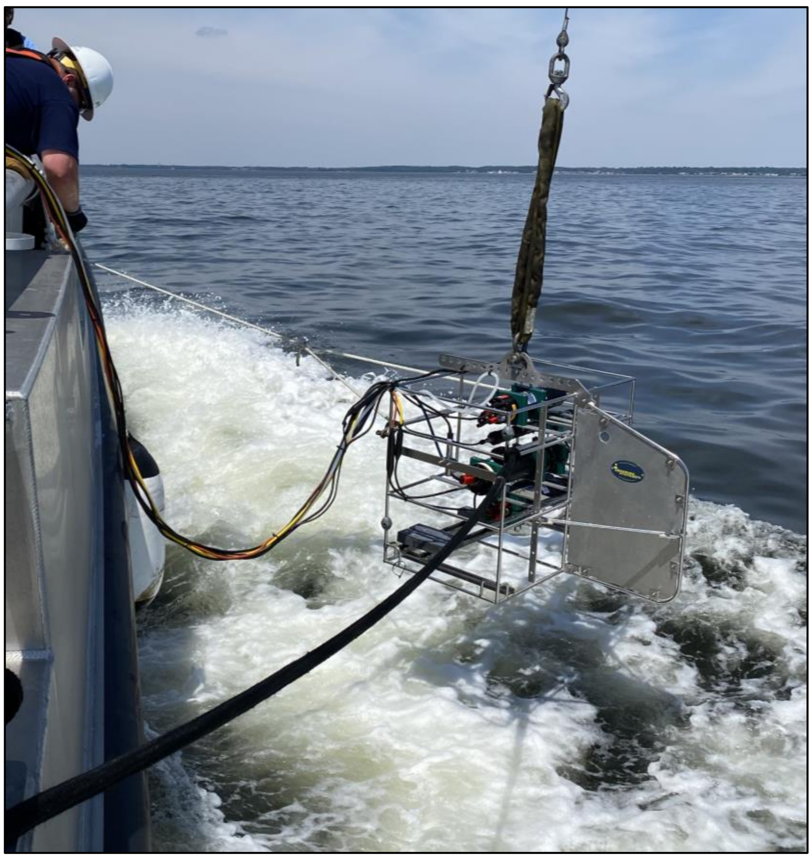
Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

Surface Water Droplet Size Distribution Instrument Laboratory Validation, Tank Deployment, and Field Evaluation

Final Report

December 2024



Michel Boufadel, Wen Ji, Zhaonian Qu, and Ruixue Liu

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Authors:
Michel Boufadel
New Jersey Institute of Technology

Wen Ji
New Jersey Institute of Technology

Zhaonian Qu
New Jersey Institute of Technology

Ruixue Liu
New Jersey Institute of Technology

Prepared under 140E0123R0007
By
New Jersey Institute of Technology
323 DR MARTIN LUTHER KING JR BLVD,
NEWARK, NJ 07102

US Department of the Interior
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ABOUT THE COVER

Cover image by Ann Slaughter. OSPR Project 1156 – "Surface Water Droplet Size Distribution Instrument Laboratory Validation, Tank Deployment, and Field Evaluation". The surface monitoring kit shakedown test at Raritan Bay, New Jersey.

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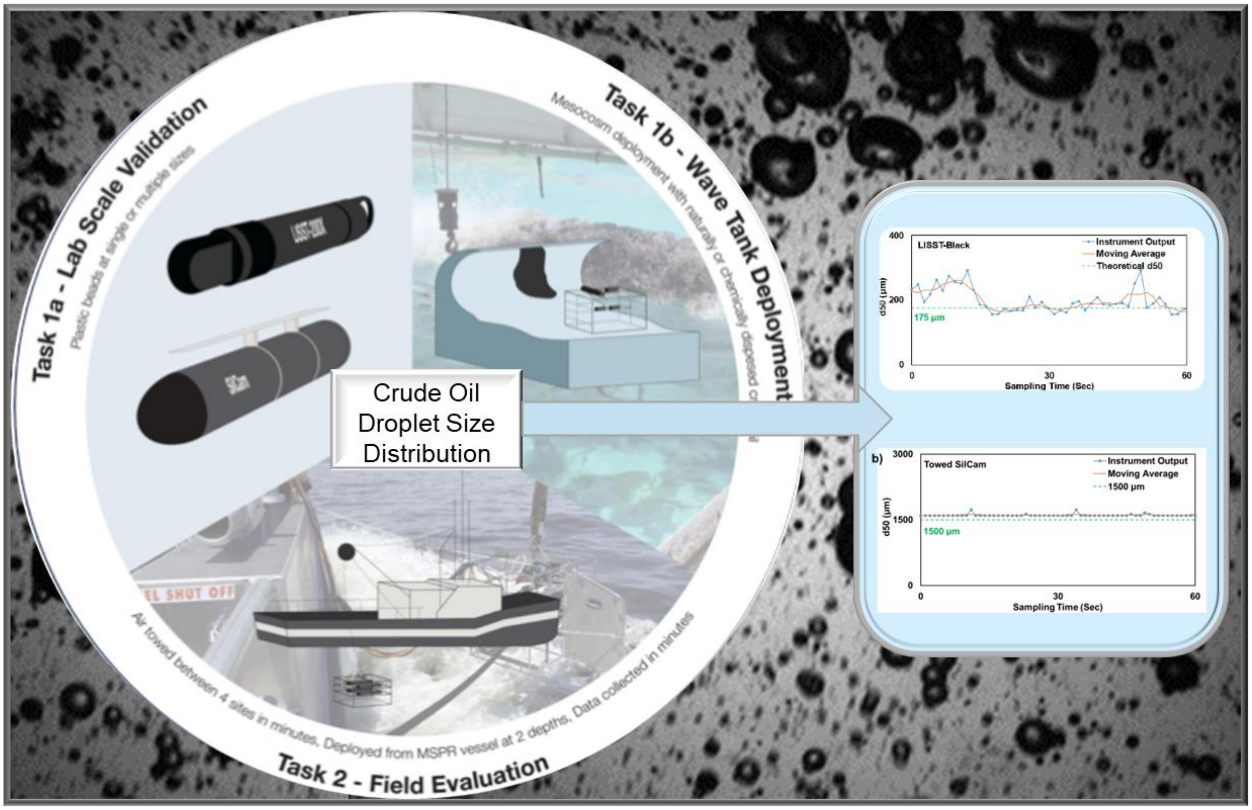
GRAPHICAL ABSTRACT



EXECUTIVE SUMMARY

Monitoring the use of dispersants on surface oil slicks has been an element of oil spill response in the US since the 1990s. The monitoring has been performed under the guidance of the Special Monitoring of Applied Response Technologies (SMART) protocols that were developed by multiple Federal agencies and managed by the National Response Team (NRT). The US Environmental Protection Agency (US EPA) released a new Rule specifying monitoring requirements under Subpart J of the National Contingency Plan (NCP) for dispersant use in response to major oil discharges. The new Subpart J Monitoring Requirements entail, among other things, the measurement and reporting of droplet size distribution (DSD) of oil and dispersed oil.

The Laser In-Situ Scattering and Transmissometry (LISST-Black) produced by Sequoia Scientific, and Towed Silhouette Camera (Towed SilCam) produced by SINTEF are novel instruments for detecting DSD in oil spill response. the LISST-Black is an integrated package combining a LISST-200x with fluorometers optimized for detecting petroleum. The LISST-200x for DSD measurement covers the particle range from 1 µm to 500 µm. The fluorometers are Turner Designs Cyclops-7Fs (G for refined fuels, O for crude oil, and C for chlorophyll), mounted with special brackets and cabling made by Sequoia Scientific. The Towed SilCam works based on a restricted path length telecentric system. It gives information about the instrument depth (m), the UVF (UV fluorometer) sensor response, the oil droplet size measured by the Towed SilCam (d50, volume median diameter) and the oil volume in predefined bins.

The New Jersey Institute of Technology (NJIT) has been conducting tests under a contract funded by the Bureau of Safety and Environmental Enforcement (BSEE). Together with the ShadowGraph camera produced by Bellamare (bellamare-us.com), the performance of the three instruments on a fast repeatable and reliable data acquisition is of significant interest. The goal of this project is to evaluate the performance of the LISST-Black, the Towed SilCam, and the ShadowGraph camera at various scales – laboratory, wave tank and field. The laboratory tests were conducted in a water tank at NJIT using polyethylene microspheres. Six bead sizes (20 µm, 100 µm, 250 µm, 500 µm, 1000 µm, and 1500 µm) were selected for this project, which were tested both individually (only one size at a time) and combined (two or three sizes mixed equally based on mass). The wave tank tests at the Ohmsett facility located in Leonardo, New Jersey were conducted in June and November 2023, both with Hibernia oil that was either untreated or chemically dispersed. The LISST-Black and Towed SilCam results were collected, as well as other instruments, including the LISST-200x, ShadowGraph, SeaOWL fluorometer, multi-parameter sonde and a standalone Cyclops fluorometers. The field evaluation was conducted at Raritan Bay, New Jersey, by deploying a new surface monitoring system from a small boat, without involving crude oil. Two out of three proposed deployment methods were successful, the third towed option was not feasible due to crane limitations.

The NJIT water tank results indicated that when only one-sized bead was used, the Towed SilCam and the ShadowGraph were able to obtain consistent and reliable results. However, when two or three sized beads were used, the Towed SilCam underestimated the bead sizes in two of the four cases. For the LISST-Black, due to a wide flow-through chamber, when detecting beads

at small sizes (e.g., smaller than 100 µm), it could overestimate the values as there could be overlapping in the laser path – in these cases, adding a path reduction module could be necessary. The Ohmsett wave tank results indicated that the major readings (peak or near-peak values) from the Towed SilCam and ShadowGraph were comparable. The LISST-Black and LISST-200x data were also similar for chemically dispersed oil. The fluorometer results showed that SeaOWL was the most sensitive, even though the Cyclops was used on both the LISST-Black and the Towed SilCam. The shakedown tests successfully demonstrated static deployment at various depths, smooth data collection, and transitions at high speeds between stations. Data collected was consistent, with intended variations across depths and locations. Several engineering issues were identified, including communication, instrument installation, cable management, equipment stowage, as well as instrument frame security through air-towing, and water sample collection. Recommendations for improvements have been provided.

These laboratory, wave tank and field tests provided data to illustrate the optimized DSD detecting ranges for the three instruments under various conditions and scales. In addition, the tests supplied information on the deployment of the instruments, including several water quality instruments, and developed data acquisition protocols for real-time monitoring. The findings have immediate implications on the application of the Subpart J rule and oil spill response.

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1 Project Introduction

Monitoring the use of dispersants on surface oil slicks has been an essential element of oil spill response in the US since the 1990s. This occurred under the auspices of the Special Monitoring of Applied Response Technologies (SMART) protocols that were developed by multiple Federal agencies and managed by the National Response Team (NRT) (USCG et al. 2006). In 2013, the NRT released additional guidance for Environmental Monitoring for Atypical Dispersant Operations to cover subsea application and/or prolonged surface application (USEPA et al. 2013). In January 2022, the US Environmental Protection Agency (US EPA) released a new Rule (40 CFR § 300.913) for the monitoring of dispersants under Subpart J of the National Contingency Plan (NCP). The new Subpart J Monitoring Requirements entail, among others, the measurement and reporting of droplet size distribution (DSD) of oil and dispersed oil. An overview of the monitoring requirement is described in a recent Fact Sheet published by the US EPA (USEPA 2023), which underscores the objective of DSD monitoring to see a shift of the oil droplets to smaller sizes following an effective surface dispersant application (Figure 1).

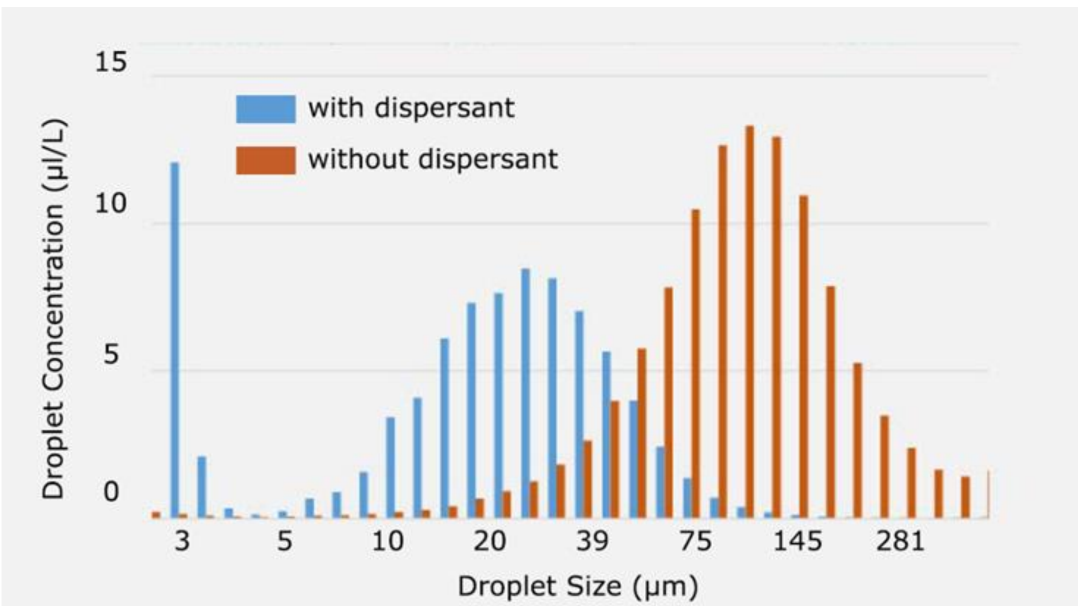


Figure 1 The role of dispersant on the droplet size distribution.
Illustration about the role of dispersant on the droplet size distribution; source: USEPA (2023) (https://www.epa.gov/system/files/documents/2023-11/h-epa-monitoring-dispersants-oil-droplet-size-distribution.pdf), illustration about the role of dispersant on the droplet size distribution.

BSEE Response Research Branch contracted with the New Jersey Institute of Technology (NJIT) to better understand how surface water dispersant monitoring, as specified by the NCP SubPart J Monitoring Rule, can be practically implemented with existing technology, with specific emphasis on detection of oil and dispersed oil droplets in depths of 1 to 5 meters.

1.1 Instrument Introduction

Four instruments capable of measuring droplets were investigated for this research project: two versions of the Laser In-Situ Scattering and Transmissometry (LISST-200x and LISST-Black) both produced by Sequoia Scientific; the Towed Silhouette Camera (Towed SilCam) prototype developed and produced by SINTEF; and the ShadowGraph produced by Bellamare LLC (bellamare-us.com). Together, other instruments were used either to justify the data consistency (Turner Cyclops, Chelsea UviLux, and Sea-Bird Scientific SeaOWL fluorometers), or to collect background water chemistry information (Aqua Troll 600).

LISST-200x

The LISST-200x has a measuring range from 1.0 – 500 µm in 36 size bins, and the measuring concentration according to the manufacturer is from 0.5 to 700 mg/L (https://www.sequoiasci.com/product/lisst-200x/). It is an upgrade on the LISST-100x which is now discontinued by Sequoia.

LISST-Black

The LISST-Black is an integrated package combining a LISST-200x with three Turner Cyclops fluorometers mounted with special brackets and cables made by Sequoia Scientific (Figure 2). The fluorometers are Cyclops-7FG for refined fuels, Cyclops-7FO for crude oil, and Cyclops-7FC for chlorophyll.

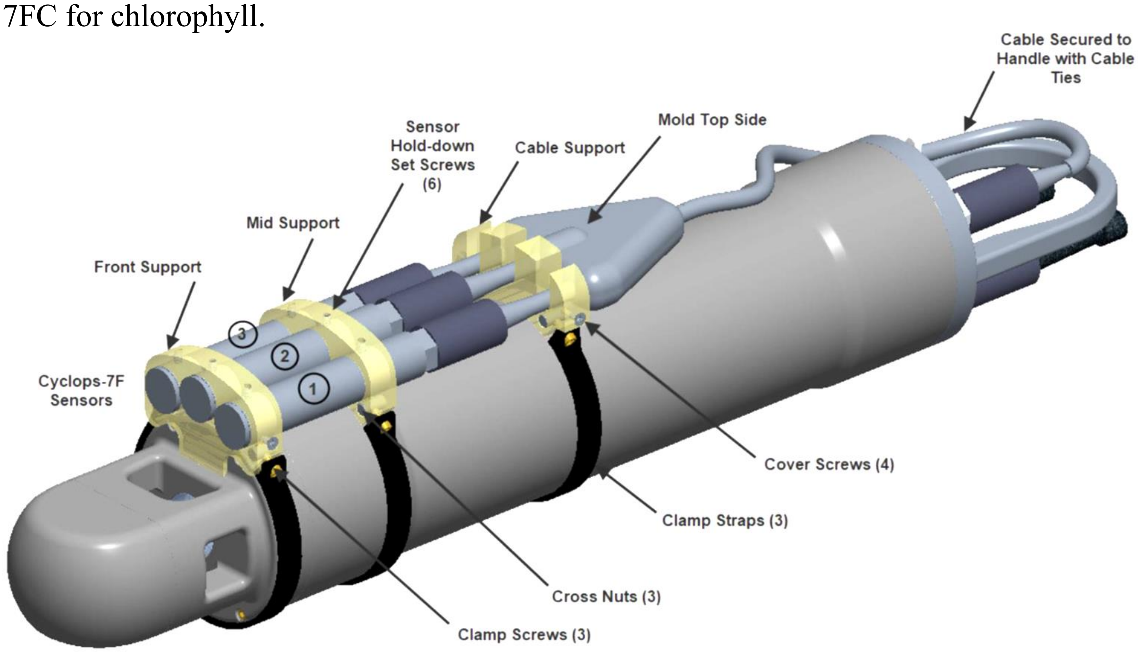


Figure 2 Schematic of LISST-Black.
The mounting parts on a LISST-Black (Image: LISST-200x User's manual, including LISST-HAB & LISST-Black, Sequoia, WA, US).

ShadowGraph camera

The ShadowGraph camera (BellaMare, LLC) has illumination and telecentric imaging pods facing each other, with optimal particle detection range from 50 µm to 3000 µm. An original (raw) image is converted to a binary image (black and white), and the ellipse-fitting algorithm is adopted on the binary image, and then the diameter of each droplet is computed to obtain the DSD (Daskiran et al. 2022). NJIT further improved the data processing method and developed an in-situ data reporting protocol that both real-time images and d50 (volume median droplet diameter) results could be provided (Boufadel et al. 2024).

Towed Silhouette Camera

The Towed Silhouette Camera is a prototype (not yet commercially available) that works on a restricted path length telecentric system. It is similar to another SilCam system that was previously built by SINTEF that has been used both in large-scale experimental subsea releases of oil and gas, and in the field to quantify the distribution of suspended material such as zooplankton, marine snow, etc. (Boufadel et al. 2021; Fitzpatrick et al. 2015). Images are analyzed to provide size distribution spanning from ~ 50 µm to around 2000 µm. When operating on field conditions, the Towed SilCam is designed to be deployed from a small boat (Figure 3). Note that SINTEF also has developed a solution to launch this system autonomously, but the autonomous solution was not within scope of this current project.

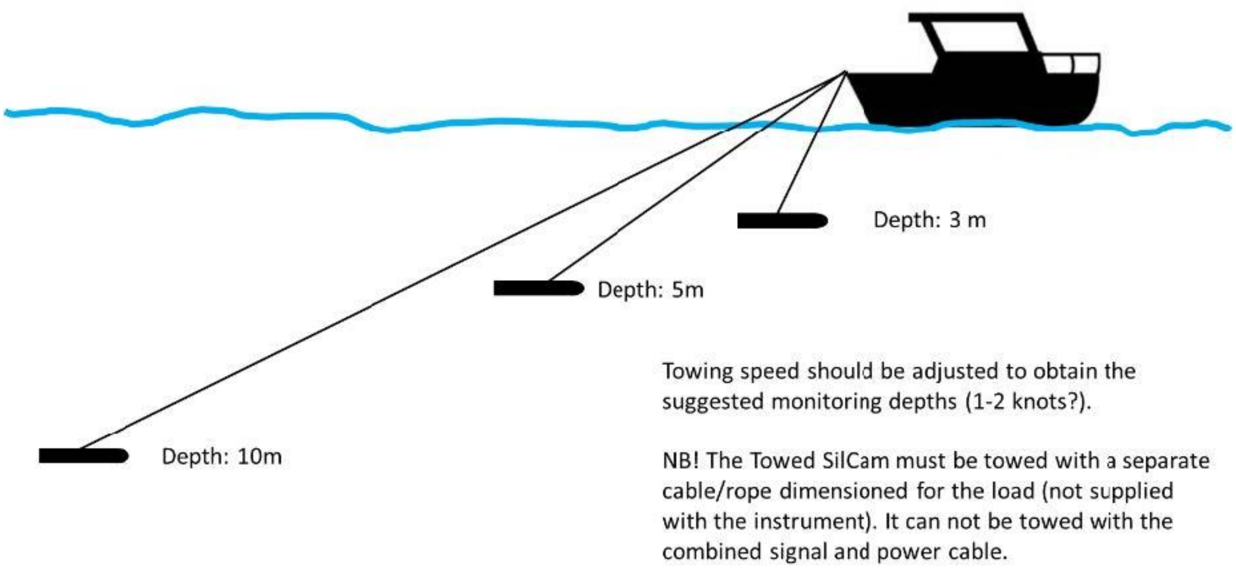


Figure 3 Illustration of a possible field operation of the Towed SilCam.
(Image: SilCam User Manual, SINTEF, Norway)

Turner Cyclops fluorometer

The Turner Designs Cyclops-7F Submersible Sensor is an accurate single-channel detector. It is designed for integration into multi-parameter systems from which it receives power and delivers a voltage output proportional to the concentration of the fluorophore, particle, or compound of interest. In this kit, a stand-alone Cyclops-7FO fluorometer sensor was used to detect crude oil. It has an excitation wavelength of 120 – 350 nm, and emission wavelength of 460 – 600 nm (Abou-Khalil et al. 2023) (https://www.turnerdesigns.com/cyclops-7f-submersible-fluorometer).

Aqua Troll 600

The Aqua Troll 600 is a fully customizable five-port multiparameter sonde with capacity for four interchangeable sensors and an antifouling wiper. It sends data to a computer through a USB adapter, or to a smartphone interface. The equipped sensors include temperature, conductivity, salinity, pH/ORP, Rugged Dissolved Oxygen (RDO), turbidity, total dissolved solids, etc. (https://in-situ.com/us/aqua-troll-600-multiparameter-sonde?srsltid=AfmBOoq34K4MqOU2xUfjJe77BK3IGenjamYmA989y5HnzyJjBE-Qcwb)

1.2 Objectives

The main objective of this project is to evaluate the LISST-Black and the Towed SilCam under selected conditions, and to investigate a methodology for simultaneously measuring droplet size and oil fluorescence at sea. The objective was achieved through two tasks, as shown in Table 1. The first task (Task 1a) included laboratory validation of the instruments' accuracy with "beads" of given sizes at select concentrations, using a similar approach to that adopted by NJIT in a prior study using the LISST-100x (Zhao et al. 2018). Task 1b deployed and tested the instruments in the Ohmsett wave tank using Hibernia oil (fresh and weathered) and a single dispersant (Corexit 9500). The weathering process involved evaporating oil columns by heat in to obtain 10% mass loss.

Table 1 Task of the BSEE Project 1156.

Task No.	Test Scale	Test Method	Task Goal
Task 1a	Laboratory validation	A flume tank	To test the bin size ranges and accuracy of the instruments in a lab vessel using plastic beads of known sizes
Task 1b	Tank deployment	Ohmsett tank	To test deployment, tow configuration, and data processing of both instruments in oil and dispersed oil
Task 2	Field Evaluation	Raritan Bay / New York Bay	To determine the ability of the instruments to: **a)** safely deploy from ocean-going vessels, **b)** perform in both static and towed configurations, **c)** provide and transmit data in a usable format to simulated shore-based response decision-makers in a 'near real-time' format.

Task 2 consisted of a field evaluation test that was conducted in June 2024 without involving crude oil. Task 2 was a shakedown operational test, and the objectives included:

- Demonstrate capabilities of the new DSD instrumentation package from a 47' OSRV (oil spill response vessel) and identify/document any potential limitations for deployment from a small boat.
- Observe and record baseline marine conditions from all instruments in actual marine conditions.
- Train all test team personnel in instrument deployment, software use, and data management.
- Assess and revise draft User Manual based on real deployment conditions and photo-document test procedures.
- Test three (3) deployment options (Options 1 and 2 are shown in Figure 4):
    - static deployment (down-and upcast from 1-5 meters with stationary vessel),
    - static deployment (down-up cast from 1-5 meters; with air tow between simulated stations),
    - towed deployment at a fixed depth below vessel draft (e.g., 3 meters) to attempt tow at 1 to 1.5 knots.
- Obtain feedback from test team and MSRC personnel about the configuration and deployment on 47' vessel for "Lessons Learned".

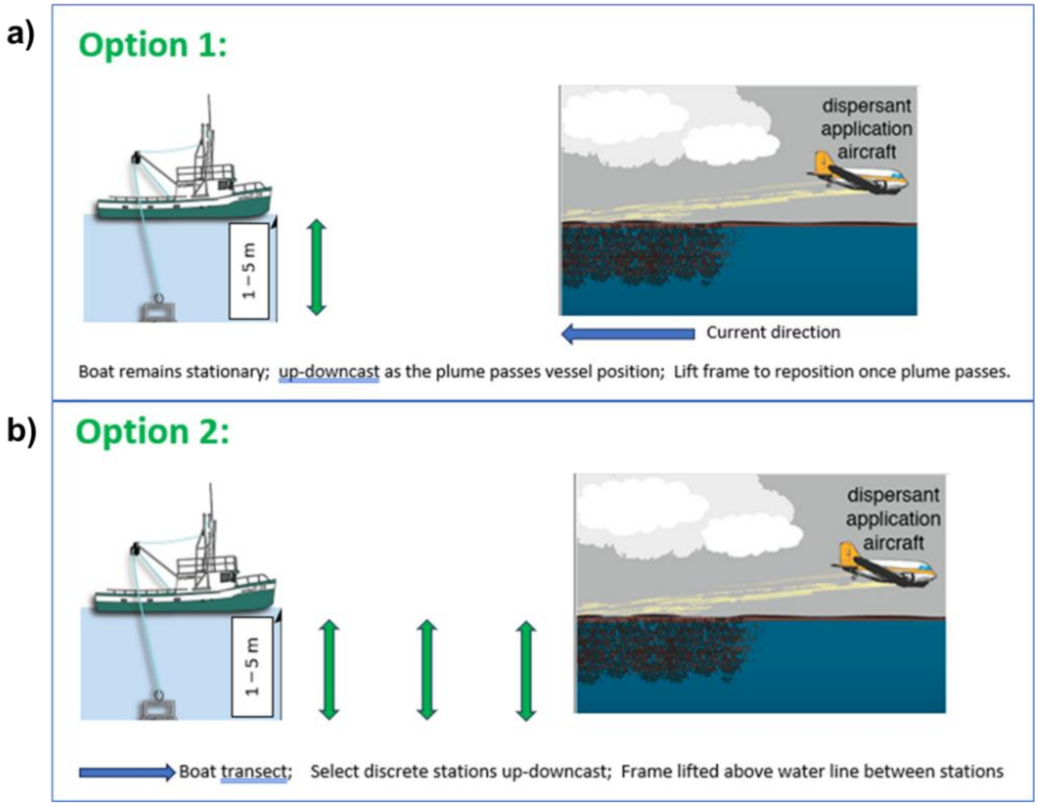


Figure 4 Field operational test options.
a) Option 1, down- and up-cast from 1-5 meters with stationary vessel; b) Option 2, down-up cast from 1-5 meters; with air tow between simulated stations. Option 3 was not conducted due to the limitation of the small vessel (crane was not capable of towing the instrument kit in water).

2 Laboratory Validation – NJIT Flume Tank Tests

The goal of the instrument testing in the laboratory was to evaluate the accuracy of measurement of droplet size detection of several instruments: Laser In-Situ Scattering and Transmissometry (LISST-Black and LISST-200x) produced by Sequoia Scientific (its range is 1 – 500 µm), the Towed Silhouette Camera prototype produced by SINTEF (its optimal range is 30 to 1200 µm, though it can read up to 2000 µm); and the ShadowGraph (its optimal range is 100 µm to 3000 µm). The ShadowGraph has been used in prior research projects by the Boufadel group such as Daskiran et al. (2022), Daskiran et al. (2021) and Liu et al. (2021).

2.1 Methods and Materials

The laboratory tests were conducted in a water tank at NJIT whose dimensions are 115 cm length × 62 cm width × 25 cm depth. The beads used for testing the LISST-Black were yellow polyethylene microspheres purchased from Cospheric LLC (CA, US). The company states that for a given size, more than 90% of the beads are within ± 0.5% of that size. The density was 1.06 g/cm^3, which makes the beads almost neutrally buoyant in freshwater. Six bead sizes were selected, which were tested individually (only one size at a time) and combined (two or three sizes mixed equally based on a mass basis) as shown in Table 2. The loading concentration was 10.0 mg/L water (i.e., 10 ppm). In order to minimize the coagulation of the beads (i.e., sticking together), the dispersant Corexit 9500A was added at the volume ratio (dispersant to beads) 1:50. Figure 5 shows the setup and the beads passing through the instrument detection windows. Figure B1 (see Appendix B) shows representative views obtained from ShadowGraph for each of the six individual bead sizes.

Table 2 Laboratory-scale evaluations at NJIT for the Towed SilCam, LISST-Black and ShadowGraph Camera.

Test No.	Bead Sizes (µm)	Instrument
1-1	20	Towed SilCam, LISST-Black
1-2	100	ShadowGraph camera, Towed SilCam, LISST-Black
1-3	250	ShadowGraph camera, Towed SilCam, LISST-Black
1-4	500	ShadowGraph camera, Towed SilCam, LISST-Black
1-5	1000	ShadowGraph camera, Towed SilCam
1-6	1500	ShadowGraph camera, Towed SilCam
1-7	100 + 20	Towed SilCam, LISST-Black
1-8	100 + 250	Towed SilCam, LISST-Black
1-9	100 + 500	Towed SilCam, LISST-Black
1-10	500 + 1500	ShadowGraph camera, Towed SilCam
1-11	100 + 500 + 1000	ShadowGraph camera, Towed SilCam
1-12	250 + 500 + 1000	ShadowGraph camera, Towed SilCam
1-13	100 + 500 + 1500	ShadowGraph camera, Towed SilCam

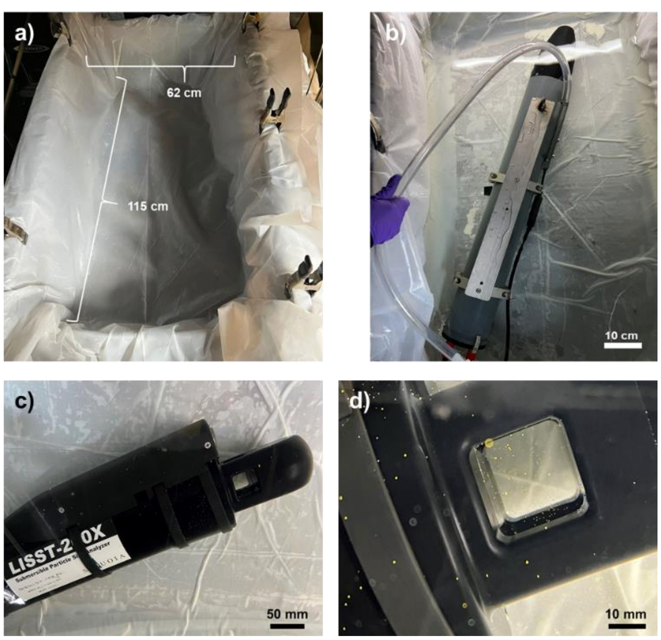


Figure 5 Laboratory validation setup.
The lab validation setups used at NJIT. a) the tank dimension; b) the beads passing through the detection window by a plastic tube; c) and d) the beads passing through the LISST-Black detection window. (Photos: NJIT)

2.2 Results

Test 1-1 was conducted with single-size 20 µm polyethylene (PE) beads, and Figure 6a shows the LISST-Black readings for 60 seconds at a frequency of 0.75 Hz, i.e., every 1.33 seconds. The moving average $d50_{ave}$ was computed based on 5 continuous readings as:

$$d50_{ave}(t_i) = (d50(t_{i-2}) + d50(t_{i-1}) + d50(t_i) + d50(t_{i+1}) + d50(t_{i+2}))/5 \quad (1)$$

Where t is the time step and i is the index and larger than 2. The real-time d50 readings ranged from 20 µm to over 90 µm, and the moving average $d50_{ave}$ was around 50 µm. The values were around double the actual bead sizes. Figure 6b shows the Towed SilCam readings at the frequency of 0.6 Hz (i.e., every 1.66 seconds), which gave only 10 non-zero readings in 60 seconds (zero readings occur when no drops are passing by the camera). These non-zero values reached around 35 µm, which was close to the actual size of 20 µm.

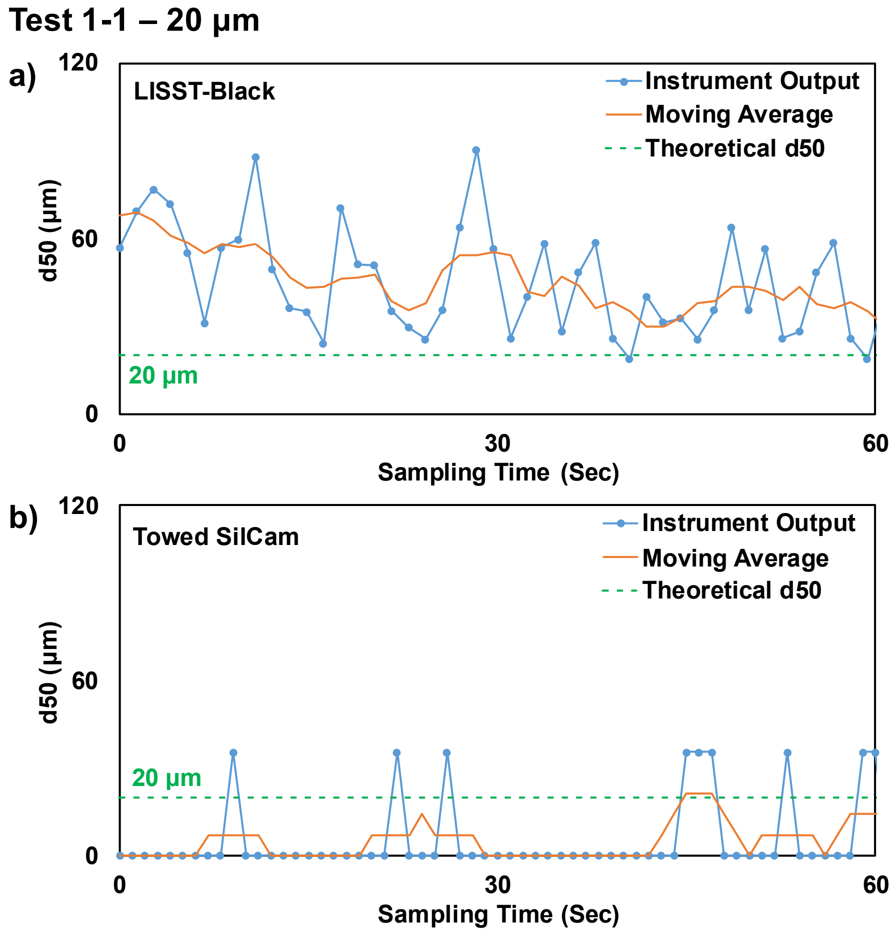


Figure 6 D50 for Test 1-1.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-1.

Test 1-2 was conducted with single-size 100 µm PE beads, and Figure 7a shows the output by the LISST-Black. The d50 readings ranged from 140 µm to around 200 µm for 60 seconds, and the moving average was around 150 µm. Figure 7b shows the output by the Towed SilCam, which ranged from around 140 µm to around 200 µm, and the moving average was also 150 µm.

Figure 7c shows the output from ShadowGraph, with a frequency of 5 Hz. The measured sizes were mostly around 150 µm with some higher readings around 180 µm. Nevertheless, the three instruments showed close readings.

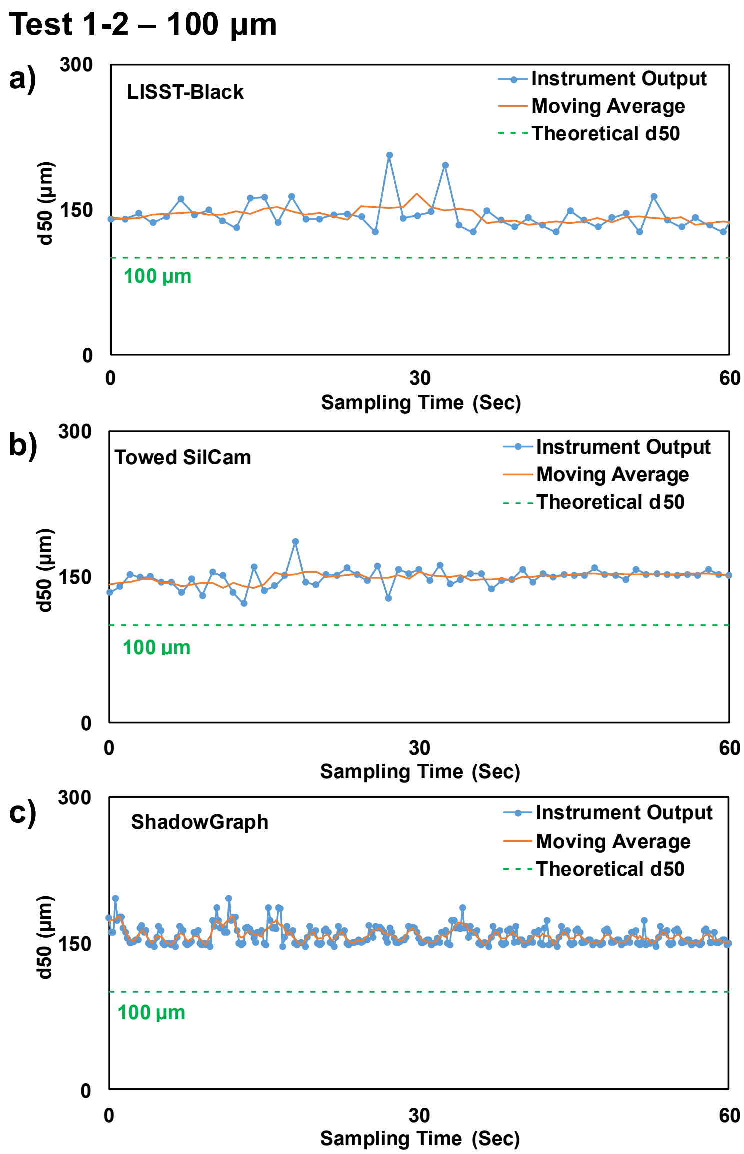


Figure 7 D50 for Test 1-2.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a), the Towed SilCam (b), and the ShadowGraph (c) for Test 1-2.

Tests 1-3 to 1-6 were conducted each with a single-size of PE beads: at 250 µm, 500 µm, 1000 µm, and 1500 µm, and the results are reported in Figures B2 to B5 (Appendix B). In these four tests, both the Towed SilCam and ShadowGraph produced consistent and repeatable results, close to the bead sizes. However, the output by the LISST-Black for the 500 µm (Test 1-4, Fig. B3a, Appendix B) were around 100 µm. This low value was probably due to the above-range bead size for the LISST-Black. Although the LISST-Black is designed to cover the range from 1.0 µm to 500 µm, the middle of last bin is at 462 µm, and droplets larger than that are aliasing into the range to provide values that are within the range (i.e., 100 or 200 µm). This outcome was noted in a prior work (Zhao et al. 2018).

Test 1-7 was conducted with equal masses of 20 µm and 100 µm PE beads (Fig. 8). In the LISST-Black, the d50 readings ranged from around 30 µm to near 150 µm, and the moving average was around 70 µm in the 60 seconds of measurement, close to the expected value, 60 = (120+20)/2 µm. Figure 8b shows that the readings by the Towed SilCam were close to 150 µm, which was similar to the case of the 100 µm beads alone. This is probably because the Towed SilCam could not detect the 20 µm beads. SINTEF indicated to the researchers during testing that the minimum range of the Towed SilCam is around 30 to 50 µm.

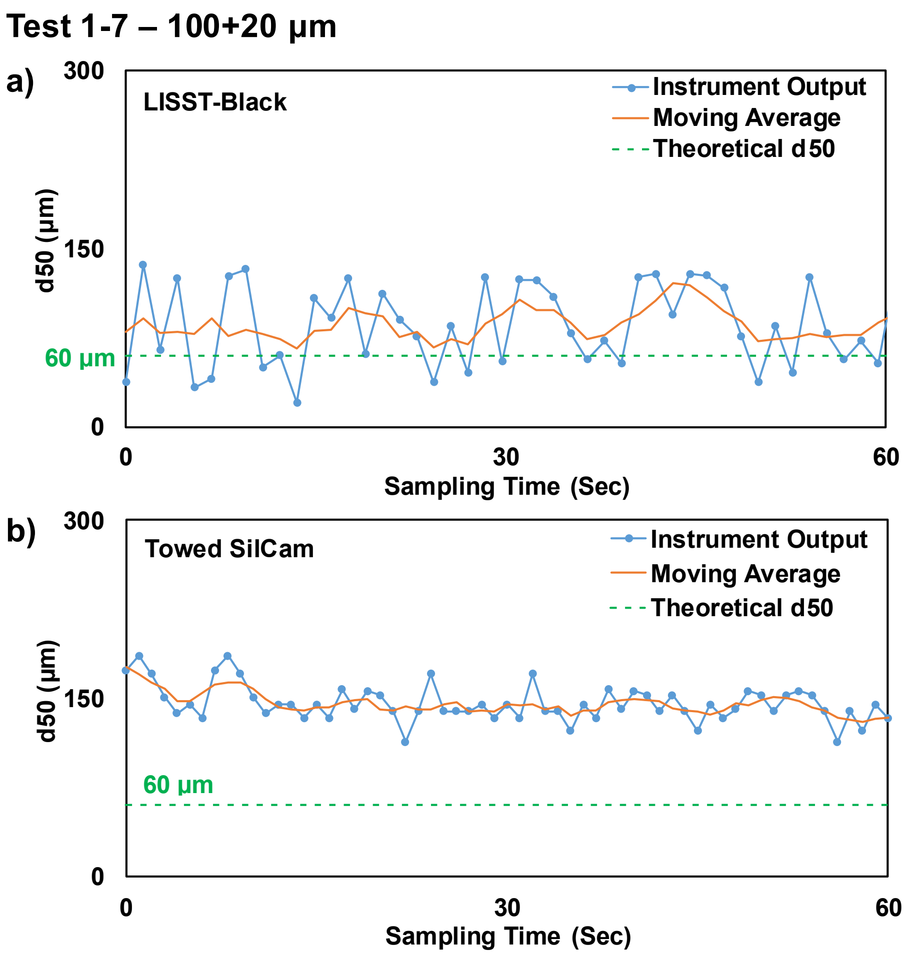


Figure 8 D50 for Test 1-7.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-7.

Test 1-8 was conducted with equal masses of 100 µm and 250 µm PE beads, and thus the expected d50 is 175 µm. The readings by the LISST-Black (Fig. 9a) ranged from around 175 µm to near 300 µm, and the moving average varied from 175 µm to 280 µm. The Towed SilCam readings (Fig. 9b) ranged from around 100 µm to over 250 µm, with a moving average around 120 µm. Thus, both instruments gave values close to the expected d50, and the Towed SilCam values were slightly lower than those by the LISST-Black.

Test 1-8 – 100+250 µm

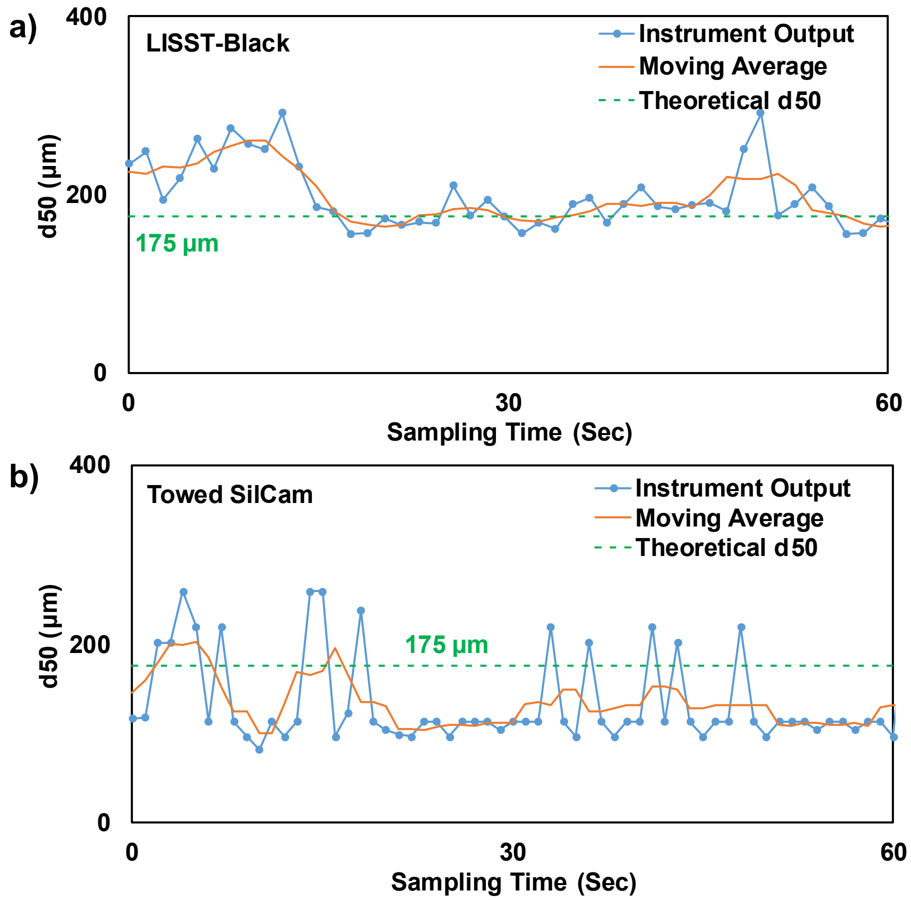


Figure 9 D50 for Test 1-8.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-8.

Test 1-9 was conducted using equal masses of 100 µm and 500 µm PE beads, and thus the theoretical d50 is 300 µm= (500+100)/2 µm. Figure 10a shows the d50 output by the LISST-Black, where the values ranged from around 200 µm to over 400 µm. Figure 10b shows the output by the Towed SilCam, which ranged from around 150 µm to 600 µm. One may note that the readings were jumpy, which might be because the number of beads passing through the window was small due to the narrow measuring channel width. In this case, it is suggested to use the moving average to report the data for better consistency.

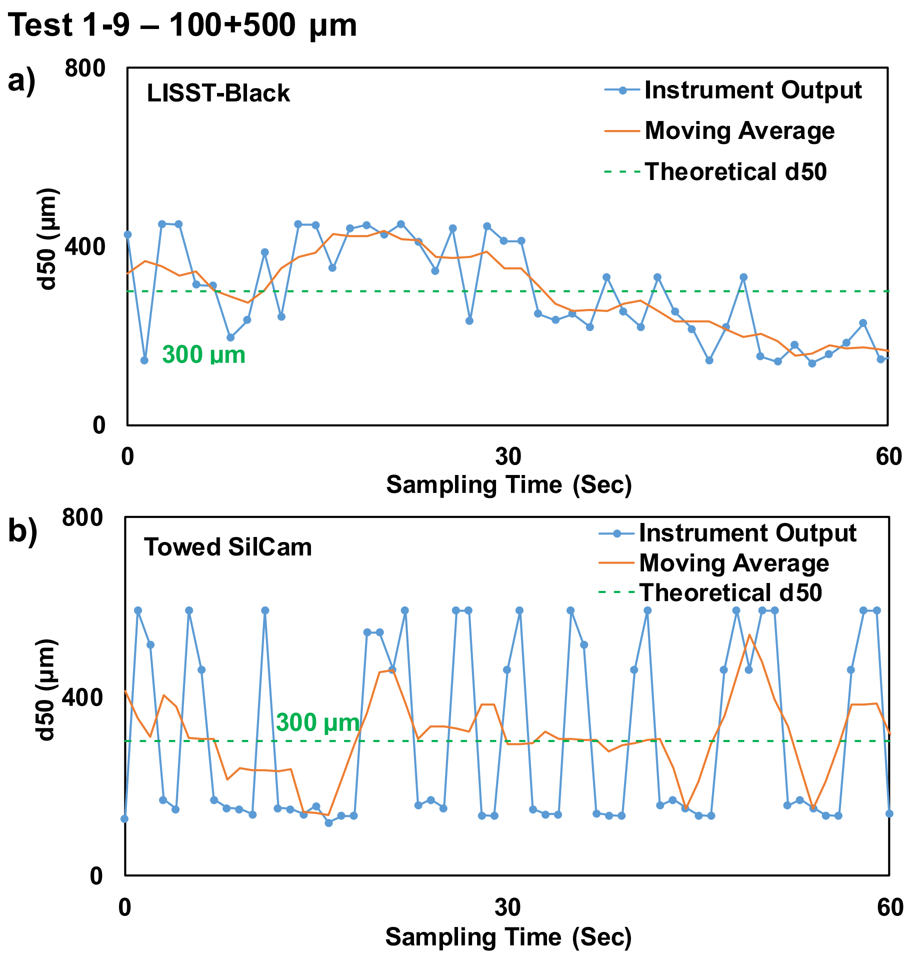


Figure 10 D50 for Test 1-9.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-9.

Test 1-10 was conducted using equal masses of 500 µm and 1500 µm PE beads. Figure 11a shows the output by the ShadowGraph, where the values were at either 500 µm or 1500 µm. The Towed SilCam readings (Figure 11b) gave a d50 around 600 µm instead of the theoretical d50 of 1000 µm. The reason could be (again) due to the small number of 1500 µm beads passing through the measuring window of Towed SilCam.

Test 1-11 was conducted by mixing equal masses of PE beads at sizes of 100 µm, 500 µm and 1000 µm. As the beads were mixed based on equal mass/volume, the d50 should be found at 500 µm as it covered the cumulative volume fraction from 33.3% to 66.6%. Figure 12a shows the computed d50 by the ShadowGraph, where the values were around 500 µm, with some values at around 1000 µm. The outputs by the Towed SilCam (Figure 12b) provided d50 around 500 µm, showing a good performance.

Test 1-10 – 500+1500 µm

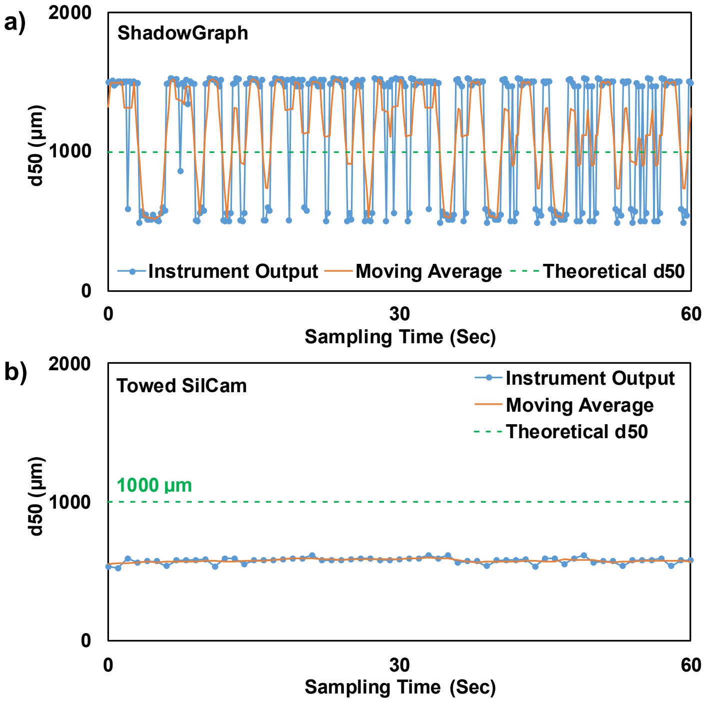


Figure 11 D50 for Test 1-10.
The volume median diameter, d50 (µm) obtained from the ShadowGraph (a) and the Towed SilCam (b) for Test 1-10.

Test 1-11 – 100+500+1000 µm

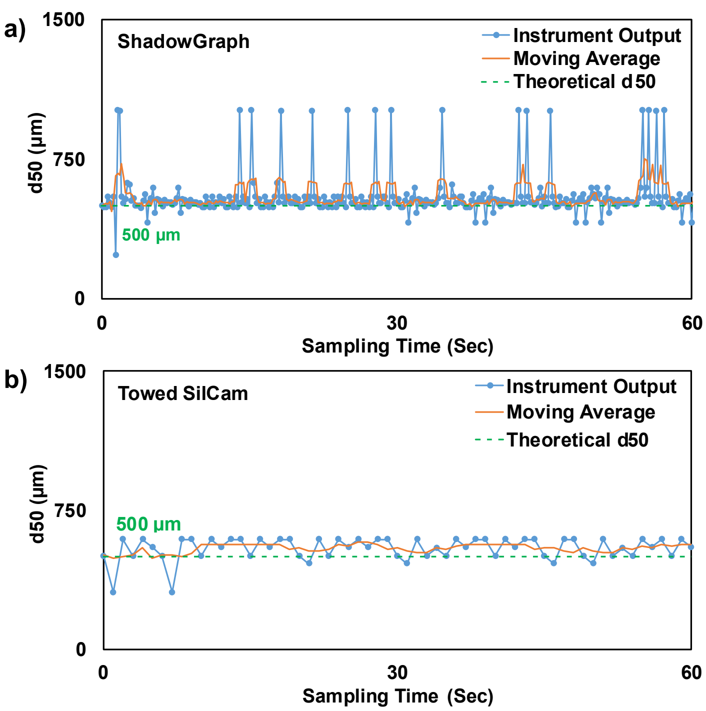


Figure 12 D50 for Test 1-11.
The volume median diameter, d50 (µm) obtained from the ShadowGraph (a) and the Towed SilCam (b) for Test 1-11.

Tests 1-12 and 1-13 were conducted by mixing three PE bead sizes (equal masses): 250 µm, 500 µm, and 1000 µm for Test 1-12, and 100 µm, 500 µm and 1500 µm for Test 1-13. The results are reported in Figures B6 and B7 (see Appendix B), respectively. For Test 1-12, the ShadowGraph readings were around 500 µm (Figure B6a), with some points at around 750 µm. The Towed SilCam readings were around 250 µm. It is possible that the detection path of the Towed SilCam (3000 µm) did not allow many 1000 µm sized beads to pass easily. For Test 1-13, both the ShadowGraph and Towed SilCam gave readings close to the expected theoretical d50, which was 500 µm. It is not clear why the ShadowGraph did not perform as well when the smaller size was 250 µm (Figure B6b).

3 Ohmsett Wave tank Tests

3.1 Ohmsett June 2023 Test

3.1.1 Methods and Materials

The Ohmsett facility (www.ohmsett.com) is located in Leonardo, New Jersey and has a wave tank whose dimensions are 203 m long × 20 m wide × 2.4 m deep. The wave tank is equipped with a flap-type wave generator, which was operated during this study to generate a breaking wave over the frame based on the approach used by the Boufadel group (Boufadel et al. 2017). The experimental matrix is reported in Table 3, which summarizes the weathering status, volume of oil and dispersant application for each experiment.

Table 3 Experiment Matrix for the Ohmsett June test.

Test No.	Instrument depth	Oil and Dispersant
2-1	0.5 m	Fresh Hibernia, 10 L, DOR=0
2-2	0.5 m	Fresh Hibernia, 10 L, DOR=0
2-3	0.8 m	Fresh Hibernia, 10 L, DOR=0
2-4	0.8 m	Fresh Hibernia, 20 L, DOR=0
2-5	0.8 m	Weathered Hibernia, 20 L, DOR=0
2-6	0.8 m	Fresh Hibernia, 10 L, DOR=1:20
2-7	0.8 m	Fresh Hibernia, 5 L, DOR=1:20
2-8	0.8 m	Weathered Hibernia, 5 L, DOR=1:20
2-9	0.8 m/0.5 m*	Fresh Hibernia, 10 L, DOR=0
2-10	0.8 m/0.5 m	Weathered Hibernia, 10 L, DOR=0
2-11	0.8 m/0.5 m	Weathered Hibernia, 5 L, DOR=0
2-12	0.8 m/0.5 m	Weathered Hibernia, 5 L, DOR=1:20

* ShadowGraph, Towed SilCam and the three fluorometers were on the upper level, Level 1, which was 0.5 m deep. The LISSTs were on the lower level, Level 2, which was 0.8 m deep. A DOR=0 refers to untreated oil where dispersant has not been applied.

Various instruments were installed on a frame placed within the wave field at the Ohmsett wave tank. Figure 13 shows the frame and instruments used for Tests 2-1 and 2-2. The ShadowGraph and the Towed SilCam were installed on the upper level 1 (at depth 0.5 m). Three fluorometers (SeaOWL, Cyclops 7F-O and UviLux), and the LISST-200x and LISST-Black were installed on the lower level 2 (depth 0.8 m). During initial testing, the team noted that the Towed SilCam was not reporting data due to an internal shift of the camera components, which resulted in unfocused images. After the prototype SilCam was refocused, data was reported for Tests 2-9 to 2-12.

Figure 13 Ohmsett June test frame.
The ShadowGraph and the Towed SilCam were installed on Level 1, and the LISST-Black and LISST-200x were installed on Level 2. (Photo: G. Coelho)

For each test, the instrument frame was lowered into the wave tank. Hibernia oil was placed in a floating boom approximately 4 ft upstream of the frame, and the boom was lifted immediately before a wave breaker occurred. The wave breaker hit the oil slick and sent the dispersed oil plume through the frame (and the instruments), as shown in Figure 14.

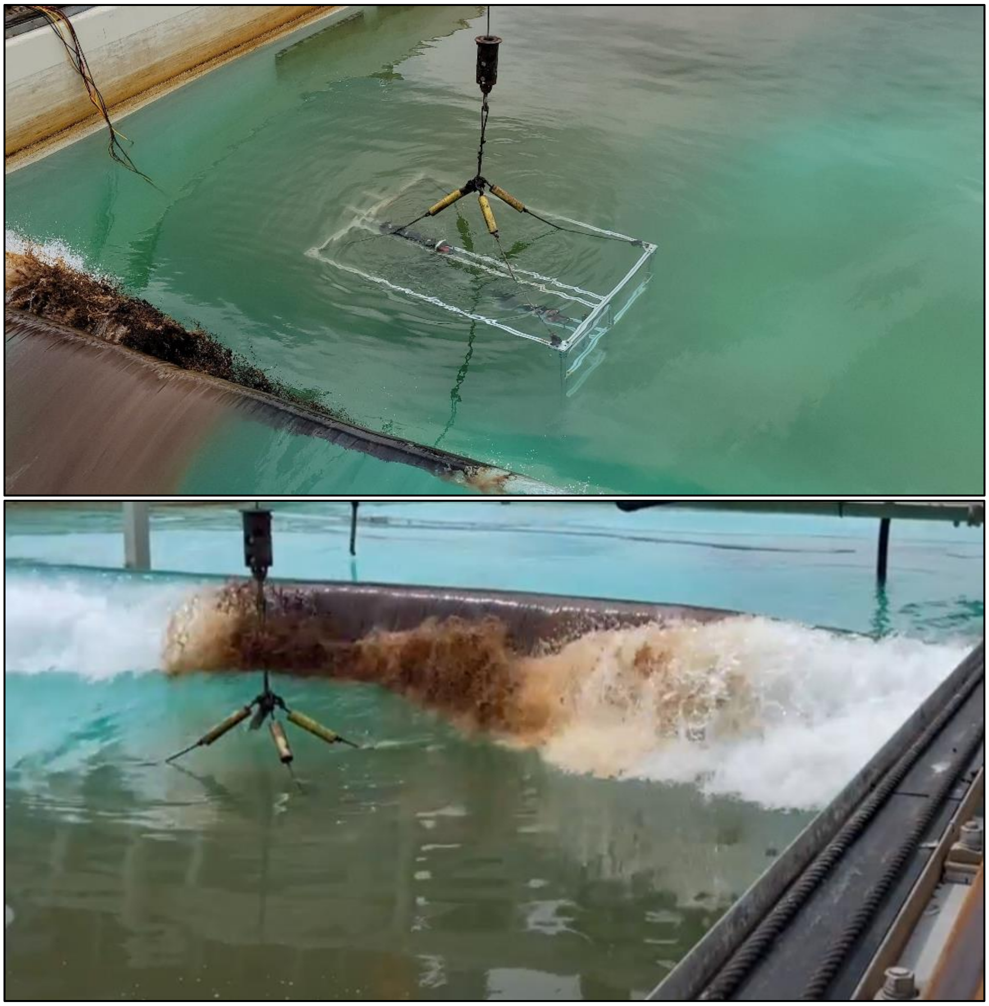


Figure 14 Wave breaking over frame
The breaker wave hits the oil slick, and the dispersed droplets move through the instrument frame. (Photos: G. Coelho)

3.1.2 Droplet Size Distribution Results

The LISST-Black data (i.e., DSD) for Tests 2-1 and 2-2 are reported in Figure 15. The d50 results show that the oil plume of 10-liter untreated fresh oil went through the sensors as evidenced by the increase in concentration to 500 µL/L or 500 ppm (by volume, see Figure 15a). The d50 (volume median diameter) increased to over 250 µm at that moment and lasted for around 30 seconds. In a subsequent replicate test (same oil amount, Figure 15b), the d50 also reached 250 µm, but the concentration was only 50 µL/L. This reflects the uncertainty of the concentration (total volume) measurement by the LISST-Black instrument as the concentration is given based on the 2D shape of the oil droplets and the diameter of an equivalent sphere. Therefore, one should use the concentration values of the LISST-Black as secondary data in terms of reliability.

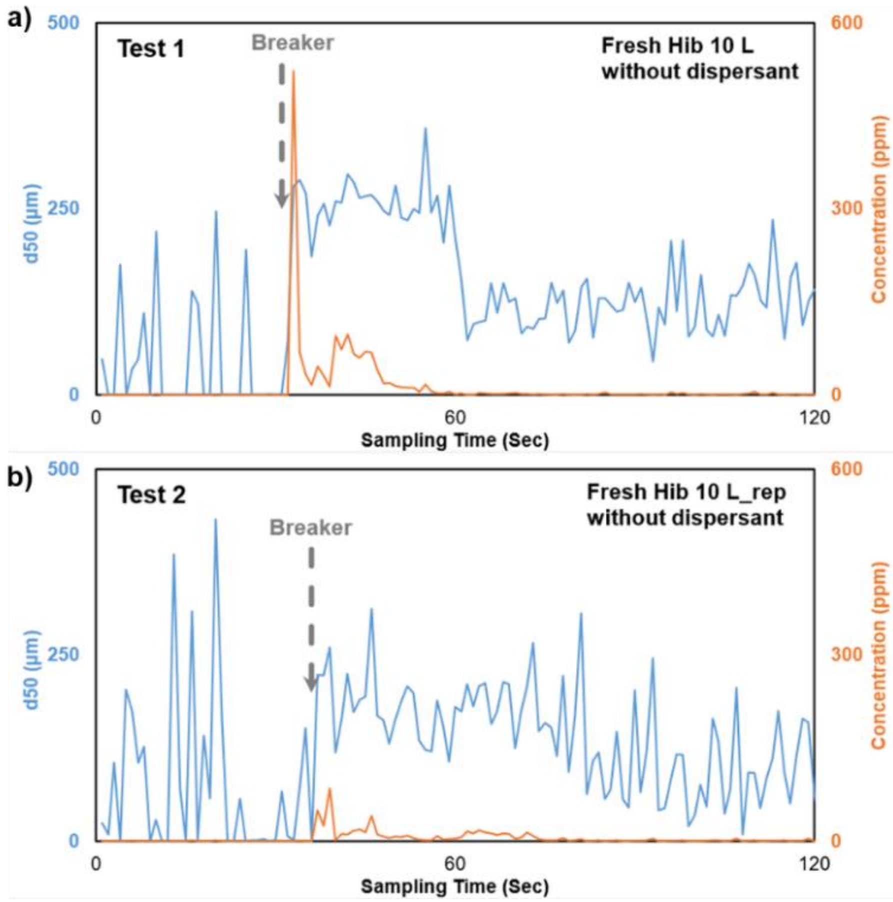


Figure 15 D50 and concentration for Tests 2-1 and 2-2.
The d50 and concentration obtained by the LISST-Black for: a) Test 2-1 and b) Test 2-2.

Figure 16 shows that the d50 results for Test 2-3 (untreated 10 L fresh oil). The data from the LISST-Black (Figure 16a) fluctuated more than the ones from the LISST-200x (Figure 16c), though both were in the 200 – 250 μm range. The concentration was very small. This is expected because the untreated oil droplets were large (more buoyant) and many of them floated back to the surface immediately after or even before reaching the depth of 0.8 m. This also explains the fluctuation of the d50 data. For Test 2-4, the LISST-Black (Figure 16b) displayed a sharp increase from around 100 μm to over 250 μm after the breaker, and the concentration increased to around 100 μL/L. However, the LISST-200x did not respond well (Figure 16d), as both the d50 and concentration did not change significantly. It is possible that the oil plume did not reach the LISST-200x. In a series of tests run by Dr. Boufadel's group in 2022 at Ohmsett, using the same frame with a larger volume of oil, the oil concentration captured by the ShadowGraph was found to be around 10 μL/L at 0.8 m depth (Liu et al. 2024) – given the fact that the LISST-Black in this test captured a concentration of around 100 μL/L, users should be aware that the uncertainties of untreated dispersion (even 20-liter oil was loaded) could be easily biased.

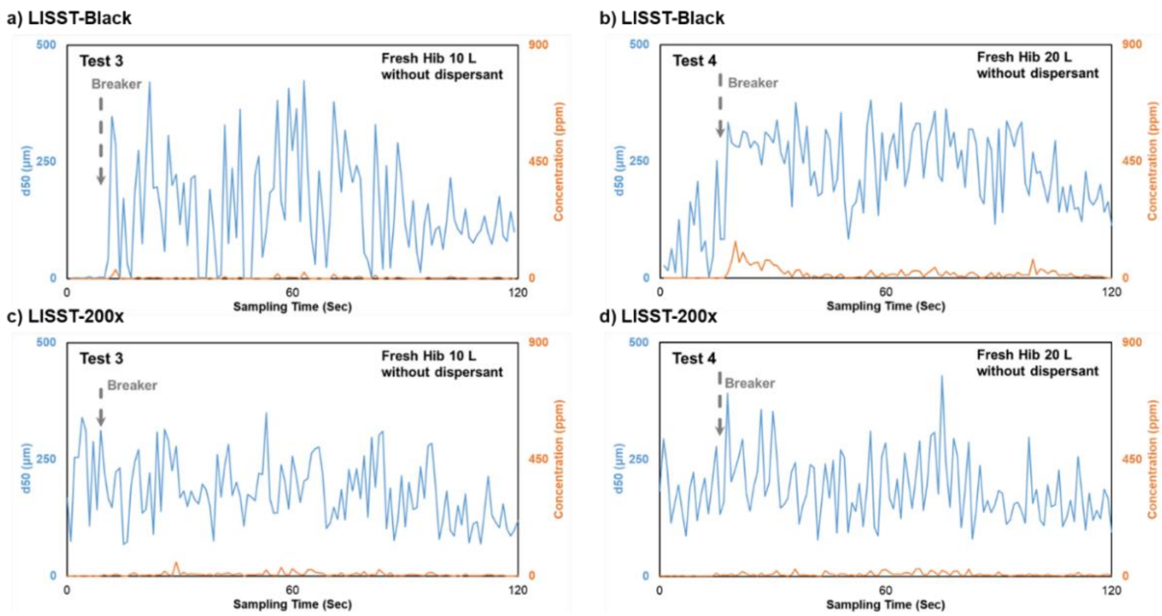


Figure 16 D50 and concentration for Tests 2-3 and 2-4.
The volume median diameter, d50 (µm) and concentration results obtained from the LISST-Black (a and b) and LISST-200x (c and d) for Tests 2-3 (left column) and 2-4 (right column).

Figure 17a shows that the LISST-Black results provided clear information on the d50 and concentration in Test 2-5 (untreated 20 L weathered oil), as both quantities increased sharply after the breaker. However, the LISST-200x (Figure 17c) did not perform well as no sizeable change was detected. For Test 2-6 (chemically dispersed 10 L fresh oil), both the LISST-Black (Figure 17b) and LISST-200x (Figure 17d) detected the chemical dispersion of the fresh oil, as the d50 decreased sharply from 100 µm to less than 10 µm, and the concentration increased and showed a peak at around 250 µL/L.

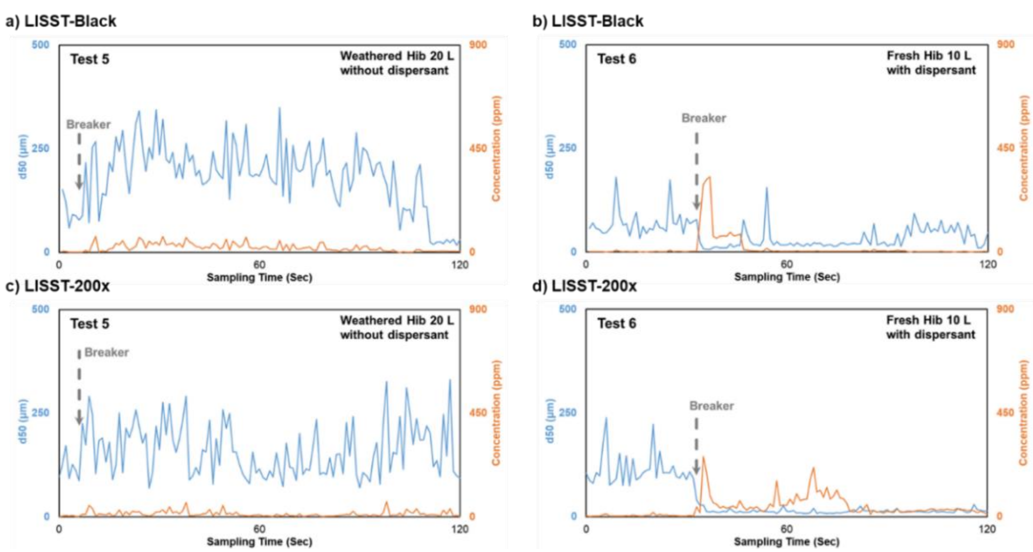


Figure 17 D50 and concentration for Tests 2-5 and 2-6.
The volume median diameter, d50 (µm) and concentration results obtained from the LISST-Black (a and b) and LISST-200x (c and d) for Tests 5 (left column) and 6 (right column).

The d50 obtained from the LISST-Black (Figure 18a) for Test 2-7 (chemically dispersed 5 L of fresh oil) decreased to less than 10 µm and the concentration slightly increased (as the total loading volume was only 5 liters). However, the d50 by the LISST-200x (Figure 18c) increased after the breaker, which could be due to the occasional large droplets being detected, as there was only one data point (at the peak). Test 2-8 was conducted with chemically dispersed 5 L weathered oil. The concentration based on the LISST-Black reached near 900 µL/L, and the d50 decreased gradually to less than 10 µm (Figure 18b). However, the d50 and concentration data from the LISST-200x did not change after the breaker (Figure 18d). The NJIT researchers surmised that the oil plume likely did not reach the LISST-200x due to the small volume of oil used.

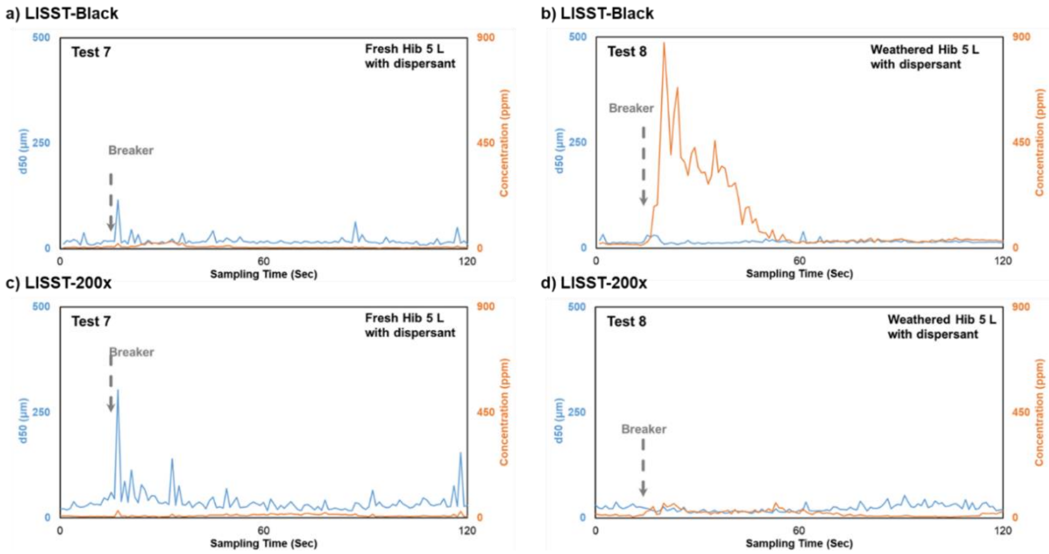


Figure 18 D50 and concentration for Tests 2-7 and 2-8.
The volume median diameter, d50 (µm) and concentration results obtained from the LISST-Black (a and b) and LISST-200x (c and d) for Tests 2-7 (left column) and 2-8 (right column).

The d50 and concentration data of Tests 2-9 to 2-12 from the LISST-Black and LISST-200x are reported in Figures 19 and 20. Note that for these tests, the two instruments were installed on the (same) lower Level 2 (at 0.8 m depth). But as the water in the tank was not refreshed, the dispersant applied on the previous tests could have impacted oil dispersion. As dispersant was used in Test 2-12, the images obtained by the ShadowGraph did not show the droplets due to the small sizes, thus no valid data could be collected.

Figure 19a shows that the d50 obtained from the LISST-Black in Test 2-9 had a sharp increase after the breaker when it reached around 350 µm; the concentration also increased significantly after the breaker to reach around 300 µL/L. For the LISST-200x (Figure 19c), the d50 increased rapidly to around 300 µm, and the concentration to 250 µL/L. The numbers were slightly different for the LISST-Black and LISST-200x, but the trends for both concentration and d50 in the following two minutes after the breaker were very comparable.

The d50 and concentration data from the two instruments in Test 2-10 (10 L untreated oil, Figure 19b and d) showed similar results, as the curves in the two minutes after the breaker were comparable to each other.

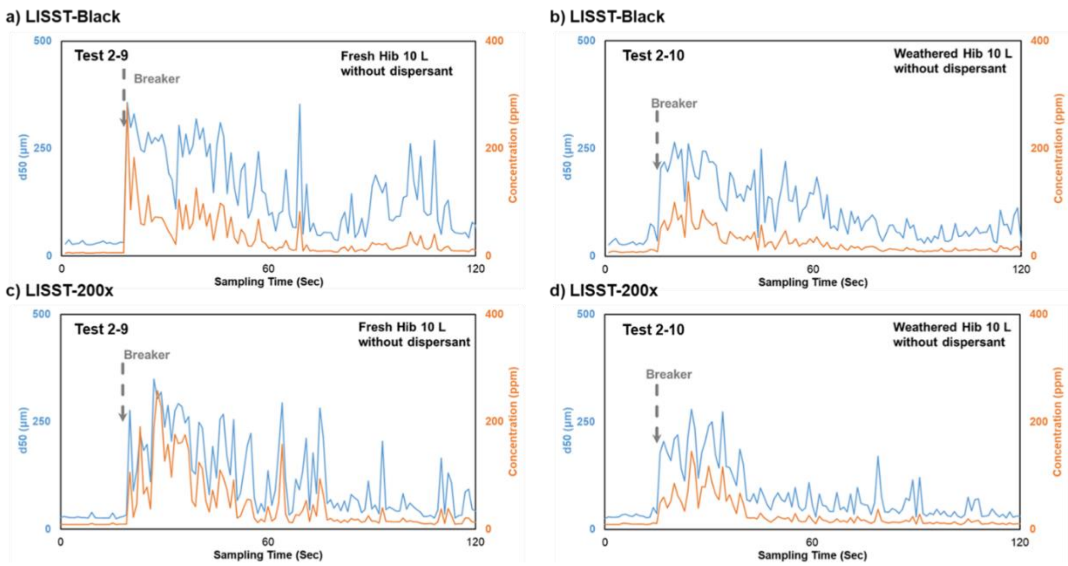


Figure 19 D50 and concentration for Tests 2-9 and 2-10.
The volume median diameter, d50 (μm) and concentration results obtained from the LISST-Black (a and b) and LISST-200x (c and d) for Tests 2-9 (left column) and 2-10 (right column).

Figure 20a shows the results obtained from the LISST-Black for Test 2-11. After the breaker, the d50 increased to around 250 µm and the concentration increased to 50 µL/L. The data from the LISST-200x (Figure 20c) showed a similar increase, except the significant readings lasted for a longer time (around 60 seconds). For Test 2-12 (chemically dispersed 5 L weathered oil), the d50 from the LISST-Black (Figure 20b) decreased after the breaker, and the concentration increased significantly to around 150 µL/L. The d50 obtained from the LISST-200x also decreased (Figure 20d), but the concentration only slightly increased to around 50 µL/L, much smaller than those from the LISST-Black. This outcome has been flagged to be investigated in any future testing.

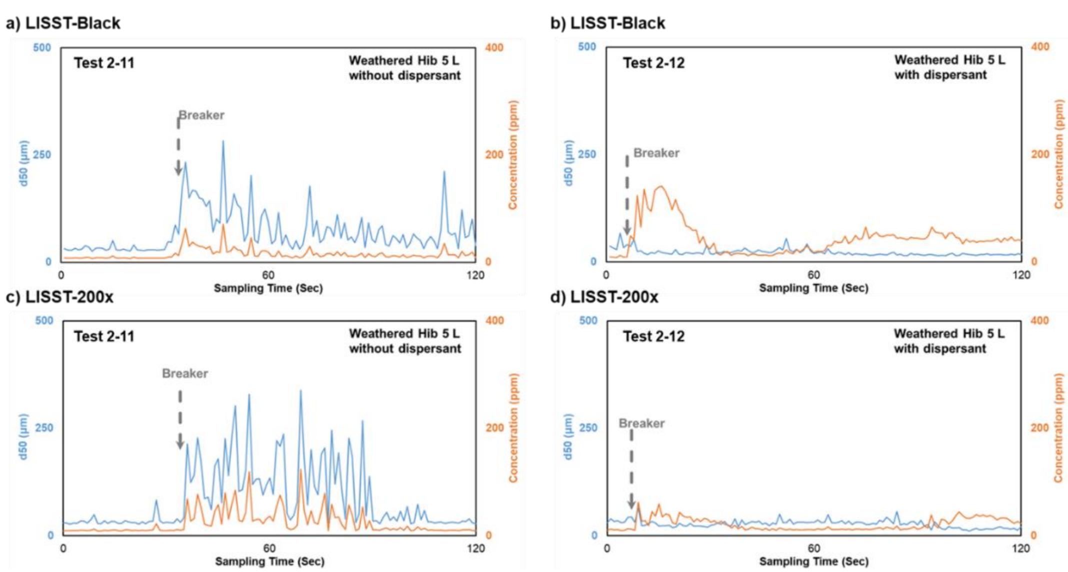


Figure 20 D50 and concentration for Tests 2-11 and 2-12.
The volume median diameter, d50 (μm) and concentration results obtained from the LISST-Black (a and b) and LISST-200x (c and d) for Tests 2-11 (left column) and 2-12 (right column).

Thus, it seems that for the chemically dispersed oil (Test 2-6 as with dispersant, and Test 2-9 to 2-12 as the water surface tension had changed), the LISST-Black and LISST-200x data were highly comparable, but for the untreated oil the data from the two instruments were somewhat different, which is probably due to the uncertainty in capturing low oil concentrations in the water column.

The Towed SilCam was re-installed on Level 1 (i.e., at 0.5 m depth) for Tests 2-9 to 2-12 (the data captured using the LISST instruments are reported in prior Figures). Note that both the Towed SilCam and ShadowGraph detected air bubbles for the first few seconds after the breaker (Figure 21), so the images cannot be used to interpret the oil DSD data when the bubble concentration is large for the two instruments.

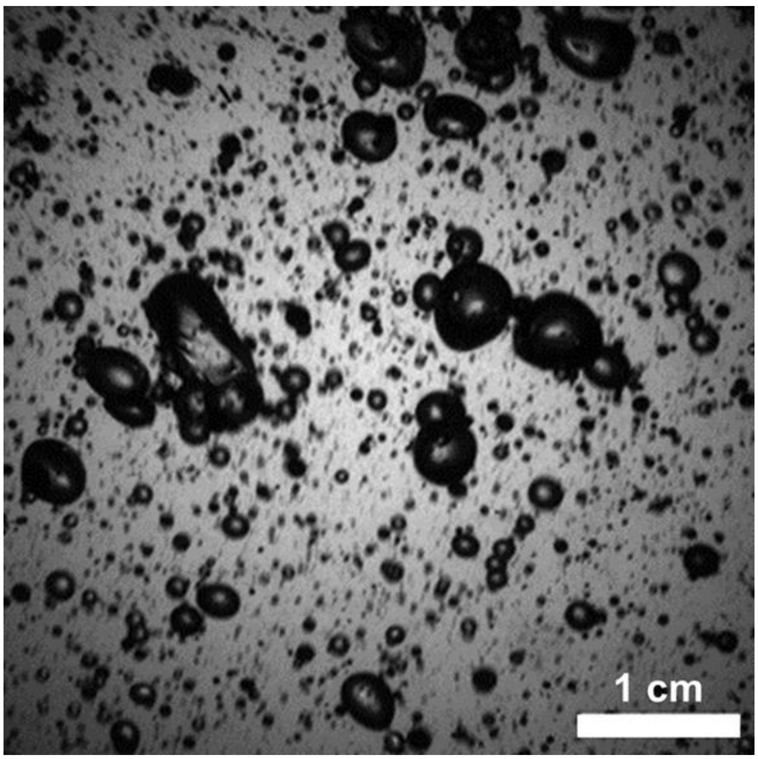


Figure 21 Air bubbles and oil droplets in the ShadowGraph camera view.
An image output from ShadowGraph camera showing many air bubbles after the breaker. (Photo: NJIT)

The data from the Towed SilCam and ShadowGraph for Tests 2-9 to 2-12 are reported in Figures 22 to 25. In Figure 22, the Towed SilCam showed readings of d50 at around 700 μm and around 300 μm, with one peak at around 1800 μm. Based on Figure 22a, it is a challenge to decide on the value of the d50 to adopt from ShadowGraph during a response operation; selecting only the peak values would overestimate the representative value of the d50, and taking the average over the whole-time interval will provide a very small value considering that there are too many zero readings. The researchers suggest to consider the average top 10% or 20% of the d50 as a representative value when interpreting the measured data.

The ShadowGraph showed continuous readings from around 500 μm to 1000 μm (Figure 22b). The ranges of data from the Towed SilCam and ShadowGraph were comparable, but the frequency of the Towed SilCam is 1 Hz (every one second) while that of ShadowGraph is 5 Hz (five per second). Thus, the Towed SilCam might not capture the data as frequently as the ShadowGraph does, especially when the oil concentration is small (there were many "0" readings in the Towed SilCam data). However, using the moving average, the two instruments gave comparable results. Realistically, it is not likely that data for the response is needed at 5 measurements per second or even at one per second.

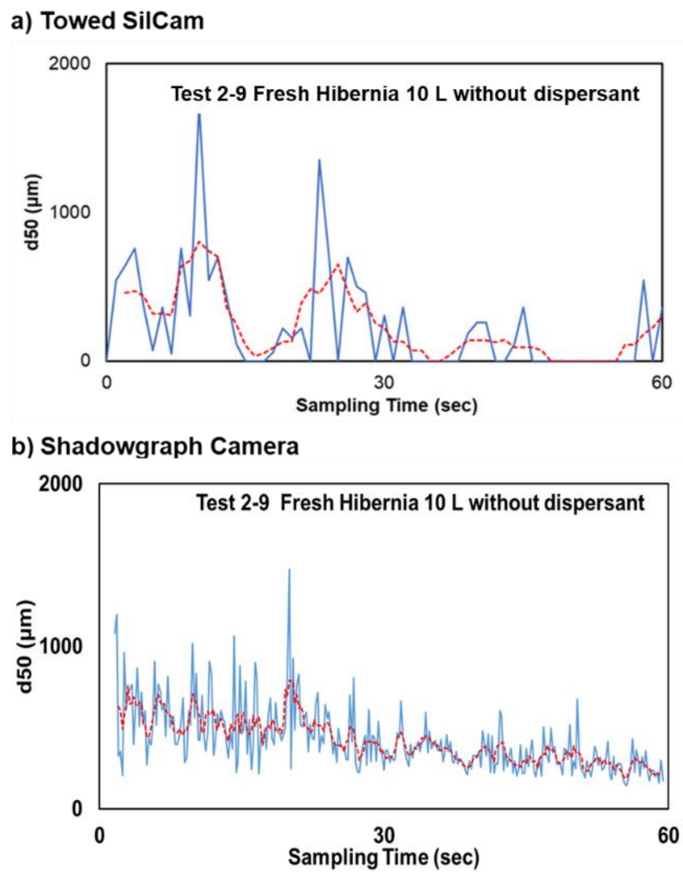
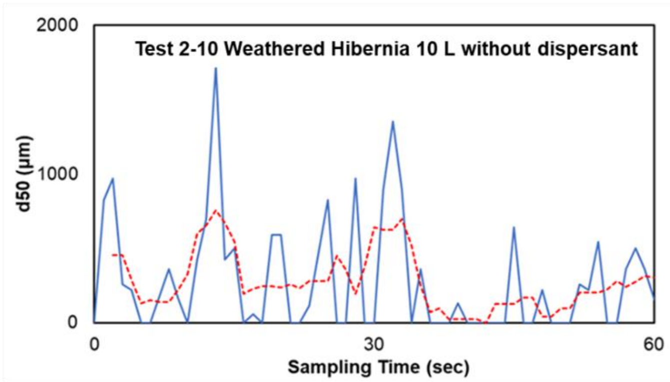


Figure 22 Towed SilCam and ShadowGraph Camera results for Test 2-9.
The volume median diameter, d50 (μm) obtained from: a) the Towed SilCam, and b) the ShadowGraph for Test 2-9. The breaker hit at T=0. The blue line is the instrument output while the red dash line is the moving average.

In Test 2-10 (10 L untreated fresh oil), the Towed SilCam showed d50 values over 1000 μm (Figure 23a). The challenge of the large number of zeros (which are recorded when no drops are passing by the camera) persists in these graphs. The data was more abundant from the ShadowGraph (Figure 23b), and the peak values were comparable to those of the Towed SilCam.

a) Towed SilCam



b) Shadowgraph Camera

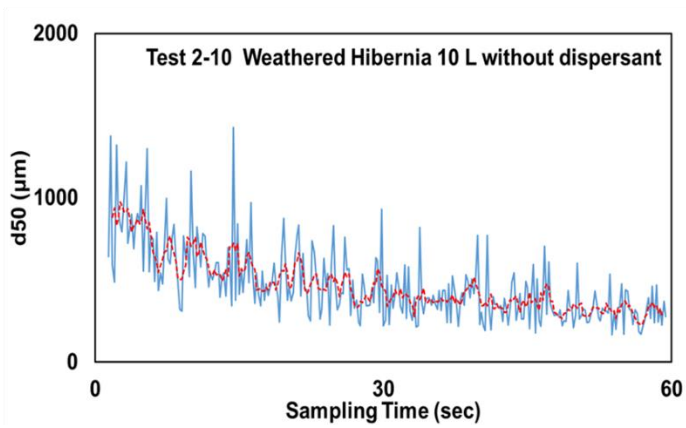


Figure 23 Towed SilCam and ShadowGraph Camera results for Test 2-10.
The volume median diameter, d50 (µm) obtained from: a) the Towed SilCam, and b) the ShadowGraph for Test 2-10. The breaker hit at T=0. The blue line is the instrument output while the red dash line is the moving average.

When less oil was used (Test 2-11, 5 L untreated oil), the d50 obtained from the Towed SilCam (Figure 24a) showed a maximum value of around 500 µm; while that obtained from the ShadowGraph showed maximum values up to 1800 µm. Also, the ShadowGraph showed a gradual decrease after the breaker until around 20 seconds. This further suggests that the low frequency of the Towed SilCam might have underestimated the d50 of the untreated oil when its concentration is low.

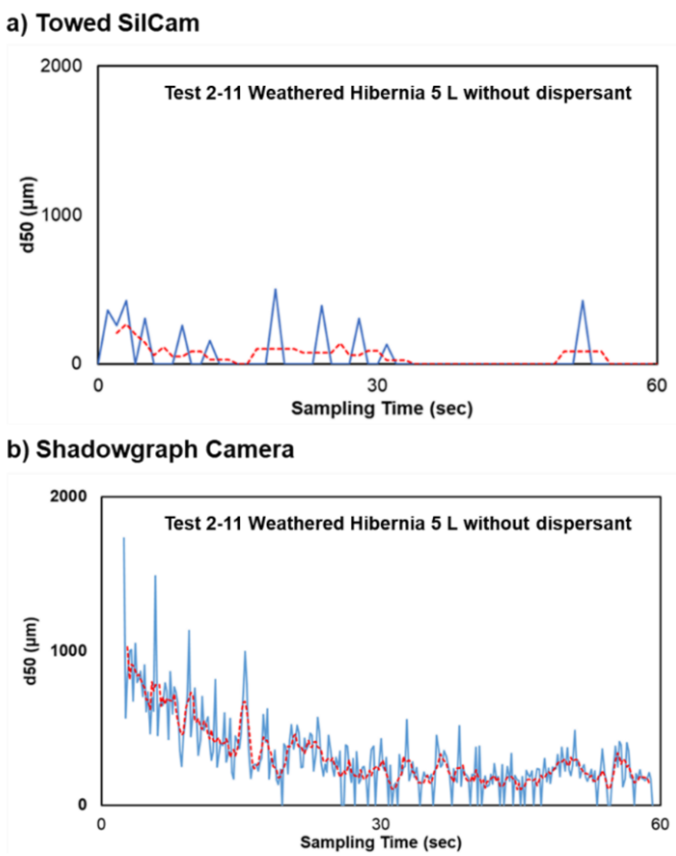


Figure 24 Towed SilCam and ShadowGraph Camera results for Test 2-11.
The volume median diameter, d50 (µm) obtained from: a) the Towed SilCam, and b) the ShadowGraph for Test 2-11. The breaker hit at T=0. The blue line is the instrument output while the red dash line is the moving average.

3.1.3 Fluorometer Results

Three fluorometers (Cyclops, SeaOWL and UviLux) were used for Tests 2-3 to 2-12, which were installed on Level 1 as shown in Figure 13. Figure 25a showed that at a lower position (0.8 m depth), the three fluorometers did not obtain valid data for the untreated fresh oil (Test 2-3) which likely did not reach the instruments. When the dispersant was added in Test 2-6, Figure 25b shows that all the three fluorometers detected the chemically dispersed oil and the curves were comparable, except for the Cyclops, which only detected for around 20 seconds. The fluorescence data obtained by the LISST-Black readings for all the cases were low (same as background data, including with chemically dispersed oil). With results from another Ohmsett test (report in next section), it was found that the gain ratio (ratio between highest and dimmest intensities) in the mounted fluorometer Cyclops could not be changed in the LISST-Black, thus, it was not able to provide reliable values when the concentration was too low or too high (the detailed oil concentration range is discussed in the next section).

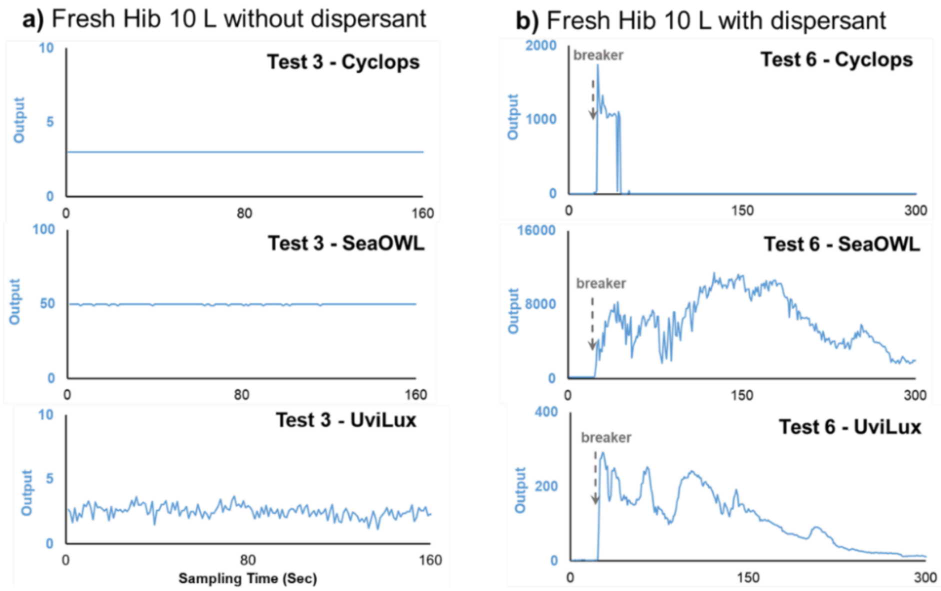


Figure 25 Fluorometers output data for Tests 2-3 and 2-6.
The output from the fluorometers Cyclops, SeaOWL and UviLux for Tests 2-3 and 2-6.

Figure 26 reports the fluorescence findings by the three fluorometers for 20 L fresh (Test 2-4, Figure 26a) or weathered untreated oil (Test 2-5, Figure 26b). Though more oil was released in these cases, the Cyclops and UviLux could not detect the untreated oil, whereas the SeaOWL detected both untreated oils. The signals for the fresh oil were more than two times larger than those of the weathered oil, which is because the fresh Hibernia had higher fraction of aromatics that are lost during evaporation for weathered samples, and SeaOWL is sensitive to these light aromatic fractions. This reflects the high sensitivity of the SeaOWL fluorometer, considering it was 0.8 m deep under the surface.

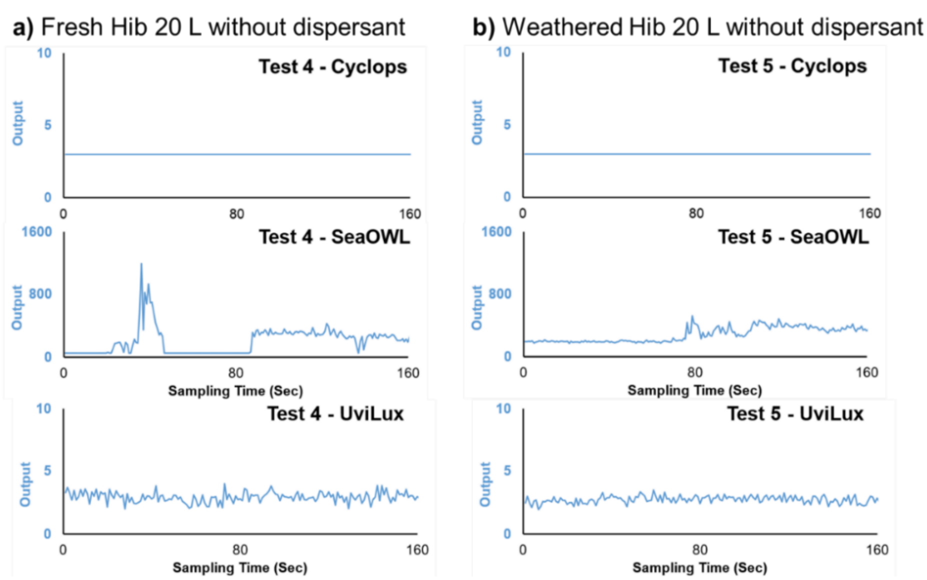


Figure 26 Fluorometers output data for Tests 2-4 and 2-5.
The output from the fluorometers Cyclops, SeaOWL and UviLux for Tests 2-4 and 2-5.

Figure 27 shows cases with chemically dispersed 5 L oil. For the fresh chemically treated oil (Test 2-7, Figure 27a), it was detected by the SeaOWL and UviLux, and the readings were comparable after the breaker occurred. The Cyclops did not detect in this case. For the weathered oil (Test 2-8, Figure 27b), all three fluorometers captured the oil, and the readings by the SeaOWL and UviLux were comparable. The readings by the Cyclops matched the other two fluorometers for a short duration.

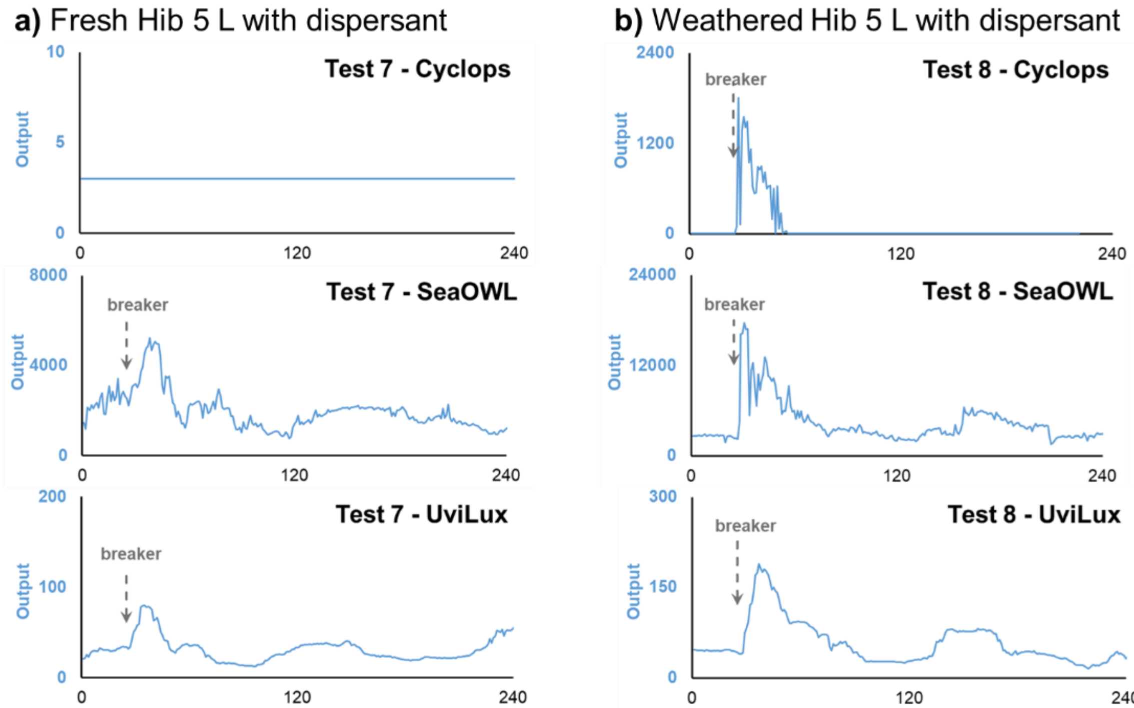


Figure 27 Fluorometers output data for Tests 2-7 and 2-8.
The output from the fluorometers Cyclops, SeaOWL and UviLux for Tests 2-7 and 2-8.

The Cyclops captured the signature of the untreated fresh oil (Test 2-9, Figure 28a) but not the untreated weathered oil (Test 2-10, Figure 28b). The SeaOWL showed a larger increase for fresh oil (Figure 28a) by comparison to weathered oil (Figure 28b). The UviLux detected the untreated oil, but the noise was large due to the contaminated wave tank, so the readings were close to the background values. As there was oil in the wave tank before this test, the background readings of the UviLux readings were relatively high compared to the maximum reading of the untreated weathered oil (maximum intensity was around 8, while the background intensity was around 4).

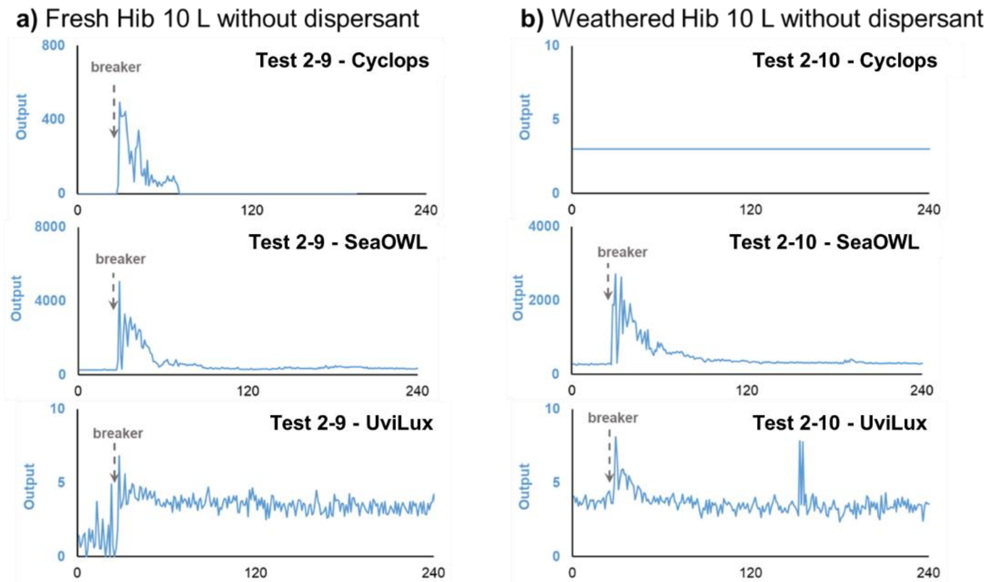


Figure 28 Fluorometers output data for Tests 2-9 and 2-10.
The output from the fluorometers Cyclops, SeaOWL and UviLux for Tests 2-9 and 2-10.

In Tests 2-11 and 2-12, five liters of weathered oil were used without and with dispersant, respectively. The fluorometry results are shown in Figure 29. The Cyclops gave small readings for the untreated oil and a large value for the chemically dispersed oil. SeaOWL showed a significant reading for the untreated oil and a much larger reading for the chemically dispersed oil. The UviLux, again, showed low readings for the untreated oil, less than double the background, but it showed large values for chemically dispersed oil, comparable to the SeaOWL. These results are consistent with the findings of the BSEE project 1154 (https://www.bsee.gov /optimized-underwater-detection-of-dispersed-oils-using-scanning-fluorometry-0).

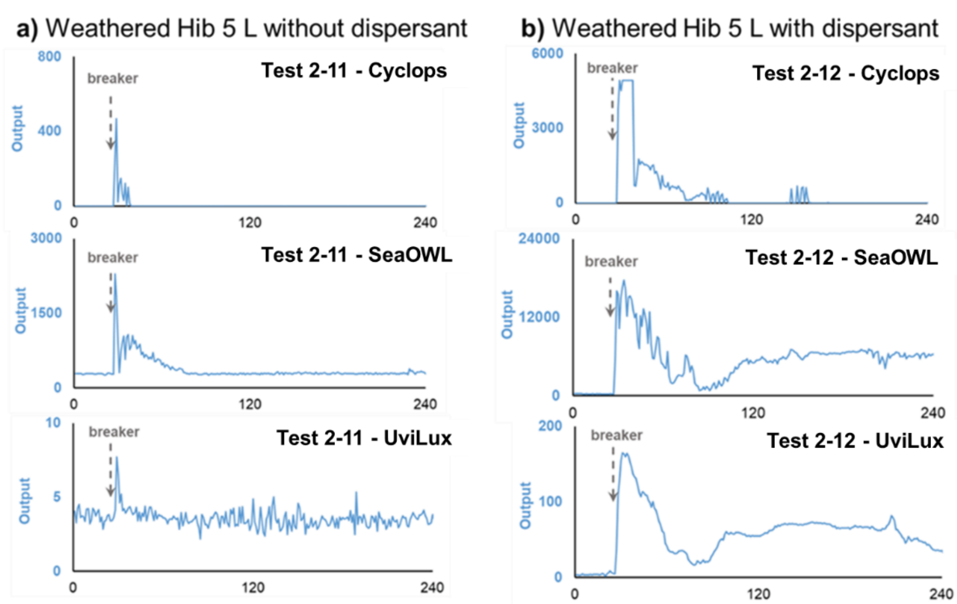


Figure 29 Fluorometers output data for Tests 2-11 and 2-12.
The output from the fluorometers Cyclops, SeaOWL and UviLux for Tests 2-11 and 2-12.

Thus, based on the fluorometer results from Tests 2-3 to Tests 2-12, the SeaOWL was found to be the most sensitive fluorometer, and the Cyclops and UviLux were less sensitive in this test. Considering the Cyclops readings from the LISST-Black and the Towed SilCam were not reasonable (did not change in all cases), this sensor needs to be examined by further lab-scale oil tests.

3.1.4 Towed SilCam Evaluation

The Towed SilCam was evaluated for towing configuration and performance at depth and speed (see Figures 30a and 31a). As expected, when towed at increasing speeds without adjustment of the tow line, the instrument slowly planed towards the surface. The addition of 12 pounds (lbs) of ballast weight to the instrument backplate corrected this (see Figures 30b and 31b). Once weighted, the instrument stabilized at an approximate 1 m depth up to a maximum tow speed of 4 knots towing speed.

Figure 30 Towed SilCam towing tests.
The Towed SilCam towing test a) without and b) with (12 lbs) added weight (as ballast). (Photos: G. Coelho)

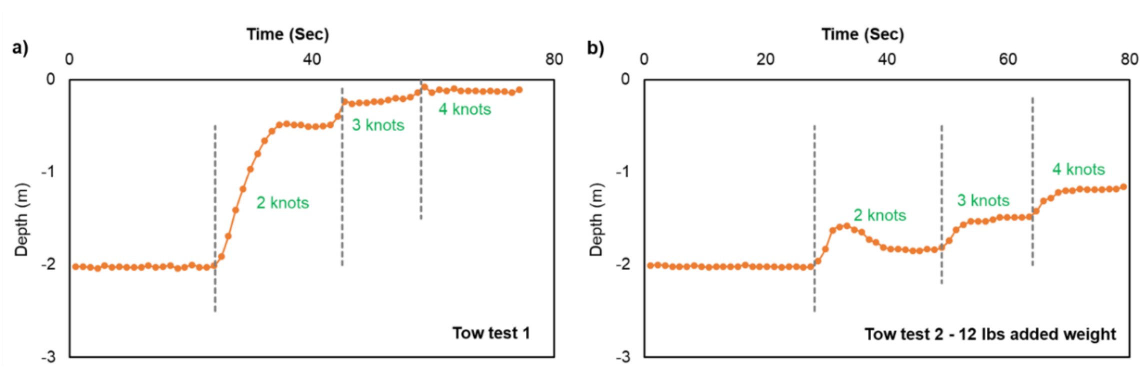


Figure 31 Depths of the Towed SilCam in towing tests.
The depths of the Towed SilCam in the towing test (no oil) at various speeds a) without and b) with the 12 lbs added weight (for ballast).

3.2 Ohmsett November 2023 Test

3.2.1 Methods and Materials

Table 4 shows the experimental matrix for the November 2023 test week at Ohmsett. In Tests 3-1 to 3-6, the ShadowGraph was mounted on the top level (Figure 32), which was 0.3 m deep. The LISST-Black was mounted on the second level (0.55 m deep), with the sampling hose above it, which was connected to a peristaltic pump. The LISST-200x and the fluorometer Cyclops 7F-O were mounted on the third level, which was 0.7 m deep.

Table 4 Experimental matrix for the Ohmsett November tests.

No.	Oil and Dispersant	Instrument
Instruments in Horizontal Direction:		
3-1	Fresh HIB, 10 L, DOR=0	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-2	Weathered HIB, 10 L, DOR=0	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-3	Fresh HIB, 10 L, DOR=1:20	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-4	Weathered HIB, 10 L, DOR=1:20	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-5	Fresh HIB, 10 L, DOR=1:20	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-6	Weathered HIB, 10 L, DOR=1:20	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-T1*	Tank residual oil	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
3-T2	Tank residual oil	[ShadowGraph], [LISST Black, sample hose], [LISST 200, Cyclops]
Instruments in Vertical Direction:		
3-7	Fresh HIB, 10 L, DOR=0	ShadowGraph, LISST Black, sample hose, LISST 200, Cyclops
3-8	Weathered HIB, 10 L, DOR=0	ShadowGraph, LISST Black, sample hose, LISST 200, Cyclops
3-9	Fresh HIB, 10 L, DOR=1:20	ShadowGraph, LISST Black, sample hose, LISST 200, Cyclops

* The T1 and T2 tests were towing tests, where the frame was towed at 2 – 4 knots through the tank.

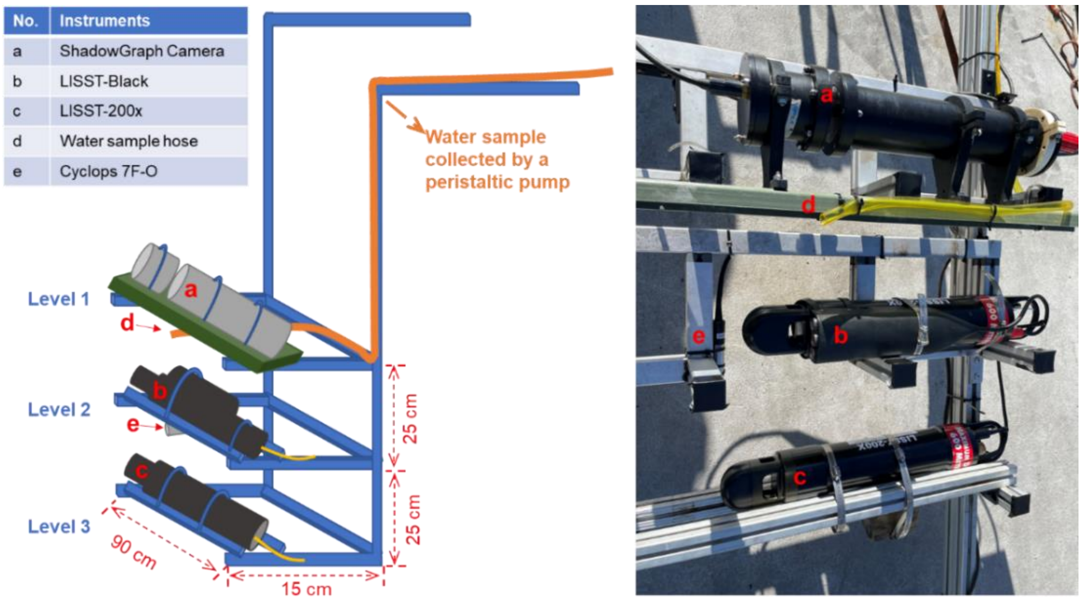


Figure 32 Instrument frame for Tests 3-1 to 3-6.
The instruments mounted on the frame horizontally in Tests 3-1 to 3-6. (Left Image: NJIT. Photo: BSEE)

Note that a more compact frame (compared to the one used in June test) was adopted in this November test to conduct 4-knots towing tests and evaluate a vertical deployment of these instruments. In Tests 3-7 to 3-9, the ShadowGraph, the LISST-Black and LISST-200x were all mounted vertically on the frame, and the fluorometer and sampling hose were mounted close to the detection windows (Figure 33).

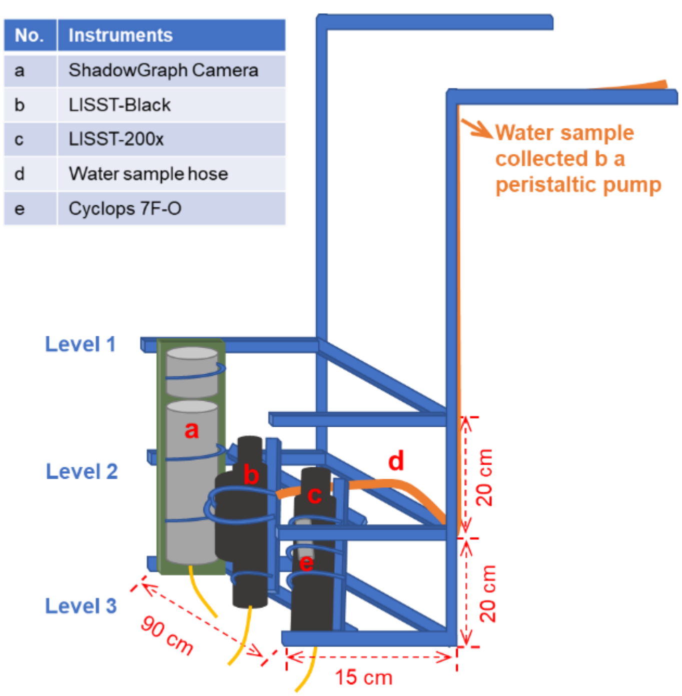


Figure 33 Instrument frame for Tests 3-7 to 3-9..
The instruments mounted on the frame vertically in Tests 3-7, 3-8, and 3-9. (Image: NJIT)

In Tests 3-1 to 3-9, the oil was released upstream of the frame the same way as in the June tests, without and with dispersant (see Table 4), wherein concentration and droplet size data were collected after the untreated or chemically dispersed oil was hit with a breaking wave. In Tests 3-T1 and 3-T2 (Table 4) the instruments were mounted horizontally (similar to Tests 3-1 to 3-6), and the frame was towed at 2 knots to 4 knots through the oils to evaluate the robustness of the instrument array under towed conditions.

3.2.2 Results

The Ohmsett tank tests provided data from multiple instrument tests. The d50 results measured from the ShadowGraph were described as in Table 5. Also listed are the outputs from the LISST-Black and LISST-200x, including the DSD (d50), the volume concentration, and the fluorescence intensity from the LISST-Black integrated Turner Cyclops fluorometer and a standalone Turner Cyclops fluorometer. Note that the fluorometer data were not calibrated, thus only the direct intensity signals (in mV) were provided.

Table 5 D50 obtained from each instrument at Ohmsett.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
d50 (µm) by ShadowGraph	230	230	180	180	110	250
d50 (µm) by LISST-Black	120	130	20	100	10	100
d50 (µm) by LISST-200x	80	100	20	80	10	75
Volume Conc. (µL/L) by LISST-Black	0	0	1200	1000	400	300
Volume Conc. (µL/L) by LISST-200x	0	0	3000	500	500	200
Fluorometer intensity by LISST-Black	10	5	saturated	1600	saturated	saturated
Fluorometer intensity by Standalone	0	10	1000	100	1300	300

The d50 data obtained from the ShadowGraph were in the range from 100 µm to around 250 µm, while those from LISSTs showed a range of 10 µm to 150 µm. This is mainly because the measuring range for these instruments are different, and this is why researchers suggested combining the droplet size distribution data from these instruments for a broader bin sizes range (Daskiran et al. 2022; Liu et al. 2021).

For the concentration data, the volume concentrations from the two LISSTs showed significant fluctuation, which indicated the uncertainty of volume concentration data by the two LISSTs (the optimal transmission rate should be between 30% to 80%). Saturated oil concentration could cause major uncertainty for the laser detection methods. The fluorescence intensity obtained from the integrated fluorometer within the LISST-Black was easily saturated even though the oil concentration was not significant (Tests 5 and 6 in Table 5), while the stand-alone Cyclops sensor provided reasonable readings (correlated to those volume concentrations from LISST readings).

Figure 34 shows the d50 results obtained from the ShadowGraph in Test 3-1 (oil without dispersant). After the waves break the oil into smaller droplets, the minimum d50 was around 230 µm based on the captured droplets in the ShadowGraph view. Figure 35 shows the d50, the volume concentration and the fluorescence response obtained from the LISST-Black and LISST-200x plus the fluorometer Cyclops. Note that the LISST-Black was 0.25 m higher than the LISST-200x and the fluorometer. The d50 results from the LISST-Black gave an average value of 100 µm and those from the LISST-200x showed a value around 75 µm, which is probably because the latter was 0.25 m deeper than the prior. The volume concentration from both instruments was low, as the fresh oil was untreated. The integrated fluorometer within the LISST-Black (also Cyclops 7F-O) and the stand-alone Cyclops both gave low response signals, as the dispersed concentration was low.

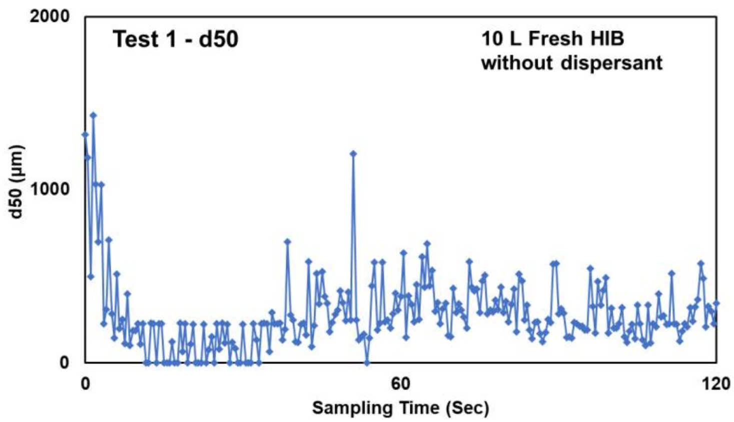


Figure 34 D50 obtained from ShadowGraph Camera in Test 3-1.
The d50 results obtained from ShadowGraph camera in Test 3-1.

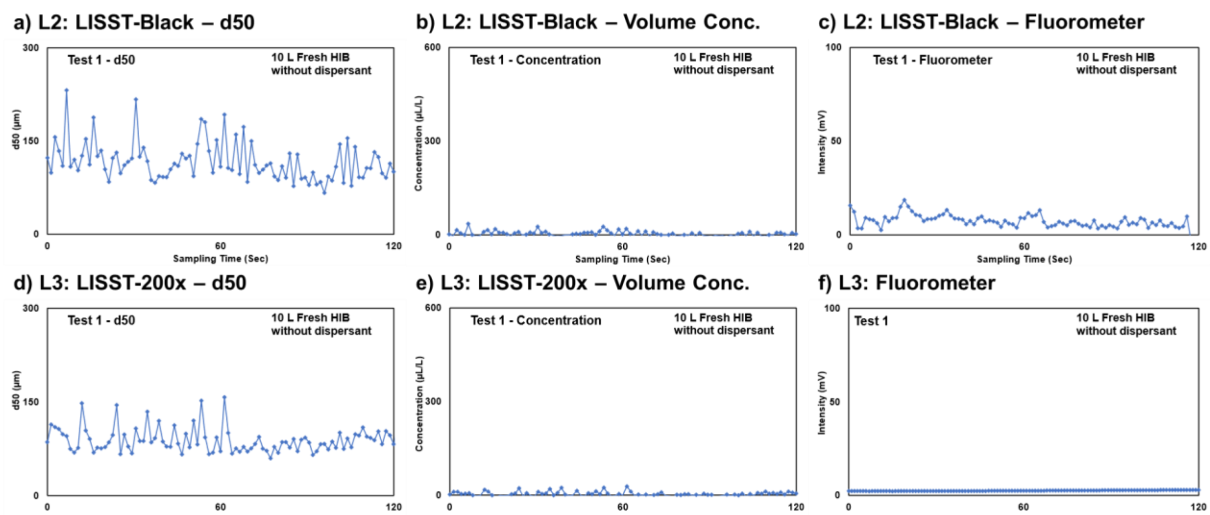


Figure 35 D50, concentration and fluorescence obtained from LISSTs in Test 3-1.
The d50 results (a and d), volume concentration (b and e) and fluorometer readings (c) obtained from the LISST-Black and LISST-200x, respectively, in Test 3-1. The fluorometer Cyclops 7F-O obtained fluorescence signals individually (f).

Figure 36 shows the d50 results obtained from the ShadowGraph in Test 3-2. The waves broke the untreated weathered oil in smaller droplets (same as Test 3-1), and the minimum d50 was around 230 µm, similar to Test 3-1. Figure 37 shows that the d50 results from LISST-Black were on the average equal to 100 µm and those from LISST-200x were around 75 µm. The volume concentration and the fluorescence signals from both instruments were low.

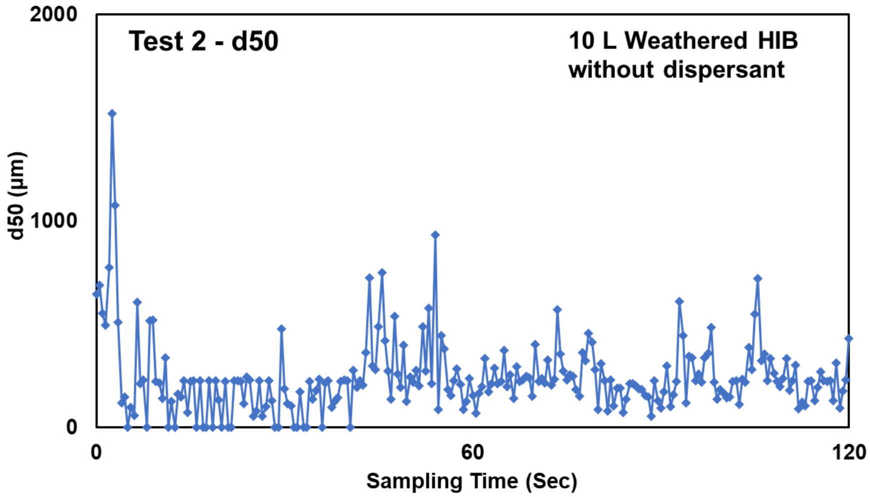


Figure 36 D50 obtained from ShadowGraph Camera in Test 3-2.
The d50 results obtained from ShadowGraph camera in Test 3-2.

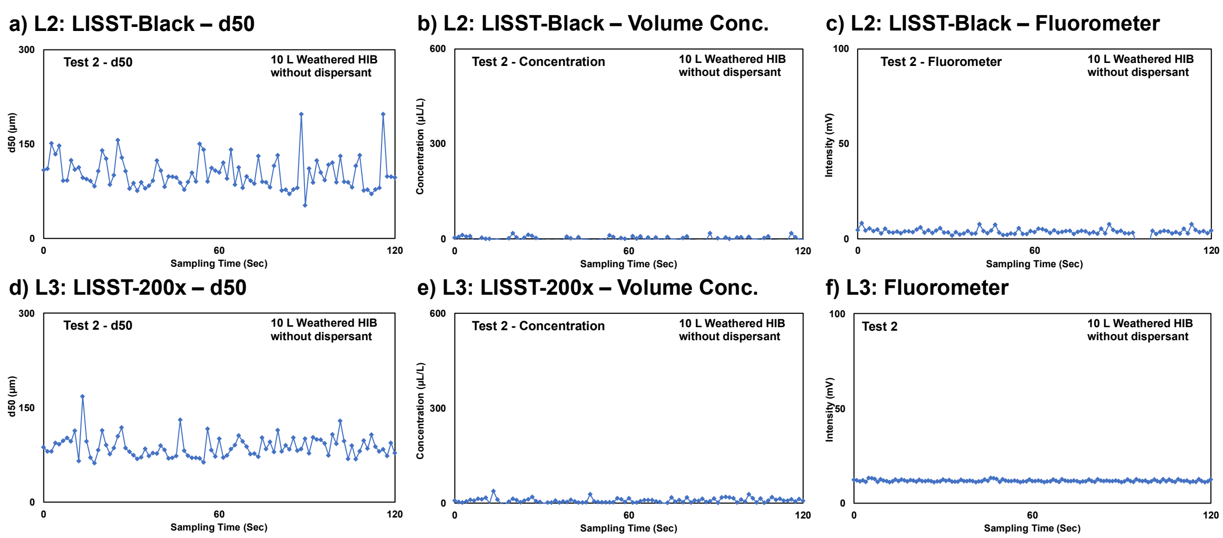


Figure 37 D50, concentration and fluorescence obtained from LISSTs in Test 3-2.
The d50 results (a and d), volume concentration (b and e) and fluorometer readings (c) obtained from the LISST-Black and LISST-200x, respectively, in Test 3-2. The fluorometer Cyclops 7F-O obtained fluorescence signals individually (f).

Figure 38 shows the d50 results obtained from the ShadowGraph in Tests 3-3 to 3-6, where Tests 3-3 and 3-5 were duplicates for chemically dispersed fresh oil, while Tests 3-4 and 3-6 were duplicates for chemically dispersed weathered oil. For the fresh oil, the average d50 was around 110 – 180 µm based on the ShadowGraph results, and the images were saturated within a short time (Figure 38a and 38c). For the weathered oil, the sizes were larger at around 180 to 250 µm (Figure 38b and 38d).

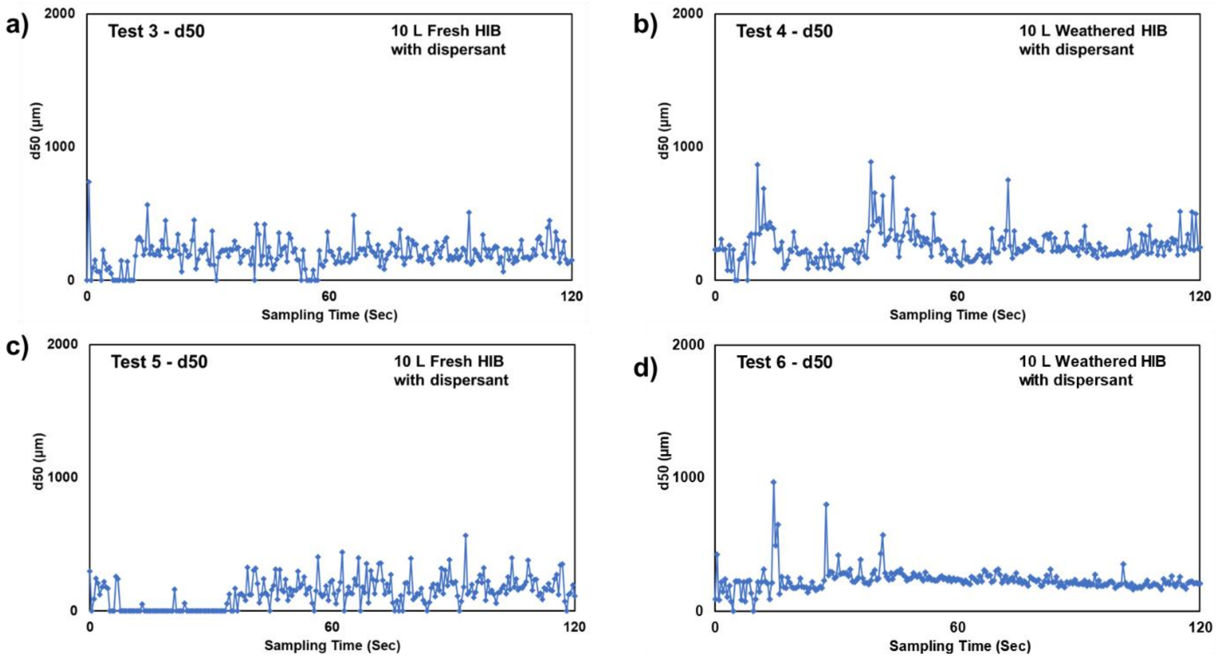


Figure 38 D50 obtained from ShadowGraph Camera in Tests 3-3 to 3-6.
The d50 results obtained from ShadowGraph camera in a) Test 3-3, b) Test 3-4, c) Test 3-5 and d) Test 3-6.

Figure 39 shows the LISST-Black, LISST-200x and the fluorometer results in Test 3-6, which was a representative case for Tests 3 to 6 (all chemically dispersed). The results for Tests 3 to 5 were given in Appendix C, Figure C1 to C3. Figure 39a and 39d show that the d50 from both LISSTs were around 70 µm as the oil was well dispersed by the dispersant. Note that the wave tank was significantly contaminated by previous tests, which led to noise in all the tests – this should be the reason the d50 was still high. Nonetheless, the volume concentration shows a clear hit of the oil plume as it reached 400 µL/L (Figure 39b and 39e) after the breaker, and after 50 seconds it decreased to around 50 µL/L as the background. An interesting finding is that the fluorometer mounted on the LISST-Black (Figure 39c) was saturated mostly, while the individual one obtained reasonable readings (Figure 39f). A possible reason is that the fluorometer Cyclops 7F-O was able to output intensity at three different resolutions (×1, ×10, and ×100). When operating the stand-alone fluorometer, the software allows the manual selection of the resolution (gain ratio), and the gain setting for the output readings were suggested to be 300 to 3000. However, the resolution for the integrated fluorometer within the LISST-Black could not be adjusted based on oil concentration, so it is easily biased (saturated) when the oil concentration is close to its upper limit at around 2000 µL/L (Figure 39c). Nonetheless, these higher concentrations are not typical for spilled oil conditions (Boehm et al. 2016; Lee and Page 1997; Neff and Stubblefield 1995; Sammarco et al. 2013; Wolfe et al. 1994).

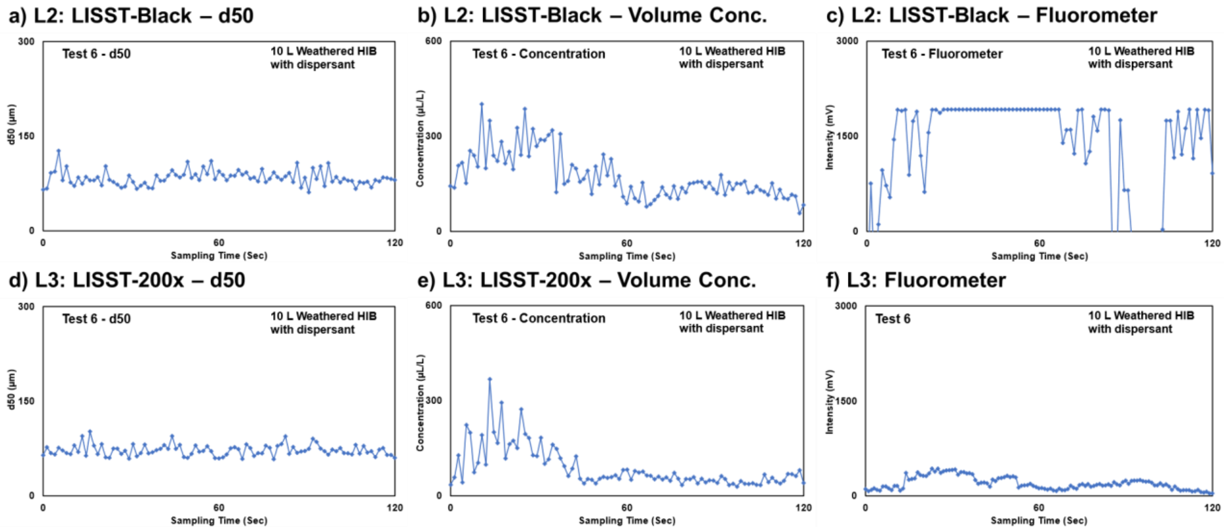


Figure 39 D50, concentration and fluorescence obtained from LISSTs in Test 3-6.
The d50 results (a and d), volume concentration (b and e) and fluorometer readings (c) obtained from the LISST-Black and LISST-200x, respectively, in Test 3-6. The fluorometer Cyclops 7F-O obtained fluorescence signals individually (f).

The instruments were mounted vertically on the frame in Tests 3-7 to 3-9 (Table 4). However, it was found that in the vertical position, the windows of the three instruments were easily contaminated by either trapped air bubbles or were irreversibly coated and fouled with oil, rendering any data as flawed and unusable. Data from these tests are not reported since this vertical configuration of the instruments caused obvious fouling.

At the end of the test period, the team conducted a few towed tests (3-T1 and 3-T2, instruments were horizontally mounted) to assess the ruggedness of the instruments (i.e., would the cables remain connected, would there be vibration issues with the sensors). These tests were needed to ensure that the instruments could tolerate the next phase of towed testing. No obvious problems were observed with the instrument performance, all continued to provide a steady data flow.

3.3 Ohmsett May 2024 Test

Based on lessons learned from previous tests, a new stainless-steel frame (Figure 40) was manufactured by Moorings Systems, Inc. and was operationally tested at the Ohmsett wave tank on May 29, 2024. The frame was designed to have considerable flexibility in ballast positions and in lifting point positions.

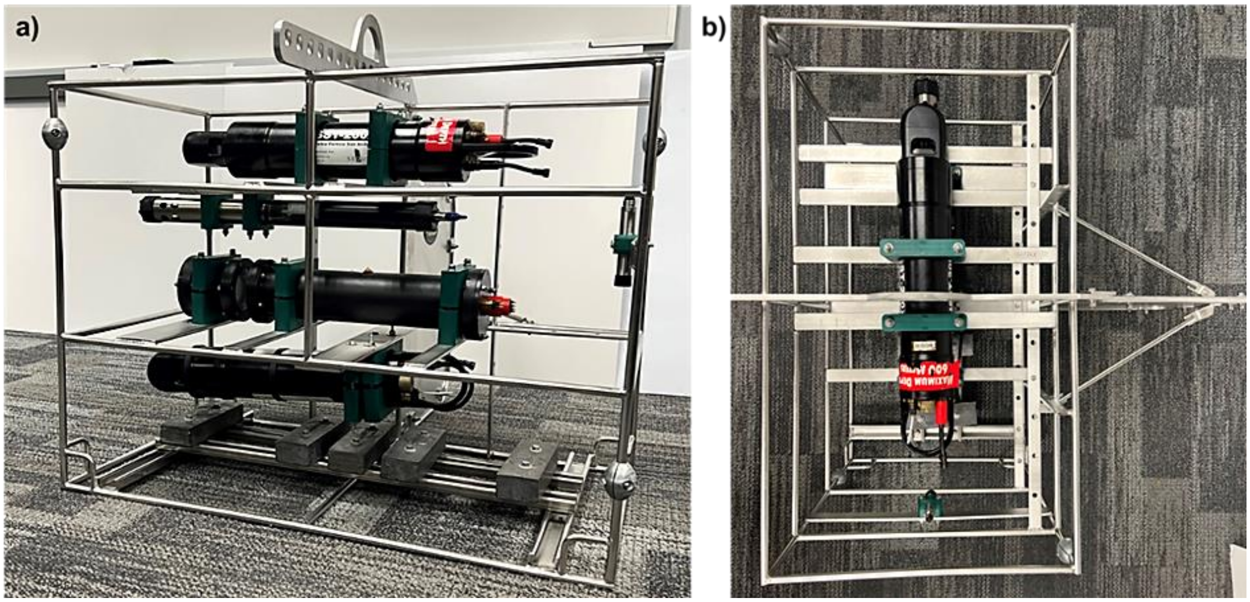


Figure 40 a) Instrumented frame, b) top view instrument frame.
a) Side view, b) Top view (Photos; NJIT).

This effort assessed the characteristics and behavior of the newly constructed frame with a full instrumentation package attached. No oil or dispersant were used for this test event. The functional test assessed the center of gravity and center of buoyance of the fully instrumented frame with the intent of making lead ballast adjustments, and lift-point adjustments for upcast/downcast in a stationary position in calm water, waves, and harbor chop conditions. In addition, the test assessed the behavior of the fully instrumented frame when towed at speeds varying from 0.5 to ~3 kts in calm water and harbor chop conditions (Figure 41).

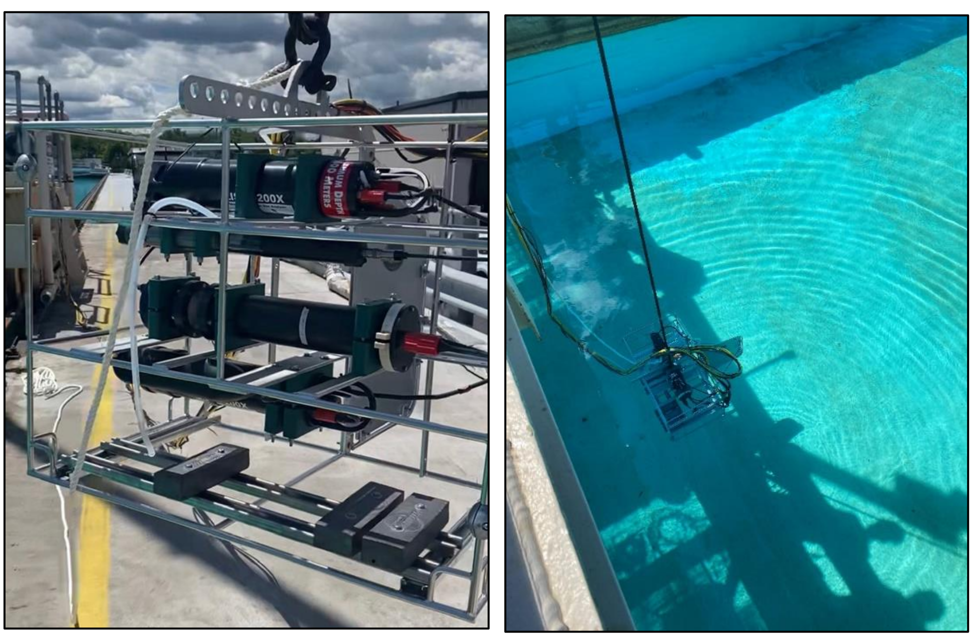


Figure 41 Instrumented frame at Ohmsett.
a) Instrumented frame on deck, b) Instrumented frame in wave tank (Photos; A. Slaughter).

The researchers successfully accomplished the operational test parameters of the instrumented frame in preparation for the next phase – deployment at sea.

4 Field Shakedown Test

The shakedown tests were conducted at Raritan Bay, New Jersey, on June 25, 2024. The basic surface monitoring instrument kit information is available on the previous Task 1 report. The deployment was conducted from a marine vessel, the *MSRC (Marine Spill Response Corporation) Titan*, a 47' Rozema oil spill response vessel (Figure 42).

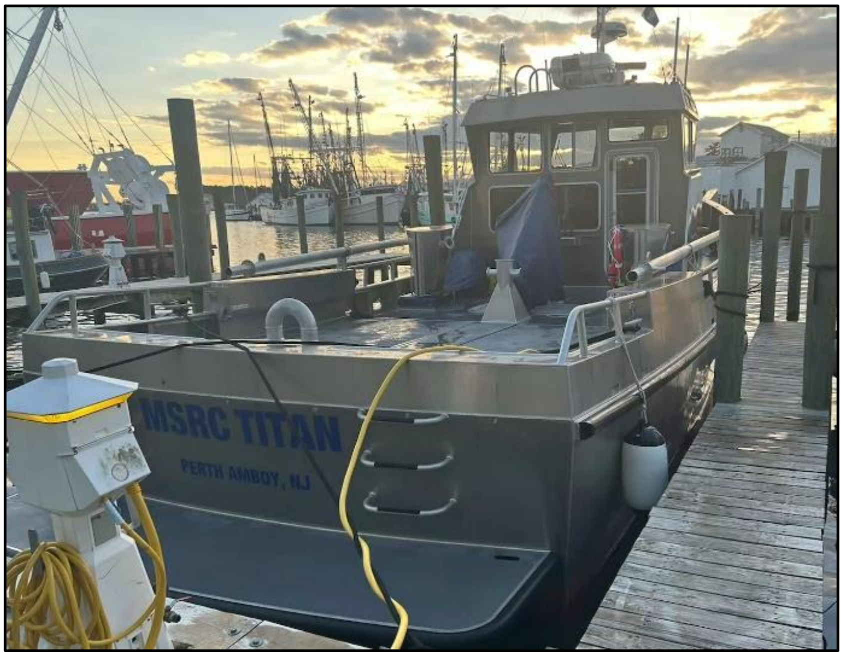


Figure 42 MSRC Oil Spill Response Vessel.
The MSRC Titan, a 47' Rozema oil spill response vessel (OSRV) designed for booming operations. It is equipped with a life raft certified for 8-people, which will accommodate the two MSRC crew plus BSEE's 6-member research team. (Photo: G. Coelho)

4.1 Experiment Preparation

The Operational Test Plan for the field deployment of the surface water monitoring kit is described in in Table 6.

While underway to the test stations, the instruments were installed on the frame by two people within 90 minutes. Following the installation, cables were connected between each instrument and the laptops, and data transfer tests were conducted.

Table 6 Field Operational Test Plan.

Event #	Description`	Objectives	Notes
Pre **(0730-0830)**	Preparation and Load Safety Briefing Test Event Briefing	a) Load equipment on vessel. b) Safety briefing. c) Review test event schedule. d) Get underway. e) Begin configuring for first event.	Take screenshot of trip log on the vessel Nav screen for the data file.
1 **(0830-0930)**	Frame deployment without DSD instruments (load only GoPro camera and AquaTroll) -Stationary vessel -Down- and Up-cast from 1 to 5 m	a) Practice lift and deployment procedure with crane. b) Identify cable routing from frame to laptops. c) Confirm routing & tie-off for back-up safety line including line tending during down-/up- cast. d) Observe GoPro imagery for visibility. e) Confirm AquaTroll readouts.	Grab screen shot from Nav screen when team reaches operating area. Note the sea state and winds.
2 **(0930-1200)**	**Frame Deployment Configuration 1** with fully instrumented frame. (See Option 1 [Figure 4]) -Stationary vessel -Static deployment from <u>1 to 5 m</u>	a) Rotate personnel through equipment management. b) Review data.	
3 **(1200-1230)**	**Air tow** the fully instrumented frame.	a) Determine if this package can be towed out of the water (0.5 m above surface) to expedite deployment along transect. b) Identify max speed for air tow in this sea state. c) Monitor handling lines to stabilize frame during air tow.	This is sea state dependent. Record sea state and capture information for these conditions. Capture photos.
4 **(1230-1400)**	**Frame Deployment Configuration 2** with fully instrumented frame. (See Option 2 [Figure 4]) -Vessel conducts a straight line transect -Static deployment from <u>1 to 4 m</u> depth.	a) Conduct a straight line 400 m transect and time the transect run for down/up cast at four stations along transect. Start clock then proceed to Station 1. Air tow or stow on deck between stations: *Station 1: at ~100 m along transect;* *Station 2: at ~200 m along transect;* *Station 3: at ~300 m along transect;* *Station 4: at ~400 m along transect.* b) Review data.	Capture Lat/Lon at all four stations. Collect instrument data at 1 m and 4 m. Collect water sample at 1 m and 4 m at each transect (for a total of 8 simulated samples – water is not going to be analyzed, so empty bottles as needed).

5 **(1400-1445)**	**Frame Deployment Configuration 3** with fully instrumented frame. Towed deployment at 3 m (only) tied off to side rail.	a) Identify method for transferring frame system from crane hook to rail. b) Document this process (notes, video, photos). c) Attempt a slow tow at 0.5; 1.0 and 1.5 kts. d) Review video to determine behavior of frame near to hull.	The MSRC Titan crane is not dynamic load rated to perform tows from the crane. There will be an attempt to do a slow 1 knot tow while tied off to rail.
Post **(1445-1530)**	Return to Base	a) Hot wash discussion with test team and MSRC personnel. b) Breakdown and pack equipment. c) Unload equipment.	Capture lessons learned.

4.2 Test 1, Stationary test in different depths

The test team departed from the Carteret Marina, NJ (40°34'11.3"N, 74°12'50.4"W) and arrived Raritan Bay, NJ/NY (40°29'30.5"N, 74°15'20.2"W) for the first instrument deployment test (Events 1 and 2, Table 6).

4.2.1 Set-up

The surface monitoring instrument kit was deployed by the crane on the OSRV (Figure 43). Note, due to the limited capacity of the crane, towing the instrument kit in the water (Option 3, Figure 4; Test Event 5, Table 6) was not achievable, and thus only stationary tests (Options 1 and 2, Figure 4; Test Events 1 and 2, Table 6) were conducted. Section 4.2 describes the air tow testing (Test Events 3 and 4, Table 6).

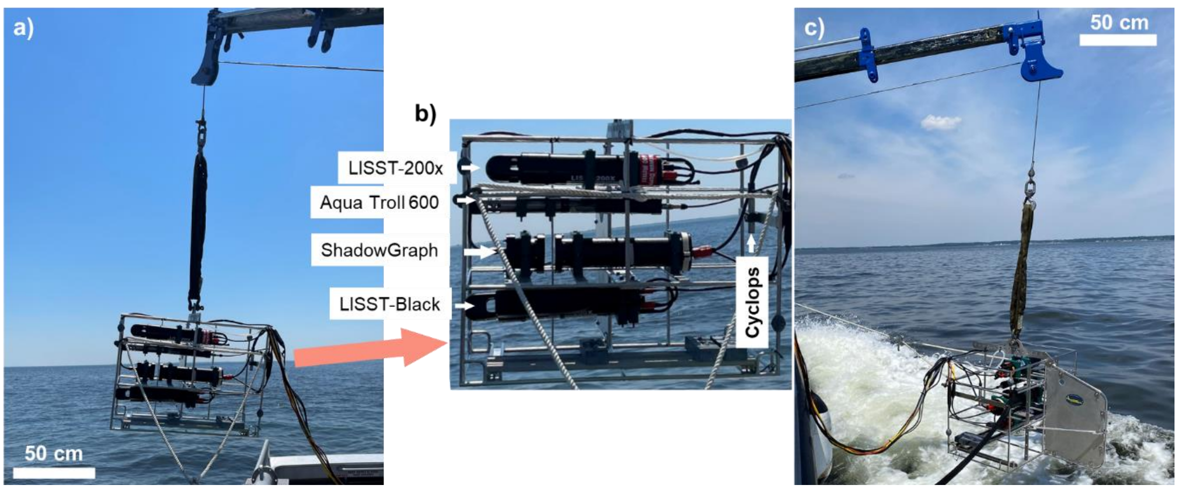


Figure 43 Surface monitoring kit field deployment.
The surface monitoring kit was deployed by a crane on the vessel (a), where the LISST-200x, Aqua Troll 600, ShadowGraph, LISST-Black and Cyclops fluorometer were installed as shown in (b), and the instrument kit was air-towed in option 2 as shown in (c). (Photos: BSEE).

In the first stationary test, the instrument kit was initially deployed to a depth of 1 m (based on the measurement by the Aqua Troll 600), and then to 3 m and 4 m in the first station. The kit was not able to reach 5 m due to the limited cable length of the Turner Cyclops fluorometer. Next, the vessel moved to a second station and the instrument kit was deployed to depths of 1 m and 3 m. Data collected from different instruments are provided in the following sections; however, note the following four considerations. 1) As there was no oil expected in the tested water, the fluorescence signals were not available in the LISST-Black or Cyclops fluorometer. 2) The ShadowGraph camera was programmed to detect spherical droplets; therefore, it did not output valid data even with visible particles in the view (mostly elongated shapes). 3) The data were not collected for scientific purposes or quantitative comparisons, but only to test the operational functionality of the instruments as part of the entire surface water monitoring system.

4.2.2 Data Evaluation

Figure 44 shows the droplet size distribution (d50 averaged per 10 seconds, volume median diameter) collected by the LISST-200x, LISST-Black, and ShadowGraph camera for the first station at different depths. The LISST-200x data (Figure 44a) at 1 m depth showed d50 around 100 µm, larger average sizes than those in 3 m and 4 m depths (smaller than 50 µm), which could be due to the suspended biomass near the surface or floating materials as this is a river estuary. The LISST-Black data showed small values lower than 50 µm for all depths (Figure 44b). The d50 collected from ShadowGraph camera (Figure 44c) were around 200 – 500 µm as its measuring range (100 µm to over 2000 µm) is larger than the LISSTs (1 – 500 µm).

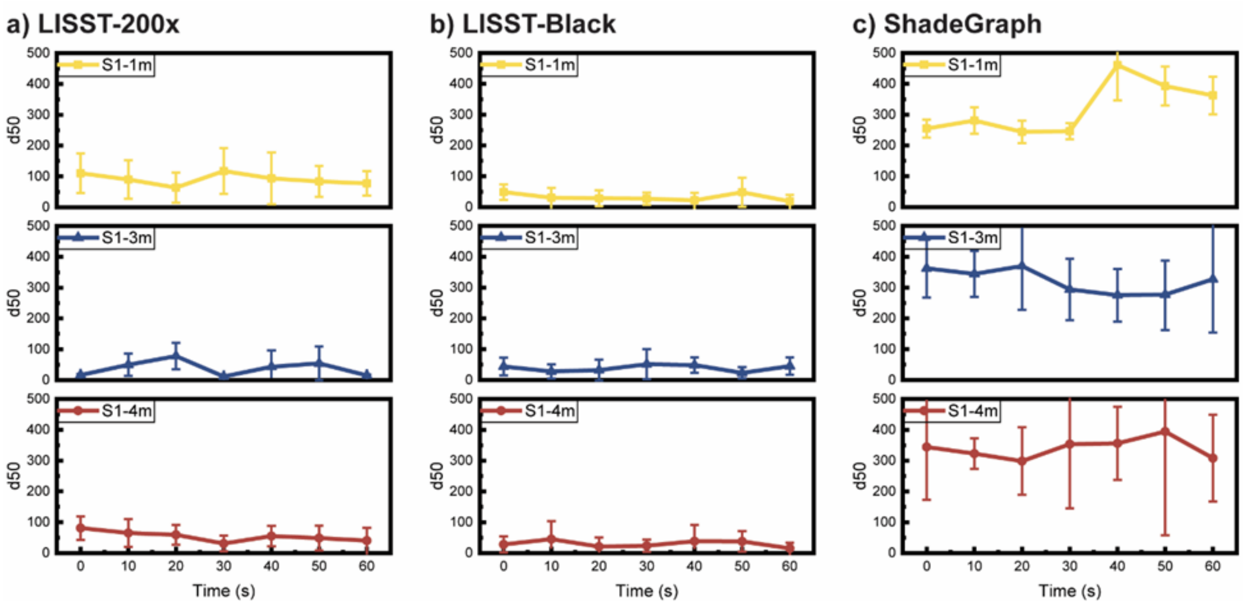


Figure 44 D50 data for Stationary Test 1.
Droplet size distribution data collected by a) LISST-200x, b) LISST-Black, and c) ShadowGraph camera (averaged per 10 seconds) in Stationary Test 1 at depths of 1 m, 3 m, and 4 m.

Figure 45 shows the water chemistry data obtained by the Aqua Troll 600. Seven typical parameters were selected and reported for the two depths, and, as the data were not collected for quantitative purposes, these values were normalized to the 1 m depth data.

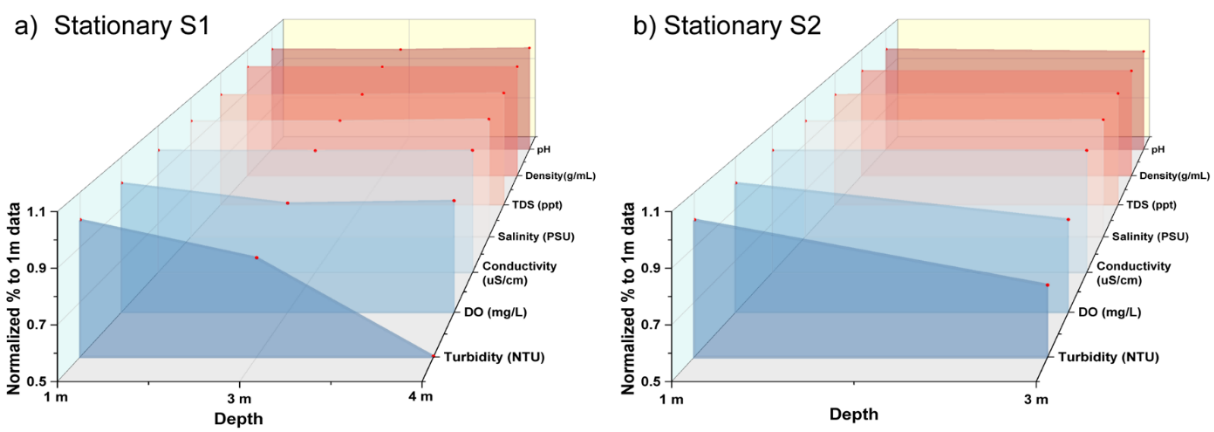


Figure 45 Aqua Troll data for stationary tests.
Water chemistry data collected by Aqua Troll 600 in a) stationary test 1 at 3 depths of 1 m, 3 m, and 4 m; and b) stationary test 2 at depths of 1 m and 3 m.

Both Figure 45a and b show that the turbidity and dissolved oxygen (DO) changed significantly for different depths, where in the first station, the water turbidity at 4 m depth was only 50% of that in 1 m depth, and in the second station, the turbidity at 3 m depth was also lower than 75% of that in 1 m depth. This matches the data from the LISST-200x and confirms the data consistency. The DO was 10 – 20% lower in deep water than that in 1 m shallow water, which matches the reported data by other researchers in estuary water (Scully 2016; Yin et al. 2004). The parameters of conductivity, salinity, total dissolved solids (TDS), density, pH, etc., were also reported in Figure 45, which did not show differences in different depths. This outcome was expected, and these data should be homogenous in the same station within different depths.

Figure 46 shows the images output from ShadowGraph camera at the two stations. There were fiber-shaped materials in the ShadowGraph view, which were more abundant in the 1 m depth in both stations. However, as the shapes were not spherical, the system excluded them in droplet size distribution analysis, and thus no direct data were output. This reflects a challenge to the droplet size measurement in any field monitoring – many suspended solids could be in the range of 1 – 500 μm and be scanned by the LISSTs. Though the LISST can differentiate the shape of detected items, unexpected readings are not excluded in the analysis. When the oil spills in unclear waters, the surface monitoring could be challenging with LISSTs or similar instruments.

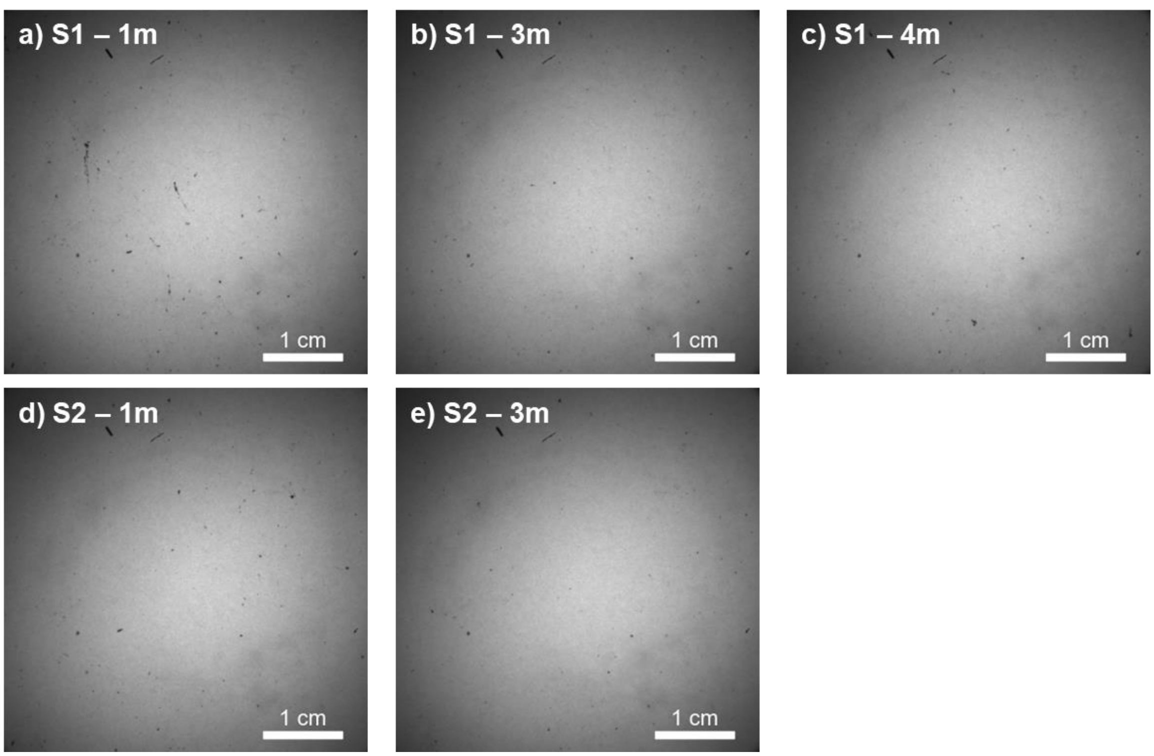


Figure 46 ShadowGraph camera images in stationary tests.
The first row (a, b and c) represents results from stationary test 1 at three depths, and the second row (d and e) represents results from stationary test 2 at 1 m and 3 m depths, respectively.

Figure 47 shows the droplet size distribution (d50) collected by the LISST-Black for the two stations and different depths. In these two stations, the data collected by the LISST-Black at all depths showed similar distribution curves within the 60 seconds. The maximum droplet sizes were found at around 200 µm at all depths. This is an estuary area where suspended solids could be relatively abundant (if compared to marine surface water). Nevertheless, the data were only collected to show the instrument kit capacity, and not for water quality justification.

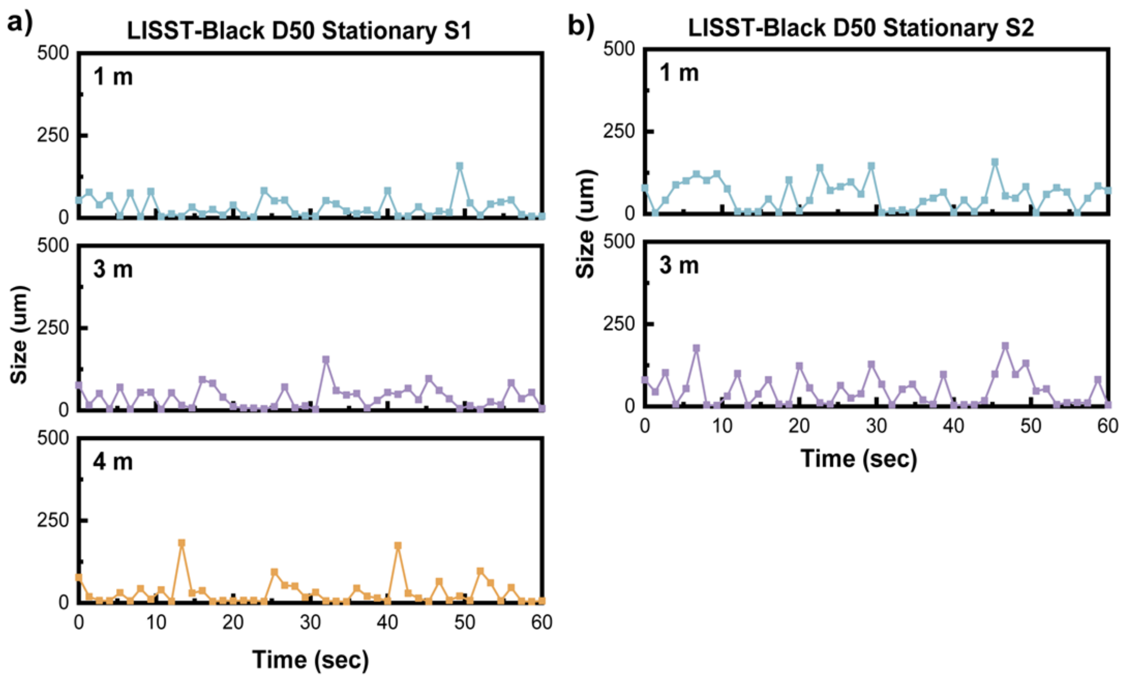


Figure 47 LISST-Black data for stationary tests.
Droplet size distribution data collected by the LISST-Black in a) stationary test 1 at 3 depths of 1 m, 3 m, and 4 m; and b) stationary test 2 at depths of 1 m and 3 m.

4.3 Test 2, Transition test by air-towing instrument kit

4.3.1 Set-up

After the stationary tests, the instrument kit was air towed following the Test Plan Event 3 (Table 6). The frame was hung above the water (see Figure 43c) and tied by an extra rope to ensure its stability when the vessel was moving quickly during transitions.

Test Plan Event 4 (Table 6) was then conducted by moving along a straight line 400 m transect and timing the transect run for down/up cast at four stations along the transect. There was approximately 100 m between stations, and the instrument kit was air towed between stations.

4.3.2 Data Evaluation

Figure 48 shows the data collected by the LISST-200x in the four stations, at both 1 m and 4 m depths. Note that the minimum data collecting was 56 seconds at the 1 m depth, while 33 seconds at the 4 m depth. Figure 48a shows that there were large particles at around 250 µm in the first two locations, and barely any particles in the third and fourth locations at the 1 m depth. When the frame was downcast to 4 m depth, only the first station had some particles around 50 µm.

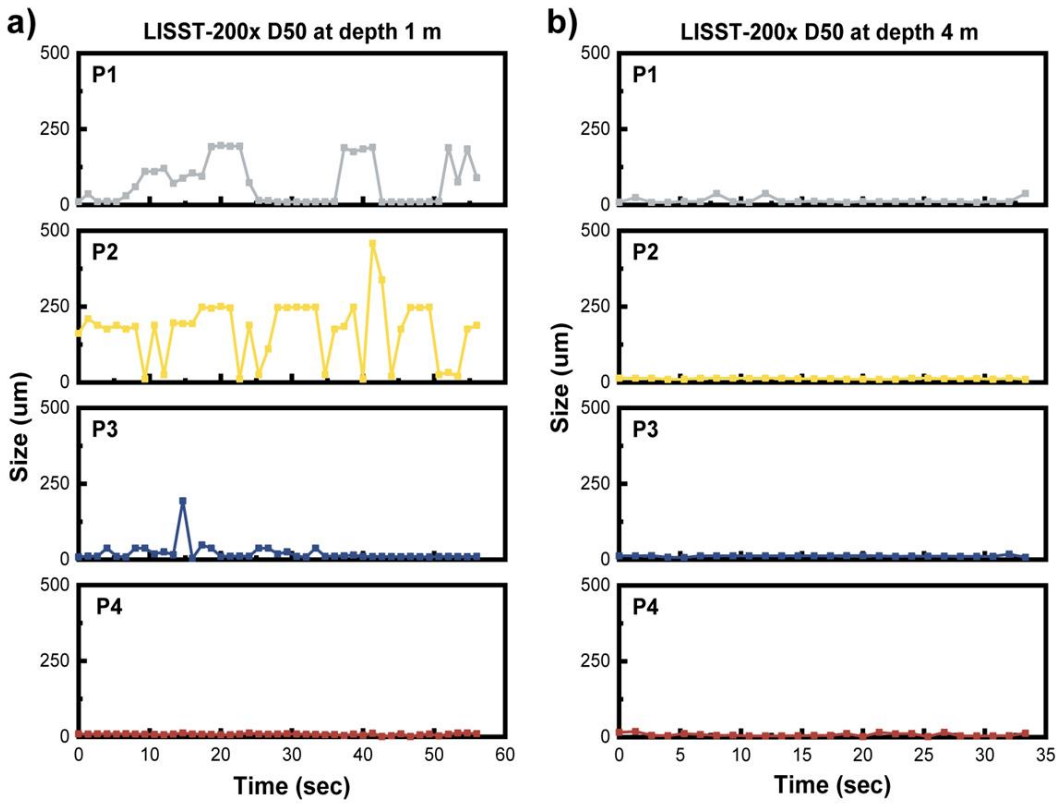


Figure 48 LISST-200x data for transition tests.
Droplet size distribution data collected by the LISST-200x in transition tests from position 1 to 4 at the depth of a) 1 m, and b) 4 m.

The water chemistry data for the four stations are shown in Figure 49. Among the seven measured parameters, turbidity and dissolved oxygen (DO) had the most fluctuated data for the four stations. Turbidity peaked at Station 2 at 1 m depth and increased by approximately 50% at 4 m depth from Station 1 to Station 4. The DO data had a ~20% variance among the four stations at both 1 m and 4 m depths. The difference might be due to the fact that there was a border of estuary water and marine seawater between P2 and P3, so the water data at P1 and P2 (estuary water) should be expectedly different with those at P3 and P4 (marine water).

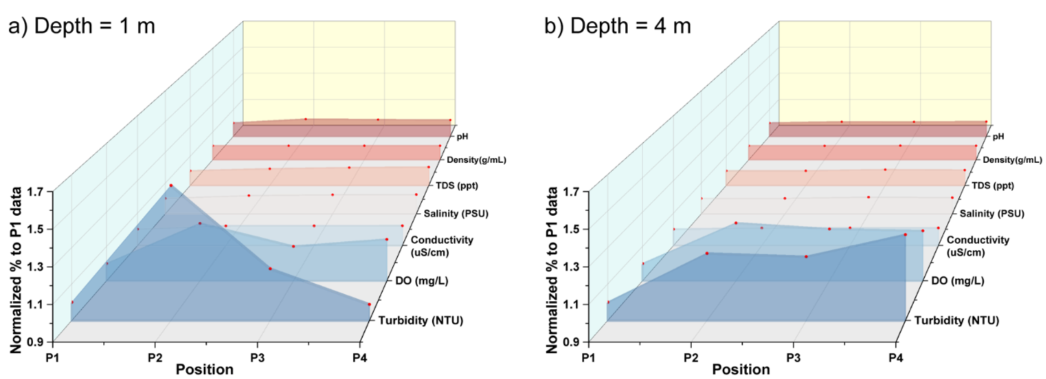


Figure 49 Aqua Troll data for transition tests.
Water chemistry data collected by Aqua Troll in the transition tests for four stations at a depth of a) 1 m, and b) 4 m.

Figure 50 shows the images output from ShadowGraph camera at 1 m and 4 m depths for the four stations. The images displayed some small, irregular particles, with a slightly higher abundance at 1 m depth across all positions. And also due to the shape of the particles, the camera did not provide valid d50 data.

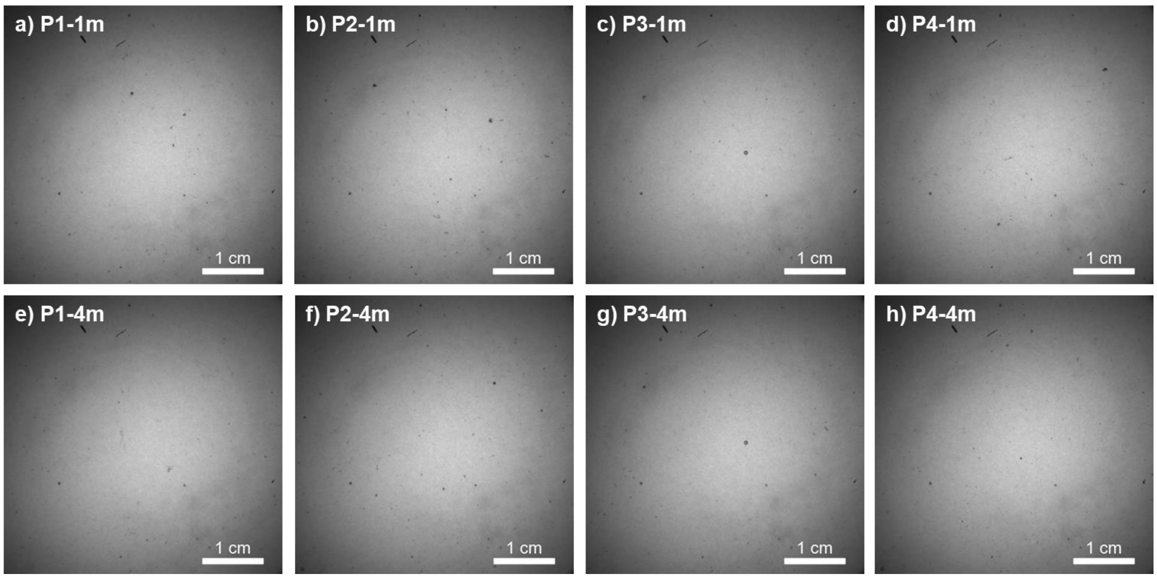


Figure 50 ShadowGraph images in the transition tests.
The first row (a, b, c and d) represents results for P1 to P4 stations, respectively, at 1 m depth, and the second row (e, f, g and h) represents results for P1 to P4 stations, respectively, at 4 m depth.

Figure 51 shows the data collected by the LISST-Black in the four stations, at both 1 m and 4 m depths. Figure 51a shows that there were large particles at around 250 µm in the first two stations, and few particles in the third and fourth stations at the 1 m depth. When the frame was downcast to 4 m depth, there were particles only at the first station around 50 µm. When comparing the data from the LISST-200x (Figure 48), the LISST-Black showed a similar response at corresponding depths, even though the depth measurements were based on Aqua Troll data, and the LISST-Black was positioned about 0.5 meters lower than the Aqua Troll.

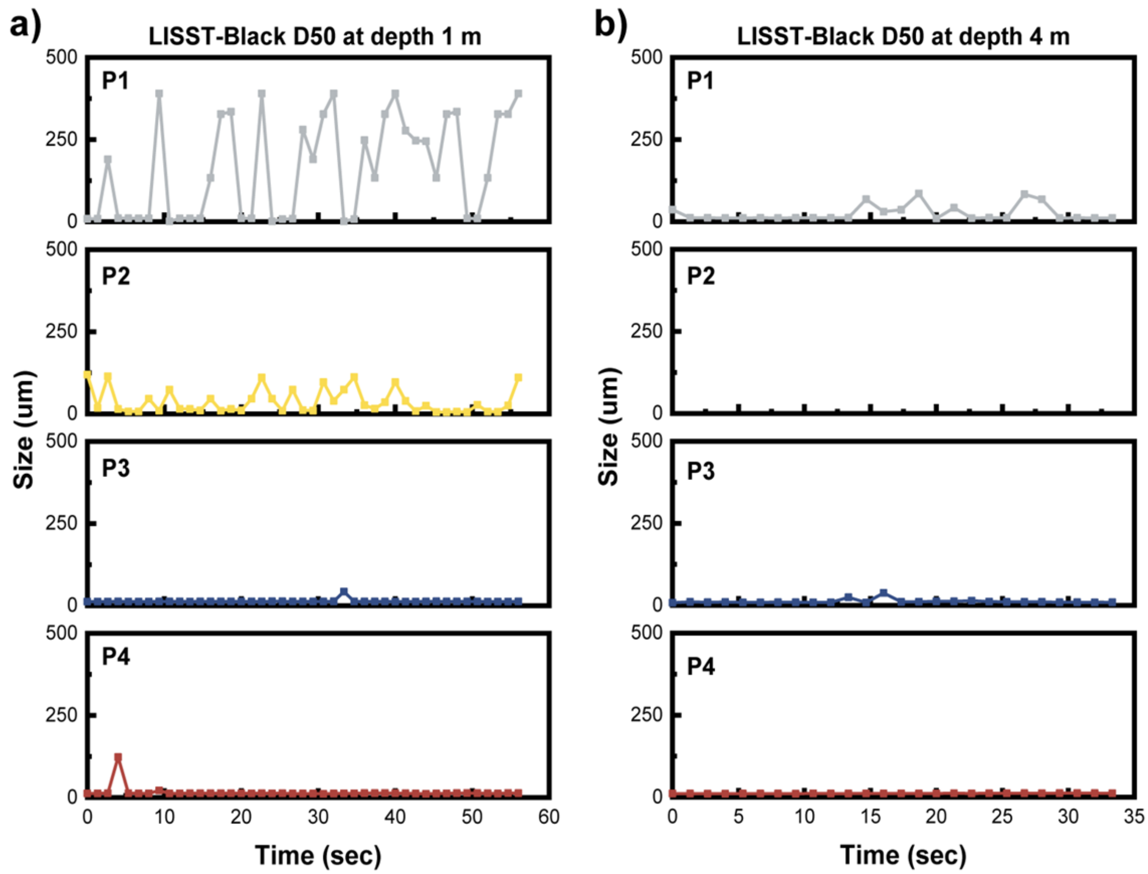


Figure 51 LISST-Black data for transition tests.
Droplet size distribution data collected by the LISST-200x in transition tests from position 1 to 4 at the depth of a) 1 m, and b) 4 m.

In the Test 2 transition test, the two LISSTs data and the Aqua Troll corresponding data (turbidity) showed somehow similarity in positions and depths, which confirmed the quick monitoring accuracy and consistency of this instrument kit. Figure 52 shows the efficiency of the transition test where the whole monitoring took around 13 minutes (800 seconds), and most of the time was consumed during transitions (around 2 minutes each for 100 m distance, including deploying the instrument kit to the 1 m depth). The LISSTs data in Figures 48 and 50 showed consistency in the measuring time, which were 56 seconds for 1 m depth and 33 seconds for 4 m depth, respectively. Thus, it is suggested that the data-collecting time frame for each depth could be 1 minute.

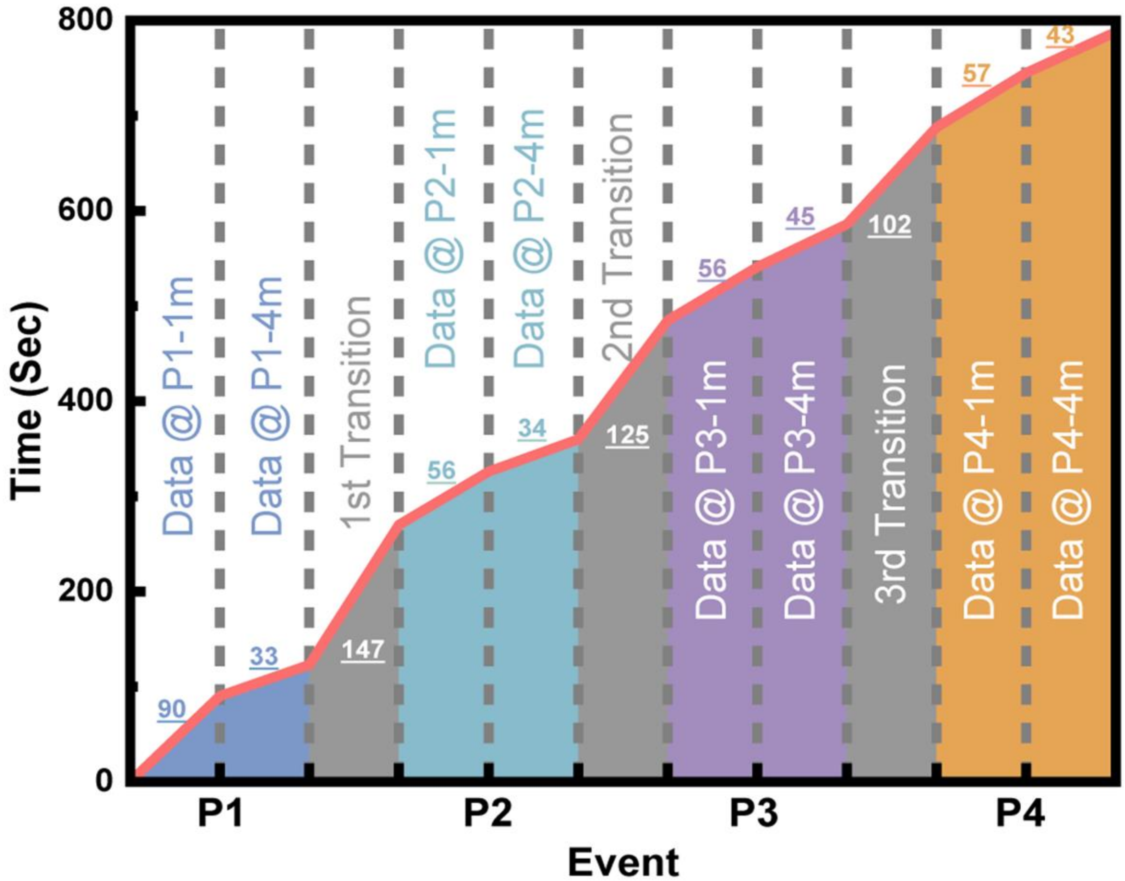


Figure 52 Transition time in four stations.
The instrument kit was air-towed between stations. At each station, it was down-cast to 1 m depth for about 1 minute of data collection, and then to 4 m for another 1 minute of data collection.

5 Recommendations

Monitoring the use of dispersants on surface oil slicks has been an element of spill response in US waters for the past three decades (Boufadel et al. 2006; King et al. 2018; Lewis et al. 1995). Concurrent to the SMART revision effort that began a year ago, the US Environmental Protection Agency (US EPA) released a new Rule specifying monitoring requirements under Subpart J of the NCP for dispersant use in response to major oil discharges and certain dispersant use situations in the navigable waters of the United States and adjoining shorelines. There are elements of this new SubPart J Monitoring Requirements that require the measurement and reporting of droplet size distribution of dispersed oil and other water quality parameters. When this Rule was released, it became evident that implementing the monitoring package that had been developed for subsea dispersant injection was not applicable to surface oil slick dispersant application and a new instrumentation package was required.

The investigations in this report (laboratory water tank tests, mesocosm wave tank tests, and Raritan Bay field shakedown tests) provided data to illustrate the optimized DSD detecting ranges for the three instruments under various conditions and scales. For clarification, it is worth noting that the size of the beads in Task 1a had a narrow size distribution for instrument testing, while dispersed oil has a much wider size distribution. Also, as the tests were designed for both physical (untreated) and chemical dispersion, the oil concentration varied largely from case to case, which could occur in a real spill. Thus, testing with oil allowed for more comprehensive and realistic situations. Lastly, the water in the Ohmsett tank for the June 2023 test was not refreshed, therefore, dispersants applied during previous tests could have impacted oil dispersion. However, the wave tank water condition did not impact achieving the instruments' test requirements for the deployment tests.

Task 1 Laboratory and Wave Tank Testing

Based on Task 1 laboratory and wave tank tests, following are primary suggestions for the application of the dispersant monitoring instruments:

a. The ShadowGraph camera, the LISST-Black and LISST-200x must be used horizontally (the Towed SilCam was designed to be towed, and thus, horizontally). It was found that in the vertical position, the windows of the three instruments were easily contaminated by either trapped air bubbles or were irreversibly coated and fouled with oil, rendering any data as flawed and unusable. Data from these tests are not reported since this vertical configuration of the instruments caused obvious fouling.

b. The ShadowGraph Camera, Towed SilCam, and the LISST-Black functioned well up to a towing speed of 4 knots; higher towing speeds were not tested. Images cannot be used to interpret the oil DSD data when the bubble concentration is large for both ShadowGraph and Towed SilCam.

c. As a prototype in development, the Towed SilCam's hardware and software improvements are being investigated and refinements are being pursued to increase the ruggedness of the system.

d. When reporting the Towed SilCam data, it is suggested to take the average of an upper percentile of the data (top 10%, top 30%) because excluding the zeros from the measurements might not be sufficient.

e. The ShadowGraph camera brightens the detection background, making the focus consistent even though its aperture is 2 cm and, therefore, capable of providing consistent and reliable readings. While the SilCam provides a narrower focus range, a large fraction of beads was found not focused on the view, which might underestimate the bead sizes. Another possible reason is the detection channel is only 3 mm wide, and when the beads consist of many larger ones (i.e., > 1 mm), it is possible that some of these beads were unable to through the channel. Thus, users are suggested to closely monitor the readings when droplet sizes are larger than 1 mm, and make sure consistent readings are reached before recording them.

f. The LISST instrument is reliable in providing droplet sizes in the range of 20 to 500 µm.

g. The LISST instrument (regardless of whether 200x or Black) has high uncertainty in estimating the oil phase volume (thus, volume concentration). This might be because when detecting beads at small sizes (e.g., smaller than 100 μm), the LISST-Black could overestimate the values as there could be overlapping in the laser path. In these cases, adding a path reduction module could be necessary.

h. When operating the stand-alone fluorometer, make sure to manually adjust the resolution (gain ratio), and the gain setting for the output readings are suggested to be 300 to 3000. While for the integrated fluorometer within the LISST-Black, users need to monitor its output to ensure the values are in the optimal range.

i. The detection range of the LISST-Black fluorometer is not adjustable (i.e., the gain ratio could not be changed). However, its values cover the typical range of spilled oil concentration, thus, the data would be reliable.

Task 2 Field Evaluation

After a successful Task 2 field evaluation, Table 7 provides recommendations for improvements for future deployment of the new surface monitoring system from a small boat.

Table 7 Encountered issues and recommendations in Task 2.

No.#	Issues	Recommendations
1	The instrument installation was time-consuming and difficult while working on the deck with small screws and bolts.	Improve installation time by assessing and converting to easier instrument connections to the frame (e.g., such as quick connects or electronic devices).
2	During this deployment, some instruments had excessively long cables, while others barely had a minimum length to be able to conduct the testing.	Order new cables for the full instrumentation suite that are the same length between 20 to 25 meters. The length should be sufficient to deploy to a depth of 5 meters below the surface, account for the vessel freeboard, routing over vessel coaming, and traverse across the deck to the interior space to connect to the laptops.
3	During this deployment, the excess cables were poorly managed and become tangled on the deck.	The heavier cables should be put on either single spools, or multiple cables housed on a divided spool so that all cables can be deployed and bundled in a tidy fashion to prevent trip hazards and damage to the cables.
4	As the system is presently designed with frame's instrument installation, computer cable setup, and sampling management system occurring on the deck, and the instrument software operation and analysis occurring below deck, four people are required.	With redesigned connections (#3) and possibly streamlined computer setup, the number personnel required may be decreased.
5	Communications were difficult between the team operating the instrumentation frame on the aft deck and the team running the laptops and cell phones.	Handheld radios are required to coordinate top-side activities (frame deployment) with vessel interior team running laptops and associated instrumentation software.
6	A peristaltic pump was planned for water sample collection, however, two different failures occurred during the deployment.	A new water collection system must be identified and incorporated into the instrument array. Consider using either a manually triggered "bottle

	First, the tubing sprung a leak. Later the pump shut down due to the extreme temperatures on the steel deck of the vessel. The air temperature exceeded 90F during the deployment and the vessel deck was extremely hot. While the team was unable to measure the steel deck temperature, it likely exceeded 130F.	on a stick" (single samples), or a miniature rosette that could collect multiple discrete samples during a transect.
7	When towing the frame from one station to the next, the frame was left suspended (air-towed) above the water to optimize the time to deploy it to the next station (Figure 43c). When suspended only from the crane hook, the frame swung considerably (1 to 2-meter swing) overhead when the vessel was transiting at 10 knots.	For the vessel to quickly transit from one station to the next at >10 knots, the instrument frame should be equipped with two shackles on the top forward rail of the frame to facilitate a 2-point attachment for a tag line to tie-off on a forward cleat. Similarly, a single tag line should also be tied to the top back rail of the frame to tie-off on an aft cleat. .
8	After unpacking the gear on the aft deck, the team left all boxes stowed on the vessel deck. This would have posed a problem in rougher sea states because the various cases and boxes could have slid around on the deck or potentially fallen overboard.	For future deployments, identify a vessel's interior location to store boxes, pelican cases and other gear bags. This may not be possible on small vessels (under 50' LOA). In this situation, consider unpacking the equipment on the vessel deck, then offloading the cases to a shore-based storage locker or vehicle.

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7 Abbreviations and Acronyms

[Short Form]	[Long Form]
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
CO	Contracting Officer.
COR	Contracting Officer's Representative
D50	Volume median diameter
DSD	Droplet Size Distribution
HIB	Hibernia
LISST	Laser In-Situ Scattering and Transmissometry
OSPD	Oil Spill Preparedness Division
OSRR	Oil Spill Response Research
MPRI	Multi-Partner Research Initiative
NCP	National Contingency Plan
NJIT	New Jersey Institute of Technology
NRT	National Response Team
PE	Polyethylene
SilCam	Silhouette Camera
SMART	Special Monitoring of Applied Response Technologies
USCG	US Coast Guard
USEPA	US Environmental Protection Agency

Appendixes

Appendix A: Technical Summary

REPORT TITLE: Surface Water Droplet Size Distribution Instrument Laboratory Validation, Tank Deployment, and Field Evaluation

CONTRACT NUMBER(S): 140E0123C0007

FISCAL YEARS(S) OF PROJECT FUNDING: FY2023

CUMULATIVE PROJECT COST: $575,000

COMPLETION DATE OF REPORT: 10 December 2024

BSEE COR(S): Ann Slaughter

BSEE CO(S): David Villani

PROJECT MANAGER(S): Michel C. Boufadel

AFFILIATION OF PROJECT MANAGER: New Jersey Institute of Technology

ADDRESS: 323 Dr. MLK Jr Blvd, Newark, NJ 07102

PRINCIPAL INVESTIGATOR(S)*: Michel C. Boufadel

KEY WORDS: Oil spill response, Towed SilCam, LISST-Black, Surface Instrument, ShadowGraph camera, Droplet size distribution

* The affiliation of the Principal Investigators(s) may be different than that listed for Project Manager(s).

Appendix B: Supplementary results for NJIT water tank tests

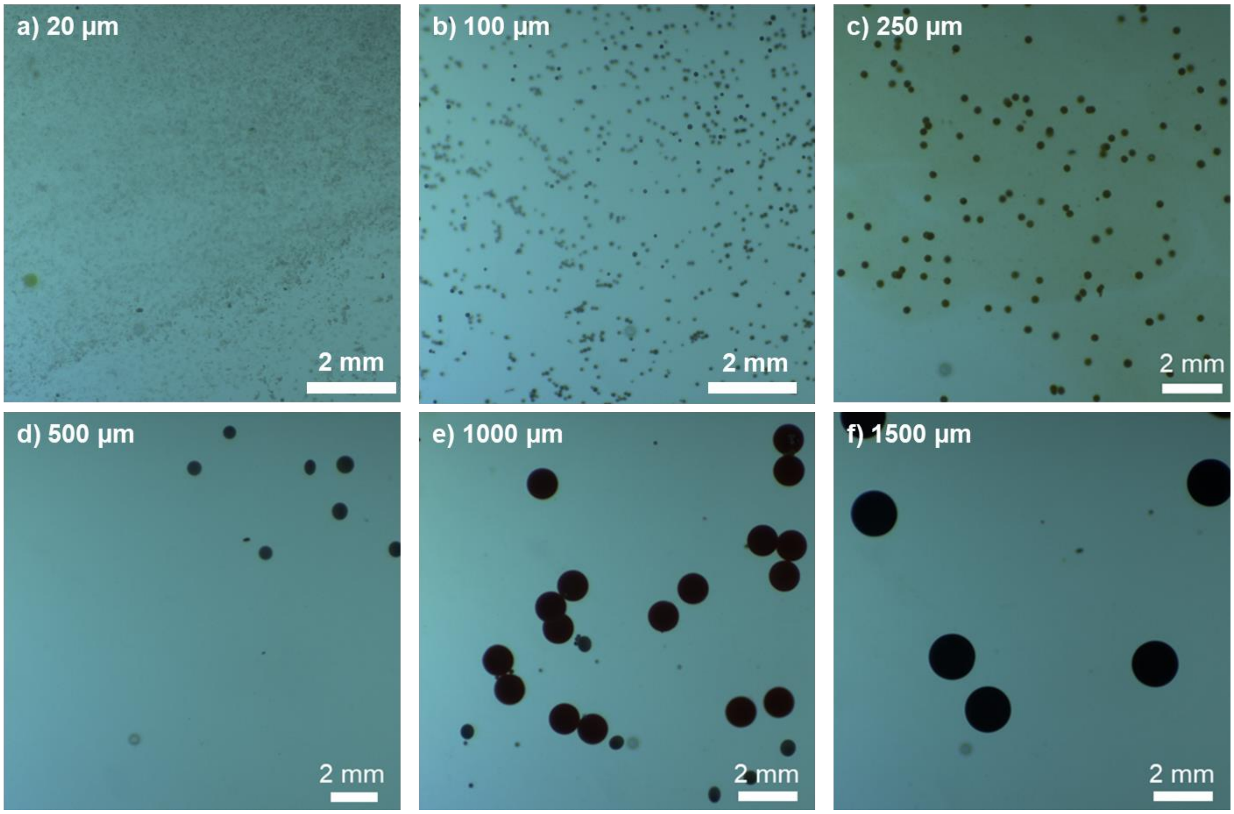


Figure B1. The output image files from Towed SilCam in Tests 1-1 to 1-6 for beads: a) Test 1-1, 20 µm beads; b) Test 1-2, 100 µm beads; c) Test 1-3, 250 µm beads; d) Test 1-4, 500 µm beads; e) Test 1-5, 1000 µm beads; f) Test 1-6, 1500 µm beads. Note the pattern of beads clustering together for (a) and (b), and to some extent (e).

Test 1-3 – 250 µm

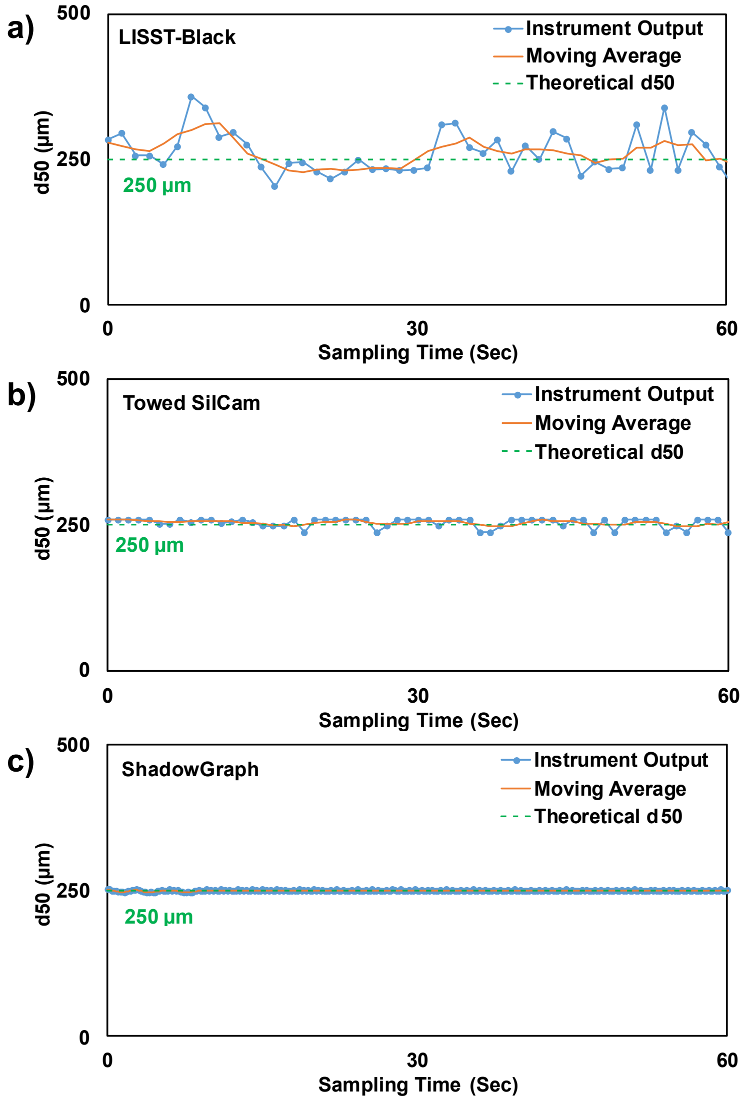


Figure B2. The volume median diameter, d50 (µm) obtained from the LISST-Black (a), Towed SilCam (b) and ShadowGraph camera (c) for Test 1-3.

Test 1-4 – 500 µm

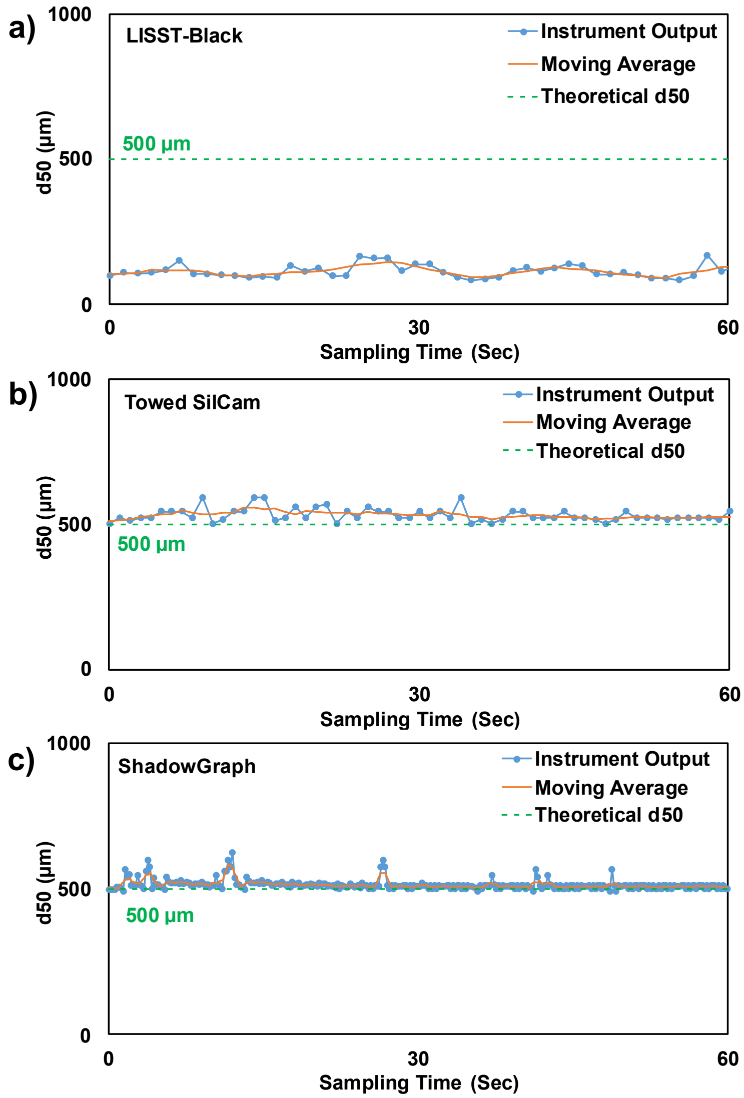


Figure B3. The volume median diameter, d50 (µm) obtained from the LISST-Black (a), Towed SilCam (b) and ShadowGraph camera (c) for Test 1-4.

Test 1-5 – 1000 µm

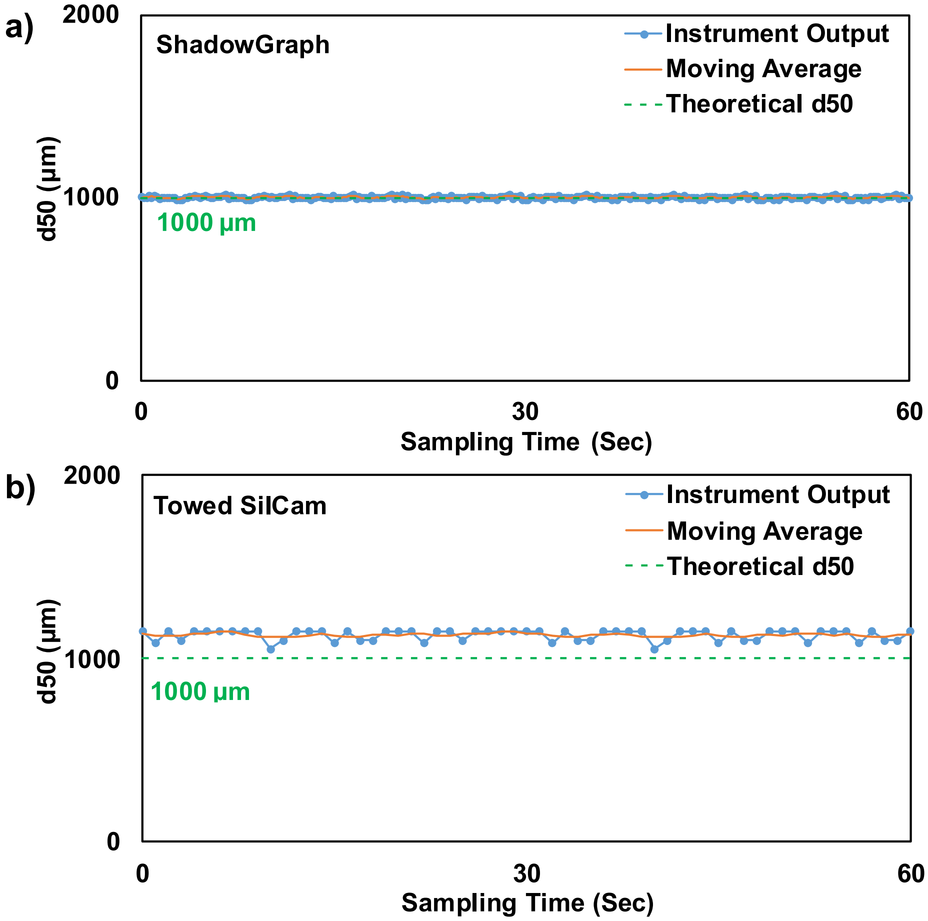


Figure B4. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-5.

Test 1-6 – 1500 µm

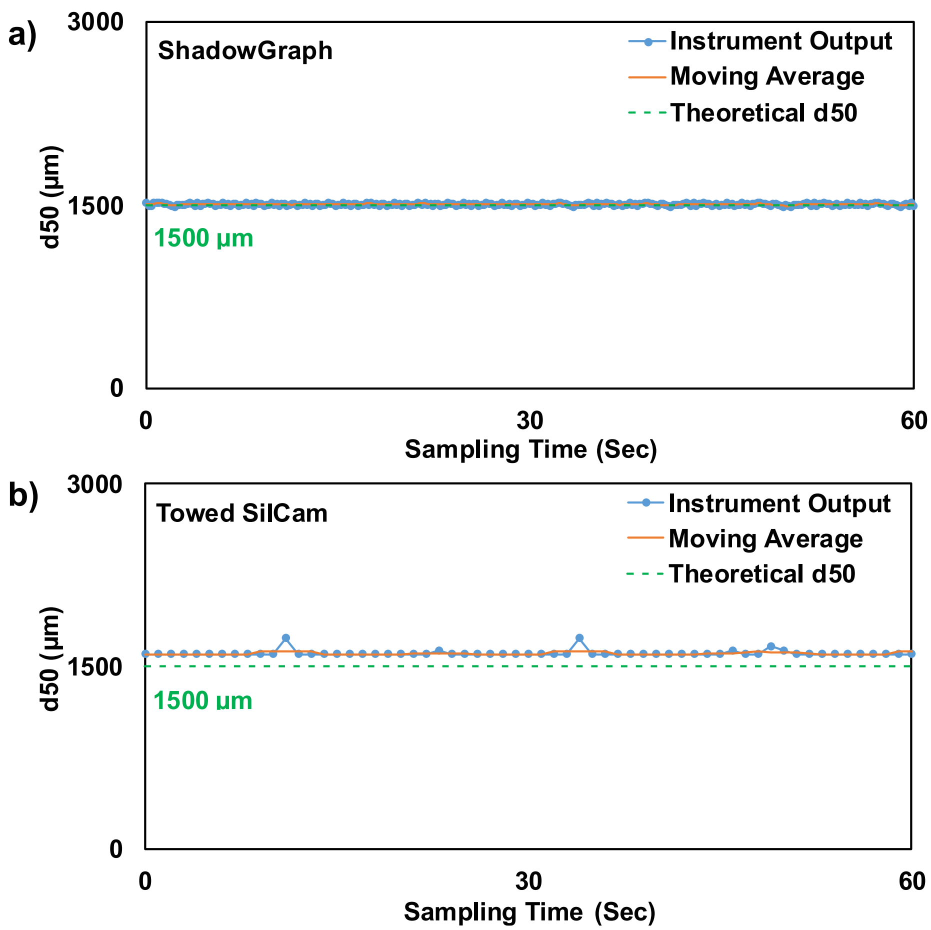
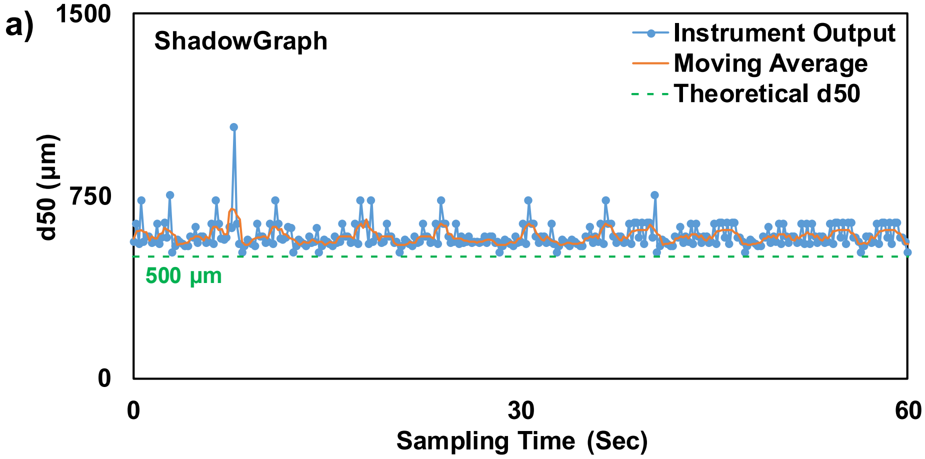


Figure B5. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-6.

Test 1-12 – 250+500+1000 µm



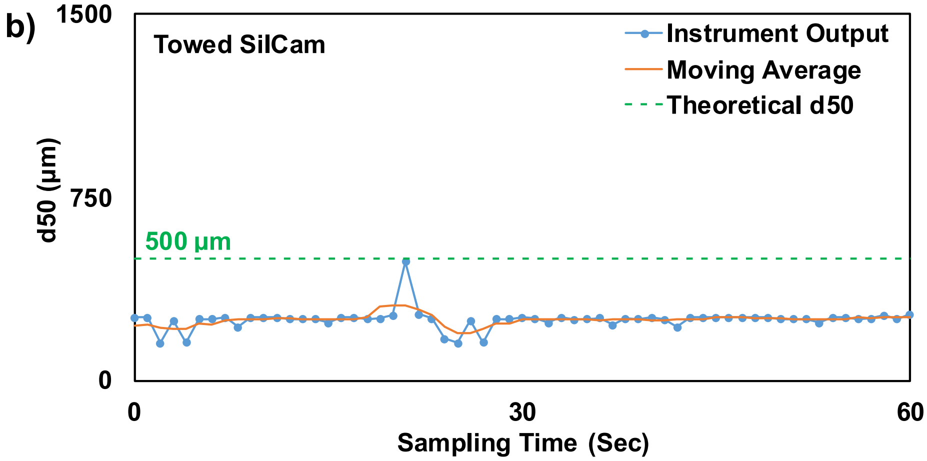


Figure B6. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-12.

Test 1-13 – 100+500+1500 µm

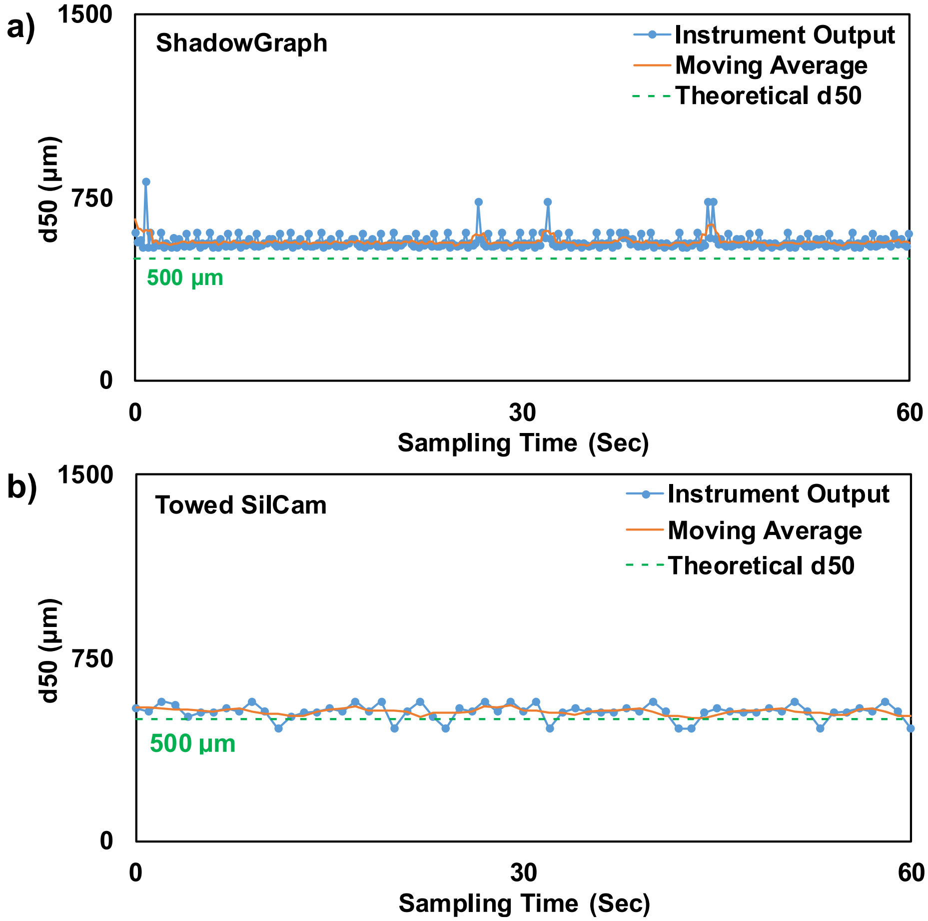


Figure B7. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-13.

Appendix C: Supplementary results for Ohmsett tests

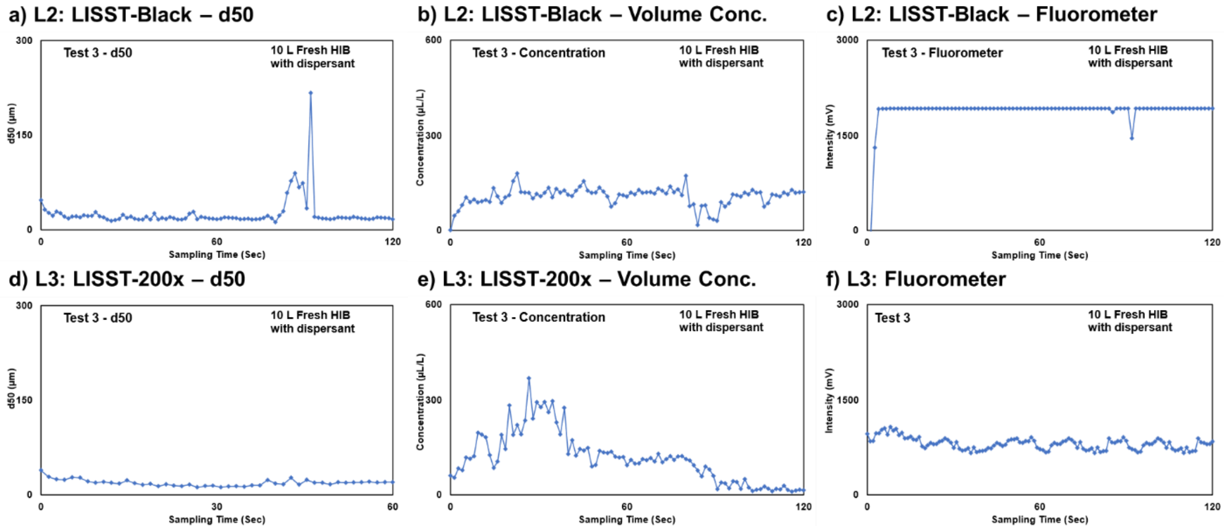


Figure C1. The d50 results (a and d), volume concentration (b and e) and fluorometer readings (c) obtained from the LISST-Black and LISST-200x, respectively, in Test 3-3. The fluorometer Cyclops 7F-O obtained fluorescence signals individually (f).

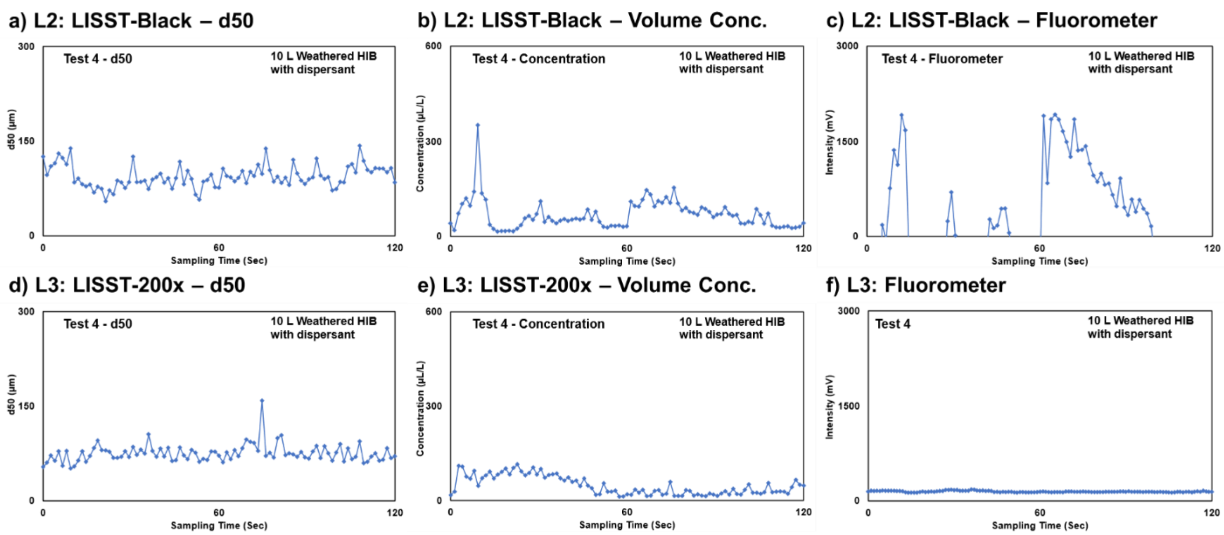


Figure C2. The d50 results (a and d), volume concentration (b and e) and fluorometer readings (c) obtained from the LISST-Black and LISST-200x, respectively, in Test 3-4. The fluorometer Cyclops 7F-O obtained fluorescence signals individually (f).

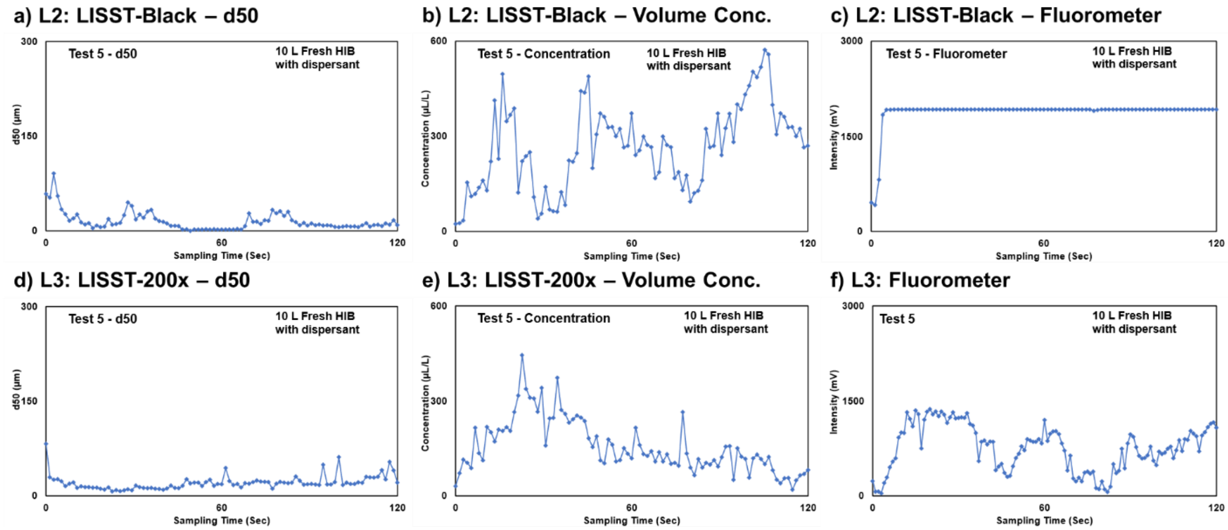


Figure C3. The d50 results (a and d), volume concentration (b and e) and fluorometer readings (c) obtained from the LISST-Black and LISST-200x, respectively, in Test 3-5. The fluorometer Cyclops 7F-O obtained fluorescence signals individually (f).

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The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Safety and Environmental Enforcement (BSEE)
The mission of the Bureau of Safety and Environmental Enforcement works to promote safety, protect the environment, and conserve resources offshore through vigorous regulatory oversight and enforcement.

BSEE Oil Spill Preparedness Program
BSEE administers a robust Oil Spill Preparedness Program through its Oil Spill Preparedness Division (OSPD) to ensure owners and operators of offshore facilities are ready to mitigate and respond to substantial threats of actual oil spills that may result from their activities. The Program draws its mandate and purpose from the Federal Water Pollution Control Act of October 18, 1972, as amended, and the Oil Pollution Act of 1990 (October 18, 1991). It is framed by the regulations in 30 CFR Part 254 – *Oil Spill Response Requirements for Facilities Located Seaward of the Coastline*, and 40 CFR Part 300 – *National Oil and Hazardous Substances Pollution Contingency Plan*. Acknowledging these authorities and their associated responsibilities, BSEE established the program with three primary and interdependent roles:

- Preparedness Verification,
- Oil Spill Response Research, and
- Management of Ohmsett - the National Oil Spill Response Research and Renewable Energy Test Facility.

The research conducted for this Program aims to improve oil spill response and preparedness by advancing the state of the science and the technologies needed for these emergencies. The research supports the Bureau's needs while ensuring the highest level of scientific integrity by adhering to BSEE's peer review protocols. The proposal, selection, research, review, collaboration, production, and dissemination of OSPD's technical reports and studies follows the appropriate requirements and guidance such as the Federal Acquisition Regulation and the Department of Interior's policies on scientific and scholarly conduct.