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Abstract

Drifting Acoustic Spar Buoy Recorders (DASBRs) were deployed six times in the San Nicolas Basin from 4 to 15 January 2018 for a total of 120 hours of recordings. Echolocation clicks of Cuvier's beaked whales were detected on 47 discrete occasions. Based on the diving behavior of this species, each occasion probably represents a deep-foraging dive. The average number of new deep-foraging dives per hour was 0.38. Cuvier's beaked whale echolocation clicks were detected in 12.4% of all recording minutes. Data from this study will be used as a measure of relative abundance of beaked whales to compare with other areas where DASBRs have been deployed.

Introduction

Cuvier's beaked whales (*Ziphius cavirostris*) are frequently seen in the San Nicolas Basin within the Navy's Southern California Offshore Range (SCORE), and in particular, within the Southern California Anti-submarine Warfare Range (SOAR) (Schorr et al. 2014). The network of hard-wired Navy range hydrophones within SOAR frequently detect their species-specific echolocation clicks (Moretti et al. 2016). These observations suggest that the abundance of this species might be especially high there, at least at some times of the year. However, it is difficult to quantitatively compare these observations to other areas. The high number of range hydrophones greatly facilitates acoustic detections, and the high number of sightings result, in part, because the Navy's Marine Mammal Monitoring on Navy Ranges (M3R) program can localize beaked whales from acoustic detections and direct sighting personnel to areas with known beaked whales. These assets are not available in other areas, so direct comparisons of sighting rates or acoustic detection rates to other areas are not possible.

The Southwest Fisheries Science Center (SWFSC) has developed a drifting hydrophone system to detect beaked whales from their echolocation clicks (Griffiths and Barlow 2015) and has deployed this system widely in the California Current. During a 2016 survey, these devices were deployed thirty times in the California Current along the entire US West Coast for a total of ~400 recording days. In another 2016 study, eight of these devices were deployed for 12 days in the Santa Catalina Basin. A similar drifting instrument was deployed at Guadalupe Island in May 2017. Data are still being processed but will form a baseline for evaluating whether the density of Cuvier's beaked whales in the San Nicolas Basin is truly higher than other areas.

In January 2018, we conducted research focused on Cuvier's beaked whales on SOAR as part of Navy Living Marine Resources funded project (G. Schorr, PI). During this research we opportunistically deployed the SWFSC drifting hydrophone system for six drifts averaging 20 hours each. In this report we present preliminary results of acoustic detections of Cuvier's beaked whales from those deployments.

Methods

DASBRs were deployed and retrieved six times from 4 to 15 January 2018 (Table 1). Drifts averaged 20 hours each for a total of 120 hours of recordings. Five of the deployments and retrievals were from the *Phoenix*, a 7.5-m Zodiac, during photo-identification and tagging studies of Cuvier's beaked whales in the San Nicolas Basin. Additionally during this study period, an autonomous underwater vehicle (the REMUS) was deployed to evaluate the acoustic detection rate of Cuvier's beaked whales from this vehicle (a collaborative effort by the Ocean Acoustical Services and Instrumentation Systems (OASIS), the US Navy and Woods Hole Oceanographic Institution). One of the DASBRs was deployed and retrieved from the Navy Range Support Craft (RSC) that deployed the REMUS. Most of this research was conducted within the SCORE hydrophone complex known as SOAR. Members of the Navy's M3R program provided real-time information on the locations of beaked whales to facilitate this research, but DASBRs were not deliberately deployed in the immediate vicinity of real-time acoustic localizations. However, deployments targeted areas that previously had high densities of this species, or areas adjacent to recently detected beaked whales (~2nmi). Acoustic detections of beaked whales on range hydrophones were recorded during this period to facilitate later comparison to acoustic detections from the REMUS and our DASBRs.

To facilitate comparisons with DASBR data from other studies, we used the same configuration as that in the 2016 deployments by the SWFSC. DASBRs consisted of a Soundtrap ST4300 recorder with two hydrophones configured as a vertical array at ~113-m depth. The Soundtrap was configured to record continuously as consecutive 2-minute sound files. One Soundtrap (L) was set to sample at 576 kHz and to record at 288 kHz (after decimation), and the other (K) was set to sample and record at 288 kHz. The top hydrophone in the array was an HTI-92-WB and the bottom hydrophone was an HTI-96-min. Hydrophone separation was 10-m. The array was maintained in a nearly vertical orientation by a 15-lb mushroom anchor at the bottom and 3.5-lbs of buoyancy at the top of the array. Additional buoyancy was provided by a 1-m spar buoy at the surface. The spar buoy contained two Spot satellite locators to track the DASBR's movement and to facilitate recovery. A Loggerhead Instruments Open Tag was attached 50 cm below the lower hydrophone to record depth, temperature, and array tilt. A Garmin dog tracker was taped to the mast of the spar buoy to shorten the search time and facilitate more rapid recovery. The only significant change from previous studies was the use of 50-m of ¼" nylon line in place of 30-m of 3/8" bungee cord, in order to make the system more robust.

Acoustic data were converted from compressed Soundtrap format to WAV files and were analyzed using PAMGUARD software[1] (Gillespie et al. 2008) to identify beaked whale echolocation clicks. Initial processing to identify beaked whale echolocation clicks and estimate direct-path vertical bearing

[1] https://www.pamguard.org/

angles used PAMGUARD Beta v1.15.03. Echolocation signals were detected using the PAMGUARD energy-based click detector and were automatically classified by the PAMGUARD click classifier into discrete categories based on peak frequency and the presence of a frequency upsweep (Keating and Barlow 2013). Direct-path, vertical bearing angles were automatically estimated within PAMGUARD from differences in the arrival time of the same click signal on the two elements of the vertical hydrophone arrays which were estimated by cross-correlation of the filtered waveform data. The vast majority of echolocation clicks in this area were from dolphins. Characteristics of Cuvier's beaked whale clicks in this area have been described by Baumann-Pickering et al. (2014). Clicks that were likely to be from Cuvier's beaked whales were initially identified based on peak frequencies, having at least occasional upsweeps as determined by the PAMGUARD click classifier, and having vertical bearing angles that were relatively consistent over several minutes. Consistent downward bearing angles were the most effective diagnostic for identifying beaked whale echolocation clicks in the presence of larger numbers of dolphin clicks. Likely Cuvier's beaked whale detections were confirmed using four criteria: 1) presences of a clear upsweep in the Wigner plot of high SNR clicks, 2) presence of frequency peaks at 18, 22, and 34-40 kHz, 3) presence of a frequency valley or notch at 27 kHz, and 4) inter-click intervals of 250-750 msec. If a beaked whale was confirmed in a 2-minute sound file, previous and subsequent sound files were re-examined to determine whether a faint beaked whale may have been missed. The same methods were used to search for other beaked whale species.

Beaked whale dive starts and ends were identified as the times of the first and last echolocation clicks received within a maximum of 75 minutes of the first click (the maximum likely period of clicking within a long dive). In rare cases, when a period of clicking exceeded 75 minutes, this was interpreted as two dives with a break at the longest gap in clicking within that period (this could represent two dives of separate groups that overlap in time or two dives by one group with a short inter-dive period).

Results

DASBRs were deployed for six drifts totaling 119.9 hours (Table 1). Drifts primarily covered the central portion of the SOAR range (Fig. 1-2), with one drift occurring further to the south and coinciding with the location of the OASIS Remus. The direction and net speed of each drift varied each day. Array tilts were generally less than 0.5° (Fig. 3-4). Water temperature at the array was approximately 10° C (Table 1, Fig. 3-4). When the array tilt increased to above 0.5°, likely due to current shear, the array depth also decreased by ~1 m from the nominal value of ~113 m (Fig. 3-4). Detections of Cuvier's beaked whales appear to be less concentrated in the two more eastern drifts (Fig. 1).

Cuvier's beaked whales were detected on 48 discrete occasions (Table 2), which were interpreted as 48 separate deep dives. No other beaked whale species were detected. The mean duration of a clicking bout was ~32 min (sd = 17.4 min, range = 0.1 - 74.1 min). The mean number of echolocation clicks received during a clicking bout at 1,014 (sd= 1,300, range= 13 - 5,469). The short clicking bouts were likely from distant dives that were detected only intermittently for a very short duration. However, the mean duration is close to the expected duration of the clicking period of a 1-hour dive.

Two measures of relative density were calculated: the number of dive events per hour (mean= 0.38) and the percentage of 1-minute periods with echolocation clicks (mean= 12.4%) (Table 1).

Discussion

The primary purpose of the DASBR deployments in the San Nicolas Basin was to provide data for a comparison of the relative density of Cuvier's beaked whales within SOAR with the results from DASBR drifts in other areas. In 2014, a pilot study was conducted using an earlier DASBR design with less sensitive hydrophones. In that study, only 19 Cuvier's beaked whales were detected in 287 hours of recordings (Griffiths and Barlow 2016) for a mean detection rate of 0.066 dives per hour. Cuvier's beaked whales were detected in only 0.2% of 2-minute recordings (Griffiths and Barlow 2016). In 2016, the SWFSC conducted an acoustic survey of beaked whale abundance along the entire US West Coast using the same hydrophone as used in this study. Results of that survey are not yet published, but overall in the entire study area, all species beaked whales were detected less than 1% of 2-minute recordings, with Cuvier's beaked whale being approximately three fourths of all beaked whale detections (SWFSC unpublished data). Another acoustic study of Cuvier's beaked whales was conducted in the Catalina Basin in 2016, again using the same hydrophones and DASBR configuration as this study. Preliminary results from that study are not yet available.

Although data are not yet available for a detailed statistical comparison, the fraction of time with echolocation clicks of Cuvier's beaked whales in the San Nicolas Basin appears to be more than 10 times higher than any previous study with the same instruments. This supports the widely held perception that the density of Cuvier's beaked whales in the San Nicolas Basis is unusually high. A detailed comparison with other studies is needed to determine whether the number of beaked whale detections on any other drifts were as high as seen in this study.

Acknowledgements

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Table 1. DASBR deployment data for studies in the San Nicolas Basin. Dive events are the distinct periods with beaked whale echolocation clicks that are less than 75 minutes (the maximum expected clicking time during a deep dive). The number of minutes with clicks is the number of one-minute periods with detected echolocation clicks. Depth and temperature were measured 50 cm below the lower hydrophone with a Loggerhead Instruments Open Tag.

Drift	Start Time (UTC)	End Time (UTC)	Duration (hrs)	# Dive Events	Dive Events per Hour	# Minutes with Clicks	Percent Minutes with Clicks	Recorder	Buoy #	Average Depth (m)	Average Temperature (°C)
1	1/4/2018 16:24	1/5/2018 01:39	9.25	3	0.324	22	4.0%	ST4300-L	12	112.2	10.0
2	1/5/2018 18:04	1/6/2018 20:20	26.27	12	0.457	189	12.0%	ST4300-L	12	112.9	10.0
3	1/11/2018 21:40	1/12/2018 15:00	17.33	3	0.173	84	8.1%	ST4300-L	3	112.6	9.9
4	1/12/2018 22:04	1/13/2018 15:32	17.47	7	0.401	184	17.6%	ST4300-L	12	113.6	10.1
5	1/13/2018 15:58	1/14/2018 19:40	27.70	15	0.542	277	16.7%	ST4300-K	3	112.1	10.4
6	1/14/2018 16:57	1/15/2018 14:52	21.92	8	0.365	216	16.4%	ST4300-L	12	112.8	10.1
	Total		119.9	48		972					
	Mean		19.99		0.38		12.4%			112.7	10.1

Table 2. Dives detected during six DASBR drifts in the San Nicolas Basin. Dive start and end times are identified as the times of the first and last clicks received within a 75-minute period.

Drift	Detection Number	StartTimeUTC	EndTimeUTC	Duration (min)	Number Clicks
1	2	1/4/2018 20:38	1/4/2018 21:13	35.3	524
1	3	1/4/2018 23:35	1/4/2018 23:42	6.9	15
2	1	1/5/2018 18:08	1/5/2018 18:25	17.3	73
2	2	1/5/2018 19:05	1/5/2018 19:38	33.6	1648
2	3	1/5/2018 22:18	1/5/2018 23:17	58.7	275
2	4	1/6/2018 03:30	1/6/2018 04:08	37.1	2362
2	5	1/6/2018 05:54	1/6/2018 06:48	53.5	244
2	6	1/6/2018 07:07	1/6/2018 07:14	6.7	33
2	7	1/6/2018 09:18	1/6/2018 10:03	45.6	3618
2	8	1/6/2018 11:35	1/6/2018 11:56	20.9	37
2	9	1/6/2018 13:34	1/6/2018 13:58	24.2	205
2	10	1/6/2018 15:44	1/6/2018 16:27	43.5	267
2	11	1/6/2018 18:51	1/6/2018 19:42	50.9	331
2	12	1/6/2018 08:39	1/6/2018 08:39	0.1	13
3	1	1/11/2018 22:32	1/11/2018 22:56	24.3	523
3	2	1/12/2018 02:39	1/12/2018 03:15	36.3	3672
3	3	1/12/2018 11:26	1/12/2018 12:04	37.8	4042
4	1	1/12/2018 23:51	1/13/2018 00:38	47.1	173
4	2	1/13/2018 03:28	1/13/2018 03:38	10.6	89
4	3	1/13/2018 05:40	1/13/2018 06:24	44.4	1163
4	4	1/13/2018 07:22	1/13/2018 08:36	74.1	2731
4	5	1/13/2018 09:50	1/13/2018 10:50	60.6	5469
4	6	1/13/2018 12:53	1/13/2018 13:26	33.3	200
4	7	1/13/2018 15:08	1/13/2018 15:22	13.6	98
5	1	1/13/2018 17:45	1/13/2018 18:32	47.1	991
5	2	1/13/2018 21:50	1/13/2018 21:57	7.3	37
5	3	1/14/2018 00:04	1/14/2018 00:40	35.7	749
5	4	1/14/2018 01:25	1/14/2018 02:02	36.6	249
5	5	1/14/2018 02:27	1/14/2018 02:44	17.3	30
5	6	1/14/2018 04:19	1/14/2018 04:51	31.3	1509
5	7	1/14/2018 05:51	1/14/2018 06:21	29.9	695
5	9	1/14/2018 07:27	1/14/2018 07:34	6.4	181
5	10	1/14/2018 08:55	1/14/2018 08:57	1.9	48
5	11	1/14/2018 11:35	1/14/2018 12:11	35.9	2809
5	13	1/14/2018 12:52	1/14/2018 13:36	43.8	332
5	14	1/14/2018 13:37	1/14/2018 14:21	43.9	758
5	15	1/14/2018 16:51	1/14/2018 17:21	30.2	22
5	16	1/14/2018 05:06	1/14/2018 05:48	41.4	1193
5	17	1/13/2018 23:26	1/13/2018 23:36	10.2	191
6	1	1/14/2018 18:14	1/14/2018 18:56	41.5	2728
6	2	1/14/2018 20:56	1/14/2018 21:49	52.7	1285
6	3	1/14/2018 23:19	1/15/2018 00:03	43.8	2634
6	4	1/15/2018 02:02	1/15/2018 02:09	6.5	66
6	5	1/15/2018 04:57	1/15/2018 05:16	19.4	1142
6	6	1/15/2018 05:27	1/15/2018 05:49	21.7	43
6	7	1/15/2018 07:00	1/15/2018 07:53	52.8	1810
6	8	1/15/2018 13:36	1/15/2018 14:07	31.2	370

Figure 1. Drifts observed for six DASBRs deployed in the San Nicolas Basin. Starting locations are indicated by green triangle to the west of the drift number. Red circles indicate locations where echolocation clicks of Cuvier's beaked whale dive were first detected.

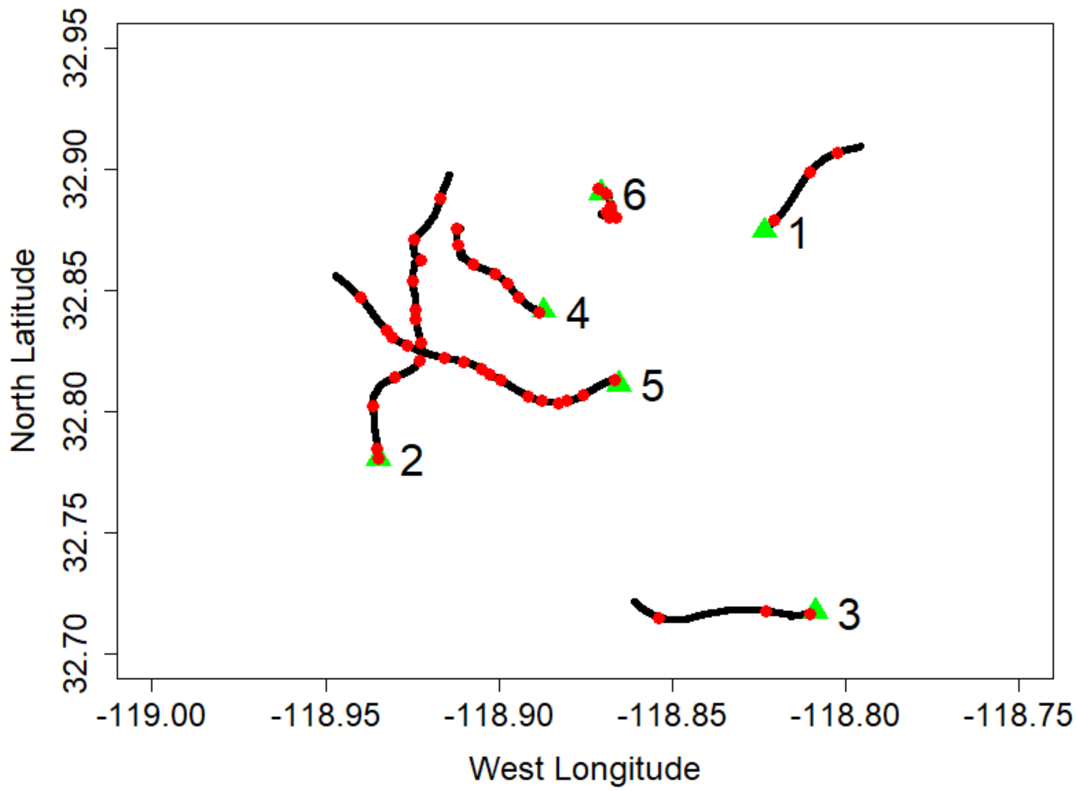

Figure 2. DASBR drifts (yellow lines) from Fig. 1 superimposed on a map of seafloor bathymetry in the San Nicolas Basin. Red circles indicate the locations of Cuvier's beaked whale dive starts and white lines indicate boundaries of Navy-designated areas within SOAR.

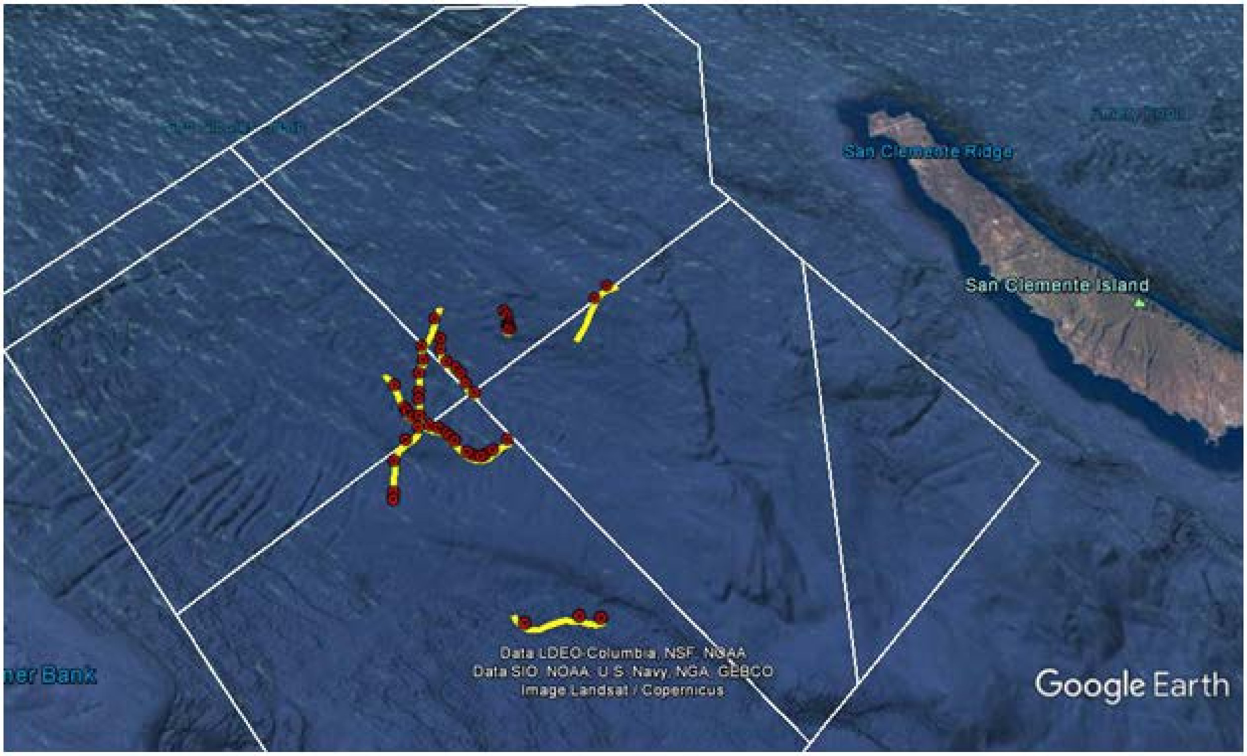

Figure 3. Array tilt, temperature, and depth for drifts 1, 2, 3, 4, and 6 measured with a Loggerhead Instruments Open Tag. Depth and temperature outliers occur during deployments and retrievals.

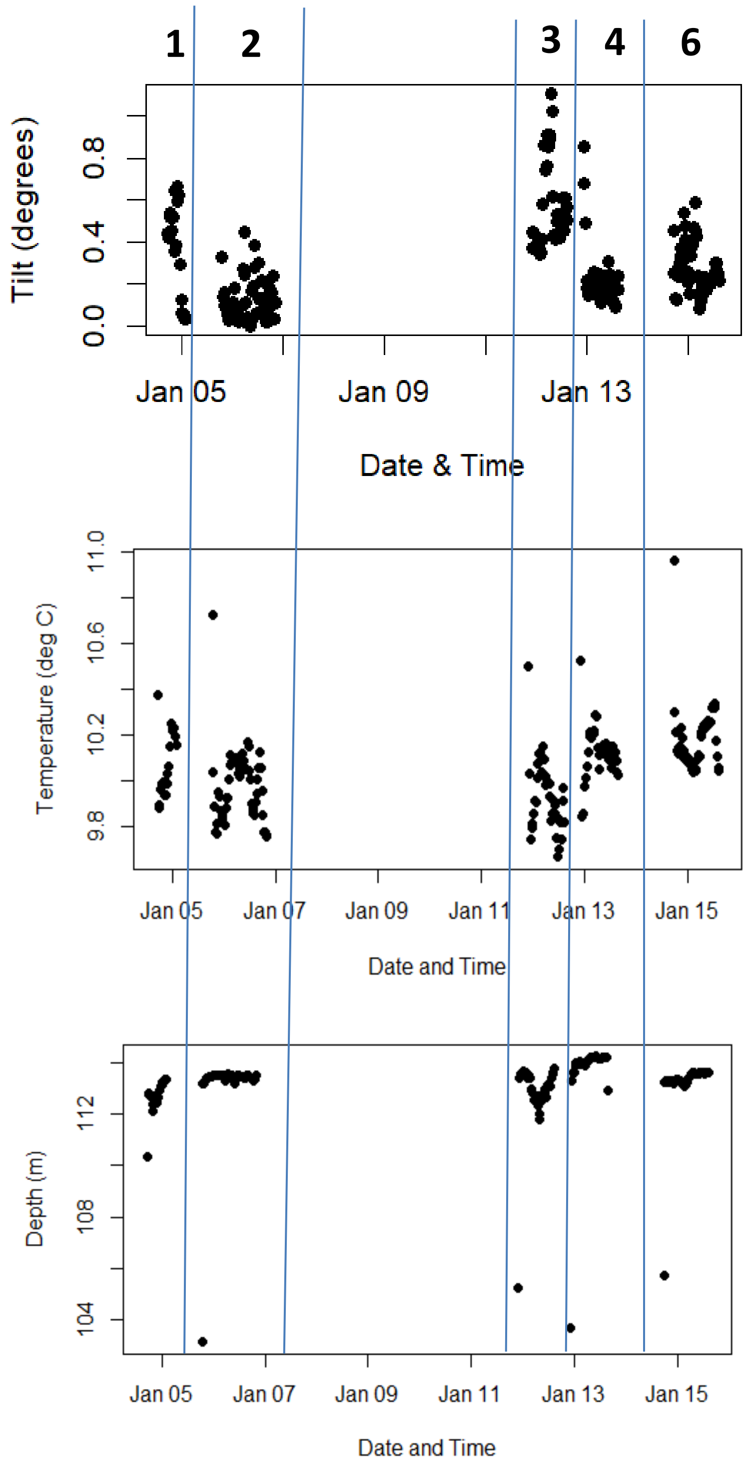

Figure 4. Array tilt, temperature, and depth for drift 5 measured with a Loggerhead Instruments Open Tag. Depth and temperature outliers occur during deployments and retrievals.