Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

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

Draft Final Report

December 2024

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US Department of the Interior
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Sources: a) BSEE (2019), b) DOI [2021], c) National Technical Information Service (2021)

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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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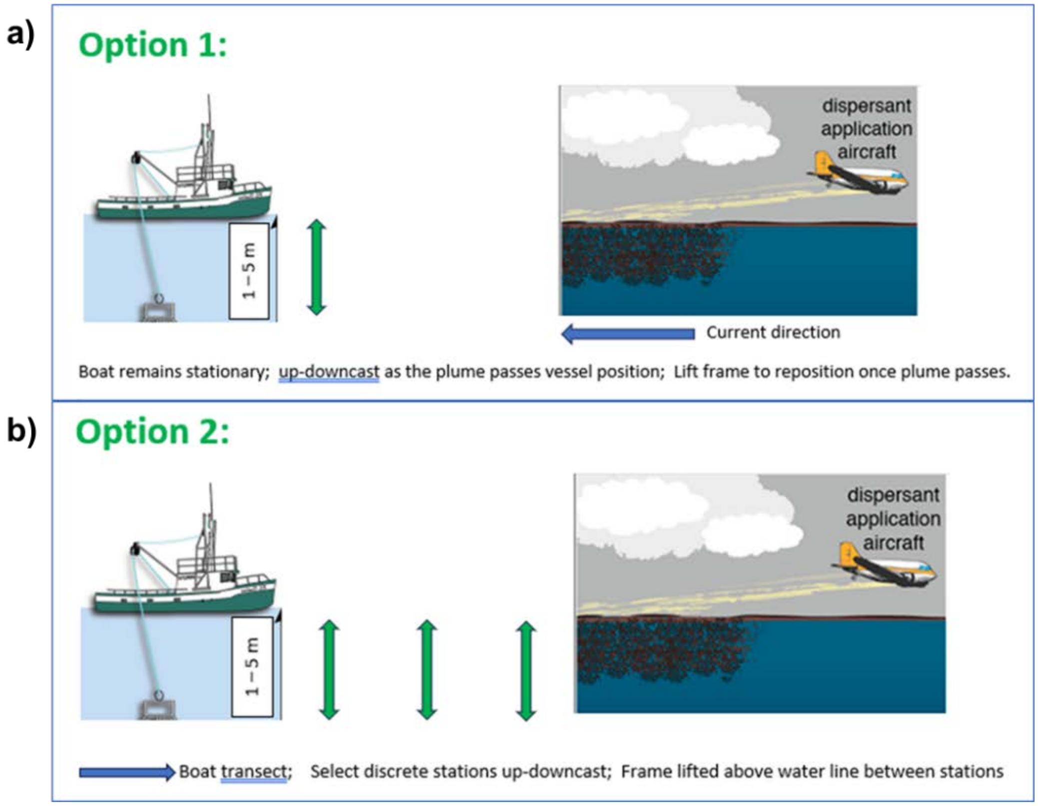


Figure 4 Field operational test options.
a) Option 1, down- and up-cast from 1-5 meters with stationary vessel; b) Option 2, down-up cast from 1-5 meters; with air tow between simulated stations. Option 3 was not conducted due to the limitation of the small vessel (crane was not capable of towing the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

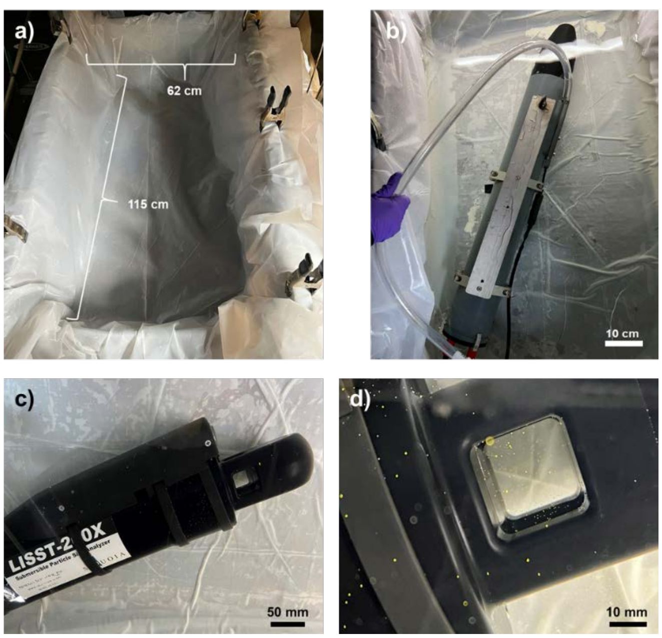


Figure 5 Laboratory validation setup.
The lab validation setups used at NJIT. a) the tank dimension; b) the beads passing through the detection window by a plastic tube; c) and d) the beads passing through the LISST-Black detection window. (Photos: NJIT)

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.

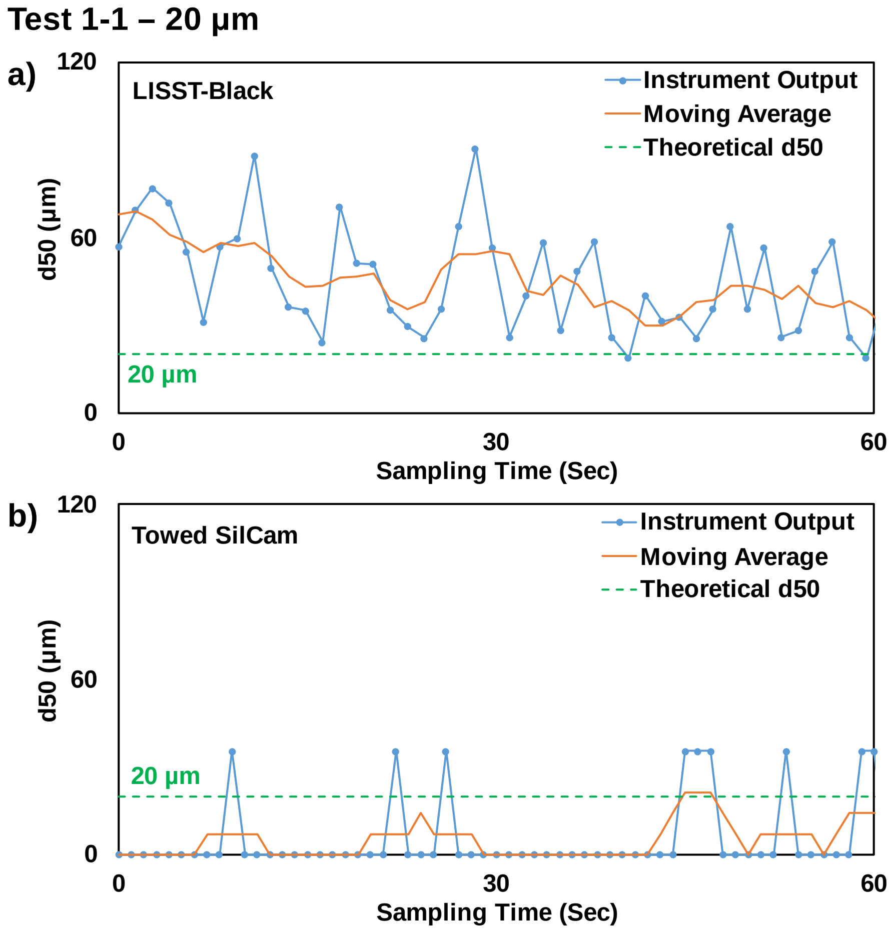


Figure 6 D50 for Test 1-1.

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.

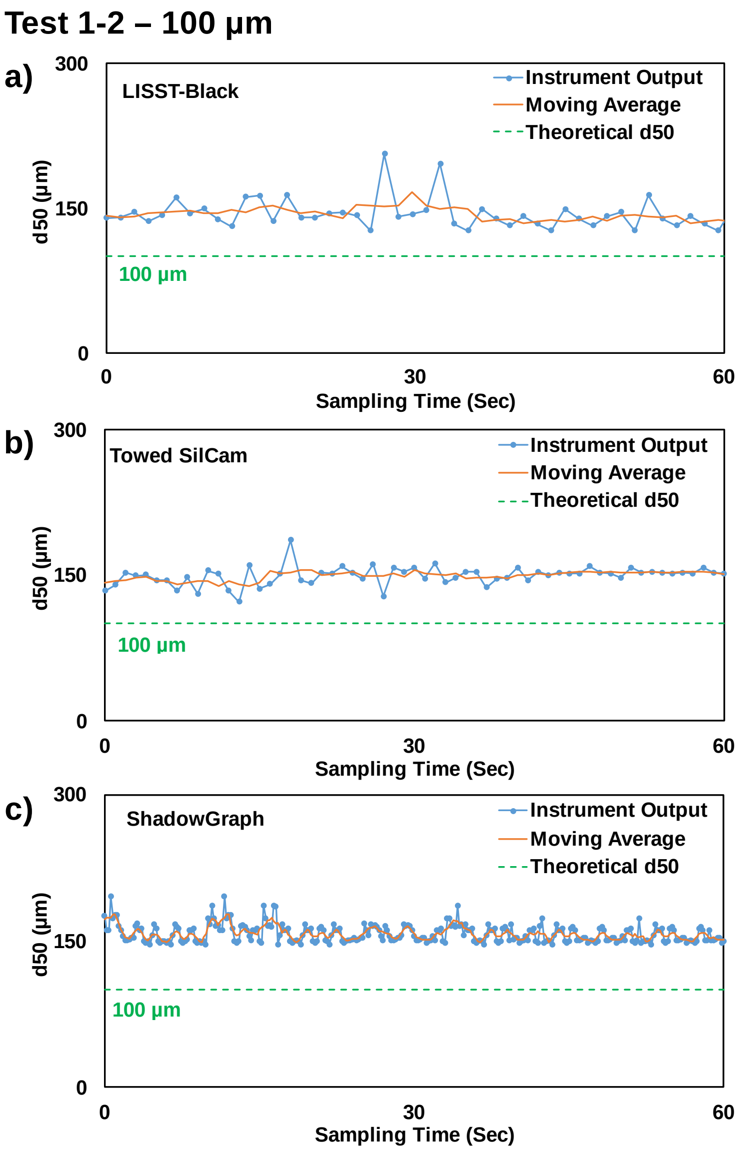


Figure 7 D50 for Test 1-2.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a), the Towed SilCam (b), and the ShadowGraph (c) for Test 1-2.

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.

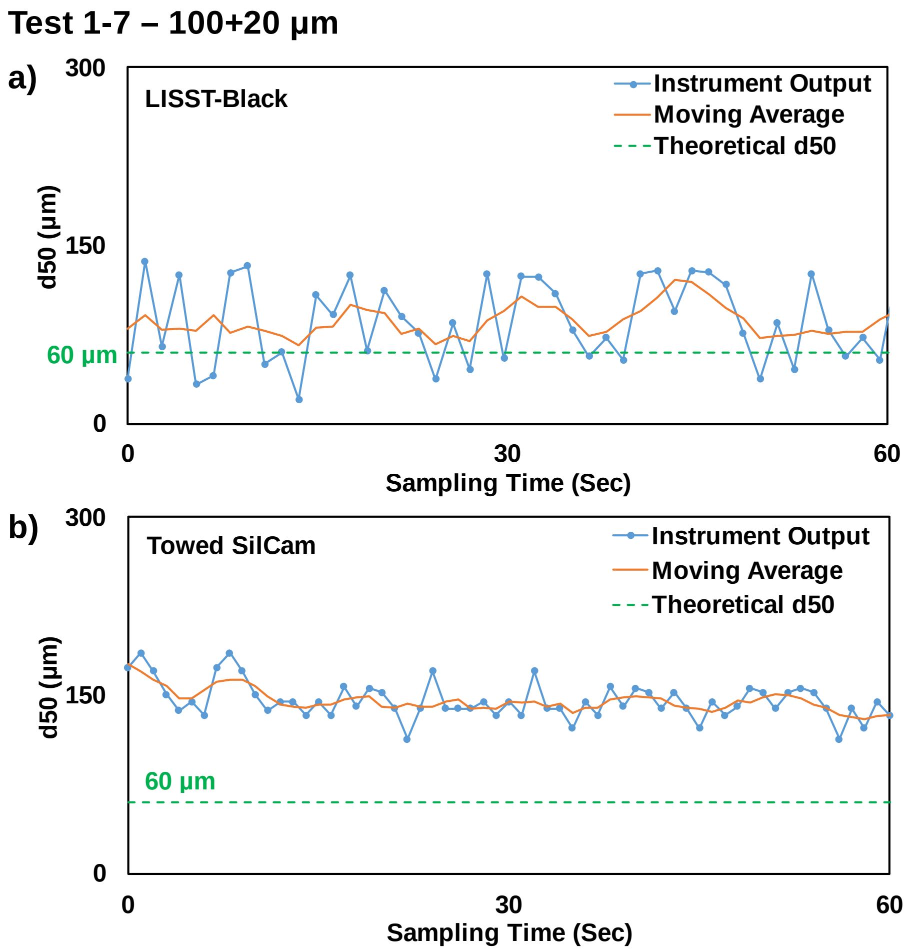


Figure 8 D50 for Test 1-7.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-7.

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

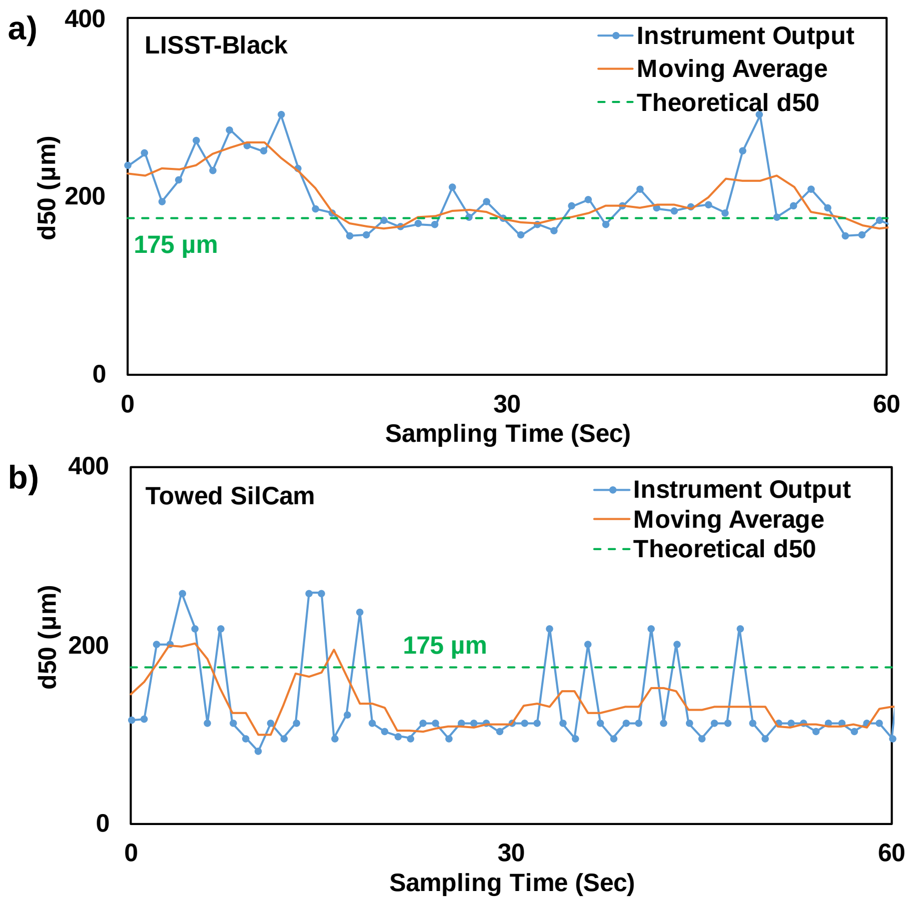


Figure 9 D50 for Test 1-8.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-8.

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.

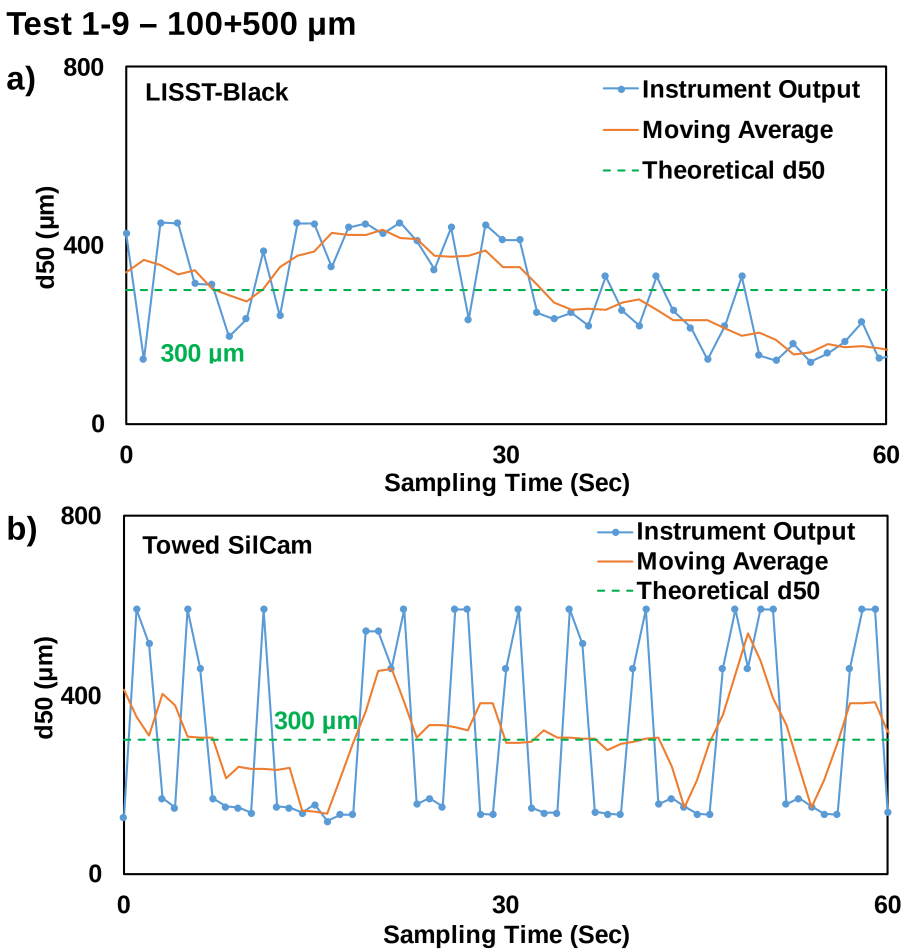


Figure 10 D50 for Test 1-9.
The volume median diameter, d50 (µm) obtained from the LISST-Black (a) and the Towed SilCam (b) for Test 1-9.

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

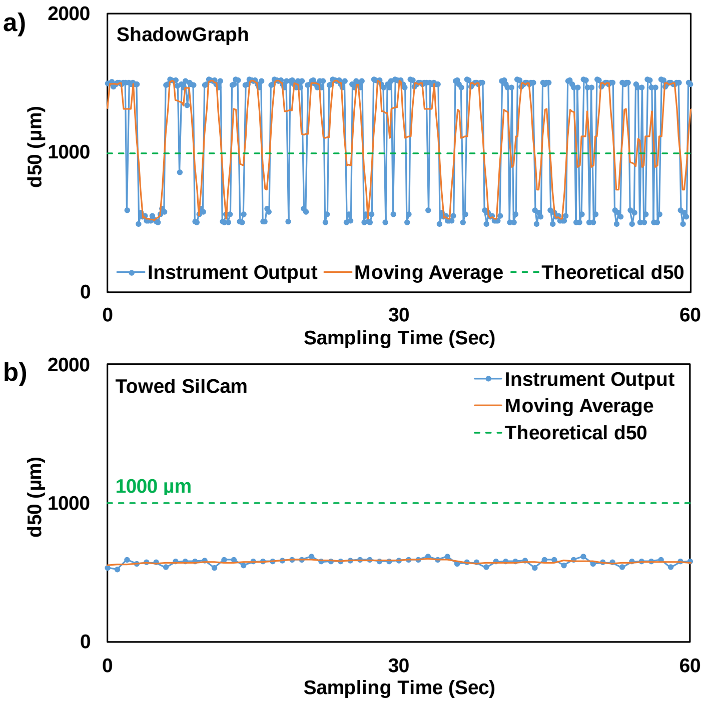


Figure 11 D50 for Test 1-10.
The volume median diameter, d50 (µm) obtained from the ShadowGraph (a) and the Towed SilCam (b) for Test 1-10.

Test 1-11 – 100+500+1000 µm

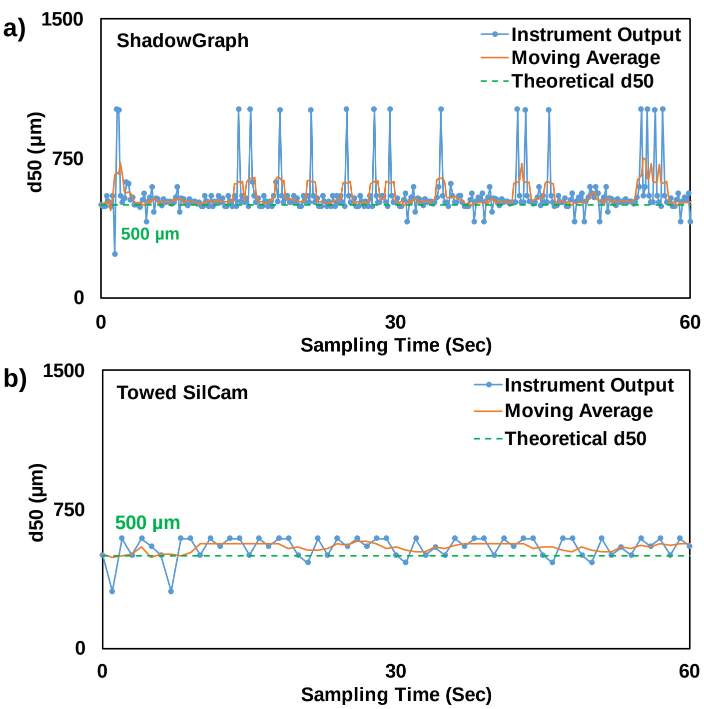


Figure 12 D50 for Test 1-11.
The volume median diameter, d50 (µm) obtained from the ShadowGraph (a) and the Towed SilCam (b) for Test 1-11.

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.

Appendix B: Supplementary results for NJIT water tank tests

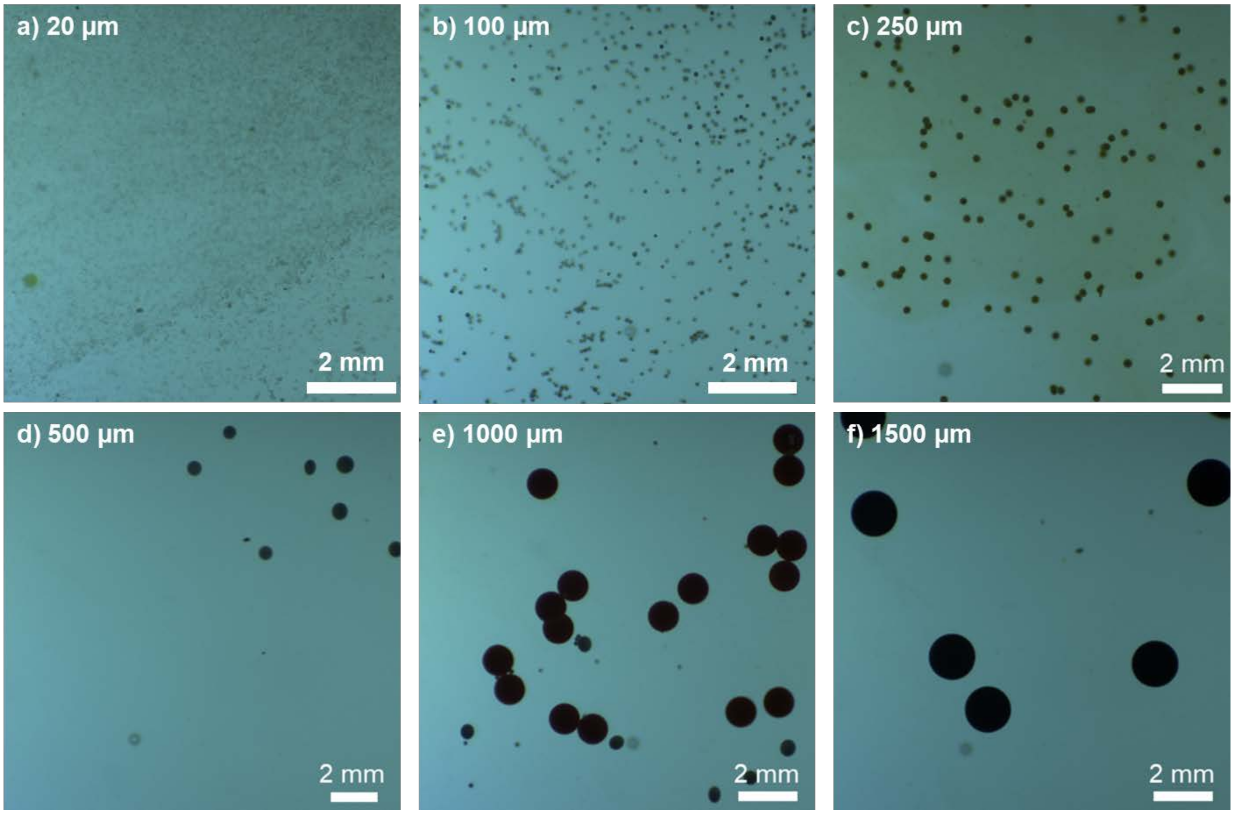


Figure B1. The output image files from Towed SilCam in Tests 1-1 to 1-6 for beads: a) Test 1-1, 20 µm beads; b) Test 1-2, 100 µm beads; c) Test 1-3, 250 µm beads; d) Test 1-4, 500 µm beads; e) Test 1-5, 1000 µm beads; f) Test 1-6, 1500 µm beads. Note the pattern of beads clustering together for (a) and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

Test 1-3 – 250 µm

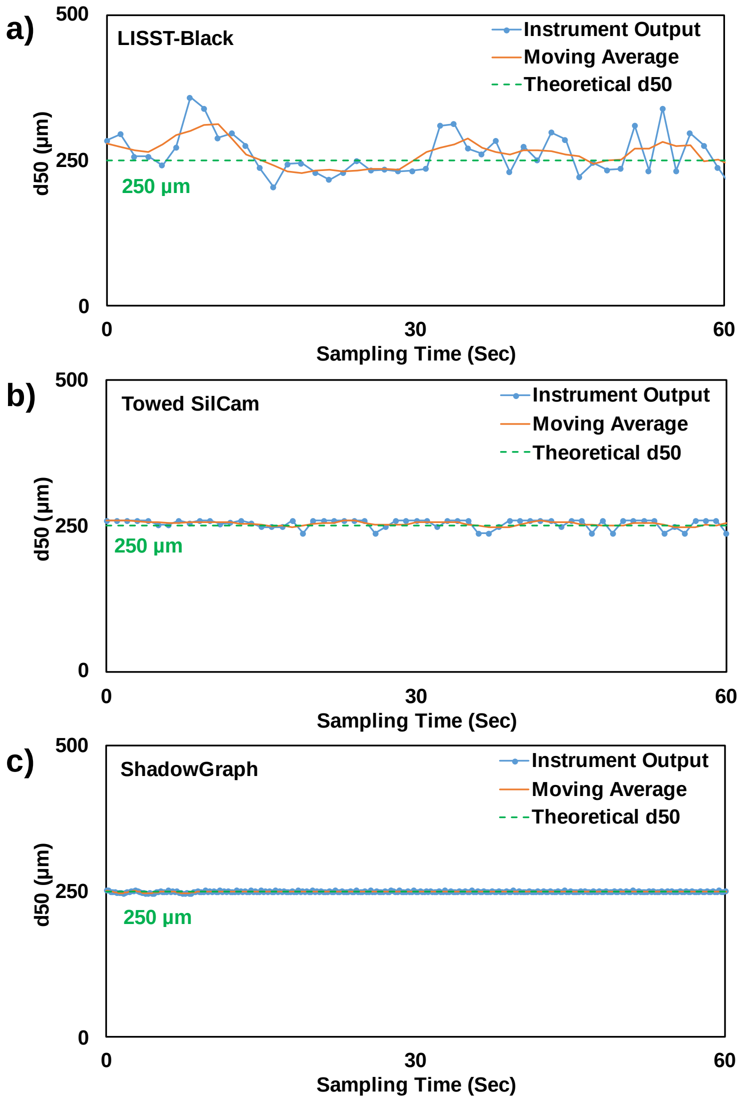


Figure B2. The volume median diameter, d50 (µm) obtained from the LISST-Black (a), Towed SilCam (b) and ShadowGraph camera (c) for Test 1-3.

Test 1-4 – 500 µm

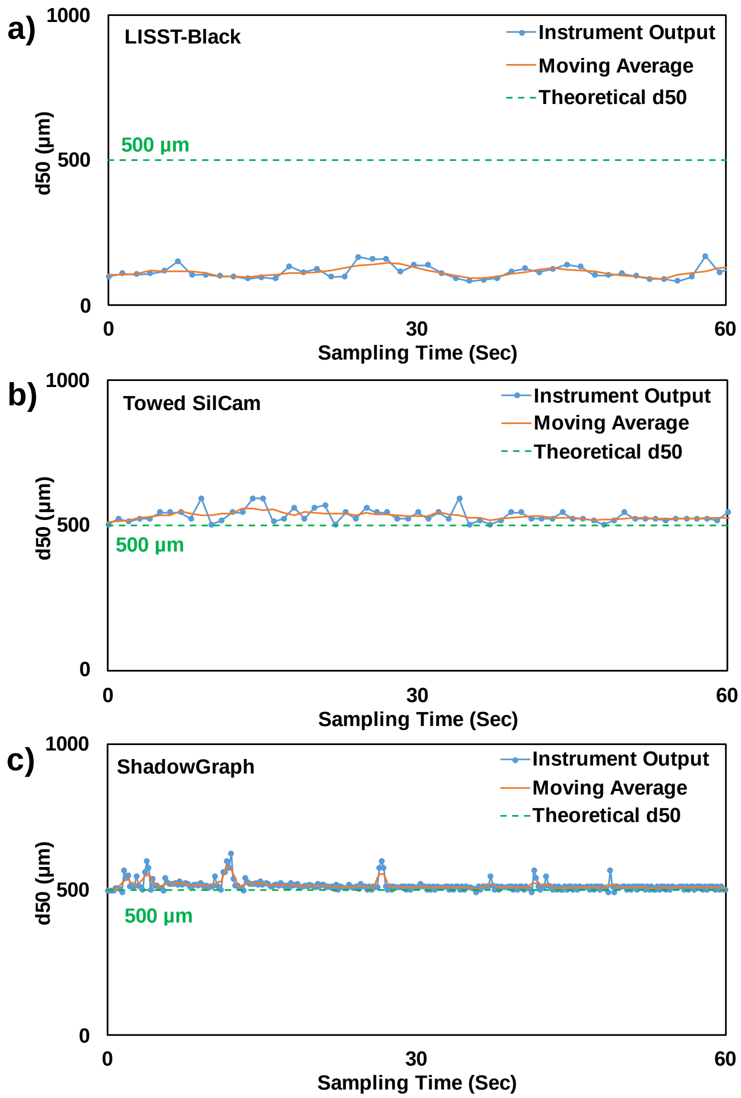


Figure B3. The volume median diameter, d50 (µm) obtained from the LISST-Black (a), Towed SilCam (b) and ShadowGraph camera (c) for Test 1-4.

Test 1-5 – 1000 µm

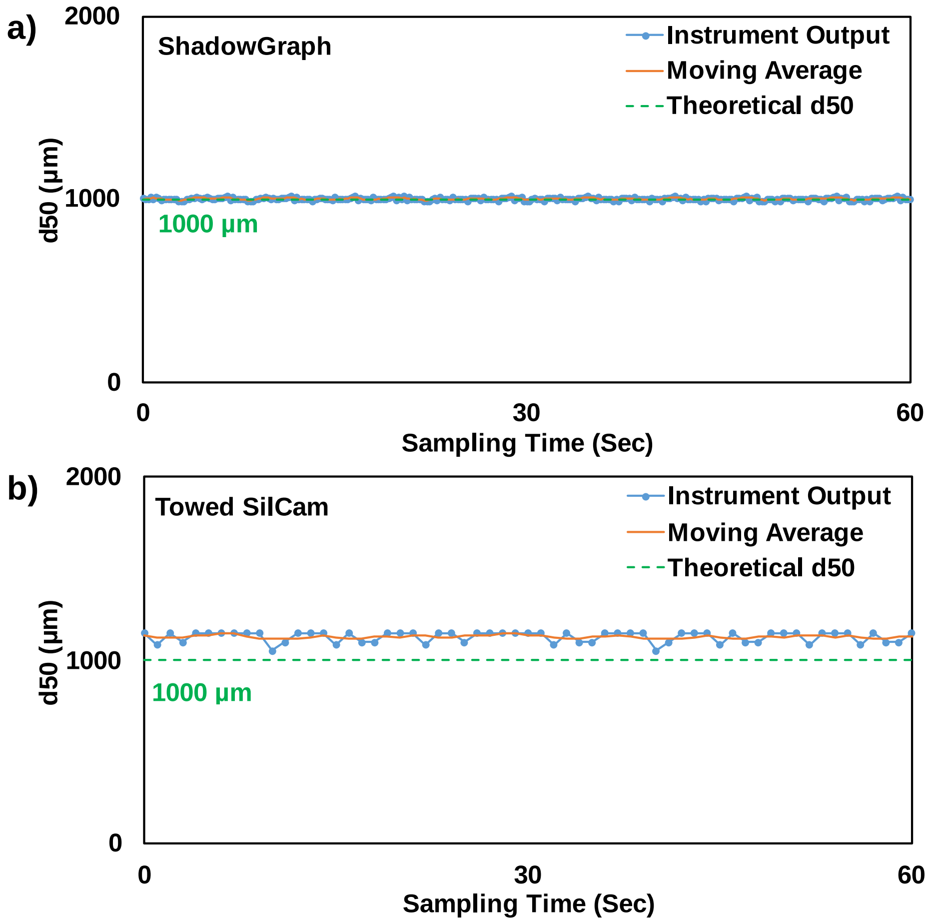
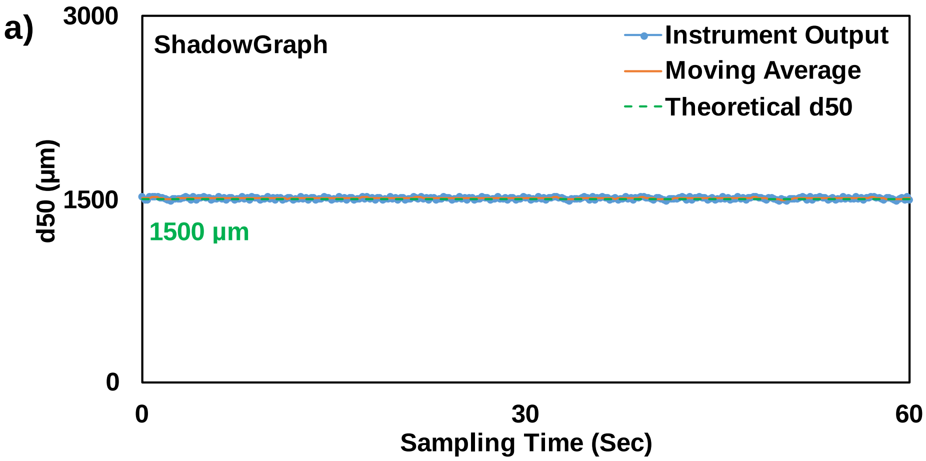


Figure B4. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-5.

Test 1-6 – 1500 µm



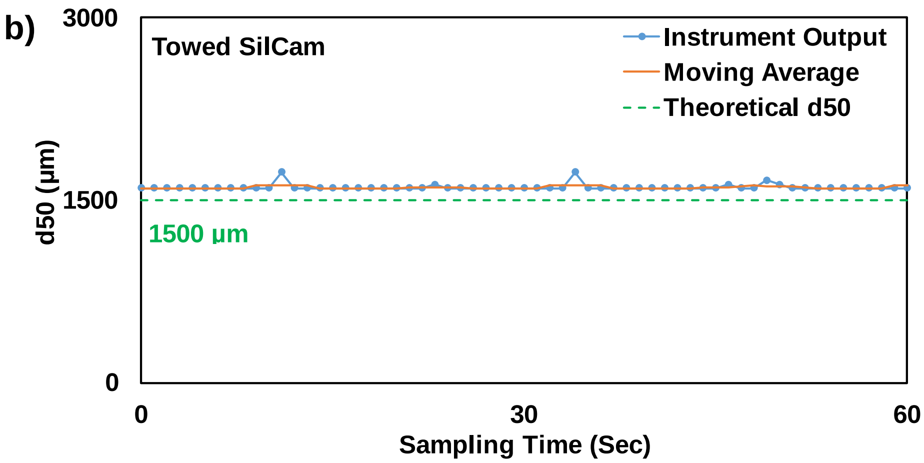


Figure B5. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-6.

Test 1-12 – 250+500+1000 µm

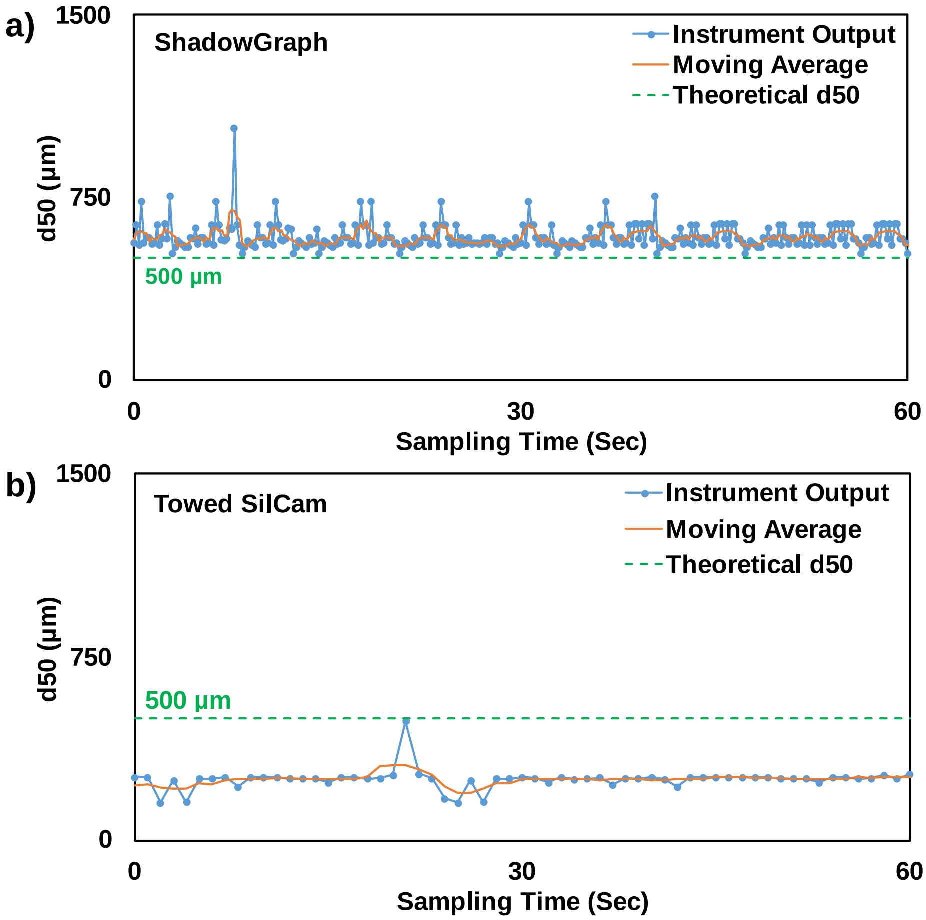
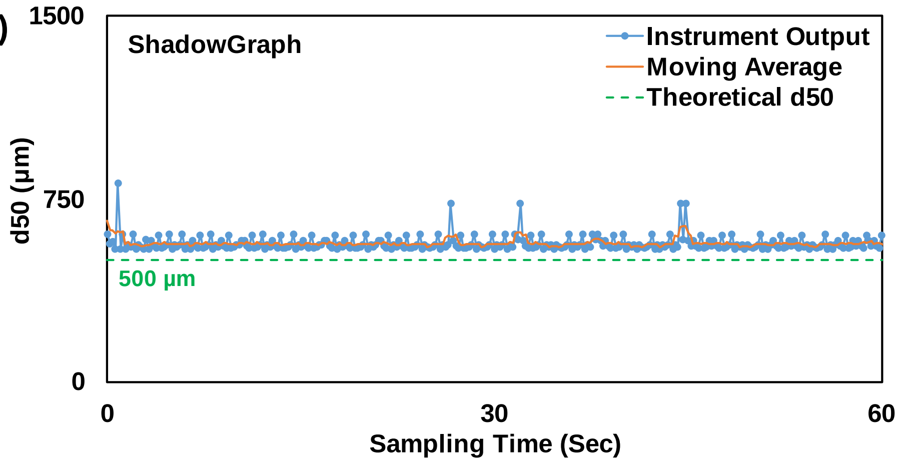


Figure B6. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-12.

Test 1-13 – 100+500+1500 μm

a)



b)

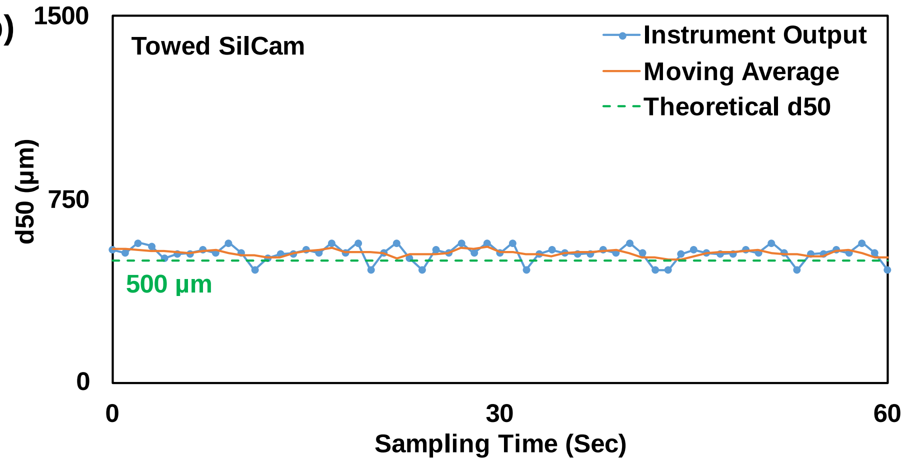


Figure B7. The volume median diameter, d50 (µm) obtained from the ShadowGraph camera (a) and Towed SilCam (b) for Test 1-13.

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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.