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MONTEREY, CALIFORNIA

JAMES RIVER ESTUARY ACOUSTIC FIELD EXPERIMENT

by

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The James River Estuary acoustic field experiment of 2019 (JRE2019) was designed to focus on acoustic characteristics of the James River estuarine environment using simple instrumentation, and correlate the acoustical characteristics to observational parameters such as current profiles and geological descriptors. A central objective is the investigation of the impact of bubbles on sound propagation within the estuarine front. Experimentation was conducted over a 9-day period in April, 2019, and was sponsored by the Office of Naval Research (ONR). This report provides technical details of the logistics, instrumentation, execution and initial results of the acoustical observations made during this field effort. Further analysis and results will be published separately in scientific journal articles.

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ABSTRACT

The James River Estuary acoustic field experiment of 2019 (JRE2019) was designed to focus on acoustic characteristics of the James River estuarine environment using simple instrumentation, and correlate the acoustical characteristics to observational parameters such as current profiles and geological descriptors. A central objective is the investigation of the impact of bubbles on sound propagation within the estuarine front. Experimentation was conducted over an 8-day period in April, 2019, and was sponsored by the Office of Naval Research (ONR). This report provides technical details of the logistics, instrumentation, execution and initial results of the acoustical observations made during this field effort. Further analysis and results will be published separately in scientific journal articles.

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I. INTRODUCTION

A. OVERVIEW OF THE EXPERIMENT

The James River Estuary acoustic field experiment (JRE2019) was one of a series of field experiments funded by the Office of Naval Research (ONR) within the Undersea Remote Sensing (USRS) program directed by Dr. Reginald Beach (ONR 322LO), conducted to obtain a better understanding of the estuarine river environment and its acoustical dynamics through *in situ* field observations and modeling. The experimental data is intended to establish correlations between the acoustical and physical characteristics of the riverine environment based on closely linked high-resolution measurements of environmental parameters; specifically, the contribution of bubbles subducted at the tidal intrusion front (TIF) to acoustic transmission loss is of particular interest. Instrumentation included single, omni-directional hydrophones, acoustic current doppler profilers (ADCP), conductivity-temperature-depth sensors (CTD) and temperature sensors deployed on anchored mini-catamarans (mini-cat) and bottom-moored tripods.

Estuaries present challenges as they are a dynamic environment in a transition zone between inland rivers and the sea. Few studies have been performed in the estuarine environment and even fewer with closely linked high-resolution measurements of environmental parameters. This analysis will further the understanding of fine-scale estuarine dynamics, facilitate the development of a predictive capability in estuarine environments for direct application to future U.S. Navy operations (e.g. SOF, NAVSPECWARCOM special boat squadrons, Explosive Ordnance Disposal (EOD) and mine warfare assets), and will be used to assess Navy systems' sonar performance in energetic and constrained environments. This report provides technical details of the logistics, instrumentation, execution and initial results of the acoustical observations made during this field effort. Additional reports and scientific journal papers will document the scientific analysis and discoveries that result from this experiment.

II. ENVIRONMENT

A. DESCRIPTION OF THE ESTUARINE AREA OF STUDY

This experiment was conducted over a 8-day period at a depth of ~8-10m near the mouth of the James River in the greater Chesapeake Bay region in the vicinity of (IVO) Newport News Point (NNP) near Hampton, VA. Figure 1 shows an overview of the area.

Figure 1. Overview of the experimental region. The James River separates the cities of Newport News (to the north) and Portsmouth (to the south).

The James River is the southernmost drowned-river valley tributary to Chesapeake Bay with its fluvial source to the west (Nichols *et al*., 1991). It has a channel-shoal bathymetry, consisting of a main channel bounded on the northern and southern sides by shallow shoals (Li *et al*., 2017). The natural channel is clearly seen throughout the estuary; the dredged navigation channel is evident in the center of the plot near NNP in figure 2. What this 50 m resolution bathymetry does not show is the Monitor-Merrimack Memorial Bridge-Tunnel (MMMBT) "ditch" in which the tunnel lies. The MMMBT tunnel ditch is evident in Fig. 3, which displays 5 m resolution bathymetry obtained by the Humminbird SOLIX15 sonar system. The water depth was approximately 17 m to the immediate west and east of tunnel ditch and exceeded 17 m in some areas of the ditch itself. It appears that after the tunnel ditch was dredged and the tunnel sections laid down

and connected, the tunnels were only partially covered with sediment and rock. There are two traffic tunnels (one for northbound traffic and the other for southbound traffic), that are 12.7 m diameter (Personal Communication, MMMBT Chief Engineer). The tubes are separated by approximately 1 m, making the center-to-center separation to be about 13.5 m. Figure 4 displays a visual of the tunnels from during construction of the MMMBT. There appears to be a small 'ridge' between the tunnels. The sharp discontinuities in the riverbed affect the current flow during both flood and ebb. John Richardson and Jim Goins at the Virginia Institute of Marine Science conducted the survey with the Humminbird system during a period shortly after the field experiment.

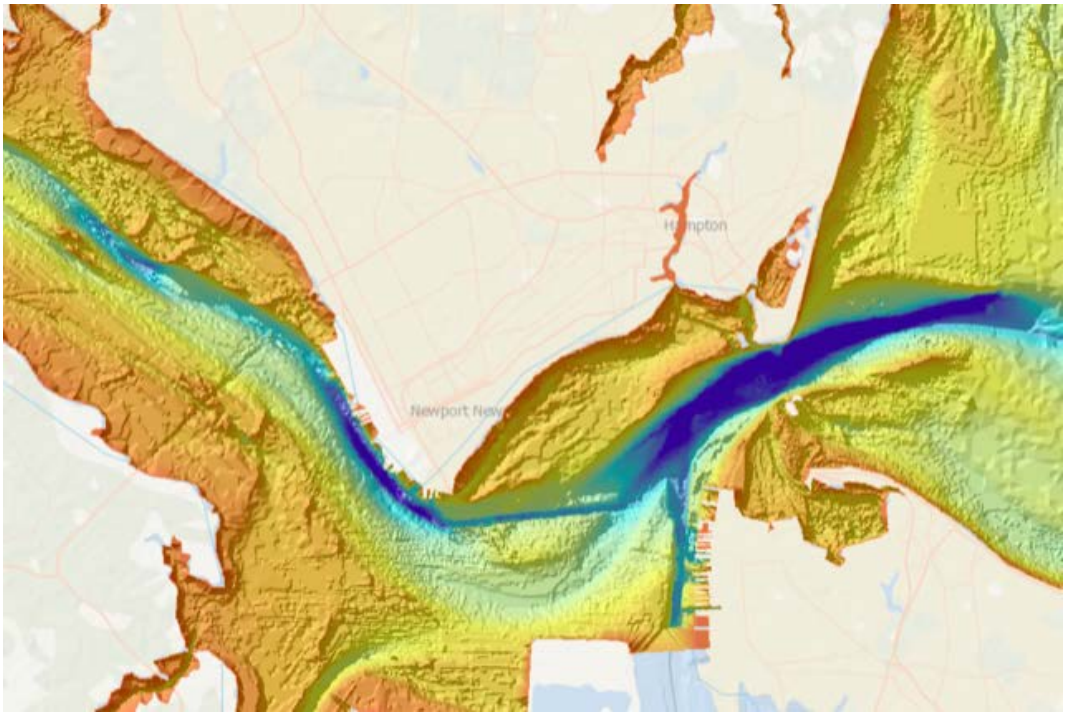

Figure 2. James River Estuary Bathymetry (USGS). https://usgs.gov

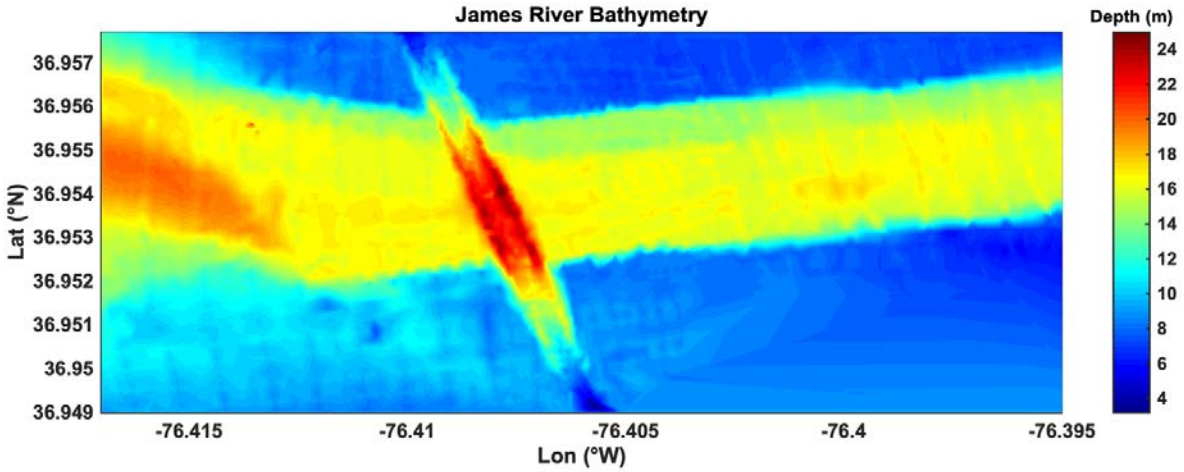

Figure 3. James River Estuary Bathymetry IVO NNP, showing the MMMBT ditch (Humminbird sonar operated by VIMS).

The oceanographical and acoustical feature of interest was the system of tidally-induced salinity fronts that consistently develop in a small area near NNP, just to the west of the MMMBT. The front forms during the early phase of each flood tide regardless of lunar phase or tidal range, moves upriver with increasing current flow, and is bounded by a strong counter-clockwise eddy over the shoals on the north side of the river (Kuo *et al*. 1990; Shen *et al.*, 1999). During early flood, the saline waters of the Chesapeake Bay initially accumulate on the northern shoals to the east of the northern MMMBT entrance, forming an east/west front along the northern bank of the navigation channel; once the tidal forcing is sufficient to overcome the slackening ebb flow of the fresh river water, the salt water advances upriver, around the MMMBT northern entrance portal, under the ebbing fresh river water, forming a three-dimensional (3D) estuarine salt wedge. This 3D front extends from the foot of the salt wedge at the riverbed up to the surface, forming a v-shaped surface expression called the "tidal intrusion front" (TIF). Figure 4 is modeled surface salinity (Woods Hole Oceanographic Institution, top) showing the salt water just beginning to advance west of NNP and backscattered radar data (Oregon State University, bottom) on April 24, 2019 later in flood as it advanced to the west. The TIF is characterized by lines of bubbles and foam (Fig. 5) created by the energetic convergence of the two water masses – breaking waves inject bubbles below the surface and the negative velocities of the salt water subduct the bubbles to depth (often to the riverbed), forming acoustically significant "bubble curtains," as shown in Fig. 6. The impact on acoustic propagation by the bubbles and the temperature-and salinity-induced sound speed gradients is the focus of this acoustic field experiment.

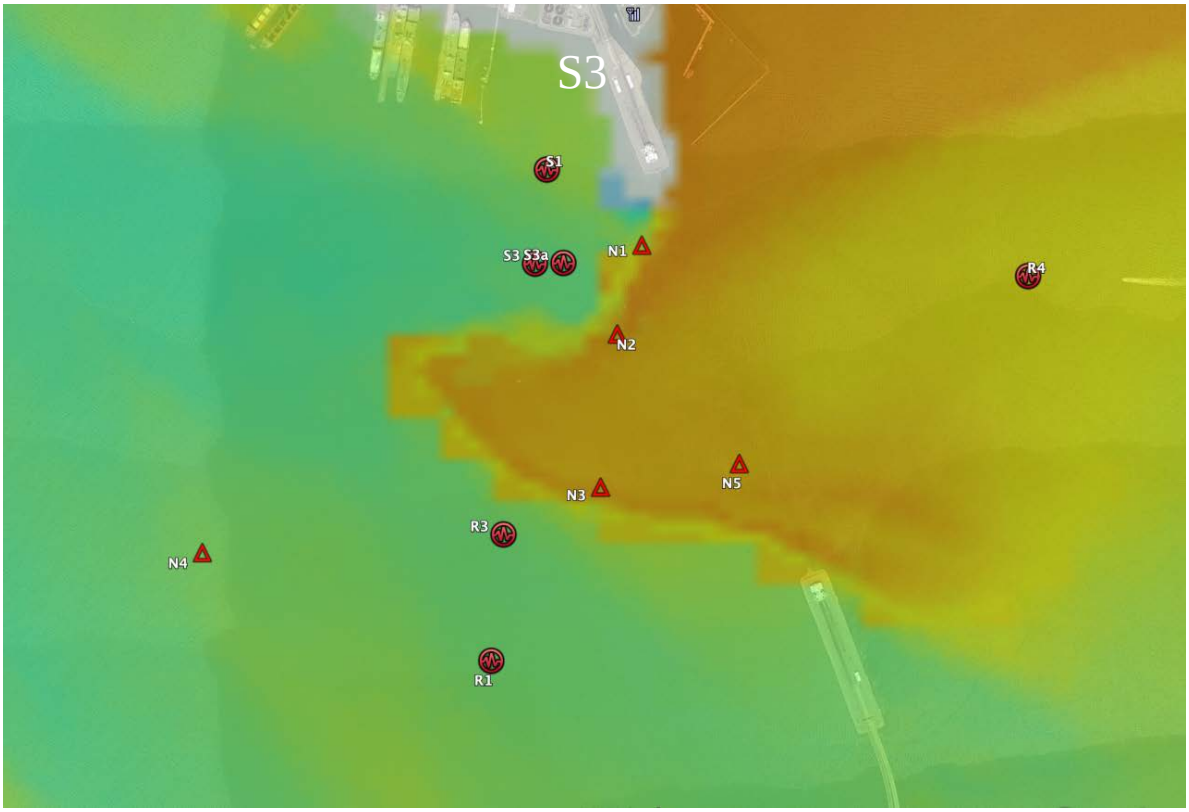

Figure 4. Modeled surface salinity (WHOI) on 19 April 2019 at 1100L, showing the tidal intrusion front advancing during flood around the northern terminus of the MMMBT, across the tunnel ditch and upriver toward the acoustic assets. Asset placement is in red. Triangles represent mooring locations, R1, R3 and R4 indicate locations of surface-deployed acoustic receivers, and S1, S3 and S2a indicate positions occupied by the source throughout the experiment.


Figure 5. James River Estuary tidal intrusion front between salty and fresh water during flood tide.

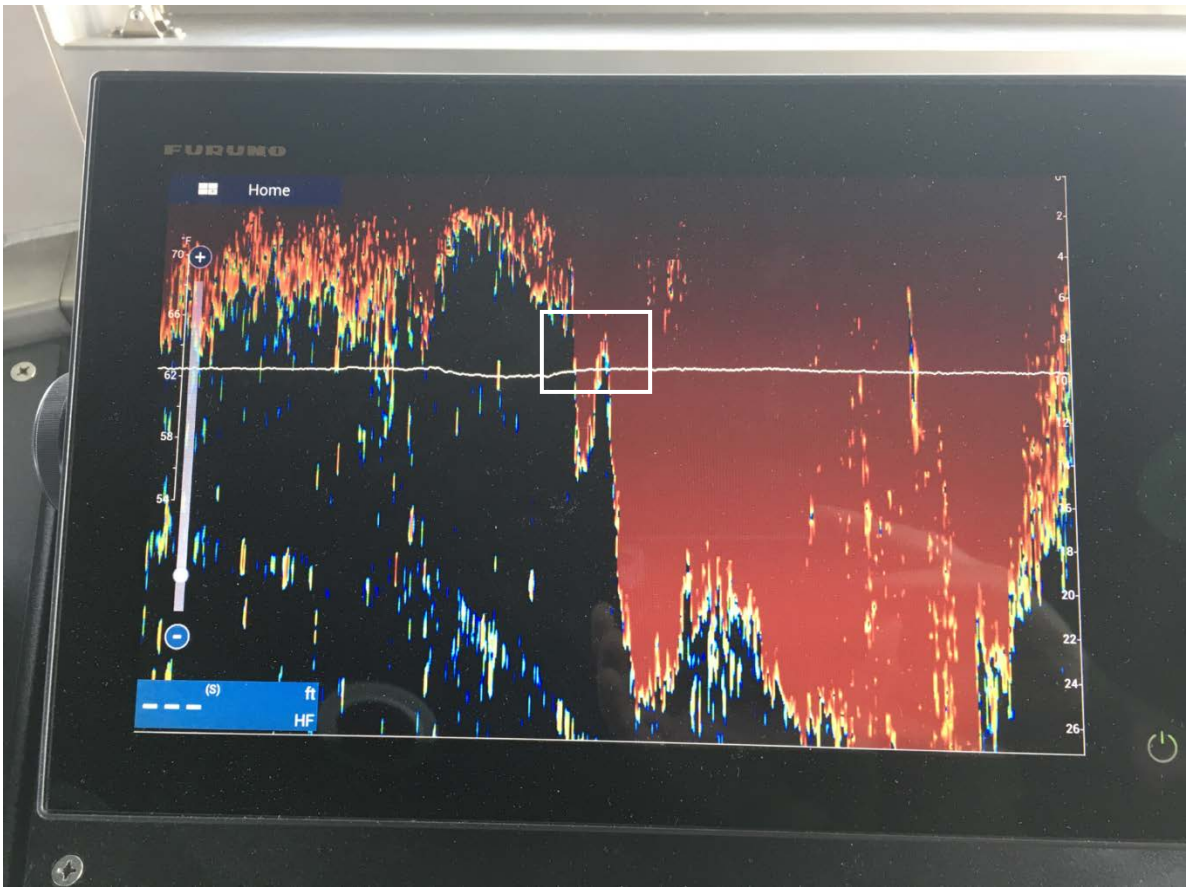

Figure 6. Shipboard 200 kHz echosounder data, showing the subducted bubbles at the front shown in Fig. 4. The negative velocities at the front subduct bubbles to depth.

III. EQUIPMENT

A. SHIP AND SCHEDULE

Over the course of the experiment from 18-25 April 2019, all equipment was deployed and recovered from the Virginia Institute of Marine Science's Research Vessel Virginia (R/V Virginia). The activities detailed in this report focus on the low-to-mid-frequency acoustic propagation portion of the experiment; other principal investigators (PIs) were engaged in other related work. See Fig. 7 for a picture of R/V Virginia.

Figure 7. R/V Virginia. Picture from viims.edu.

B. BOTTOM MOORINGS

Three tripods and two small stanchion moorings were deployed on the riverbed. Small, internally recording, omnidirectional hydrophones (Acousonde) and ADCPs were deployed on spiders at N1, N2 and N3 for the duration of the experiment. Two of these were called "Spiders," small fiberglass frames with three legs and weights to resist movement by currents. The Acousonde is a sealed unit containing a hydrophone, along with depth, attitude and orientation sensors to internally record data to be downloaded later. The ADCPs operated at 1200 kHz and were in 4 Beam, Janus configuration with a 20˚ beam angle.

See Fig. 4 for a visual representation of asset locations near the Monitor-Merrimac Memorial Bridge Tunnel (I-664) and Table 3 for asset latitudes and longitudes. Spider C2 was deployed with an ADCP at site N1, on the north side of the navigation channel, close to the northern tunnel entrance. Spider 24 was deployed at site N3, to the west of the tunnel and south of the navigation channel. Stanchion #1 was deployed at site N4 with an Acousonde, a little less than 1 nm to the west of N5 at which an Acousonde deployed. Finally, a tripod from Woods Hole Oceanographic Institute (WHOI) was deployed at site N2, just west of the bridge-tunnel in the center of the navigation channel. This WHOI tripod was of heavier construction for a deeper area with stronger current. It had an ADCP with the same sampling rate as the others in the experiment and a CTD sensor.

The assets were strategically placed to observe the acoustic signal from source station S3 as a function of time, range and azimuth IVO the estuarine front that was known to twice daily traverse the experimental area. Additionally, hydrophones at N5, N4 and N3 were designed to observe the time and range dependence of the sound radiated by the traffic tunnel.

Table 1. Acousonde Deployments during JRE2019 Project on 4/18/19

Acousonde #	Date and Time (Z) Deployed	Date and Time (Z) Recovered	Location	Depth (m)	Lat (N)	Long (W)
A060	18 April 19 2151Z	1327Z 25 APR	Site N4 (Stanchion #1)	7	36˚57.920’	076° 25.556’
A062	18 April 19 2225Z	1223Z 25 APR	Site N5 (Stanchion #2)	8	36˚57.024’	076° 24.464’
A061	18 April 19 2042Z	1255Z 25 APR	Site N3	11	36˚57.026’	076° 24.746’
WHOI Tripod	18 April 19 2255Z	1146Z 25 APR	Site N2		36˚57.404	076° 24.803’

Table 2. “Spider” Locations with ADCP and/or Acousonde

Spider #	Acousonde #	ADCP	Date and Time (Z) Deployed	Date and Time (Z) Recovered	Location	Lat (N)	Long (W)
C2	N/A	7290	18 April 19 2024Z	25 April 19 1418Z	N1	36 ˚ 57.454’	076° 24.806’
24	A061	2595	18 April 19 2042Z	25 April 1255Z	N3	36 ˚ 57.026’	076° 24.746’

Table 3. Site Locations

Site	On Bottom Latitude (N)	On-Bottom Longitude (W)
N1	36˚57.404	76˚ 24.806
N2	36˚57.324	76˚ 24.712
N3	36˚57.026	76˚ 24.746
N4	36˚57.920	76˚ 25.556
N5	36˚57.084	76˚ 24.464

C. VERTICAL LINE ARRAY

The Vertical Line Array, or VLA, was used to observe the depth-dependence of the acoustic signal before, during and after the passage of the estuarine front. The mini-cat was anchored for approximately 8 hours at a time during daylight hours. The four-phone VLA (Cetacean Research Technology C57) was a suspended below a small inflatable, one-man fishing pontoon craft ("mini-cat"); the electronics (Zoom F8n 8-channel recorder, CRT 8-channel pre-amp, MasterClock GPS500 timecode generator and 12v

inverter) were contained inside a water-tight box on the top of the mini-cat. The box was covered with aluminum foil to reflect the sun to limit the risk of high internal temperatures. An RBR Solo Temperature sensor (#101610) was placed in the box with the recorder to measure internal temperature. Maximum observed internal temperature was 105˚F on 23 and 24 April, with 21 and 22 April logging max temperatures of 81˚F and 76˚F, respectively.

Figure 8 shows the VLA deployed at site R3, 1.17 nm south of the S1 source station. The VLA phones occupied depths of equal spacing below the mini-cat of approximately 1 m, 3 m, 5 m and 7 m. They were color-coded to ensure identical placement each day. Figure 9 shows the components inside the water-tight case.

Figure 8. The Vertical Line Array (VLA) deployed in the James River Estuary.

Figure 9. The electronics inside the watertight case shown on the mini-cat in Fig. 8. The case contained the Zoom F8n 8-channel recorder (blue), the 8-channel pre-amp (gray/white), the GPS time-code generator (cream) and the 12v inverter (red).

D. SOUND SOURCE

The sound source was a Lubell Lab's high-power broadband piezoelectric underwater acoustic transducer (LL1424-HP). It was deployed as part of the apparatus named "the coffin," a wooden box housing the electronics required to autonomously transmit the acoustic signals. The coffin was deployed on an inflatable mini-cat and contained four 12 vdc marine deep-cycle batteries, a 2 kW DC-AC inverter (AIMS PWRIG200012120S), an uninterruptible power supply (Tripp-Lite UPS), a signal generator (SIGENT SDG1032X), a signal amplifier (Crown CDi2000), a bridge (Lubell AC1424HP) which delivered the amplified acoustic signal to the source suspended below the mini-cat. The source transmitted a linearly frequency-modulated (LFM) broadband signal ('chirp') in the 500-5000 Hz band. A monitoring hydrophone (Greenridge Sciences Acousonde 3A) was attached to the line from which the source was suspended at a depth of 1.5 m to record the transmitted signal. Additional floatation (foam) was attached to the underside of the coffin for extra buoyancy. Figure 10 shows the underside of the coffin; Fig. 11 shows the equipment inside the coffin.

Figure 10. The underside of the “coffin” (hanging from the ship's crane) showing the additional floatation, the anchor chain/line and the line from which the acoustic source was suspended.

Figure 11. Electronic equipment inside the coffin which powered and delivered the signal to the source.

E. BANSHEE

The "Banshee" (named after a comic book superhero whose superpower was emitting powerful sound) consisted of a four channel BioSonics DTXtreme echosounder system deployed on a mini-cat (Fig. 12). The echosounder system was powered by a single 12 vdc deep-cycle marine battery, its electronics were housed in an orange watertight box atop the mini-cat, and the four echosounder transducers, along with an ADCP instrument, were mounted on a wooden plate 1 m below the waterline (Fig. 13). The echosounder system transmits a Wifi signal that allows real-time data visualization and analysis while recording (over short distances), as well as playback and post-processing capabilities. The Banshee was useful in collecting real-time data as the ship passed over the front to visualize bubble entrainment in the front. The Banshee was designed to be deployed either at anchor to allow autonomous collection of data at one location over periods of hours, or in a towing configuration to collect data along transects. The Banshee was successfully deployed on 24 April in a towed configuration alongside the ship using the ship's crane; instead of towing, the ship and Banshee drifted with the wind and current in order to image the flood-tide front along the northern wall of the navigation channel (Fig. 14). Effort was made to position the ship north of the channel, then drift across the front with the ship's clutch disengaged, to minimize bubbles from the ship's propellers ("prop

wash") from contaminating the data. The ship drifted across the front several times that day to gather data; the Banshee was lifted out of the water while the ship reset its position.

Figure 12. The Banshee deployed from the ship's crane alongside the R/V Virginia on 24 April. The 12 vdc marine battery is in the black box on the left, the BioSonics electronics is housed in the orange watertight case and the excess cable is secured on the right.

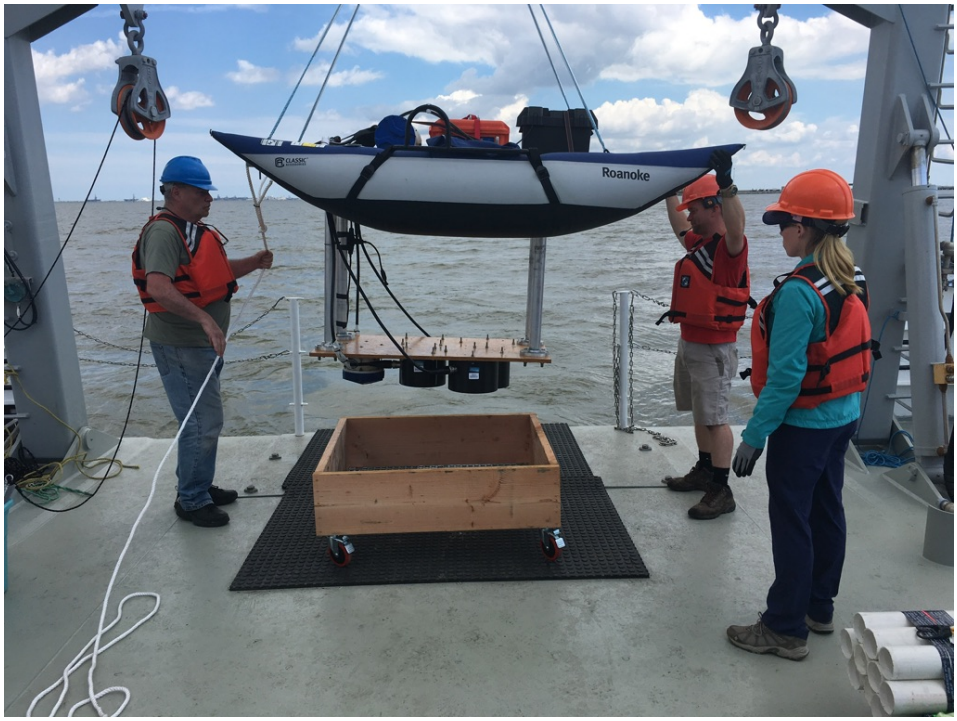

Figure 13. The Banshee during deployment from the fantail, showing its underwater substructure; four echosounder transducers and an ADCP were mounted on the wooden plate 1 m below the waterline.

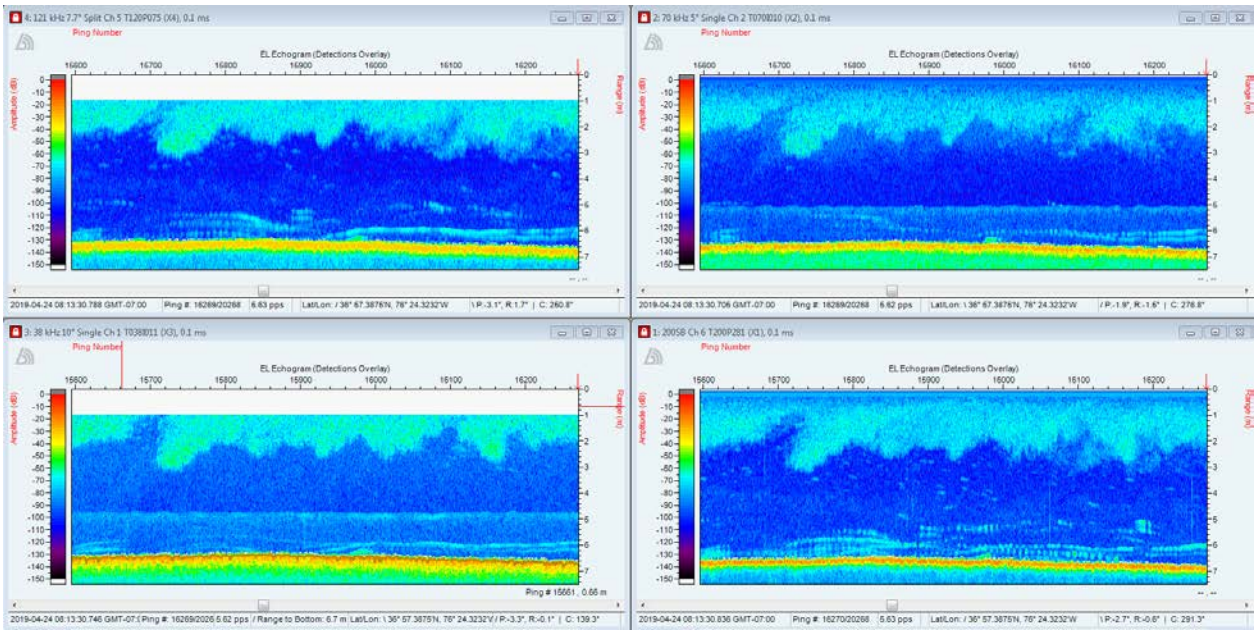

Figure 14. Four channels of BioSonics data as seen on the laptop aboard R/V Virginia while Banchee was deployed on 24 April. The strong scattering (light blue) is from entrained bubbles at the front along the northern wall of the navigation channel to the east of the tunnel ditch.

F. MINI-MOORING

The Mini Mooring consisted of three Acousondes deployed on a vertical line suspended below an anchored surface buoy. The three hydrophones occupied depths of 2.3 m, 3.5 m and 5.5 m. Weight at the bottom of this line ensured the line remained approximately vertical in the water column– in essence, creating another vertical line array. The Mini-Mooring was deployed at site R4 on 23 and 24 April to observe the acoustic signals propagating to the east from the source at S3a through (parallel to) the bubble-laden front along the northern wall of the navigation channel. Analysis of these signals will be compared to those observed at N5 which propagated to the south (perpendicular to the front).

G. BUBBLE DEVICE

One final piece of equipment was used during the experiment. The bubble device consisted of a Conductivity, Temperature and Depth sensor (RBR CTD #060315), two acoustic projectors (OceanSonics icTalkHF and icTalkLF) and a hydrophone (OceanSonics icListen) mounted on a makeshift frame and hand-deployed over the side of the ship by line (Fig. 15). Foam was fixed between each piece of wood to limit vibration and noise that may by picked up by the hydrophone. An anchor weight was fixed to the bottom of the device to provide some mass to keep the bubble device vertical in the water column. The device was deployed over the side of R/V Virginia primarily

during the drift across the front while operating the Banshee and gathering BioSonics data in the vicinity of the Mini Mooring at site R4.

The CTD monitored the environment while the hydrophone collected the signals emitted by the two projectors. The icTalkLF emitted a one second long LFM chirp from 1 to 8 kHz, and the icTalkHF emitted a 1 second long LFM chirp from 10 to 100 kHz. The transmission paths from sources to receiver were approximately 15 cm. The concept is based on Terrill and Melville (2000) and is designed to acoustically observe the frequency-dependent attenuation and travel time through the bubbly mixture in the front in order to extract bubble size distribution.

Figure 15. The bubble device was deployed over the side of R/V Virginia on 24 April during the same period that the Banshee was in the water.

IV. EXPERIMENT

Experimentation was conducted from 18 April through 25 April 2019 in the James River Estuary. The tidal cycle and the passage of the tidally-induced salinity front drove timing of the experiment each day. The James River Estuary experiences semi-diurnal tides, meaning that there are two low tides and two high tides daily. The semi-diurnal tide experiences inequity in that the high and low water levels each day are not the same, and are notated as higher high water and lower low water at the extremes. Verified low and high tide times at Sewell Point Station #8638610 during the experiment are found in Table 5. In Fig. 16 a visual is provided of the tidal levels. Over the course of the experiment it can be seen that the difference between the tidal levels gradually decrease as the tidal cycle moves from spring tide to neap tide. Spring tide was on 19 April, and neap tide was recorded on 26 April. The salt water intrusion front is seen throughout the entire tidal cycle.

Table 4. Verified High and Low Tide levels and Time during JRE2019 at Sewell's Point Station #8638610

Date	Time (GMT)	Verified (ft)
4/20/2019	2:18	3.58
4/20/2019	8:42	0.37
4/20/2019	14: 36	3.15
4/20/2019	20:42	0.13
4/21/2019	3:00	3.61
4/21/2019	9:30	0.12
4/21/2019	15:18	3.15
4/21/2019	21:24	0.37
4/22/2019	3:42	3.6
4/22/2019	10:12	0.64
4/22/2019	16:00	3.18
4/22/2019	22:18	0.66
4/23/2019	4:30	3.46
4/23/2019	11:06	0.64
4/23/2019	16:48	2.95
4/23/2019	23:00	0.73
4/24/2019	5:06	3.03
4/24/2019	11: 36	0.76
4/24/2019	17:54	2.75
4/24/2019	23:54	0.99
4/25/2019	6:06	3.18
4/25/2019	12:30	1.07
4/25/2019	18:30	2.94

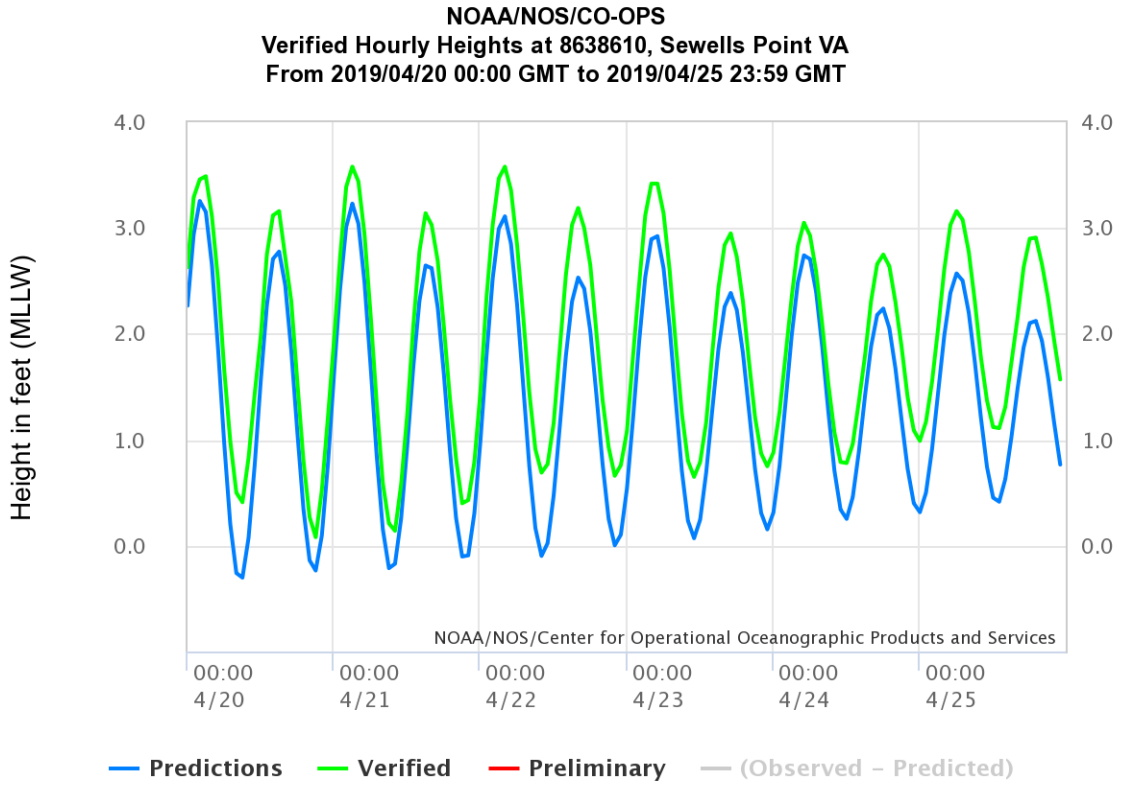

Figure 16. Tidal cycle heights as recorded at Sewells Point NOAA Station #8638610 during JRE2019. The slight difference in tidal variation can be seen as the tidal cycle moves to neap tide.

Each day, underway time of the R/V Virginia was dictated by the tidal cycle and the predicted times of high and low tide. The objective was to place the equipment in the water early in the flood tide so that sound transmission began in entirely fresh water and data recorded included acoustic transects of fresh water. Data was subsequently collected during frontal passage as the flood tide entered the sound source transmission path. This ensured that the sound transmission loss and sound propagation differences were recorded and could be studied.

On the first day, 18 April, R/V Virginia was underway at 1102Z for a verified high tide time of 1436Z. The day was used to place equipment that would be on station for the duration of the experiment. The moored stations N1, N2, N3, N4 and N5 were all deployed that day. Tables 2, 3 and 4 describe the stations, equipment at each, their locations and the deployment and recovery times.

Log entries from 18 April 2019 are as follows:

0229Z – ADCP 2595 tests OK. Downloaded program JRE19.whp.

0242Z – ADCP 7290 tests OK. Downloaded program JRE19.whp.
0257Z – ADCP 5542 tests OK. Downloaded program JRE19.whp.
1159Z – Depart Weems, on the Rappahannock River for the James River.
1835Z – Finished preparing the four moorings. ADCP 2595 on Spider 24, ADCP 7290 on Spider C2.
1845Z – First line out in Bluewater Yachting Center to pick up passenger.
1850Z – Underway
1907Z – Start ADCP 7290 on Spider C2.
1920A – Start ADCP 2595 on Spider 24. Both ADCPs respond correctly; unable to hear over engine noise.
2024Z – Deploy Spider C2 with ADCP 7290 at site N1(on bottom time).
2030Z – Anchors away at N1.
2040Z – Deploy Spider 24 with ADCP 2595 and Acousonde A061 at site N3 (on bottom time).
2057Z – Anchors away at N3.
2151Z – Deploy Station #1 with Acousonde A060 at site N4 (on bottom time).
2158Z – Anchors away at N4.
2225Z – Deploy Station #2 with Acousonde A062 at site N5 (on bottom time).
2230Z – Anchors away at N5.
2255Z – Deploy WHOI Tripod at site N2 (on bottom time).
2301Z – Anchors away at N2.
0004Z (19 April 2019) – First line over at Bluewater Yachting Center.

Due to weather, experimentation was unable proceed on 19 April and R/V Virginia did not go underway.

On 20 April, the day was used to master the deployment and recovery process of the gear and reposition Spider C2 slightly from site N1 to site N1a. The reposition was necessary to accommodate another experiment underway concurrently. Log entries for the day are as follows:

1102Z – R/V Virginia underway.
1153Z – Reupload batteries in Castaway 5002.
1628Z – Coffin deployed.
1641Z – Anchors away at coffin location 36° 58.17N, 076° 26.23W.
1700Z – Coffin Recovered.
1725Z – Coffin deployed with weights and four batteries at 36° 58.061N, 076° 26.506W.
1739Z – Coffin recovered.
1905Z-1910Z – VLA deployed and recovered. Weight too far forward.
1912-1917Z – VLA deployed and recovered. Weight more aft.
2213Z – N1on deck at 36° 57.404N, 076° 24.819W.
2231Z – N1 in water at 36° 57.418N, 076° 24.662W.
2238Z – Anchors away at N1a at 36° 57.433N, 076° 24.675W.
2340Z – R/V Virginia in port at Bluewater Yachting Center.

On 21 April R/V Virginia was underway at 0909Z for a high tide time of 1518Z. On this day, the VLA and the coffin were used to transmit and collect signal through the front between R1 and S1 west of the bridge-tunnel. The VLA was deployed at location R1 and the source was deployed at S1. In this configuration, sound was transmitted and received in the north to south direction as the estuarine front came from the east. Table 5, below, gives details on equipment used, deployment and recovery times.

Table 5. Equipment Deployment on 21 April

Equipment	Time and Location Deployed	Time and Location Recovered	Gear Notes	Site
VLA (Receiver)	1042Z 36° 56.927N, 076° 24.744W	1826Z 36° 56.948N, 076° 24.965W	RBR Solo Temp sensor #101610	R1
Coffin (Source)	1250Z 36° 57. 363N, 076° 24.274W	1846Z, 36°57.505N, 076° 24.870W	Lubbell hydrophone, Acousonde A065	S1

Log entries from 21 April are as follows:

0909Z – R/V Virginia underway from Bluewater Yachting Center.
0946Z – Program RBR Solo Temperature #101610 to start at 0955Z, 5 second sampling rate. Estimated logging ends on 12/1/2023.
1042Z – VLA platform deployed; anchors away (includes RBR Solo Temp #101610). 36° 56.927N, 076 ° 24.944W = R1.
1239Z – Program RBR Solo Temperature #101596. Set to start at 1250Z. Five second sampling rate. Estimated logging ends on 9/1/2023.
1250Z – Lubell source in water, broadcast driven by electronics in coffin (on fantail) at 36° 57.363N, 076˚24.274W
1340Z – Fully outfitted coffin anchored and is broadcasting with Acousonde A065 and RBR Solo Temp #101596. 36° 57.518N, 076° 24.855W. A065 depth is 1.5 m.
1826Z – VLA platform aboard. 36° 56.948N, 076° 24.965W.
1846Z – Coffin aboard. 36° 57.505N, 076° 24.870W.
1938Z – In port Bluewater Yachting Center.

On 22 April R/V Virginia was underway at 0939Z, for a high tide time that was verified that day to be at 1600Z. The coffin and VLA were immediately prepared for deployment. The coffin was deployed at S1, and the VLA was deployed at R3. The Banshee was also deployed on 22 April, but experienced complications – the BioSonics cables did not connect to the deck box. It was deployed via crane and remained attached to the ship this way for two short intervals before Banshee operation was suspended for the day. Table 6, below, gives details on equipment used, deployment and recovery times.

Table 6. Equipment Deployment on 22 April

Equipment	Time and Location Deployed	Time and Location Recovered	Gear Notes	Site
VLA (Receiver)	1135Z 36° 56.924N, 076° 24.947W	1944Z 36° 56.924N 076° 24.947W	RBR Temperature sensor #082173 (platform), #101610 (VLA).	R3
Coffin (Source)	1122Z 36° 57.517N, 076° 24.871W	1922Z 36° 57.153N 076° 24.847W	RBR Temperature sensor #101596, Acousonde A065, Lubbell hydrophone	S1
Banshee	1520Z; 1835 36° 57.302N, 076° 26.008W; 36° 57.15N, 076° 24.847W	1527Z; 1845Z	Connectors/cables do not match connections on gear box	

Log entries from 22 April are as follows:
0939Z – R/V Virginia underway. “Green” GPS is running.
0945Z – Preparing coffin for deployment. Replaced signal generator. RBR T sensor #101596: start at 1000Z on 22 April at 5 second sampling rate. Included Acousonde A065.
1006Z – Preparing RBR T/P for VLA platform. Sensor #082173. Start at 1030Z on 22 April at 2 Hz sampling rate (good until 5/24/2019). Attached 6 in above yellow hydrophone.
1037Z – RBR T sensor #101610 set for VLA: Start at 1045Z with a 5 second sampling rate (good until 8/2/2023).
1122Z – Coffin deployed at 36° 57.517N, 076° 24.81W.
1135Z – VLA deployed at 36° 56.924N, 076° 24.947W.
1520Z – Banshee deployed; tethered. 36° 57.302N, 076° 26.008W.
1527Z – Banshee recovered.
1739Z – Complications with Banshee; the BioSonics connector/cables do not match the connections on the deck box.
1835Z-1845Z – Second test of Banshee: rearranged weight balance works. However, line got caught on lower deck during deployment.
1922Z – Coffin recovered at 36° 56.517N, 076° 24.871W.
1944Z – Recover VLA at 36° 56.924N, 076° 24.947W. Complication: anchor line wrapped around the rudder
2004Z – After cutting the anchor line near the top (having grappled for the line below the mag) able to pull the line in and clear.
2107Z – In port Bluewater Yachting Center.

On 23 April R/V Virginia was underway at 1006Z from Hampton Harbor. Below in Tables 7 and 8 are a summary of equipment deployment. On this day the VLA was

deployed again at R3 while the Mini Mooring was deployed at R4 as another asset to measure transmission loss. The sound source, or coffin, was deployed at S3a. S3a is a position south of the I-664 northern bridge in the opening of the river (over the tunnel). This sound source positioning allowed for a more direct path between source and receiver at S3a to R4 across the approaching front and measured through the front in a more east to west transect. In addition, the bubble device was also deployed throughout the day primarily to test its operation.

Table 7. Equipment Deployment on 23 April

Equipment	Time and Location Deployed	Time and Location Recovered	Gear Notes	Depth	Site
VLA (Receiver)	1155Z 36° 86.921N, 076° 24.514W	1921Z 36° 56.913N 076 ˚24.92W	RBR Temperature sensor #082173 (platform), #101610 (VLA).		R3
Coffin (Source)	1133Z 36° 57.361N, 076° 24.859W; 1241Z 36° 57.362N, 076° 24.865W	1232Z 36° 57.362N 076° 24.865W; 1845Z 36° 57.33N 076° 24.366W	Dragged anchor. RBR Temperature sensor #101596, Acousonde A065, Lubbell hydrophone	A065: 1.5 m Source: 4.5 m	S3a
Mini Mooring	1105Z 36° 57.051N, 076° 23.957W	2105Z 36° 57.665N 076° 23.865W	Acousondes A063, A064, A066 (surface to bottom)	A063: 2.3 m A064: 3.5m A066: 5.5m	R4

Table 8. Bubble Device Deployment on 23 April

Time and Location Deployed	Time and Location Recovered
1815Z	1817Z
1821Z	1823Z
2155Z	2155Z
2210Z, In port; 37 ˚01.063N, 076˚ 20.584W Port side aft	2215Z
2216Z, In port; 37 ˚01.063N, 076˚ 20.584W Stbd stern	2221Z
2223Z, In port; 37 ˚01.063N, 076˚ 20.584W Port mid-fantail	2228Z

Log entries from 23 April are as follows:

1006Z – R/V Virginia underway from Bluewater Yachting Center.
1009Z – Prepare RBR Temperature sensor #101596 for the coffin. Starts at 1030Z, sampling rate of 5 seconds, good until 2023.
1013Z – Prepare RBR Temperature sensor #101610 for the VLA box. Start at 1045Z, sampling rate of 5 seconds, good until 2023.
1018Z – Prepare RBR Temperature/Pressure sensor #082173 for the Mini Mooring (Acousonde mooring). Start at 1045Z, sampling at 2 Hz, good until 2023.
1105Z – Deploy Acousonde Mini Mooring at 36˚ 57.057N, 076˚ 23.951W. Includes Acousondes A063, A064, A066 (surface to bottom) at 2.3 m, 3.5 m, 5.5 m depth.
1133Z – Coffin deployed at 36° 57.361N, 076° 24.859W. Includes Acousonde A065 at 1.5 m depth.
1155Z – VLA deployed at 36° 56.921N, 076° 24.954W.
1232Z – Coffin dragged anchor. Recover coffin at 36° 57.250N, 076° 24.514W.
1241Z – Coffin redeployed 36° 57.362N, 076° 24.865N.
1506Z – Preparing RBR CTD #060315 for bubble contraption. Start at 1530Z on 23 April, end at 1530Z on 25 April. Sample rate 1 Hz. Deployed bubble contraption. See table 8.
1845Z – Recovered Coffin.
1905Z – Recovered anchor for coffin at 36° 57.33N, 076 24.866W.
1921Z – Recovered VLA – 36° 56.913N, 076° 24.927W.
2105Z – Recovered Acousonde Mini Mooring – 36° 57.665N, 076° 23.865W.

2208Z – In port Bluewater Yachting Center.
2210Z-2228Z – Deployed and recovered bubble contraption for readings off starboard and port side of ship. See table 8.

On 24 April the Banshee and its instruments were prepared for deployment, as an added instrument for the day's experiment and retry after the problems of the day prior. A goal of this day was also to measure from S3a to R3 and R4 with the VLA and Mini-Mooring. At 1400Z R/V Virginia was in place east of the tunnel and drifting south across the estuarine front with the Banshee deployed, hanging from the crane with a line to the Banshee's bow. The idea of this drift was to collect CTD, noise and BioSonics data across the front with no interference from the engine of the ship. By 1401Z the ship was drifting to the southwest. The 200kHz fathometer showed bubbles all the way to the bottom of the estuary at 24 feet. After the ship repositioned itself, bubbles were seen in the water column to about 34 feet at 1446Z.
This pattern of resetting to drift across the front continued through the afternoon while the coffin and VLA operated and collected data. At 1740Z while the ship was drifting, it was noticed that the front was receding north back towards the bridge as the flood began to weaken. The experiment moved shortly thereafter to the coal piers to the northwest of the bridge tunnel to collect data for purposes outside of this technical report, and for the Navy Research Labs (PI onboard). The Banshee continued to collect data near the coal piers and was deployed via its line during southeast transit at 1830Z.

Table 9. Equipment Deployment on 24 April

Equipment	Time and Location Deployed	Time and Location Recovered	Gear Notes	Depth	Site
VLA (Receiver)	1155Z 36 ˚ 56.927N, 076˚ 24.945W	2030Z 36˚56.927N 076˚ 24.945W	RBR Temperature sensor #082173 (platform), #101610 (VLA).		R3
Coffin (Source)	1220Z 36˚57.370N, 076˚ 24.833W	1022Z 36˚58.359N 076˚ 24.820W	RBR Temperature sensor #101596, Acousonde A065, Lubbell hydrophone	A065: 1.5 m Source: 4.5 m	S3a
Banshee	1347Z drifting across front; 1808Z move to coal piers	1934Z 36˚57.870N 076˚ 25.888W	ADCP #5542 started at 1245Z. Command program: JRE19.whp	Echo-Fsounder just below surface	Hanging from crane
Mini Mooring	1129Z 36˚57.677N, 076˚ 23.877W	2111Z 36˚57.538N 076˚ 23.628W	Acousondes A063, A064, A066 (surface to bottom), RBR	A063: 2.3 m A064: 3.5m	R4

			T/P #052170	A066: 5.5m	

Log entries from 24 April are as follows:

1011Z – Prepare RBR T/P sensor #082173 for VLA. Start at 1030Z. Sampling rate of 2 Hz. Good until 5/24/2019.
1012Z – R/V Virginia underway.
1026Z – Prepare RBR Temperature sensor #101610 for VLA. Start at 1045Z, sampling at 5 seconds. Good until 9/4/2023.
1030Z – Prepare RBR T#101596 for coffin. Start at 1045Z. Five second sampling rate. Good until 9/4/2023.
1034Z – Acousondes on Mini Mooring: A063, A064, A066 (surface to bottom order) at 2.3 m, 3.5 m, 5.5 m. Acousonde on coffin (source): A065. 1.5 m depth
1048Z – Prepare RBR T/P #052170 for Mini Mooring. Start at 1100Z, sampling at 2 Hz. Good until 9/5/2023.
1129Z – Deploy Mini Mooring at R4: 36° 57 .677N, 076° 23877W.
1155Z – Deploy VLA at R3: 36° 56.927N, 076° 24.945W.
1220Z – Deploy coffin at S3a: 36° 57.370N, 076° 24.833W.
1245Z – Started ADCP #5542 on Banshee command program JRE19.whp. All command responses are correct when test (cannot hear audible signals.)
1307Z – ADCP heard pinging.
1347Z – Banshee deployed, hanging from crane, with tether from Banshee bow to ship. Deployed at 36° 57.589N 076° 23.961W.
1400Z – Plan is to drift south; reposition to north, drift across front east of tunnel. Now drifting.
1408Z – Prepare RBR Concerto CTD #60315 for Bubble Contraption. Start at 1415Z, sample rate at 1 Hz. Nominal end time 1415Z on 10/25/19.
1401Z – Turn engine on to move across front doing CTD and dBRD profiles while drifting Banshee nose down in water.
1410Z – Drifting to SW. 200 kHz fathometer shows bubbles to bottom at 24 ft. Picture taken.
1417Z – Turns on engine; picture.
1423Z – Drifting WSW in front of nonlinear current.
1448Z – Turns on; picture.
1454Z – Tidewater passed close by; prop wash/wake.
1456Z – Bubbles to ≥ 34 ft. Picture.
1459Z – Turns on; Navy ship passed; picture.
1513Z – Resetting east to sample.
1520Z – Drifting; set/drift; 246° at 1 kt.
1527Z – Bubbles to 18 ft.
1532Z – Resetting.
1535Z – Drifting, bubbles > 18 ft.
1546Z – Picture taken.
1550Z – Resetting.
1554Z – Drifting; put Banshee in on top of bubbles
1559Z – Turns on; Resetting.

1601Z – Drifting.
1605Z – Bubbles > 20 ft; picture.
1620Z – Resetting.
1630Z – Drifting.
1634Z – Bubbles > 20 ft, just south of 7 ft ledge. Good that there exists bubbles along (northern) wall (of navigation channel); it correlates to S3-R4 acoustic transect.
1638Z – Bubbles to bottom at 28 ft; picture.
1645Z – Picture.
1655Z? – Resetting.
1603Z – Drifting: dBRd at 14 ft; was 9 ft.
1715Z – Picture. Bubbles to 20 ft.
1726Z – Picture.
1728Z – Resetting.
1740Z – Drifting. Note: Looks like front recedes north back towards bridge as flood weakens.
1751Z – Bubbles; picture.
1755Z – Picture. Bubbles to 18 ft.
1808Z – Moving to coal piers; picture.
1811Z – Castaway: as we passed over the I-64 bridge-tunnel into the convergence zone (and deeper water), the tend of the line changed.
1830Z – Survey tracks next to coal piers; moving SE making way/let Banshee going backwards thru water 180°; picture.
1853Z – Turning to NW track.
1925Z – Finished 2.5 tracks; moving to recover source at S3.
1934Z – Recovered Banshee at 36° 57.870N, 076° 25.888W.
2022Z – Recover the coffin at 36° 57.359N, 076° 240820W.
2030Z – Recover VLA at 36° 56.927N, 076˚ 24.945W.
2111Z – Recover Mini Mooring – at 36° 57.538N, 076° 23.628W.
2208Z – In port at Bluewater Yachting Center.

25 April was a gear recovery day for the experiment. Tables 2, 3, and 4 list equipment recovery locations.

Log entries from 25 April are as follows:
0958Z – R/V Virginia underway from Bluewater Yachting Center.
1146Z – WHOI tripod aboard at 36° 57.210N, 076° 24.387W.
1223Z – N5 aboard at 36° 57.054N, 076° 24.524W.
1255Z – Spider 25 at N3 aboard at 36° 57.024N, 076° 24.754W.
1327Z – Stanchion #1 at N4 aboard at 36° 56.864N, 076° 25.395W.
1418Z – Spider C2 at N1 aboard at 36° 57.434N, 076° 24.785W.
1543Z – Lines out at Hampton Harbor fish market piers at 37° 01.406N, 076° 20.555W.

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