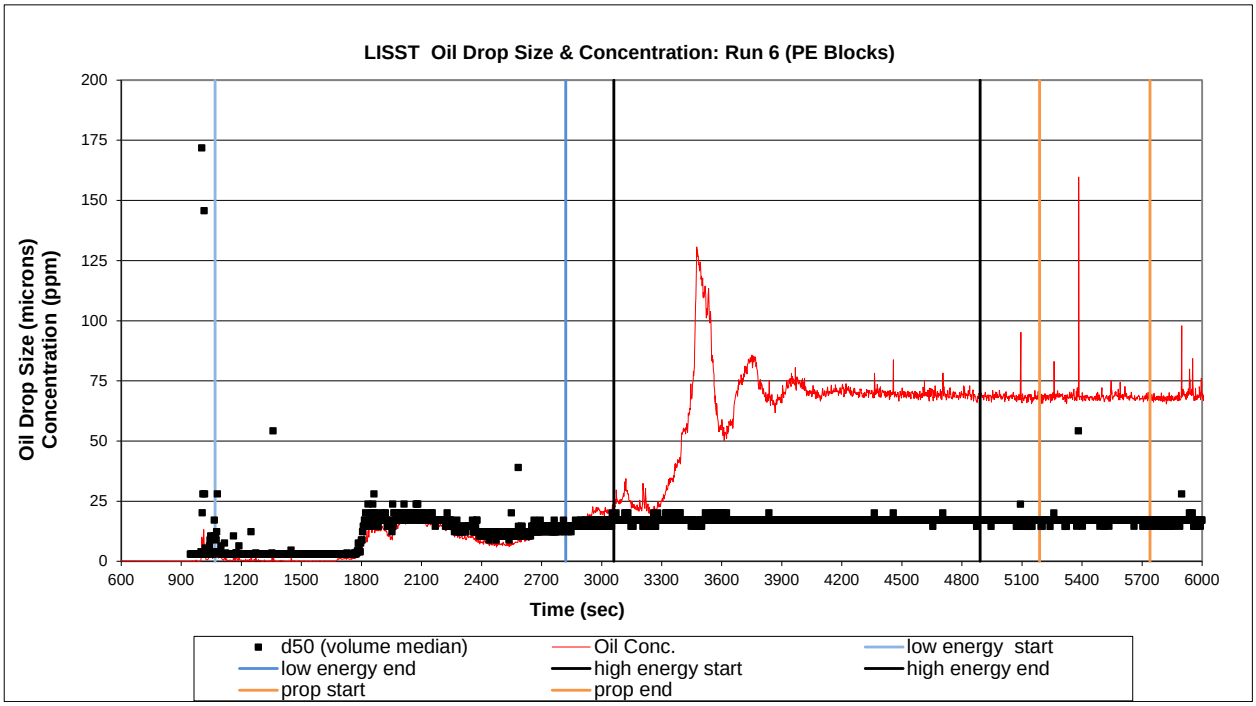

LISST Oil Drop Size & Concentration: Run 1 (Natural Ice)
Note: Light Path Reduction Module used in this Test
Oil Drop Size (microns)
Concentration (ppm)
Time (sec)
d50 (volume median)
Oil Conc.
low energy start
low energy end
high energy start
high energy end
prop start
prop end


LISST Oil Drop Size & Concentration: Run 2 (PE Blocks)
Oil Drop Size (microns)
Concentration (ppm)
Time (sec)
d50 (volume median)
Oil Conc.
low energy start
low energy end
high energy start
high energy end
prop start
prop end


LISST Oil Drop Size & Concentration: Run 3 (Natural Ice)
Oil Drop Size (microns)
Concentration (ppm)
200
175
150
125
100
75
50
25
0
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
5400
5700
6000
6300
6600
6900
Time (sec)
d50 (volume median)
Oil Conc.
low energy start
low energy end
high energy start
high energy end
prop start
prop end


LISST Oil Drop Size & Concentration: Run 4 (PE Blocks)
Oil Drop Size (microns)
Concentration (ppm)
200
175
150
125
100
75
50
25
0
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
5400
5700
6000
6300
6600
6900
7200
Time (sec)
d50 (volume median)
Oil Conc.
low energy start
low energy end
high energy start
high energy end
prop start
prop end


LISST Oil Drop Size & Concentration: Run 5 (Natural Ice)
Oil Drop Size (microns)
Concentration (ppm)
200
175
150
125
100
75
50
25
0
3900
4200
4500
4800
5100
5400
5700
6000
6300
6600
6900
7200
7500
7800
8100
8400
Time (sec)
d50 (volume median)
Oil Conc.
low energy start
low energy end
high energy start
high energy end
prop start
prop end


LISST Oil Drop Size & Concentration: Run 6 (PE Blocks)
Oil Drop Size (microns)
Concentration (ppm)
200
175
150
125
100
75
50
25
0
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
5400
5700
6000
Time (sec)
d50 (volume median)
Oil Conc.
low energy start
low energy end
high energy start
high energy end
prop start
prop end

The LISST data has been further analyzed to determine the average volume median oil drop diameters of the drop size distributions and the average oil concentration for the last 100 readings taken in each energy regime. These results are provided in Table D 2. The LISST data from Run #1 where the light path reduction module was in place are not consistent with the data from the remaining runs where the module was removed. Average values for the natural ice are provided with Run #1 included and then with the data from Run #1 removed. The average particle concentrations in the water are very similar for the natural ice and PE block tests. The oil drops in the tests with PE blocks would seem to be smaller than in the natural ice tests.

Results from the oil extraction from the water grab samples are also included in Table D 2 for comparison. The concentrations by the water analysis and the LISST are fairly consistent and the SLR values are in the same range as those measured at SINTEF. The SL Ross oil concentrations at the low energy level are a bit higher than SINTEF's.

Table D 2 LISST Average Volume Median Drop Diameter and Oil Concentration for Last 100 Measurements in Each Energy Regime + Water Grab Sample Concentration

Lisst Data Summary for Last 100 records in Energy Regime										
RUN #	Ice Type	Low			High			Prop		
		Lisst d50	Lisst Ave. Oil conc	Water Grab Oil Conc	Lisst d50	Lisst Ave. Oil conc	Water Grab Oil Conc	Lisst d50	Lisst Ave. Oil conc	Water Grab Oil Conc
		µm	ppm	ppm	µm	ppm	ppm	µm	ppm	ppm
1	Natural	53	41	25.3	86	80	72.2	77	70	57.6
2	PE	25	9	15.2	16	72	82.4	16	73	72.7
3	Natural	28	6	1.7	50	65	86.2	47	61	71.4
4	PE	22	17	24.1	20	54	63.8	19	52	67.7
5	Natural	34	14	15.9	46	65	77.2	45	60	59.5
6	PE	22	17	15.5	17	74	57.7	17	73	51.0
Average	Natural	38.5	20.2	14.3	60.7	69.9	78.5	56.3	63.8	62.9
	PE	22.9	14.1	18.3	17.8	66.5	68.0	17.4	66.1	63.8

Removed LISST data for Run # 1 in the averages below

Natural	31.2	10.0	14.3	47.7	64.8	78.5	46.0	60.7	62.9
PE	22.9	14.1	18.3	17.8	66.5	68.0	17.4	66.1	63.8

APPENDIX E LISST DATA FROM SINTEF

Data shown in Table E 1 is obtained from an average of one minute of readings immediately prior to the time of water sampling. The largest size class (bin 32) has been discarded for all figures data shown (Figure E 1 to Figure E 6) and in calculations of concentration and d50. This is due to concerns regarding possible contamination from particles exceeding 500 µm.

The data were collected in conditions in which Schileren may be present (i.e. possible temperature gradients over the sample volume). Caution should therefor be applied to the interpretation of high concentrations of apparently large particles reported by the LISST-100 (see Mikkelsen et al., 2008).

The d50 is calculated from the 50th percentile of the cumulative sum of the volume distribution for the first 31 size classes. The concentration is calculated from the sum of volume concentration over the first 31 size classes.

Table E 1 Summary of LISST data and oil concentration in water grab samples from SINTEF.

	Low energy			High energy			Prop wash		
	LISST d50 µm	LISST Conc ppm	Water grab ppm	LISST d50 µm	LISST Conc ppm	Water grab ppm	LISST d50 µm	LISST Conc ppm	Water grab ppm
Natural ice	186	7	1	118	42	63	193	105	76
Natural ice	88	1	1	72	48	77	123	86	86
Natural ice	288	2	3	80	47	90	83	54	90
PE blocks	37	3	1	48	37	92	47	36	85
PE blocks	216	55	10	29	46	88	29	46	89
PE blocks	60	5	10	33	31	66	32	31	67

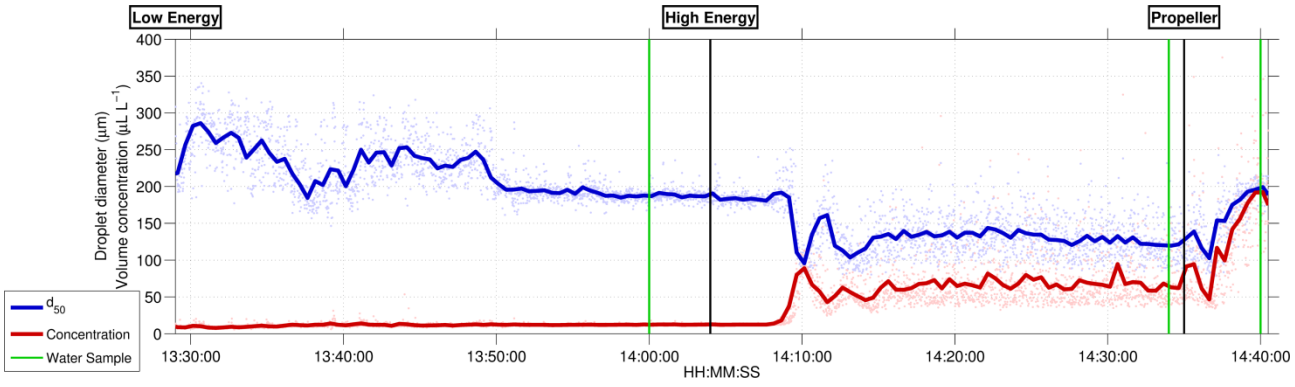


Figure E 1 Experiment 1 - Natural ice

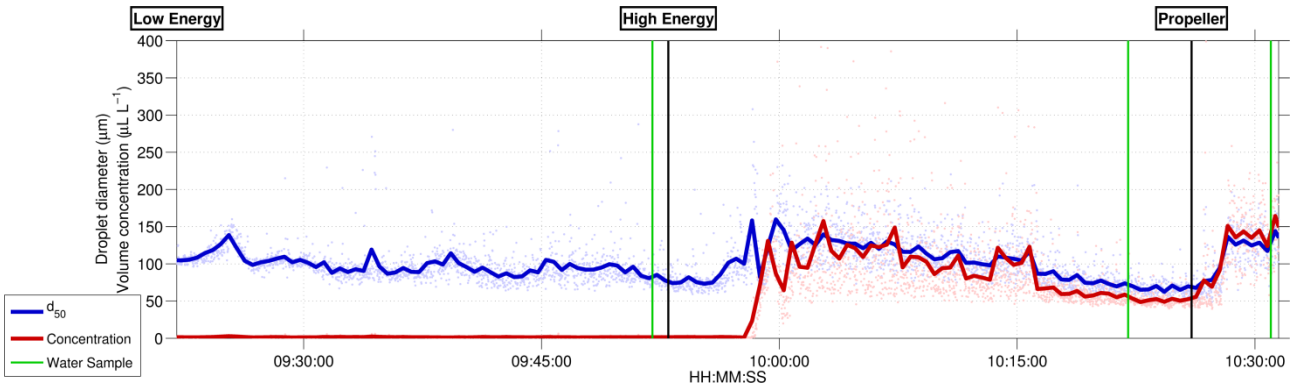


Figure E 2 Experiment 2 - Natural ice

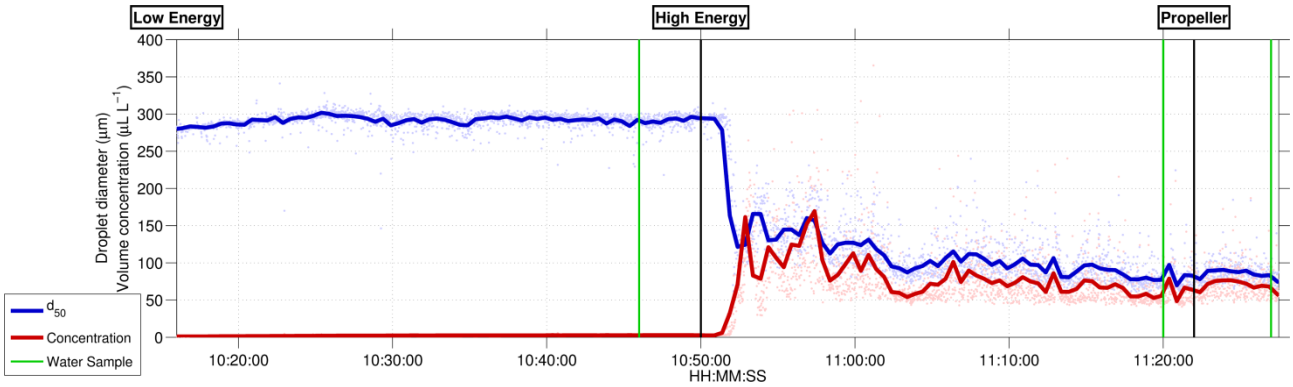


Figure E 3 Experiment 3 - Natural ice

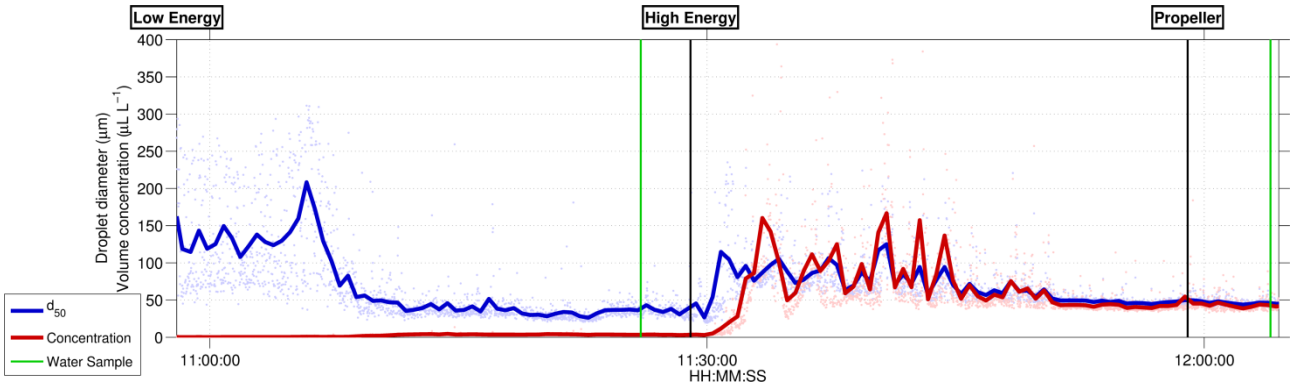


Figure E 4 Experiment 4 - PE blocks

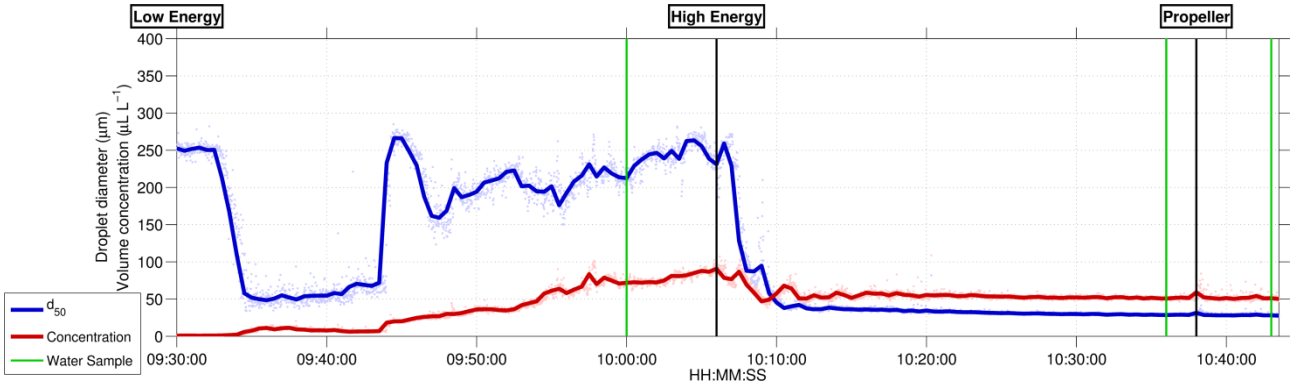


Figure E 5 Experiment 5 - PE Blocks

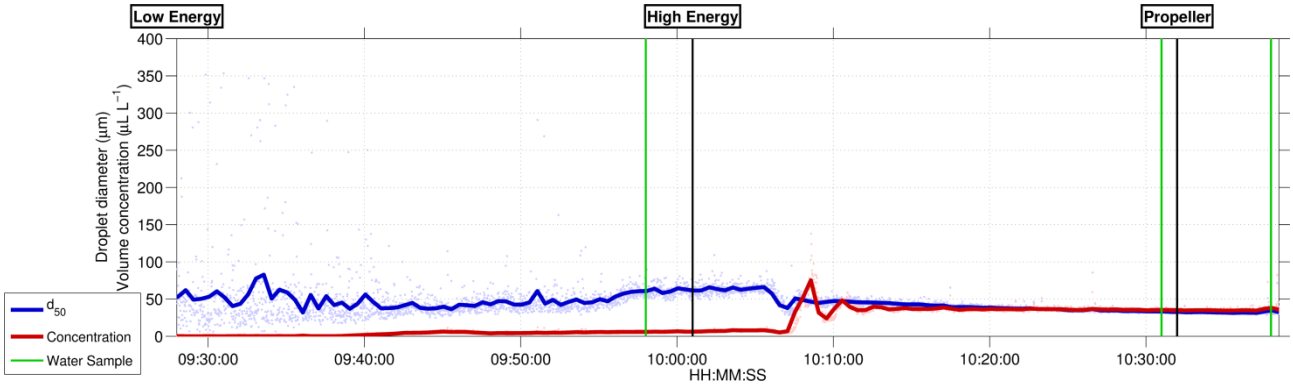


Figure E