

NPS-OC-22-001



# NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

**MOBILE BAY ESTUARY ACOUSTIC FIELD EXPERIMENT**

by

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June 2021

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## ABSTRACT

The Mobile Bay Estuary Acoustic Field Experiment 2021 (MBE2021) was funded by the Office of Naval Research (ONR) as part of the multi-university Undersea Remote Sensing (USRS) program directed by Dr. Reginald Beach (ONR 322). During the experiment, environmental and acoustic data were collected during June 9-15 in the vicinity of the mouth of Mobile Bay, focused on assessing the impact on acoustic propagation by the tidal intrusion front during flood and the ebb plume front during ebb. This report documents details of the equipment used by the Naval Postgraduate School during the study and presents initial findings. Initial findings indicate (a) that rather than being limited to a surface layer, bubbles are present through the entire water column in the "Dixey V", the persistent feature near Mobile Point formed by the convergence of seawater in the bay mouth during flood; (b) bottom currents in the bay mouth exceed 1 m/s; and (c) the bubble clouds in the Dixey V contribute to effective sound speeds well below the intrinsic sound speed of bubble-free seawater. Results of ongoing analysis will be published in peer-reviewed scientific journals.

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# I. INTRODUCTION

## A. OVERVIEW OF THE EXPERIMENT

The Mobile Bay Estuary Acoustic Field Experiment 2021 (MBE2021) was funded by the Office of Naval Research (ONR) as part of the multi-university Undersea Remote Sensing (USRS) program directed by Dr. Reginald Beach (ONR 322). The Naval Postgraduate School (NPS) was one of several universities involved in the USRS project, including Naval Research Laboratory (NRL), Woods Hole Oceanographic Institute (WHOI), Applied Research Laboratory at the University of Texas Austin (ARL/UT), Oregon State University (OSU), and the Applied Physics Laboratory at the University of Washington (APL/UW). The experimental area was centered on the entrance to Mobile Bay from the Gulf of Mexico, between Fort Morgan at Mobile Point to the east and Fort Gaines on Dauphin Island to the west. The bathymetry in this region was surveyed in April 2021 by NRL, ensuring accurate bathymetry data was known for operational considerations (e.g. equipment placement and safety of ship) as well as to assist improve model boundaries. OSU installed and operated an X-Band radar backscatter system at Fort Morgan which provided excellent characterization of surface roughness in the mouth of the bay. Much of the acoustics focus was on the "Dixey V", the persistent feature near Mobile Point formed by the convergence of seawater in the bay mouth during flood (Fig. 1). Acoustic equipment included a moored source and moored receivers to study low-to-mid-frequency (L2MF) acoustic propagation through the bubble-laden fronts; and a bubble device (termed the "dBRd") to investigate the properties of the Dixey V bubble clouds. The dBRd consisted of one acoustic projector (OceanSonics (OS) icTalkHF), three hydrophones (OS icListenHF), a digital hub (OS icLink) for clock synchronization, and a conductivity, temperature, and depth (CTD) sensor (RBR *Concerto*) strapped to the frame to provide the ability to compare the contribution of the changing salinity and temperature versus the presence of bubbles to sound speed.



Figure 1 Drone photo by UAV controlled by Oregon State University operator

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## II. ENVIRONMENT

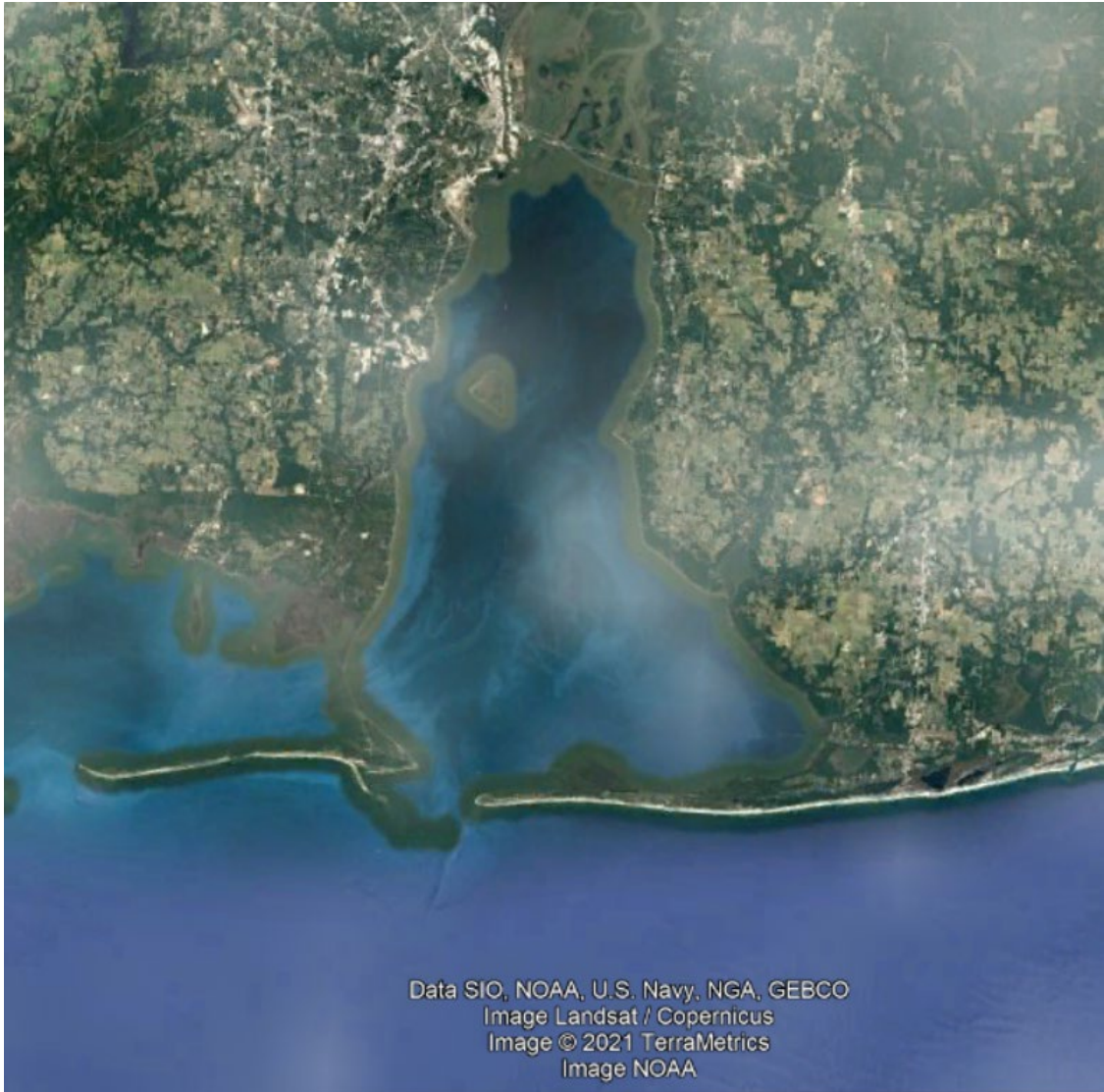
### A. DESCRIPTION OF THE ESTUARINE AREA OF STUDY

Mobile Bay (MOB) represents a large geographic that is ~55km long and an average of 17km wide. Although the water area is large, the water is consistently shallow, with a depth of ~3m, with the exception for a shipping channel that is dredged to 14m deep and is maintained at a width of 120m. Mobile Bay receives runoff from the Mobile-Tensaw River system, representing the fourth largest river discharge in the US, and the sixth largest discharge region (Lee et al. 2013). River discharge into MOB represents ~1800m<sup>3</sup>/s (Lee et al. 2019). This creates a strong ebb current which can exceed 1m/s.

In addition to these freshwater inputs, there are two paths for salt water to enter MOB (Fig. 2). The Pass aux Heron (PAH) enables water to flow from the Mississippi Sound, while the Main Pass (MP) lets water flow from the Gulf of Mexico. Having two different paths for salt water to enter MOB creates a distinct flow in the southernmost portion of MOB. Due to Dauphin Island blocking direct flow from these two paths, a difference in tide levels based on time can be seen of ~40.6° difference, or 2.7 hours (Lee et al. 2019). While approximately 86% of the flow passes through MP, the remainder passes through PAH. Along the United States Gulf Coast typical tidal ranges are <0.5m (Lee et al. 2013). Fronts are formed between the two water masses having differing properties (Fig. 1), often with lines of bubbles in the water column and foam lines on the surface.

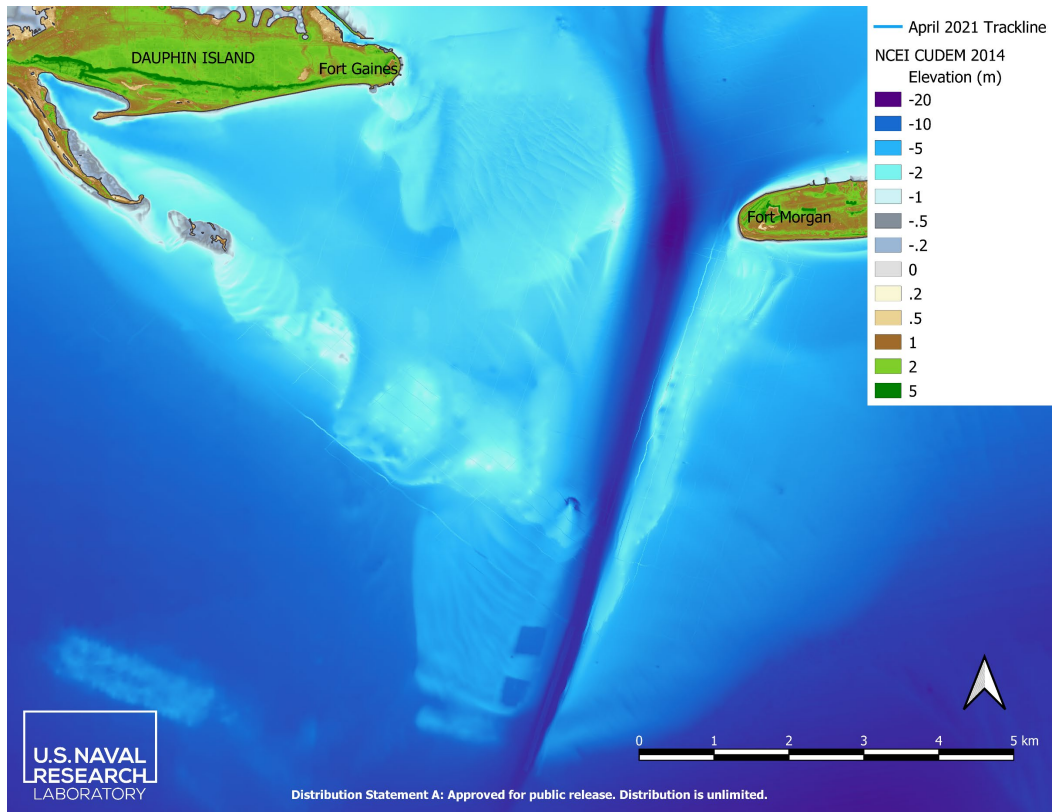
Due to each of the water masses having slightly different properties, they can be seen at the surface for where they meet (Fig. 1). As the water is typically stratified, where these bodies of water meet, a line of bubbles can be seen. These bubbles show where the surface of a salt wedge is intruding/departing MOB.

The MP bathymetry was surveyed by NRL in April 2021 using a Norbit iWBMSH STX 512 MBES at 400kHz with a swath width of 120°. Over the course of seven days, NRL completed 263km of survey lines, with 44 CTD casts. This data was post-processed and displayed in figure 3.



Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat / Copernicus  
Image © 2021 TerraMetrics  
Image NOAA

**Figure 2 Google Earth imagery of Mobile Bay**



**Figure 3 NRL Survey depths at Mobile Bay Main Pass**

### III. EQUIPMENT

#### A. SHIP AND SCHEDULE

The experiment carried out over the course of two weeks. Two vessels were used during this time by the NPS team, with both provided through the auspices of the Louisiana University Marine Consortium (LUMCON). The equipment was mobilized 05-07June. The R/V Coastal Profiler arrived in Mobile Bay 06June to transfer our equipment onboard. The R/V Coastal Profiler is a 41-foot by 16-foot Lafitte style skiff owned and operated by Louisiana State University (Fig. 4). The first day on the water was 07June and was used as a test day inside Mobile Bay. The purpose of this testing was to ensure the mini-cat had enough floatation and would support the weight of the coffin without risking the electronics, as well as to practice launching all of the equipment where there was smaller surface waves to ensure safety of the crew. Following this test, the spider was launched and recovered. The final test was to connect the spider and mini-cat and practice the launching sequence. After two attempts, it was determined to launch the mini-cat first, followed by the spider, with an anchor line to a float. Retrieval was done in reverse order, with the float line to a 25lb anchor, spider, and finally retrieving the float.

From June 10-14 the dBRd was launched while drifting across the bubble front. While drifting, the engines were turned off to limit vessel noise, while determining the effect the bubbles formed at the TIF on sound propagating across the bubble device from the icTalk to the three icListens.

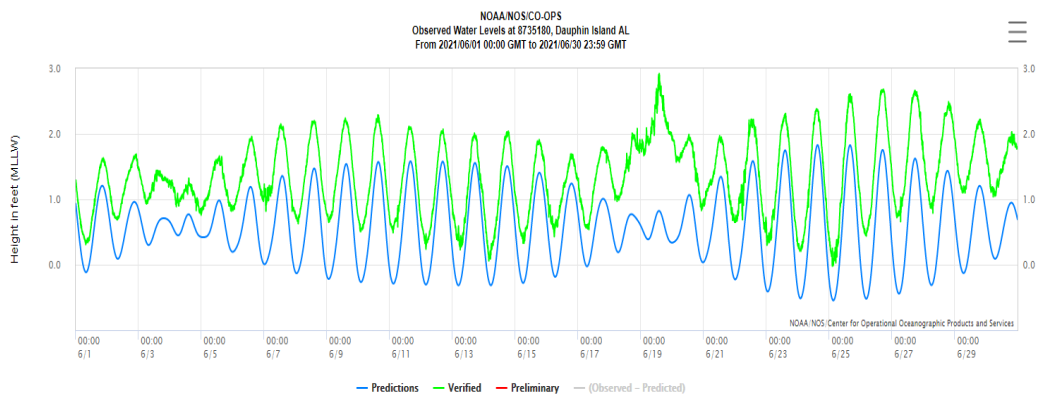


Figure 4 R/V Coastal Profiler

While returning to port on June 12, 2021, the starboard engine of the R/V Coastal Profiler had mechanical issues. LUMCON provided the R/V Caillou Boca (CB), a 24ft Boston Whaler style craft (Fig. 5). The CB was able to be used for the bubble device but was not large enough to launch the source on the spider. As such, from June 14-16 the source was not launched, and source data was dependent upon the R/V Point Sur. Typical underway times while on the CB were from 0700-1200, representing the ebb tide (Fig. 6).



**Figure 5 R/V Caillou Boca**



**Figure 6 NOAA Tide data for Dauphin Island, AL**  
 (<https://tidesandcurrents.noaa.gov/waterlevels.html?id=8735180&units=standard&bdate=20210601&edate=20210630&timezone=GMT&datum=MLLW&interval=6&action=>)

## B. SOURCE

The L2MF source and receivers were designed to be stationary for this project, to facilitate investigation of acoustic travel time through the bubble-laden estuarine fronts. The primary source was Lubell Lab's high-power broadband piezoelectric underwater acoustic transducer (LL1424-HP). The Lubell was mounted to a spider with 50lb lead weights bolted on each foot (Fig 7). The Lubell was powered and controlled from the "coffin" (described below) at the surface with a direct cable connection. There was a swivel between the source frame and the tripod to prevent the cable from twisting.



**Figure 7** Lubell source on spider. The spider was held in place with 50lb weights bolted onto each leg. A bungy chord was used to ensure the lines would not ensnare the Lubell sound source ability to swivel.

### C. LANDERS

Landers were built using threaded pipe. A center piece of either 5- or 6-way split was used to ensure the ability to assemble four legs, each of which was three feet long. Each leg was ended with a four-way split or an elbow based on availability of parts. Underneath the end of each leg and the center a six-inch threaded nipple was used to ensure the height of each was the same at each corner (Fig. 8). Using the four-way split made tightening to the correct angle far easier with the leg directly down, however the elbows worked well enough when four-way splitters were unavailable. Each lander was mounted with different equipment, summarized in Table 1, based on the desired data to be acquired at each location. Under the leg at the center of each lander a 45lb weight was mounted to each lander, with two 45lb weights being mounted on R2. R2 was placed in the region of the highest currents and was placed with the objective of measuring the local currents only and deployed with only a MAV, as such the extra weight was meant to ensure stability of the lander and prevent the MAV from tipping over.

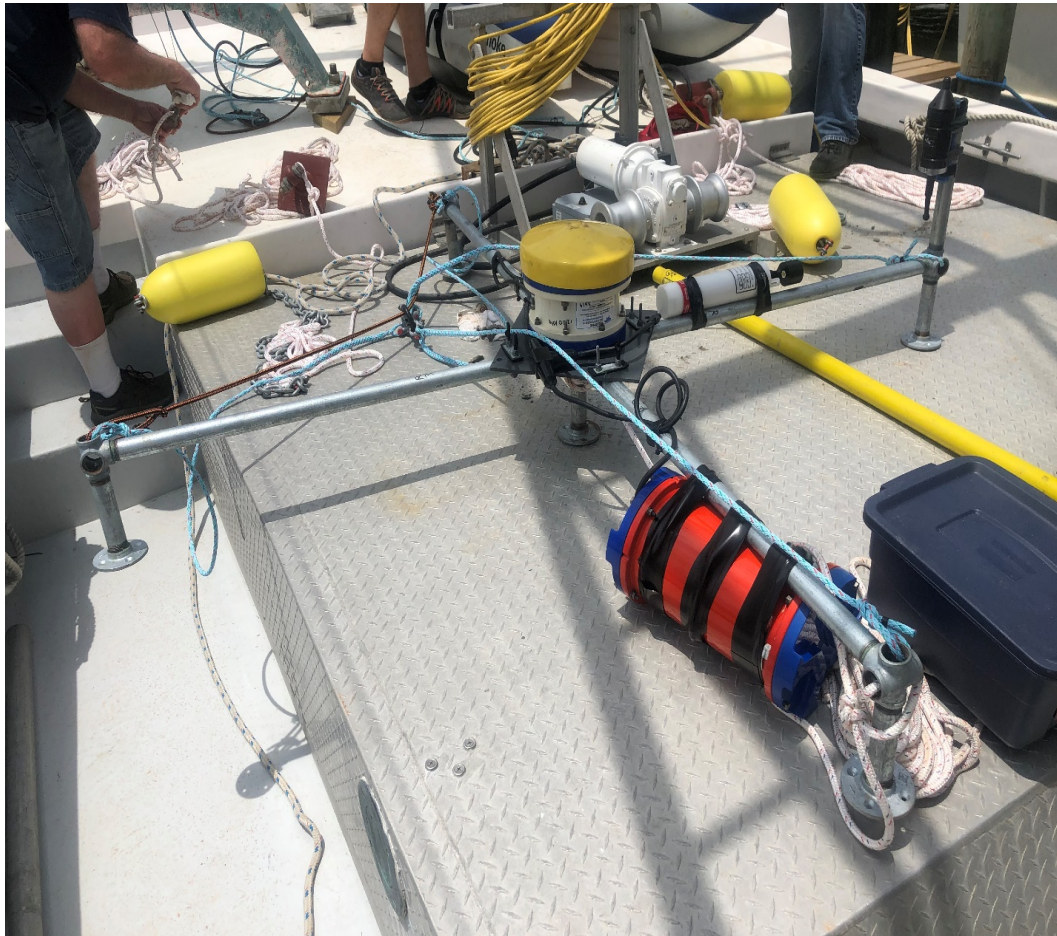


Figure 8 Receiver set up with RBR CTD, Acousonde, and ADCP used on three of the landers.

**Table 1 Equipment list on each deployed receiver and source**

Lander	Equipment	Serial Number	Lat/Long
R1	RBR CTD	60318	30°14.806'N
	MAV	10320	088°01.931'W
	Acousonde	A050	
	ADCP	2595	
R2	MAV	10307	39°13.587'N 088°01.870'W
R3	RBR CTD	60315	30°12.864'N
	ADCP	7819	088°00.842'W
	ST300	6222	
R4	RBR CTD	60319	30°12.154
	ADCP	7290	088°01.207'W
	ST300	6235	
R5	Acousonde	A066	30°13.086'N
	RBR CTD	205305	088°02.995'W
Source		Date	Lat/Long
		09June2021	30°11.324'N 088°01.641'W
		10June2021	30°11.324'N 088°01.641'W
		11June2021	30°15.725'N 088°01.878'W
		12June2021	30°15.746'N 088°01.823'W

#### D. COFFIN

The COFFIN was developed during the James River Experiment (JRE2021) and improved for this experiment. Within the COFFIN was three 24V marine batteries, a Siglent 1032X Signal Generator, a Crown CDi6000 source amplifier, and a Trimble GPS receiver (Fig. 9). The Trimble was connected to a receiver that was maintained on the mini-cat to ensure accurate GPS time to control transmission of the source. The COFFIN was connected via cable to the Lubell source to produce the sound while floating on the surface (Fig. 10). An addition during the last three days the source was launched was the use of a portable AIS (serial number 941204463) to assist with finding the COFFIN and source, enabling the research vessel to drift across the TIF during the experiment rather than sit watching the coffin. The Lubell was programmed through the Siglent 1032X Signal Generator to produce a 500-5000Hz chirp every two seconds at 180db with a 50% duty cycle. PVC pipes were added through the top of the COFFIN to act as splash screens, while allowing ventilation. Due to previous experience with how much heat was generated inside the COFFIN, a fan was added to the top of the COFFIN to aid in ventilation as well.



**Figure 9 COFFIN interior with waveform generator, three batteries, GPS receiver, amp, inverter, Lubell bridge, and cooling fan.**



**Figure 10 COFFIN on mini-cat after deployment, moored above the acoustic source on the spider tripod. Foil was added to assist in reflecting solar radiation.**

### **E. BUBBLE DEVICE**

The bubble device (dBRd) was designed using the legs of a trampoline, with holes drilled with bolts tightened to hold the legs together. This ensured a diamond shape, with the icTalks being a known distance apart. The icTalk produced a 10kHz-100kHz chirp at 130db, which could be measured by the icListens placed in accordance with figure 11. With the separation from the icTalk and icListen 1709 being 1.54m, and icTalk to icListens 1708/1710 being 0.86m, the sound speed through the bubbly liquid can be directly observed. A CTD was placed near the icTalk, which ensured the ability to calculate the intrinsic sound speed of bubble free water. The bubble device was deployed at two different depths, 0.5m and 1.5m. The depth was maintained by

either attaching the yellow buoys on the frame or by connecting them via line to the depth of 1.5m.



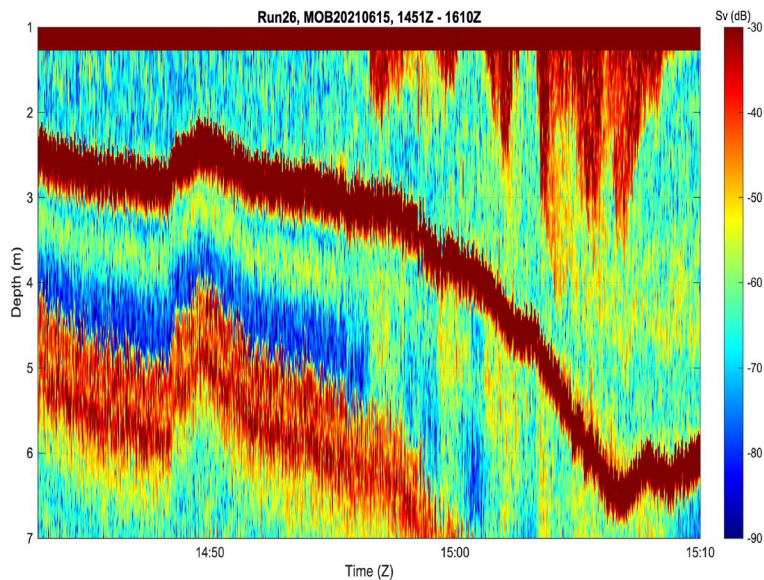
**Figure 11 Inverted dBRd prior to deployment with icTalk, icListens, icSync, and RBR visible. Yellow buoys were used to change the depth/maintain the depth of the dBRd system.**

**Table 2 Equipment on dBRd**

Equipment	Serial Number
CTD	205304
icTalk	2221
icLink	4037
icListen	1708
	1709
	1710

## F. SIDEMOUNT

A pole was designed to be mounted onboard the R/V Coastal Profiler by the ship's crew. This pole was designed to mount an ADCP, a Biosonics 420kHz transducer, and a Humminbird 360° sensor. The ADCP mounted on the sidemount was calibrated upside down, to ensure that the data received would be accurate for its orientation. The sidemount was placed over the side approximately amidship onboard R/V Coastal Profiler and was held in place with a single bolt through the pipe and a spacer that pushed against the hull near the underneath the gunwale to prevent the pole from vibrating excessively. On the R/V Caillou Boca, the sidemount was mounted on the starboard quarter, and strapped in with ratchet straps and tied with lines to prevent vibration. While the pole was in the water, the vessels were limited to <4kts of speed, which worked well for drifting across the TIF. The Biosonics was used to visualize how deep the bubbles formed at the TIF were (Fig. 12).



**Figure 12 Visual of Biosonics data. Red lines from surface represent bubbles**

## IV. EXPERIMENT

The experiment was conducted from June 5, 2021 – June 18, 2021, with data being collected from June 9-15, when a spring tide was present. The equipment was deployed spanning 4km north and 10km south of Mobile Point (Fig. 13). The time in the field was primarily based around the diurnal high tide, as measured in Table 3 from NOAA tide station located at Dauphin Island, Alabama #8735180. During an ebbing tide, the water exiting Mobile Bay encounters with water from the Gulf of Mexico, creating a “fan” of fronts outside the bay near Dixey Bar, forming a v-shaped front. Locating this “Dixey V” was done by looking at the breaking waves formed between the two different water masses, using radar data from Oregon State University (Fig. 14), as well as difference in watercolor (Fig. 15).

The MAV placed at R2 was used to measure bottom current velocity in the bay mouth, which had not been done previously. The data indicates that the model is close in the u sense, however, can be off by as much as 0.4m/s at peak velocity in v (Fig. 16). An example of RBR data from R5 was plotted (Fig. 17). This data can be used to measure when the tidal intrusion front passed this location, which can be used to correlate with the Oregon State University radar for when tidal passage occurred. In addition to using MAVs, the ADCPs deployed were used to measure current velocity (Fig. 18).

While operating the Biosonics transducer, the crew was able to visualize how deep bubbles formed by the breaking waves were carried through the water. These bubbles were seen to consistently fill the entire water column, indicating that they were not limited to just the near surface and would be a factor for sound travelling through the entire water column.

The field log for the experiment can be found in Table 4.

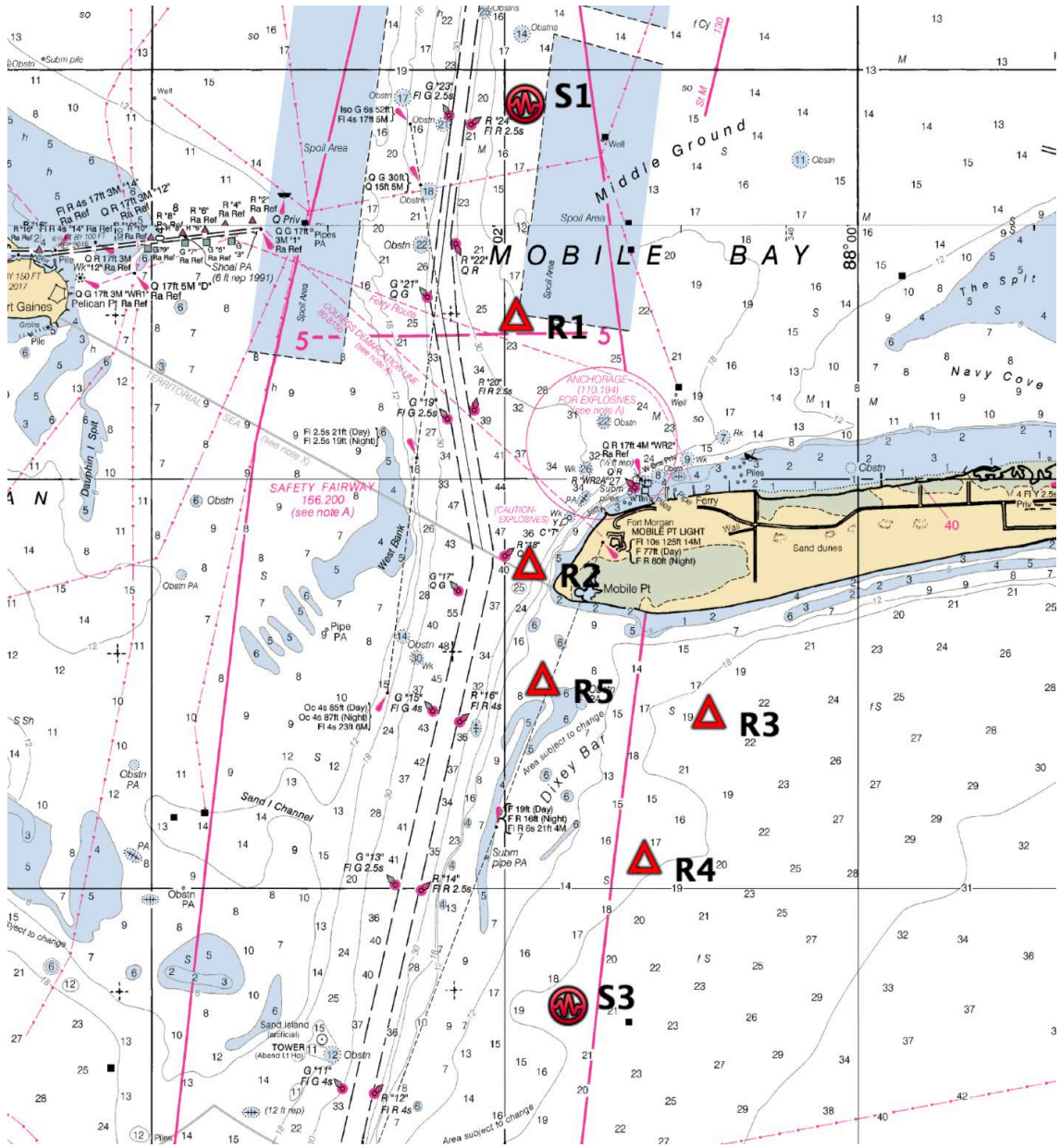
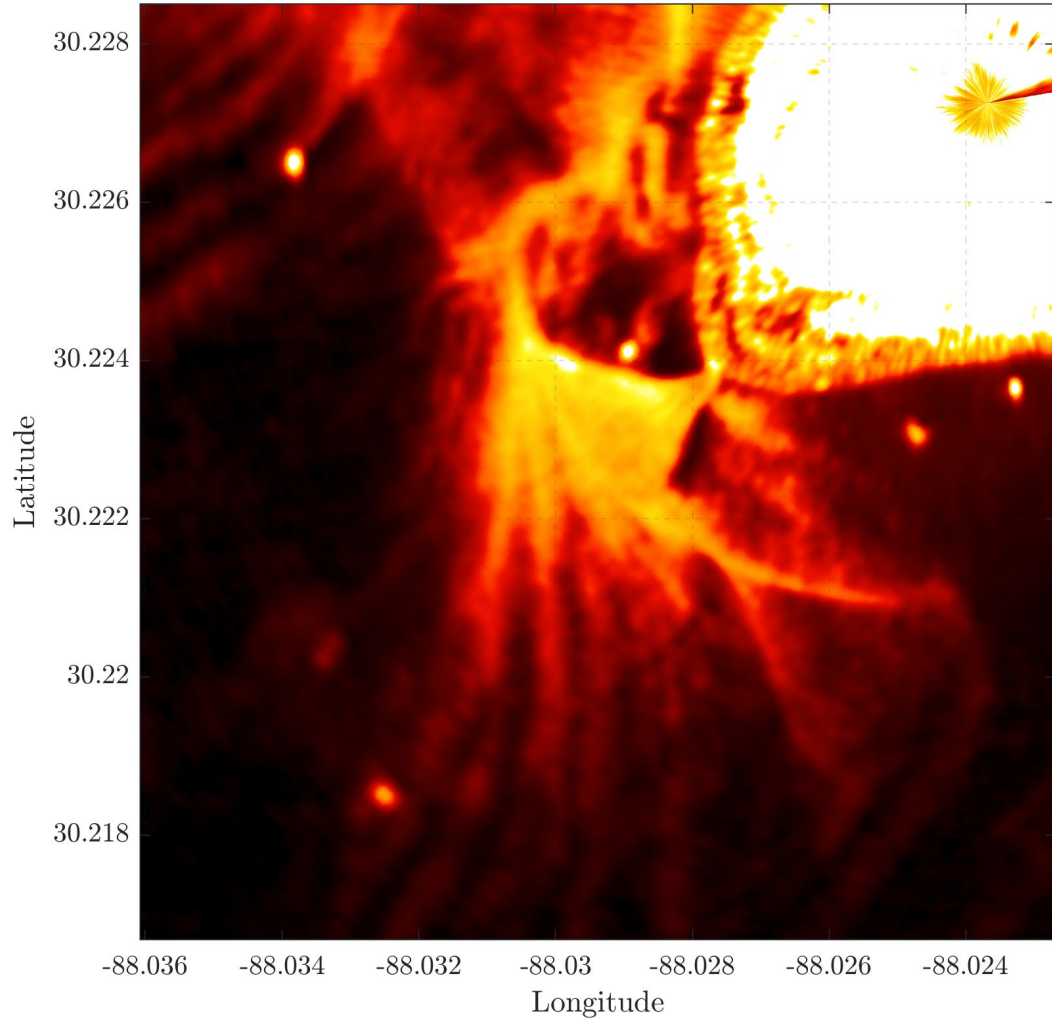


Figure 13 Approximate locations of Lubell source deployments (S) and landers (R).

**Table 3 Verified high and low tide times during experiment from <https://tidesandcurrents.noaa.gov/waterlevels.html?id=8735180&units=metric&bdate=20210601&enddate=20210630&timezone=GMT&datum=MLLW&interval=6&action=data>**

Date	Time (GMT)	Verified Height (m)
09June2021	01:24	0.197
09June2021	14:42	0.670
10June2021	02:06	0.160
10June2021	15:30	0.695
11-Jun-21	02:36	0.150
11-Jun-21	16:06	0.640
12-Jun-21	03:42	0.072
12-Jun-21	16:48	0.632
13-Jun-21	05:54	0.070
13-Jun-21	16:48	0.612
14-Jun-21	03:48	0.019
14-Jun-21	17:36	0.619
15-Jun-21	05:54	0.100
15-Jun-21	18:18	0.581

2021-06-15 14:09 UTC



**Figure 14 Radar image of the Dixey V from May 16, 2021 at 1409Z**



**Figure 15 Picture of front from near apex of the DV looking ESE toward Mobile Point. Sewater to the right, freshwater to the left**

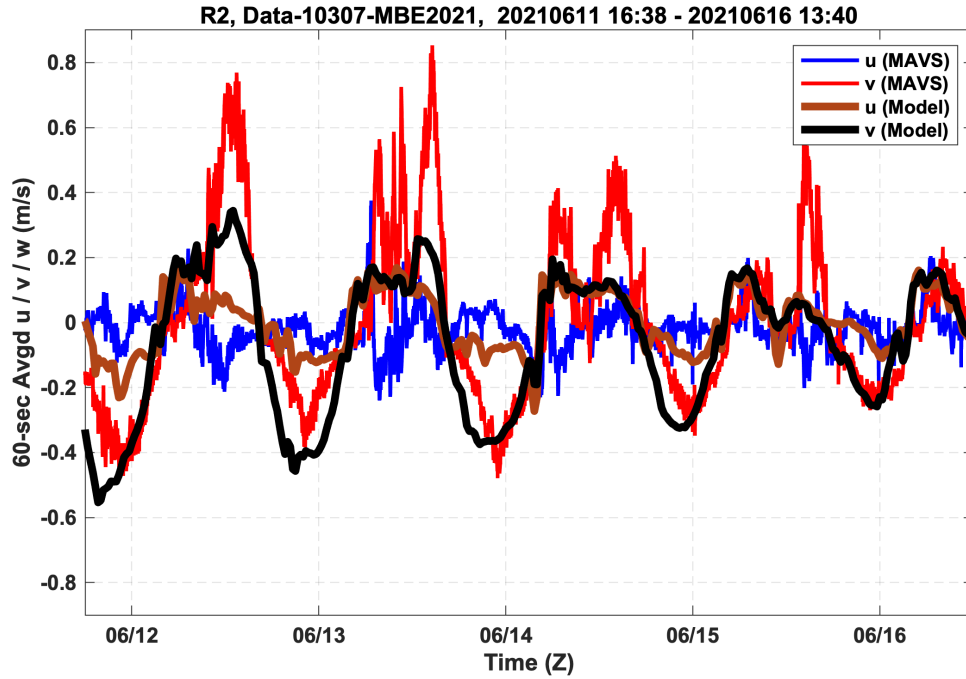


Figure 16 MAVs plot compared to model plot for MAV located at R2

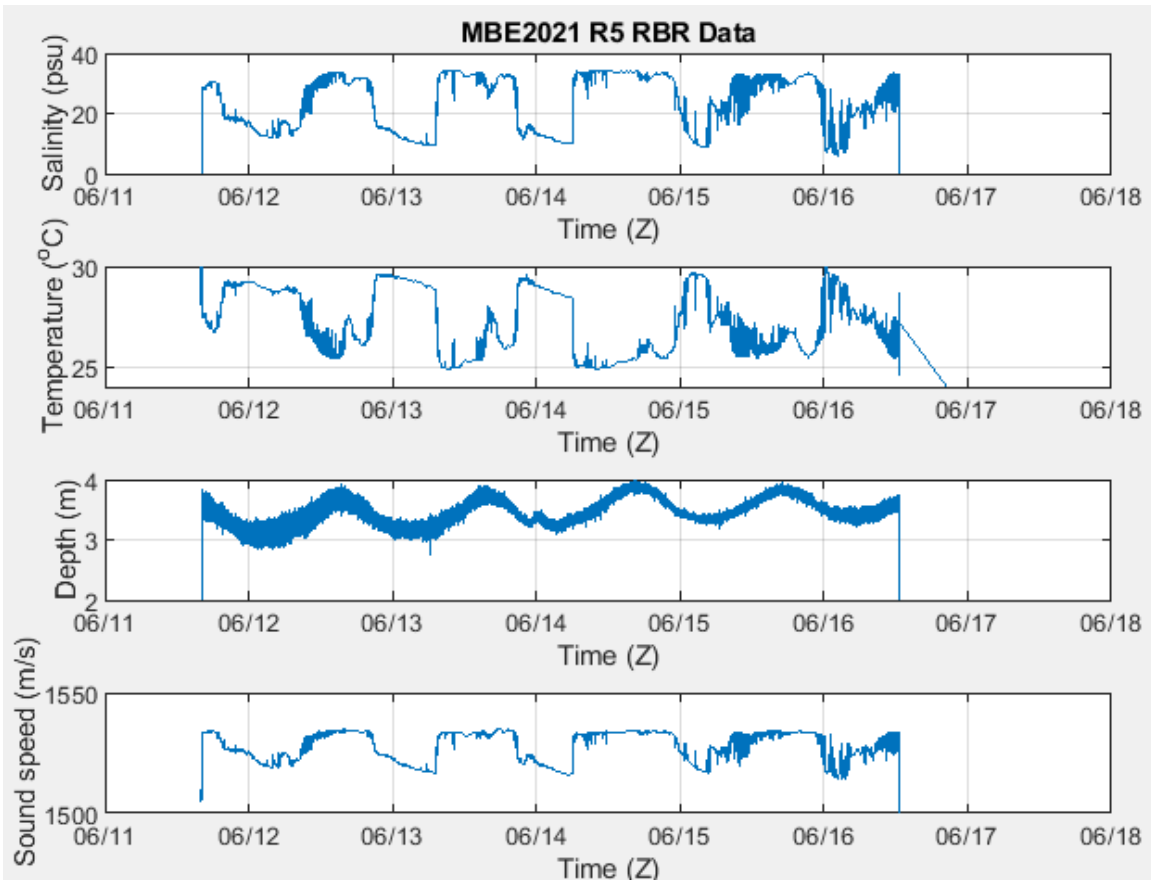


Figure 17 RBR data from R5 between June 11-16

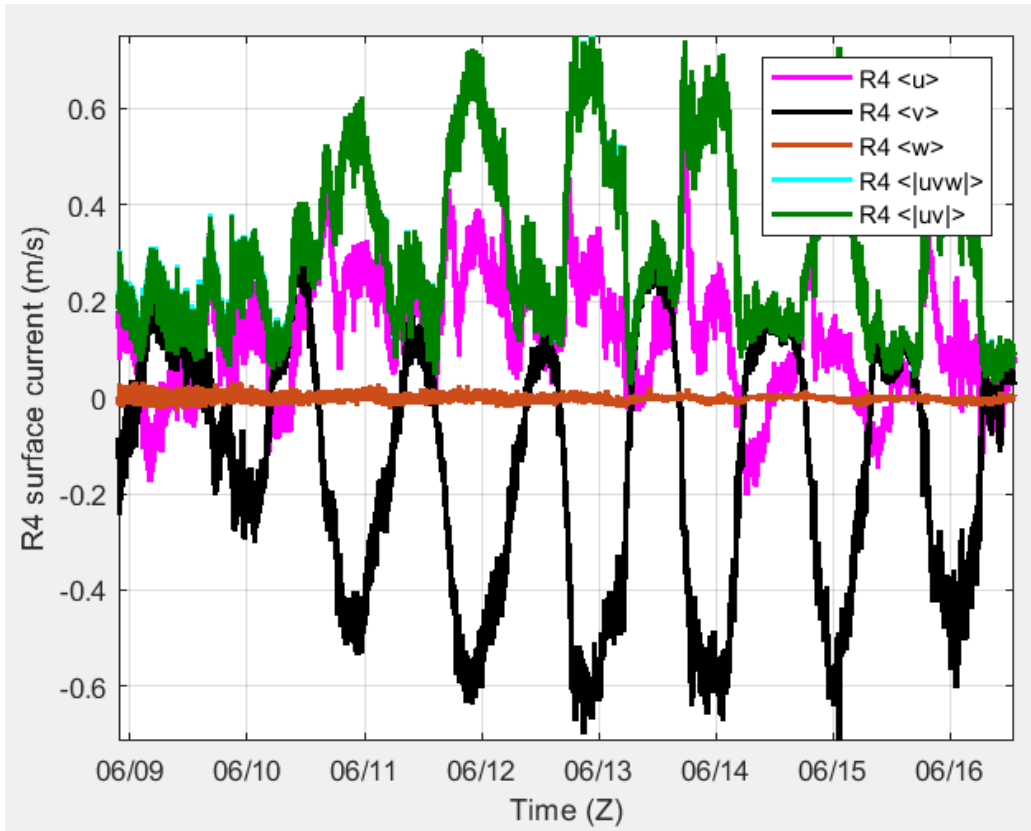


Figure 18 ADCP plots for velocity at R4 between June 9-16

Table 4 Field log

CST	UTC	Log Entry
<b>7-Jun-21</b>		
0837	1337	Lines clear at Dauphin Island, Alabama
0940	1440	End coffin float test. Float test SAT
1009	1509	Begin deployment of coffin
1016	1516	Coffin fully deployed
1033	1533	Coffin Recovered
1059	1559	Begin deployment of coffin
1105	1605	Coffin deployed
1125	1625	Lander deployed
1128	1628	Lander deployed
1135	1635	Lander recovered
1140	1640	Coffin deployed
1200	1700	Coffin Recovered
1234	1734	First line out at Dauphin Island, Alabama
<b>8-Jun-21</b>		
1108	1608	Start ADCP 7290 on R4
1116	1616	Start ADCP 7819 on R3
1340	1840	Lines clear at Dauphin Island, Alabama

1552	2052	R3 Deployed at 30°12.864'N 088°00.842'W
1636	2136	R4 deployed at 30°12.154'N 088°01.207'W
1742	2242	First line out at Dauphin Island, Alabama
<b>9-Jun-21</b>		
0905	1405	Lines clear at Dauphin Island, Alabama
1051	1551	Coffin Deployed at S3 (30°11.324'N 088°01.641'W
1059	1559	Lubell source turned on
1127	1627	Castaway CTD #1
1131	1631	Castaway CTD #2
1221	1721	Turn on over the side ADCP (serial number 2293) and Biosonics Echo Sounder
1226	1726	Tied to local oil rig, ship heading 020°
1251	1751	Sondecam in water
1338	1838	Castaway CTD #3
1334	1834	Lines clear of oil rig
1401	1901	Castaway CTD #4, ship drifting near S3
1441	1941	Stopped recording over the side ADCP
1442	1942	ADCP and Biosonics echo sounder aboard
1449	1949	Turned off Lubell source
1458	1958	Coffin aboard at S3
1600	2100	First line out at Dauphin Island, Alabama
<b>10-Jun-21</b>		
0939	1439	Lines clear at Dauphin Island, Alabama
1004	1504	Lines out at DISL to get AAA batteries
1013	1513	Lines clear at DISL
1106	1606	Deploy coffin at S3
1112	1612	Turned on Lubell source
1212	1712	Found front
1215	1715	Over the side pole in place with ADCP and Biosonics Echo Sounder
1228	1728	Turned on ADCP. Ship heading ~310°
1404	1904	Bubbler (dBRd) deployed
1423	1923	Engines off, drifting ~290°
1442	1942	dBRd recovered, engines restarted
1500	2000	Crossed what appears to be front
1506	2006	dBRd deployed. Engines off. Heading ~250°
1513	2013	dBRd recovered, engines restarted
1519	2019	dBRd deployed. Engines off. Heading ~300°
1530	2030	dBRd deployed. Engines off. Heading ~284°
1537	2037	dBRd recovered, engines restarted
1543	2043	dBRd deployed. Engines off. Heading ~284°
1556	2056	dBRd recovered, engines restarted
1619	2119	Stopped ADCP and Biosonics echo sounder

1622	2122	Over the side pole onboard
1634	2134	Lubell turned "off", but was already not transmitting
1644	2144	Coffin recovered
1659	2159	Transferred Acousonde to Craig McNeil on the Gray Goose
1746	2246	First line out at Dauphin Island, Alabama
<b>11-Jun-21</b>		
1002	1502	All lines clear at Dauphin Island, Alabama
1114	1614	Deploy S2/R5 with Acousonde (A066) and RBR CTD (205305) at 30°13.086'N 088°01.995'W
1138	1638	Deploy R2 with MAV (10307) at 30°13.587'N 088°01.870'W
1203	1703	Deploy R1 with ADCP (2595), Acousonde (A050), MAV (10320), RBR CTD (60318) at 30°14.806'N 088°01.932'W
1229	1729	Coffin deployed at S1 30°15.726'N 088°01.878'W
1230	1730	Lubell turned on
1244	1744	Over the side mount in water
1253	1753	Turned on ADCP and Biosonics Echo Sounder
1331	1831	Engines off
1233	1733	dBRd deployed
1336	1836	dBRd recovered
1342	1842	dBRd deployed. Engines off
1358	1858	Castaway CTD #5
1400	1900	dBRd recovered
1408	1908	dBRd deployed. Engines off.
1408-1418	1908-1918	CTDs 6-12
1418	1918	dBRd recovered
1514	2014	Over the side pole recovered
1543	2043	Lubell turned off
1549	2049	Coffin recovered
1645	2145	First line out at Dauphin Island, Alabama
<b>12-Jun-21</b>		
0611	1111	Lines clear at Dauphin Island, Alabama
0630	1130	icListen on source #1422
0700	1200	Coffin deployed
0704	1204	Lubell turned on 30°15.746'N 088°01.823'W
0722	1222	Over the side mount in water
0729	1229	dBRd deployed. Engines off. Heading ~210°
0736	1236	dBRd recovered. Engines on.
0740	1240	dBRd deployed. Engines off. Heading ~215°
0741	1241	CTD #13
0748	1248	dBRd recovered. Engines on.
0759	1259	dBRd deployed. Engines off.

0809	1309	Lubell stopped producing sound
0819	1319	dBRd recovered. Engines on.
0825	1325	dBRd deployed. Heading ~230°
0825-0842	1325-1342	CTDs #29-43
0843	1343	dBRd recovered. Engines on.
0846	1346	dBRd deployed
0847-0854	1347-1354	CTDs #44-51
0857	1357	dBRd recovered
0905	1405	dBRd deployed. Heading ~227°
0905-0930	1405-1430	CTDs #52-79
0931	1431	dBRd recovered
0938	1438	dBRd deployed
0940-0954	1440-1454	CTDs #80-95
0951	1451	dBRd pulled in to get cable off CTD
0955	1455	dBRd recovered
1022	1522	dBRd deployed (1.5 meters down)
***		dBRd recovered
1038	1538	dBRd deployed (1.5 meters down)
1043-1050	1543-1550	CTDs #96-101
1052	1552	dBRd recovered
1057	1557	dBRd deployed (1.5 meters down)
1101-1105	1601-1605	CTDs #102-108
1107	1607	dBRd recovered
1118	1618	Over the side mount recovered
1134	1634	SVC off (not pinging)
1140	1640	Coffin recovered
1228	1728	First line out at Dauphin Island, Alabama
<b>14-Jun-21</b>		
0746	1246	Lines clear at Dauphin Island, Alabama onboard R/V Boca
0833	1333	dBRd deployed (1.5m) Engines off. CTDs
0856	1356	dBRd recovered
0902	1402	dBRd deployed (1.5m) Engines off. CTDs
0956	1456	dBRd recovered
1008	1508	dBRd deployed (1.5m) Engines off. CTDs
1033	1533	dBRd recovered
1042	1542	dBRd deployed at surface. Engines off. CTDs
1138	1638	dBRd recovered

1157	1657	dBRd deployed. Engines off. CTDs
1224	1724	dBRd recovered
1306	1806	First line out at Dauphin Island, Alabama
<b>15-Jun-21</b>		
0708	1208	Lines clear at Dauphin Island, Alabama
0742	1242	Over the side mount in water
0757	1257	dBRd deployed at surface. Engines stopped. CTDs
0841	1341	dBRd recovered
0900	1400	dBRd deployed. Engines stopped. CTDs
0922	1422	dBRd recovered
0935	1435	Fish jumping all around boat
0936	1436	dBRd deployed. Engines stopped. CTDs
1014	1514	dBRd recovered
1020	1520	dBRd deployed. Engines stopped. CTDs
1031	1531	dBRd recovered
1042	1542	dBRd deployed. Engines stopped. CTDs
1111	1611	dBRd recovered
1119	1619	dBRd deployed. Engines stopped. CTDs
1146	1646	dBRd recovered
1150	1650	dBRd deployed. Engines stopped. CTDs
1200	1700	dBRd recovered
1206	1706	Over the side mount recovered
1249	1749	First line out at Dauphin Island, Alabama
<b>16-Jun-21</b>		
0656	1156	Cast off lines at Dauphin Island, Alabama
0732	1232	S2 recovered
0745	1245	R3 recovered
0808	1308	R4 recovered
0855	1355	R2 recovered
0919	1419	R1 recovered
0950	1450	First line out at Milk Shake Dock
1011	1511	Lines clear at Milk Shake Dock
1035	1535	First line out at Dauphin Island, Alabama

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Photo courtesy of In Memory of Bill by Chunyan Li

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