Final Report

Cetacean Studies on the Mariana Islands Range Complex in September-November 2014: Passive Acoustic Monitoring of Marine Mammals Using Gliders

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Prepared by:

H. Klinck[1,2], S. L. Nieukirk[2], S. Fregosi[2], K. Klinck[1,2],
D. K. Mellinger[2], S. Lastuka[3], G. B. Shilling[3], and J. C. Luby[3]

[1]Bioacoustics Research Program,
Cornell Lab of Ornithology, Cornell University,
159 Sapsucker Woods Road, Ithaca, NY 14850.

[2]Cooperative Institute for Marine Research Studies,
Oregon State University and NOAA/PMEL,
Hatfield Marine Science Center,
2030 SE Marine Science Drive, Newport, OR 97365.

[3]Applied Physics Laboratory, University of Washington,
1013 NE 40th Street, Seattle, WA 98105.

Submitted by:

HDR

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6. AUTHOR(S)
H. Klinck
S. L. Nieukirk
S. Fregosi
K. Klinck
D. K. Mellinger
S. Lastuka
G. B. Shilling
J. C. Luby

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Bioacoustics Research Program, Cornell Lab of Ornithology,Cornell University, 159 Sapsucker Woods Road, Ithaca, NY
Cooperative Institute for Marine Research Studies, Oregon State University and NOAA/PMEL, Hatfield Marine Science, Center, 2030 SE Marine Science Drive, Newport, OR
Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, WA

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14. ABSTRACT
A passive-acoustic glider survey was conducted in the Mariana Islands Range Complex between 19 September and 14 November 2014. The goal of the project was to investigate the spatial and temporal distribution of odontocetes and mysticetes in offshore areas adjacent to Guam, Rota, Tinian, and Saipan.

The original plan was to use two gliders to survey the offshore areas east of the Marianas Ridge to the north and south of Guam. Because of waterspace management concerns, the northern trackline was subsequently moved to the west side of the Marianas Ridge. The glider used for this survey experienced a malfunction during its transit to the deployment location and only collected environmental data during the survey. The second glider collected both acoustic and environmental data, which were thoroughly analyzed in the lab after recovery of both instruments. Even though one of the two gliders experienced a malfunction and didn't record usable acoustics data, the MIRC acoustic glider survey was successful. SG178 recorded a total of 749 h (~31 days) of acoustic data during this survey. The glider covered a distance of 833 km (695 km with the PAM system active) over ground. This was the longest passive-acoustic glider survey APL-UW and OSU conducted to date.

Odontocete acoustic encounters were abundant. The majority of the detections occurred in the last two-thirds of the survey when the glider was in both deep water and on the shelf. There were relatively few detections during the first 80 dives. Beaked whales were potentially encountered on seven occasions, three of which could be verified as Blainville's beaked whales (Mesoplodon densirostris). The remaining four encounters were classified as potential beaked whale encounters. Because of the low signal-to-noise ratio of these clicks, definite species identification was not possible. Other species detected included killer whales (Orcinus orca), Risso's dolphins (Grampus griseus), and sperm whales (Physeter macrocephalus). Vocalizations which couldn't be classified to a species level were categorized based on their acoustic characteristics similar to Munger et al. (2014).

The results of the data analysis also revealed comparatively little baleen whale activity in the area at the time of the survey. The majority of mysticete detections were a new call type which, to our knowledge, has not been described in the peer-reviewed literature to date. This vocalization consisted of a short approximate 38-Hertz tone followed by a quick upsweep to 7.5 kilohertz, and resembles the minke whale (Balaenoptera acutorostrata) "star wars" call described by Gedamke et al. (2001) and also has some characteristics of the minke whale "boing" vocalization (Rankin and Barlow, 2005). This call was recorded in 45 encounters between 14 October and 06 November 2014. Mid-frequency active sonar was detected twice (a total of 5 hours) during the beginning of the survey.

In summary, the functional glider successfully surveyed the Mariana Islands Range Complex offshore waters, which are difficult to monitor with traditional visual and acoustic methods. The environmental and acoustic data sets provided valuable information on the sound propagation conditions in the area as well as the spatial and temporal distribution of odontocetes and mysticetes in offshore areas adjacent to Guam, Rota, Tinian, and Saipan.

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Executive Summary

A passive-acoustic glider survey was conducted in the Mariana Islands Range Complex between 19 September and 14 November 2014. The goal of the project was to investigate the spatial and temporal distribution of odontocetes and mysticetes in offshore areas adjacent to Guam, Rota, Tinian, and Saipan.

The original plan was to use two gliders to survey the offshore areas east of the Marianas Ridge to the north and south of Guam. Because of waterspace management concerns, the northern trackline was subsequently moved to the west side of the Marianas Ridge. The glider used for this survey experienced a malfunction during its transit to the deployment location and only collected environmental data during the survey. The second glider collected both acoustic and environmental data, which were thoroughly analyzed in the lab after recovery of both instruments. Even though one of the two gliders experienced a malfunction and didn't record usable acoustics data, the MIRC acoustic glider survey was successful. SG178 recorded a total of 749 h (~31 days) of acoustic data during this survey. The glider covered a distance of 833 km (695 km with the PAM system active) over ground. This was the longest passive-acoustic glider survey APL-UW and OSU conducted to date.

Odontocete acoustic encounters were abundant. The majority of the detections occurred in the last two-thirds of the survey when the glider was in both deep water and on the shelf. There were relatively few detections during the first 80 dives. Beaked whales were potentially encountered on seven occasions, three of which could be verified as Blainville's beaked whales (*Mesoplodon densirostris*). The remaining four encounters were classified as potential beaked whale encounters. Because of the low signal-to-noise ratio of these clicks, definite species identification was not possible. Other species detected included killer whales (*Orcinus orca*), Risso's dolphins (*Grampus griseus*), and sperm whales (*Physeter macrocephalus).* Vocalizations which couldn't be classified to a species level were categorized based on their acoustic characteristics similar to Munger et al. (2014).

The results of the data analysis also revealed comparatively little baleen whale activity in the area at the time of the survey. The majority of mysticete detections were a new call type which, to our knowledge, has not been described in the peer-reviewed literature to date. This vocalization consisted of a short approximate 38-Hertz tone followed by a quick upsweep to 7.5 kilohertz, and resembles the minke whale (*Balaenoptera acutorostrata*) "star wars" call described by Gedamke et al. (2001) and also has some characteristics of the minke whale "boing" vocalization (Rankin and Barlow, 2005). This call was recorded in 45 encounters between 14 October and 06 November 2014. Mid-frequency active sonar was detected twice (a total of 5 hours) during the beginning of the survey.

In summary, the functional glider successfully surveyed the Mariana Islands Range Complex offshore waters, which are difficult to monitor with traditional visual and acoustic methods. The environmental and acoustic data sets provided valuable information on the sound propagation conditions in the area as well as the spatial and temporal distribution of odontocetes and mysticetes in offshore areas adjacent to Guam, Rota, Tinian, and Saipan.

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Acronyms and Abbreviations

°C	degrees Celsius
APL-UW	Applied Physics Laboratory, University of Washington
bit	Basic unit of information
cm/s	Centimeters per second
CTD	Conductivity, Temperature, and Depth
ESA	Endangered Species Act
FLAC	Free Lossless Audio Codec
GB	Gigabytes
h	Hour(s)
Hz	Hertz
ICMP	Integrated Comprehensive Monitoring Program
ICI	Inter-click-interval
ITA	Incidental Take Authorizations
kHz	Kilohertz
km	Kilometer(s)
LT	Local Time
LTSA	Long-term spectral average
m	Meter(s)
MB	Megabytes
min	Minute(s)
ms	Millisecond(s)
m/s	Meters per second
MFAS	Mid-frequency Active Sonar
MIRC	Mariana Islands Range Complex
MMPA	Marine Mammal Protection Act
NAVFAC	Naval Facilities Engineering Command Atlantic
OSU	Oregon State University
PAM	Passive-acoustic monitoring
RHIB	Rigid-hulled inflatable boat
s	Second(s)
SG	Seaglider
SNR	Signal-to-noise ratio
UTC	Coordinated Universal Time
V	Volt(s)
WAV	WAVeform audio format
μs	Microsecond(s)

1. Background and Objectives

The U.S. Navy has conducted marine species monitoring and reporting for the Mariana Islands Range Complex (MIRC) required in accordance with the Letter of Authorization under the Marine Mammal Protection Act and Incidental Take Authorization under the Endangered Species Act. Following the current 2012–2015 MIRC monitoring plan, the monitoring and reporting will provide knowledge on the occurrence and distribution of the species. Data generated via implementation of this monitoring plan will be integrated into the U.S. Navy's Integrated Comprehensive Monitoring Program.

1.1 Monitoring Questions

- Which species of toothed whales (particularly beaked whales) occur in MIRC, and what is their spatial and seasonal distribution in offshore areas adjacent to Guam, Rota, Tinian, and Saipan?
- Which species of baleen whales occur in the MIRC and what is their spatial and seasonal distribution in offshore areas adjacent to Guam, Rota, Tinian, and Saipan?

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2. Methods

2.1 General Glider Information

Underwater gliders use small changes in buoyancy to produce vertical motion, and wings to convert the vertical motion to horizontal movement, thereby propelling them forward with very low power consumption. This allows them to perform long-duration surveys autonomously (Rudnick et al., 2004). During a mission, a glider is piloted remotely, via Iridium™ satellite connection, from a control center onshore. The glider used in this project was the Seaglider™, originally developed by APL-UW (commercially available from Kongsberg Inc., Lynwood, WA, USA), which is capable of repeatedly diving to 1,000 m depth and back at a typical horizontal speed of 25 cm/s (**Figure 1 and 2**). Dive durations are usually on the order of 4-6 hours for 1,000 m dives.

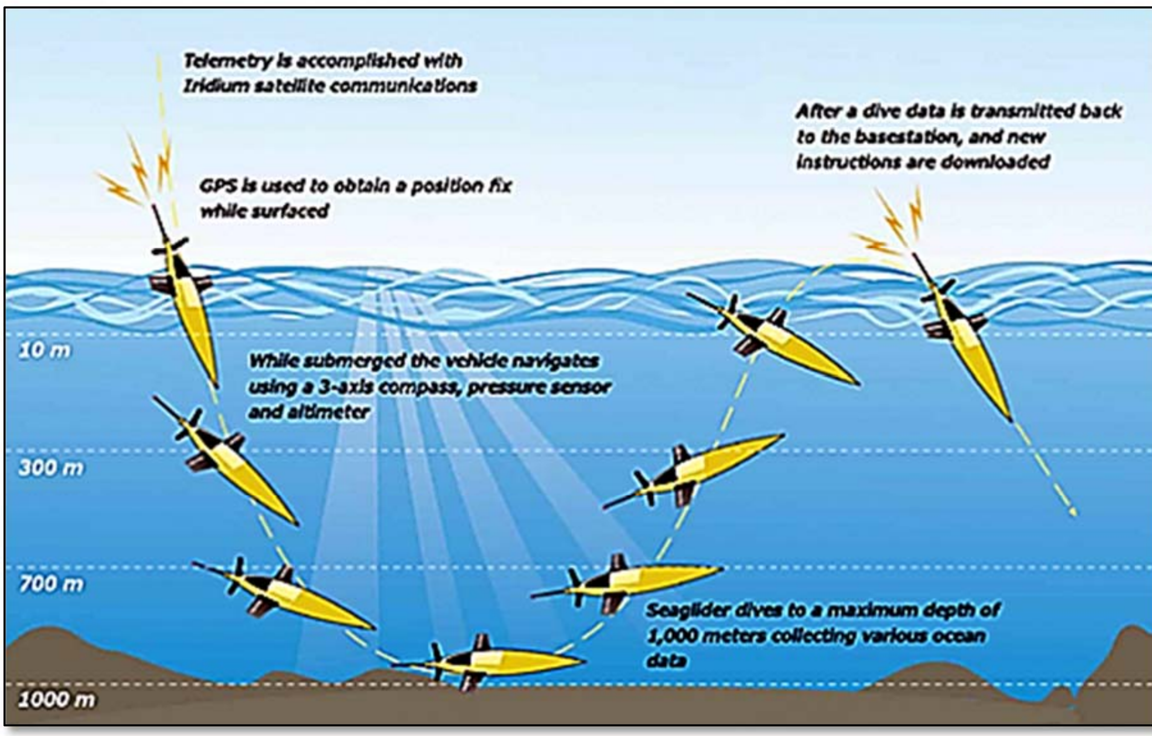

Figure 1: Mode of operation of the Seaglider™. Source: http://subseaworldnews.com.

The glider was equipped with a custom-designed and -built passive acoustic recording system (APL-UW, Seattle, WA, USA); acoustic signals were received by a single omni-directional hydrophone (type: HTI-99-HF, High Tech Inc, Gulfport, MS, USA; sensitivity: −164 dB re. 1 V/μPa, amplified by 36 decibels, and recorded at 194 kilohertz (kHz) sample rate and 16-bit resolution. Aliasing is prevented by the use of an analog 90-kHz low-pass filter (five-pole Chebyshev filter). Acoustic data were compressed using the Free Lossless Audio Codec (FLAC) and stored on flash memory drives. The passive acoustic monitoring (PAM) system was optimized for continuously collecting data in the frequency range 15 Hertz (Hz) to 90 kHz, and thus was well suited for the recording of both baleen and toothed whales. However, the bandwidth of the system did not cover the frequency range (>100 kHz) of vocalizations produced by pygmy and dwarf sperm whales (*Kogia* spp.).

The system featured an automatic 'blanking mechanism' which mutes the PAM system during periods when the glider's noisy internal steering and buoyancy mechanisms were operated. During a typical 1,000-meter (m) dive, the associated data loss was between 5 and 10 percent. Because of high noise levels at the surface, recordings were made only at depths of 25 to 1,000 m.

These gliders are typically programmed to survey across diverse bathymetric features and cetacean habitats whenever possible. The instruments carried on-board digital bathymetric maps used for deciding how deep to dive in areas where the water depths are shallower than 1,000 m. The glider's depth-choice algorithm was designed to operate best when the instrument's course is orthogonal to the isobaths. Use of this map-reading method avoided the need to use active acoustics for altimetry, which would have hindered passive-acoustic recordings. The gliders transmit selected data packages via Iridium satellite link, including position and standard conductivity, temperature, and depth profiles, to shore when surfacing between dives. The instruments typically stayed at the surface for less than 10 minutes.

In 2007, the U.S. Navy's Office of Naval Research (ONR), Marine Mammals and Biology (MMB) program started the Passive Acoustic Autonomous Monitoring (PAAM) of Marine Mammals program to develop near-real-time monitoring systems on autonomous underwater vehicles (AUVs). The program focused on passive acoustic systems for autonomous detection, classification, localization, and tracking of marine mammals on Navy exercise areas for periods in excess of a month. The passive-acoustic Seaglider used in this study is a result of this development effort. The system has been validated during several surveys, including short (week-long) deployments at both AUTEC and SCORE (Klinck et al. 2013). The PAM board (Rev. B) has been classified as a Demonstration and Validation (6.4) system. The 6.4 system encompasses integrated technologies ready to be evaluated in as realistic an operating environment as possible. The PAM board is a U.S. export controlled item, both under the Department of State's ITAR and the Department of Commerce's EAR programs.

2.2 Glider Survey

For the MIRC survey, two Seagliders were used to acoustically scan the study area for marine mammals. Both gliders, SG178 and SG179 (**Figure 2**), were deployed on 19 September 2014 at approximately 05:00 coordinated universal time (UTC) off the west coast of Guam (N13° 30.79', E144° 35.04') using a small charter vessel. The proposed tracks were designed to survey across diverse bathymetric features and cetacean habitats whenever possible (**Figure 3**).

Figure 2: Passive-acoustic Seaglider. The Seaglider™ is a commercial off-the-shelf instrument sold by Kongsberg, Inc. (Lynwood, WA, USA). The PAM system was developed and incorporated into the Seaglider by APL-UW (Seattle, WA, USA).

Prior to the survey OSU & APL-UW (Oregon State University and Applied Physics Laboratory, University of Washington) were informed by HDR that the SG179 transect line (NW of Guam) needed to be modified because of naval activities in the area. After discussions with HDR and NAVFAC, it was decided [a] to move the transect line to the west side of the Marianas Ridge, NW of Guam and [b] to start the surveys immediately off of Guam. Both gliders transited (PAM system inactive) from the deployment location to the respective survey area. After the survey area was reached, the PAM system was activated and captured sounds near-continuously in the 25 to 1,000 m depth range. The recovery of both gliders was executed about 24 nautical miles southwest of the deployment location (N13° 10.81’, E144°31.22’) on 14 November 2014 at approximately 22:15 UTC.

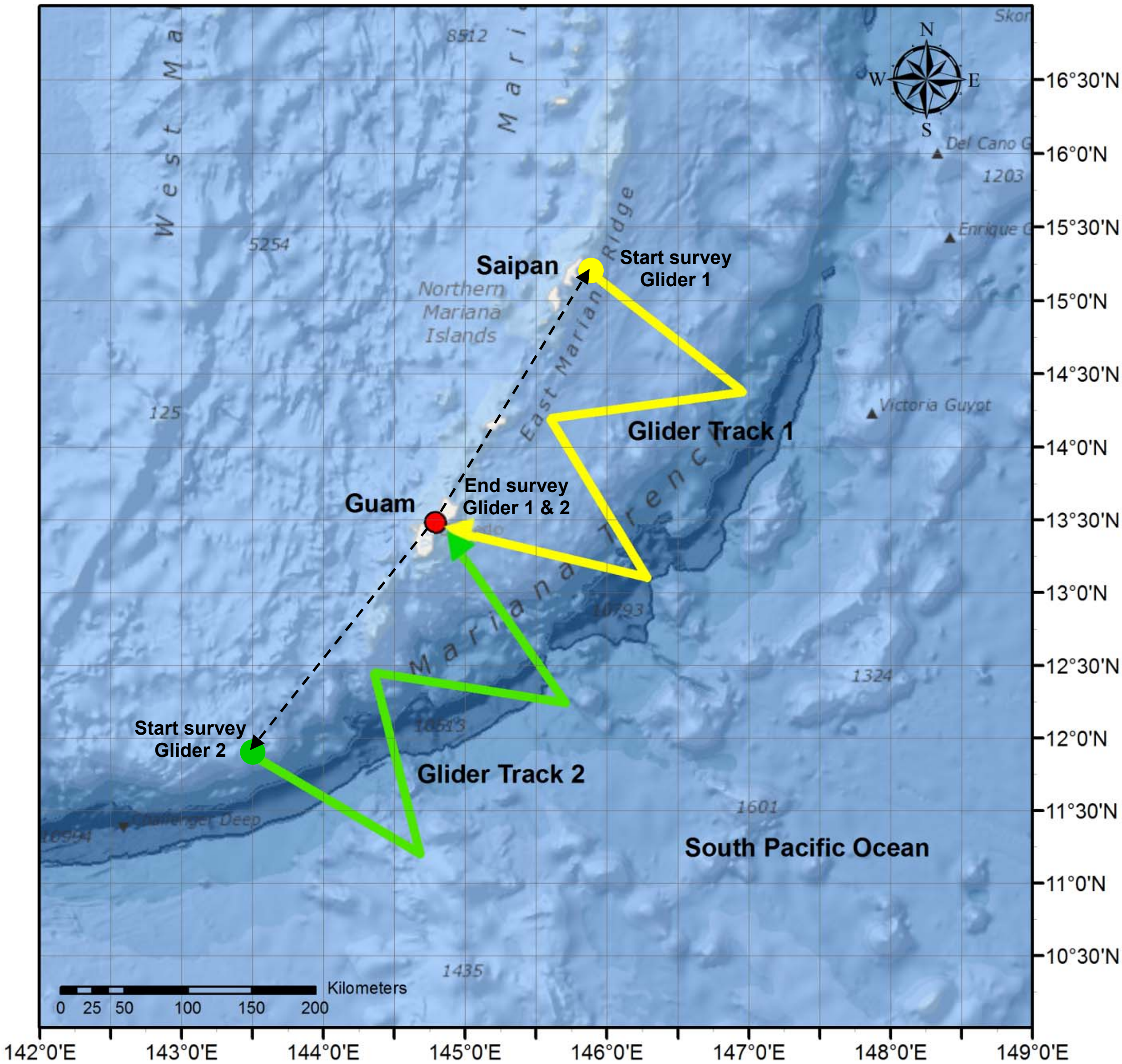

Figure 3: Proposed glider tracks (each ~600 km) for the MIRC survey. Glider 1 (yellow track) was programmed to survey the Mariana Trench in a southwesterly direction (Saipan to Guam). Glider 2 was programmed to survey the area in a northeasterly direction towards Guam. The gliders were to be deployed and recovered just off Guam, with an initial transit (~200 km) to the start of the survey line (dashed arrows).

2.3 Data Analysis

Because [a] relatively little is known about the spatial and seasonal distribution of marine mammal species in this survey area and [b] the data set was only one month in duration, the entire analysis was conducted manually by experienced analysts. Detectors and classifiers were not used for the analysis. This approach, while more labor intensive, reduced the likelihood of missed marine mammal vocal encounters.

The FLAC files were decoded to standard WAV audio file format, and three data sets with different sampling rates (194 kHz, 10 kHz, and 1 kHz) were generated for specific analyses. Analysis was primarily done on a per dive basis, where vocalizations were summarized for each dive, and the percentage of time during a dive when we detected marine mammal sounds for each species was calculated. We also tallied marine mammal sounds on an encounter basis. An encounter was defined as a period when target signals were present in the acoustic data sets, separated from other periods of signal detections by 30 or more minutes of 'silence.' Encounter data were summarized in tabular format (see **Appendix A**).

2.3.1 Environmental Data

The glider collected conductivity and temperature depth profiles as well as information on depth-averaged currents throughout the duration of the survey (including periods when the PAM system was deactivated). APL-UW processed the raw environmental data using custom software routines and provided temperature, sound speed, and depth-averaged currents plots for this report.

2.3.2 Odontocetes

The full bandwidth data (194 kHz sampling rate) were used to calculate long-term spectral average (LTSA) plots with a temporal resolution (Δt) of 5 seconds and a frequency resolution (Δf) of 100 Hz using the Triton Software Package (Scripps Whale Acoustics Lab, La Jolla, California, USA). Data slices of 15 minutes in duration were visually and aurally inspected by experienced analysts for acoustic encounters with odontocetes. Acoustic encounters were expected to be from the following odontocete species: Cuvier's beaked whales (*Ziphius cavirostris*), Blainville's beaked whales (*Mesoplodon densirostris*), Longman's beaked whales (*Indopacetus pacificus*), killer whales (*Orcinus orca*), Risso's dolphins (*Grampus griseus*), sperm whales (*Physeter macrocephalus*), short-finned pilot whales (*Globicephala macrorhynchus*), false killer whales (*Pseudorca crassidens*), bottlenose dolphins (*Tursiops truncatus*), rough-toothed dolphins (*Steno bredanensis*), melon-headed whales (*Peponocephala electra*), Fraser's dolphins (*Lagenodelphis hosei*), short-beaked common dolphins (*Delphinus delphis*), pygmy killer whales (*Feresa attenuata*), striped dolphins (*Stenella coeruleoalba*), pantropical spotted dolphins (*Stenella attenuata*), and spinner dolphins (*Stenella longirostris*).

Vocalizations of odontocetes are typically placed into three categories: echolocation clicks, burst pulse sounds, and whistles. Echolocation clicks are broadband, impulsive sounds with peak frequencies from 5 to over 150 kHz, to aid in foraging and navigation. Burst pulse signals are click trains, or rapidly repeated clicks with a very short inter click interval, that sound like a buzz or creak. Burst pulse signals are thought to have social implications and echolocation functions. Whistles are frequency modulated signals and cover (depending on species) a wide frequency range from a few hundred Hz to many kHz, have a longer duration (hundredths to tenths of seconds) and are thought to be used in social contexts.

The analysts logged species information whenever possible. The first six species listed above have species-specific call features that allow acoustic encounters to be identified to the species level.

- **Beaked whales:**
    - Cuvier's beaked whale clicks are uniquely identified by a frequency modulated click with a peak frequency of 40 kHz and an inter-click-intervals (ICIs) of over 300 ms (Baumann-Pickering et al. 2013).
    - Echolocation clicks recorded from Blainville's beaked whales have the characteristic beaked-whale frequency modulated pulse, a long click duration, and long inter pulse interval (Baumann-Pickering et al. 2013). Such upsweep clicks with peak frequencies near 35 kHz and ICIs of around 200 ms were identified as Blainville's beaked whales.
    - Longman's beaked whale clicks are not as well documented as Cuvier's and Blainville's, but from the known recorded examples, the clicks exhibit the same frequency modulation and long click duration. The peak frequency for Longman's beaked whale echolocation clicks is lower than the other two species, at 22 kHz (Baumann-Pickering et al. 2013). Little is known about their ICIs, thus the click shape and peak frequency were used as the discriminating characteristics for this report.
    - Other beaked whale click types (e.g., Cross seamount type; see Baumann-Pickering et al. 2014) have been recorded in the broader tropical Pacific, but not directly at MIRC. However, analysts were taking the potential presence into consideration while screening the data.
- **Sperm whale:** Regular echolocation clicks produced by sperm whales contain energy primarily from 2-20 kHz with peak energy from 10-15 kHz (Møhl et al., 2003). Clicks are observed during foraging dives and are characterized by a metronomic ICI of about one second (Møhl et al., 2003). Sperm whale click trains can be readily identified in the LTSA plots.
- **Killer whale:** Killer whale pulsed calls are the best described and well documented of their call types, and serve well to differentiate them from other species. Pulsed calls have energy between 1 and 6 kHz, with high frequency components occasionally reaching over 30 kHz. Duration is typically 0.5 to 1.5 seconds (Ford 1987). Aural and visual detection of pulsed calls were used for killer whale encounter identification.
- **Risso's dolphin:** Risso's dolphin echolocation clicks have a unique band pattern observable in bouts of click on an LTSA. Peak energy bands are located at 22, 26, 30, and 39 kHz, with distinct notches at 27 and 36 kHz (Soldevilla et al. 2008). This peak and notch pattern is not as apparent when looking at individual clicks, but the LTSA **(Figure 18)** shows the characteristic appearance of many hundreds of clicks that was used to identify Risso's dolphins in this report.

The remaining 11 delphinid species are very difficult to classify to the species level acoustically mainly because of missing ground-truthed data. Thus, these species were grouped by similarity of the acoustic features of their whistles, which overlap across species and thus cannot definitively be assigned to a single species without concurrent visual observations. As described by Frankel & Yin (2010) whistle acoustic characteristics in delphinids often vary geographically and as ground-truthed data for the MIRC are sparse, the following groups were used for classification (similar to Munger et al. 2014).

- **Low-frequency whistles:** This group included whistles produced by the false killer whale, short-finned pilot whale, melon-headed whale, pygmy killer whale, and rough-toothed dolphin. The defining whistle characteristics for this group were whistles that were relatively low frequency (predominately below 10 kHz). Number of inflection points/steps and frequency range of the whistles is variable and species dependent (Frankel and Yin 2010, Lima et al. 2012, Oswald et al. 2003)

- **High-frequency whistles:** This group included whistles produced by the bottlenose dolphin, pantropical spotted dolphin, short-beaked common dolphin, spinner dolphin, striped dolphin, and Fraser's dolphin. The defining whistle characteristics for this group were whistles that were higher in frequency (predominantly above 10 kHz). Number of inflection points/steps and frequency range of the whistles is variable and species dependent (Frankel and Yin 2010, Ketten 1998, Lammers et al. 2003, Oswald et al. 2003, Richardson et al. 1995)**.**
- **Low- and high-frequency whistles:** This group included encounters characterized by [a] whistles with significant energy below and above 10 kHz or [b] various whistle types which covered a wide frequency range in one encounter. This group could contain species from either of the above whistle categories.
- **Echolocation clicks and/or burst pulses:** This group included encounters which only contained echolocation clicks and/or burst pulses. The recorded clicks and pulsed calls did not contain any characteristic acoustic features enabling species identification. Many of the identified whistle encounters did include echolocation clicks and burst pulses, but because of the added information contained in the whistles, we were able to classify them more specifically by whistle frequency. Click and burst pulse encounters could potentially be associated with any of the above mentioned eleven delphinid species.

2.3.3 Mysticetes

The low- and mid-frequency data were used to calculate long-term spectral average (LTSA) plots with a Δt of 1 s and Δf of 1 Hz (1 kHz data) and a Δt of 2 s and Δf of 10 Hz (10 kHz data) using the Triton Software Package. Both LTSAs were coarsely screened visually and aurally by analysts for bioacoustic activity and general quality assurance. The actual logging of acoustic encounters was done in Raven Pro (Bioacoustics Research Program, Cornell University, Ithaca, New York, USA). Both data sets were imported into Raven Pro, time aligned, and simultaneously screened for increased efficiency (**Figure 4**).

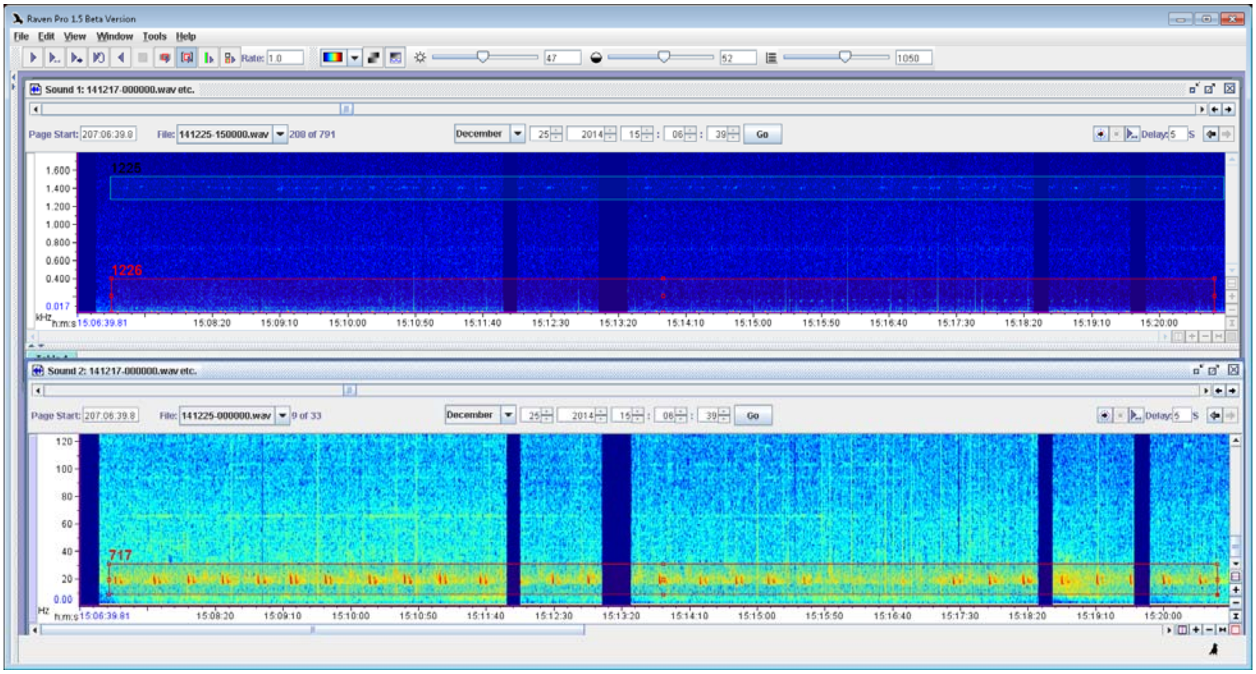

Figure 4: Example (from a HRC survey) of time aligned spectra displayed in the software Raven Pro. The upper spectrogram is the 10-kHz down-sampled data and was used to identify mid-frequency vocalizations from minke whales (blue box) and humpback whales (red box). The lower spectrogram is the 1-kHz data and was used to identify calls from fin whales (red box) and blue whales, and also provided context when identifying the mid-frequency calls.

The MIRC study area provides habitat for numerous species of baleen whales that produce low-frequency vocalizations. Sei whales (*Balaenoptera borealis*) and minke whales (*B. acutorostrata*) have been acoustically detected in the area, while visual surveys have confirmed the presence of sei (*B. edeni*) and Bryde's (*B. brydei*) whales. Based on our experience with acoustic data collected near the Marianas, this area is also used, at least seasonally, by blue whales (*B. musculus musculus* and *B. musculus brevicauda*), fin whales (*B. physalus*) and humpback whales (*Megaptera novaeangliae).*

Experienced analysts analyzed the low-frequency data for down-sweeping calls from sei whales (Baumgartner et al. 2008, Rankin and Barlow 2007), the short and variable calls from Bryde's whales (Heimlich et al. 2005,; Oleson et al. 2003) the western and central pacific blue whale calls (Stafford et al. 2011, 1999) and the 20 Hz and 40 Hz fin whale calls (Thompson et al. 1992, Watkins 1981).

The mid-frequency data were primarily analyzed for humpback whale song and social sounds (Payne and McVay 1971, Stimpert and Au 2008), and the complex minke whale calls (Gedamke et al. 2001, Rankin and Barlow 2005).

2.3.4 Mid-Frequency Active Sonar (MFAS)

The mid-frequency LTSA plots were also screened visually and aurally for occurrences of MFAS signals.

3. Results

A summary of the glider surveys is provided in **Table 1**, **Figures 5 and 6**. A total of 890 gigabytes of acoustics data (04 October to 09 November 2014) and 126 megabytes of engineering/environmental data were collected with SG178. SG178 conducted 168 dives with the PAM system active. The median recording time per dive was calculated as 4.7 hours. All dates/times reported are in UTC [dd/mm/yy hh:mm:ss].

Table 1: Summary of the glider surveys.

Glider	# of dives	Distance over ground	Distance through water
SG178	222 (168)	833 km (695 km)	923 km (777 km)
SG179	205(0)	720 km (0 km)	865 km (0 km)

Note: Values in parentheses indicate ‘PAM active’ statistics. SG179 experienced a malfunction during the transit to the survey area and didn’t collect usable PAM data.

Key: km = kilometer(s)

SG178 did not record acoustic data during the transit from the deployment location to the start point of the survey (dives 1-44) to conserve battery. Furthermore, SG178 did not record acoustic data during dives 56, 59-63, 103-105, and 198-199 (6% of total PAM active dives). The cause for this data loss was associated with PAM system “hang ups” (PAM system stopped processing incoming acoustic data; likely associated with a firmware issue). While this was easily resolved by the glider pilot by rebooting the PAM system, it sometimes took a few hours before this issue was detected. The glider recorded a total of 749 h (~31 days) of acoustic data during this survey and slightly exceeded the expected 30 days of recordings.

SG179 experienced a malfunction during the transit to the survey area. The acoustic data collected with the instrument were contaminated with electronics noise and thus had to be excluded from any further analysis. The quality of the 95 MB of environmental data (conductivity, temperature, and depth; sound speed profiles; depth-averaged current) collected during the first 145 (out of 205) dives was not impaired by the malfunction and are summarized in **Section 3.1** below.

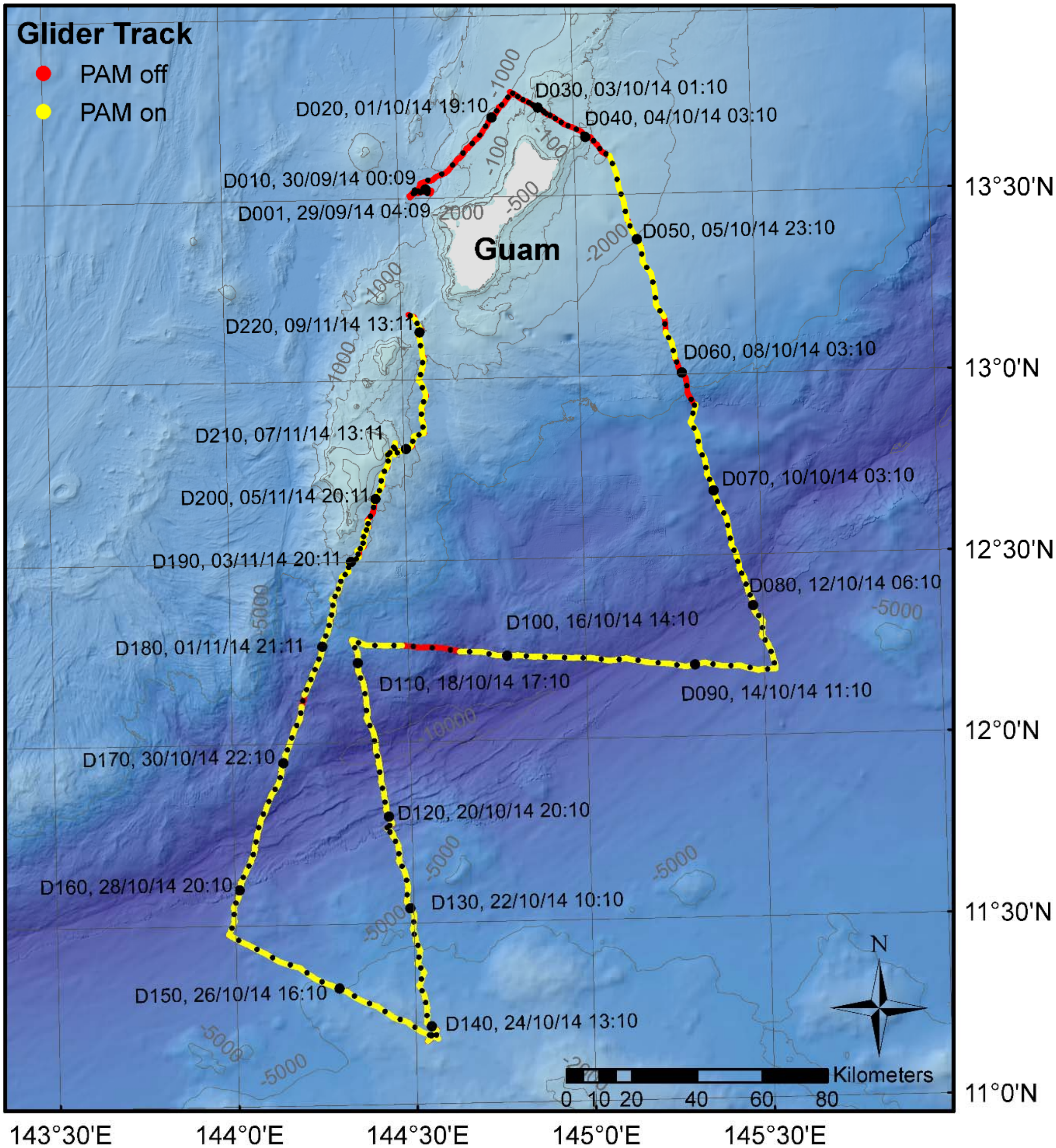

Figure 5: SG178 track line for the period 29 September–09 November 2014. Each black dot on the track line indicates the midpoint location of a glider dive; every 10th dive is represented by a larger dot. Labels indicate dive number (e.g., D001 for dive no. 1) and date/time (format: dd/mm/yy hh:mm UTC). Red sections indicate that the PAM system was OFF. The yellow marks indicate that the PAM system was active.

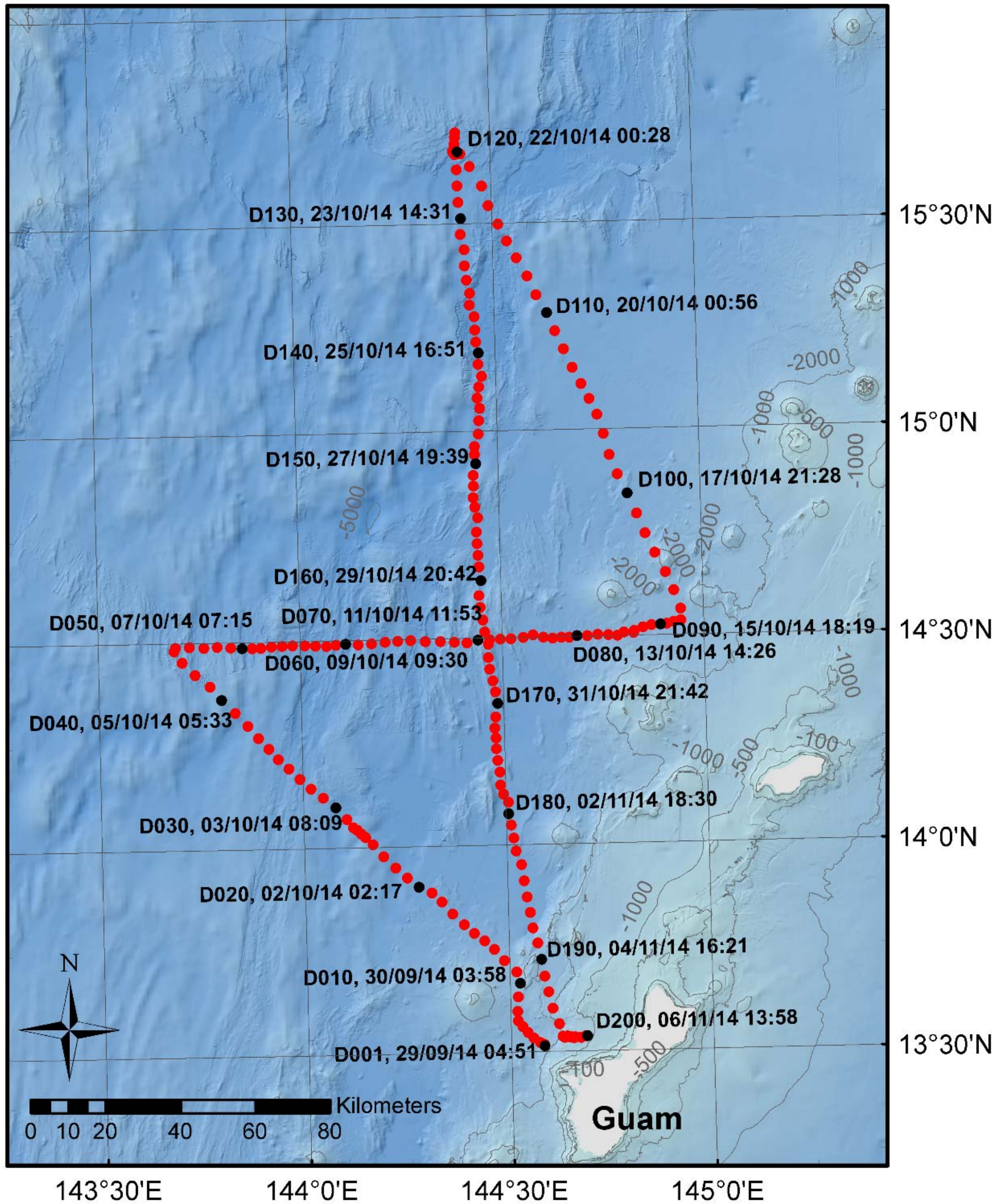

Figure 6: SG179 track line for the period 29 September–06 November 2014. Each red dot on the track line indicates the midpoint location of a glider dive. Labels indicate dive number (e.g., D001 for dive no. 1) and date/time (format: dd/mm/yy hh:mm UTC). Acoustic data were compromised by a glider malfunction. The collected environmental data were analyzed and included in this report.

3.1 Environmental Data

The results of the environmental data analysis are summarized in **Figures 7 through 10**. White areas in the plots indicate no data and are a result of dives shallower than 1,000 m (e.g., bathymetry limited dives). The sea surface temperature (**Figures 7 and 8**) varied little geographically and temporally and was around 30 degrees Celsius (°C). The profiles indicated a strong temperature gradient of approximately 20°C in the 0-300 m depth range.

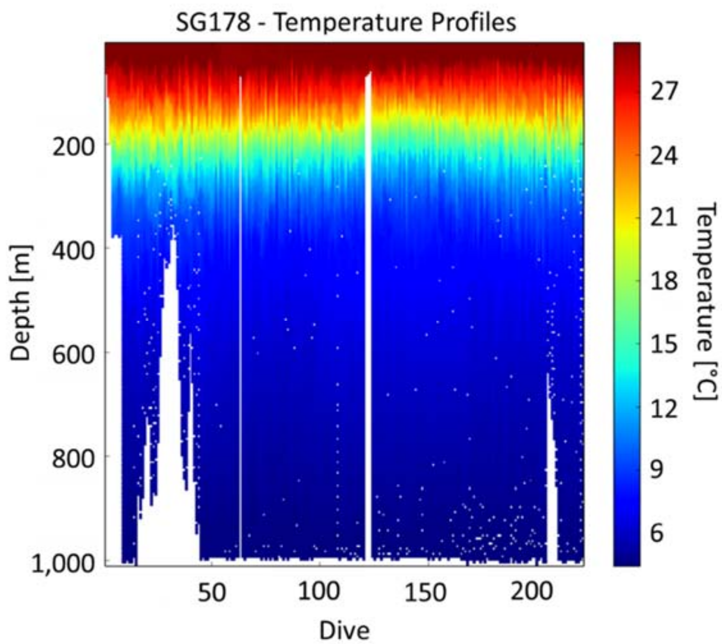

Figure 7: Temperature profiles recorded with SG178.

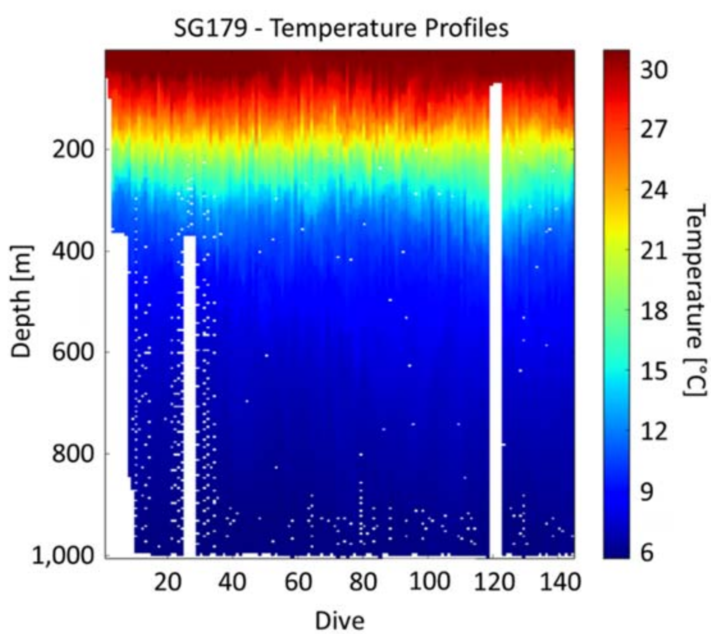

Figure 8: Temperature profiles recorded with SG179.

The sound-speed profiles (**Figures 9 and 10**) showed downward refracting sound propagation conditions and no significant surface duct. There were no significant changes observed in time and space. Furthermore, the glider did not reach the sound fixing and ranging channel axis which in the deployment area is located below the instrument's maximum operation depth of 1,000 m. Signal propagation conditions were excellent for detecting biological sounds, however, estimating the absolute detection ranges for the various signals was not possible given the scope of this effort and missing information on source levels etc.

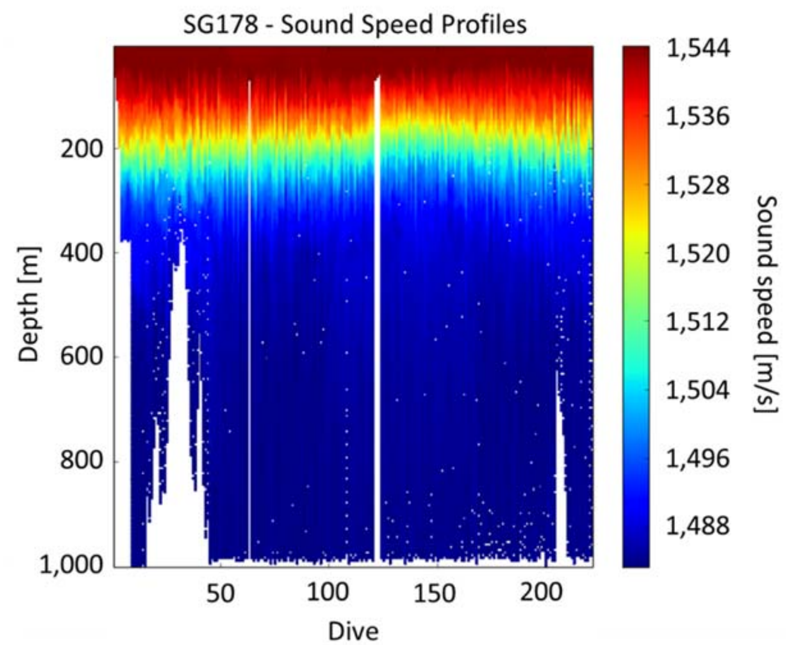

Figure 9: Sound-speed profiles recorded with SG178.

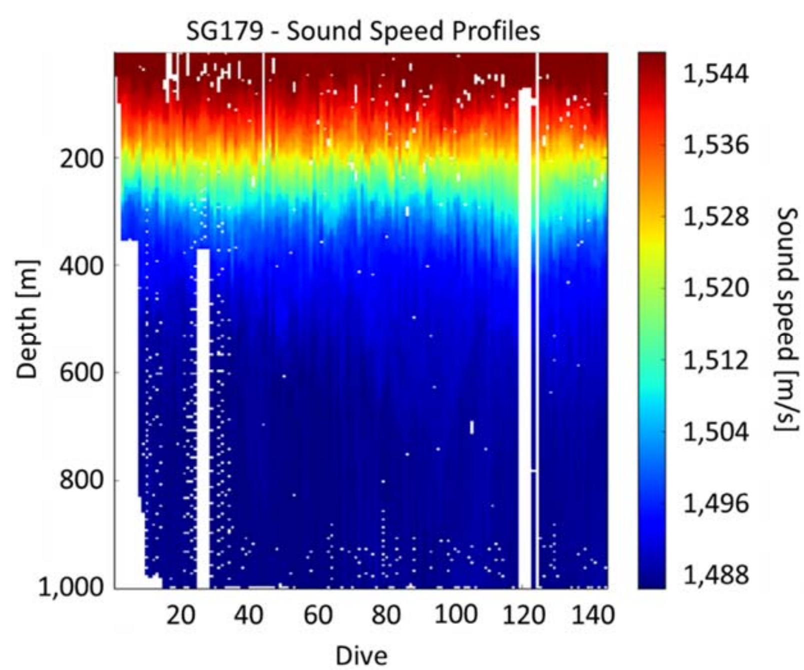

Figure 10: Sound-speed profiles recorded with SG179.

As shown in **Figure 11 and 12**, the depth-averaged ocean currents in the survey area were predominantly in a westerly direction.

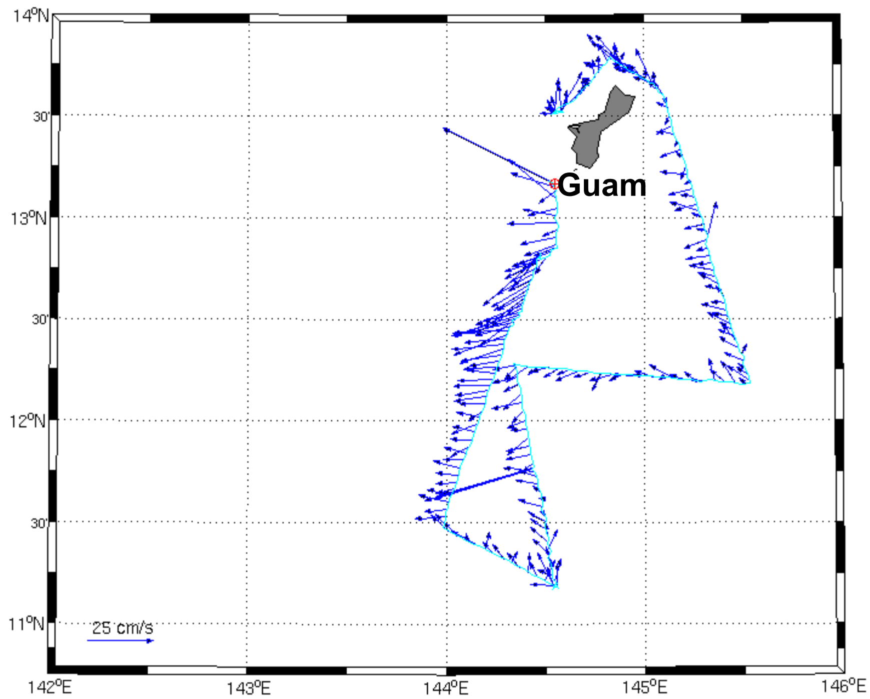

Figure 11: Depth-averaged currents measured with SG178.

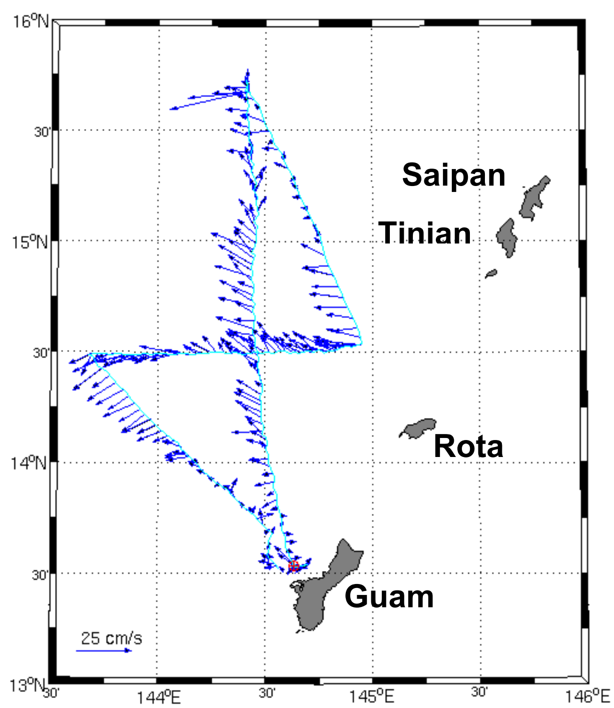

Figure 12: Depth-averaged current measured with SG179.

SG178 reported a median depth-averaged current velocity of 8.2 cm/s and a median direction of 266°. The currents reported by SG179 were slightly stronger (9.5 cm/s, median) with a similar median direction 282°.

3.2 Odontocetes

3.2.1 Beaked whales

Seven potential beaked whale encounters were registered by SG178. Three encounters were identified as Blainville's beaked whales (**Figure 13,** left panel). These encounters were detected when the glider was at depths from 73.4 to 817.4 m. The remaining four encounters were classified as possible beaked whales. Because of the low number and a reduced signal-to-noise ratio of the signals, these calls could not be classified as beaked whales with absolute certainty. The possible beaked whale (PBW) clicks seemed longer in duration than common delphinid echolocation clicks. However, the mean ICI of the PBW click trains ranged between 0.1 and 0.12 s which is more indicative for a delphinid. Because of the low SNR, the beaked whale characteristic upsweep was difficult to decipher in the spectrograms (**Figure 13**, right panel). These calls were recorded in water 1,000 to 4,000 m deep. The locations of the encounters are shown in **Figures 14 and 15.**

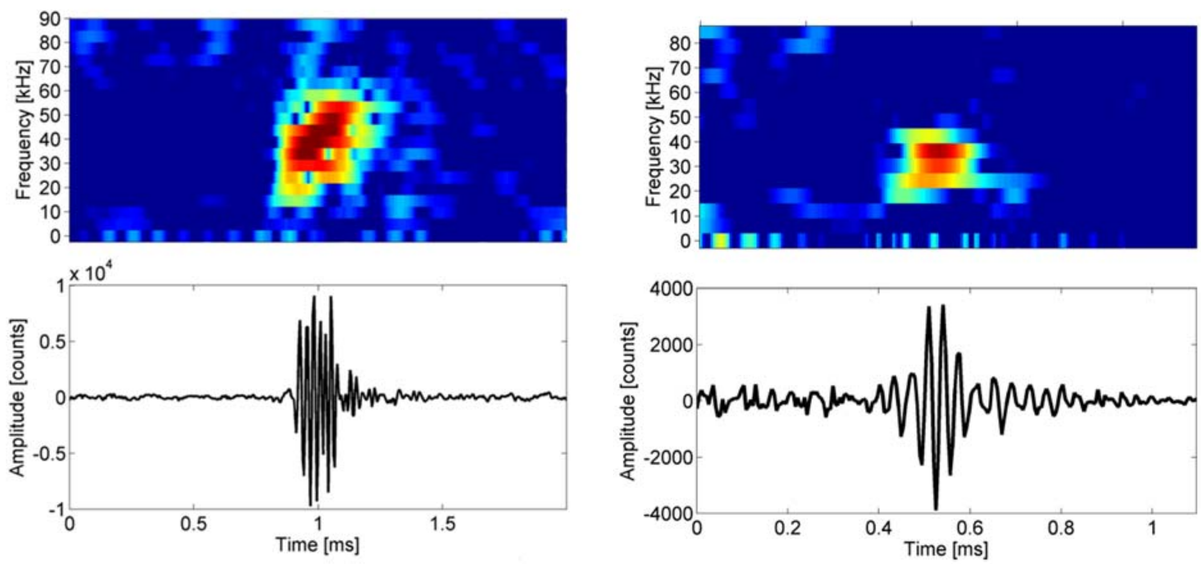

Figure 13: Blainville's beaked whale echolocation click (left) and possible beaked whale echolocation click (right) recorded with SG178. Both examples are high-pass filtered at 10 kHz. Amplitude range of waveform is ±32,768 digital counts (16 bits). Because of the low SNR, the

beaked whale characteristic upsweep was difficult to decipher in the spectrograms.

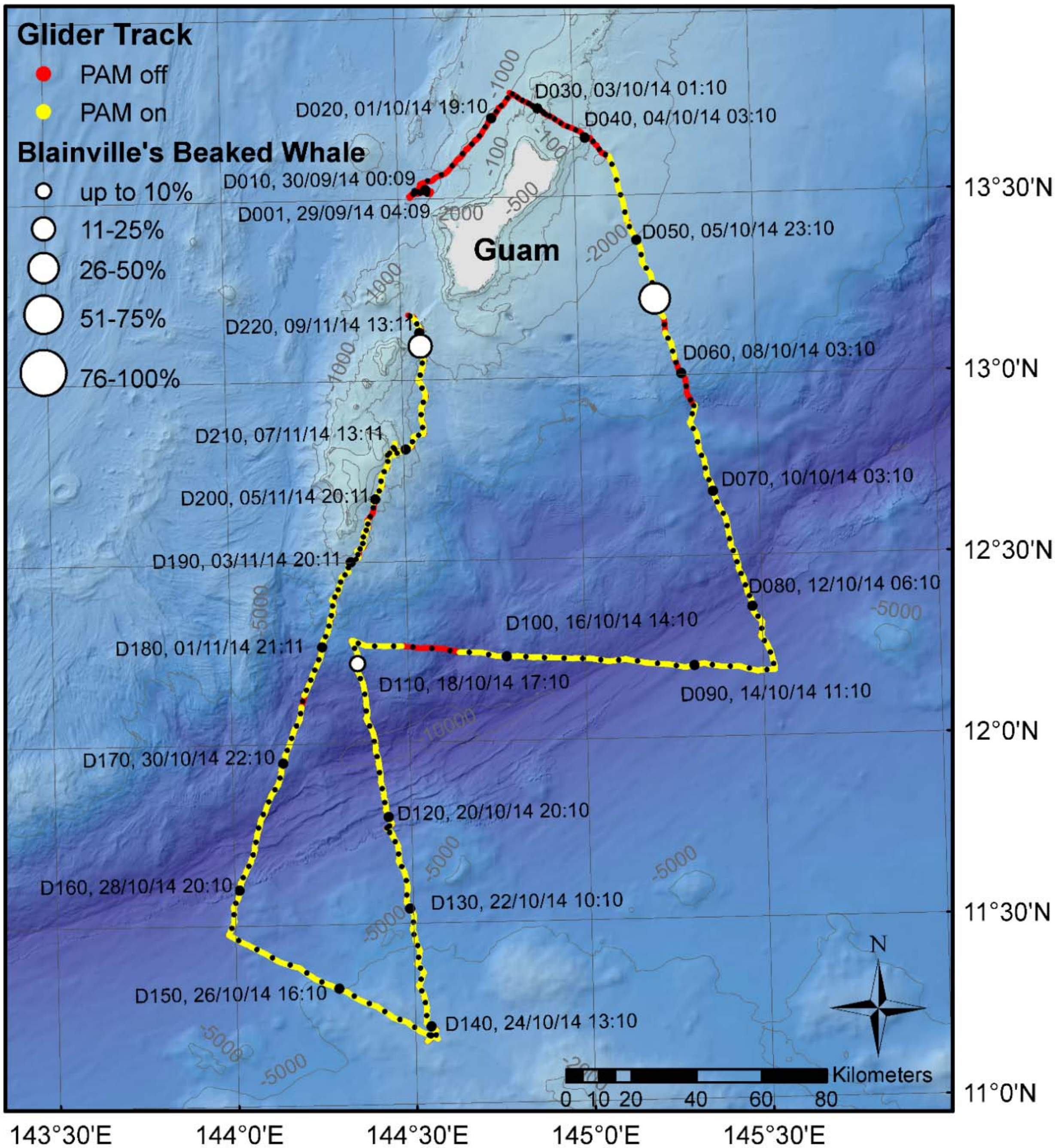

Figure 14: SG178 Blainville's beaked whale encounters. The circle size indicates percentage of recording time per dive with target signals.

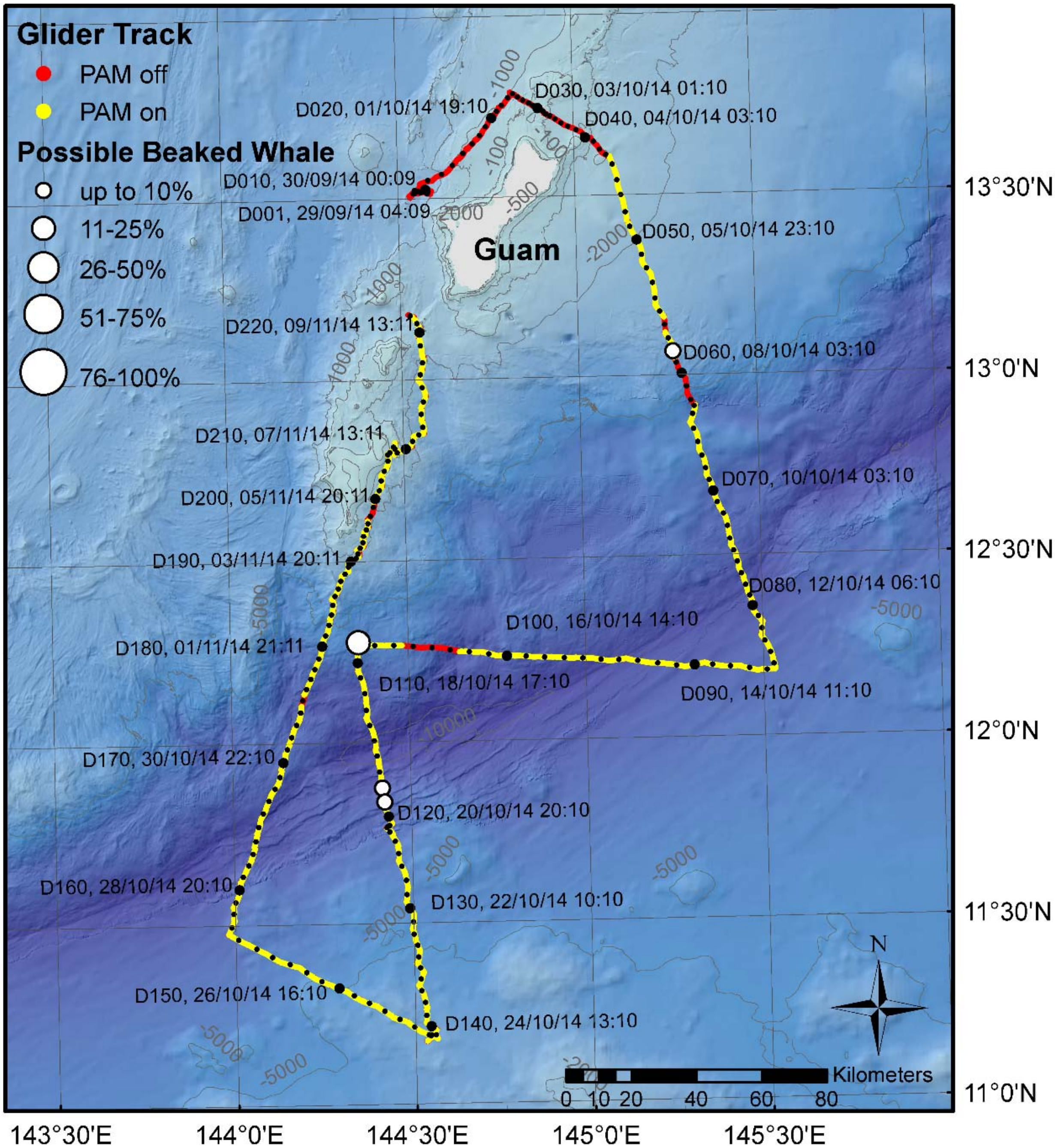

Figure 15: SG178 possible beaked whale encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.2 Killer whales

Killer whales vocalizations (**Figure 16**) were detected during three dives (**Figure 17**). All killer whale encounters occurred in water deeper than 5,000 m.

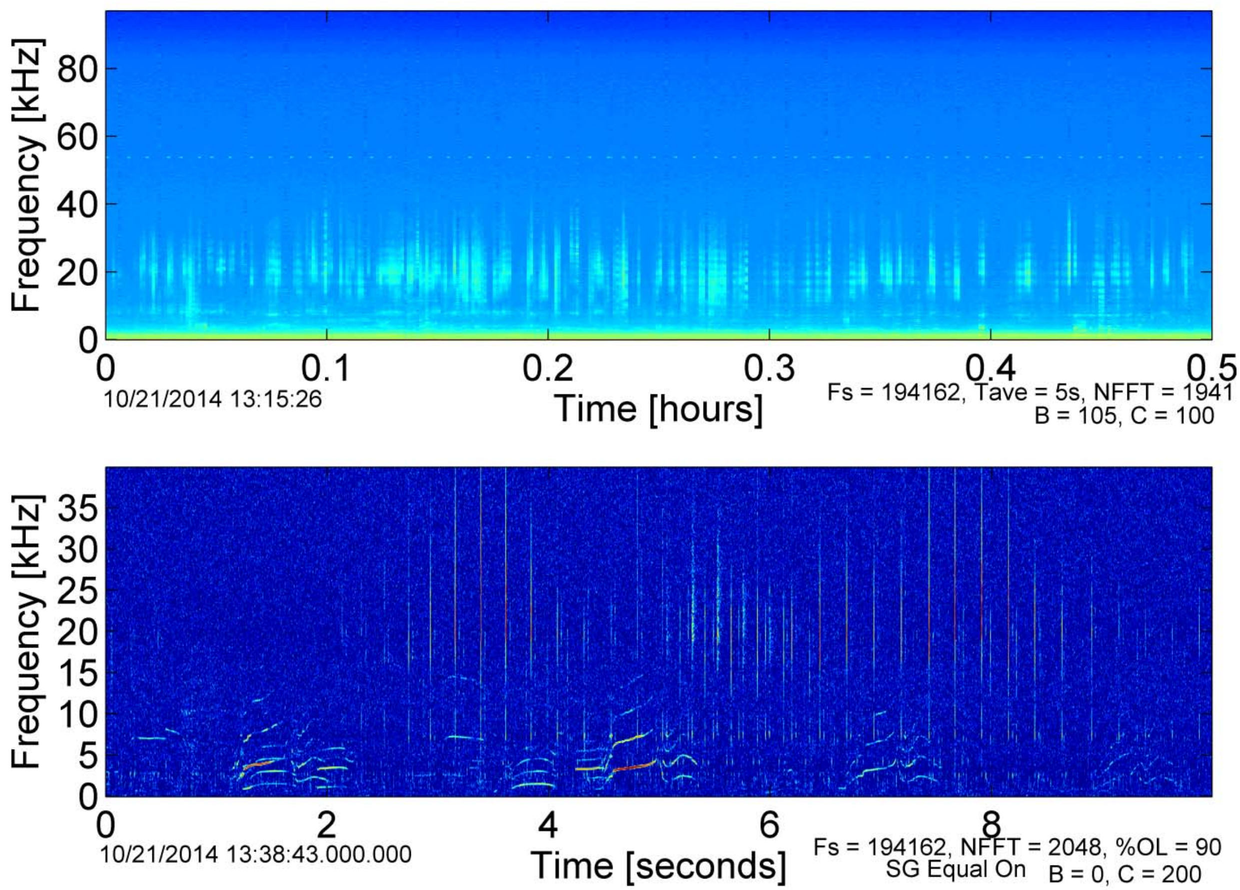

Figure 16: Killer whale vocalizations recorded with SG178 on 21 October 2014.

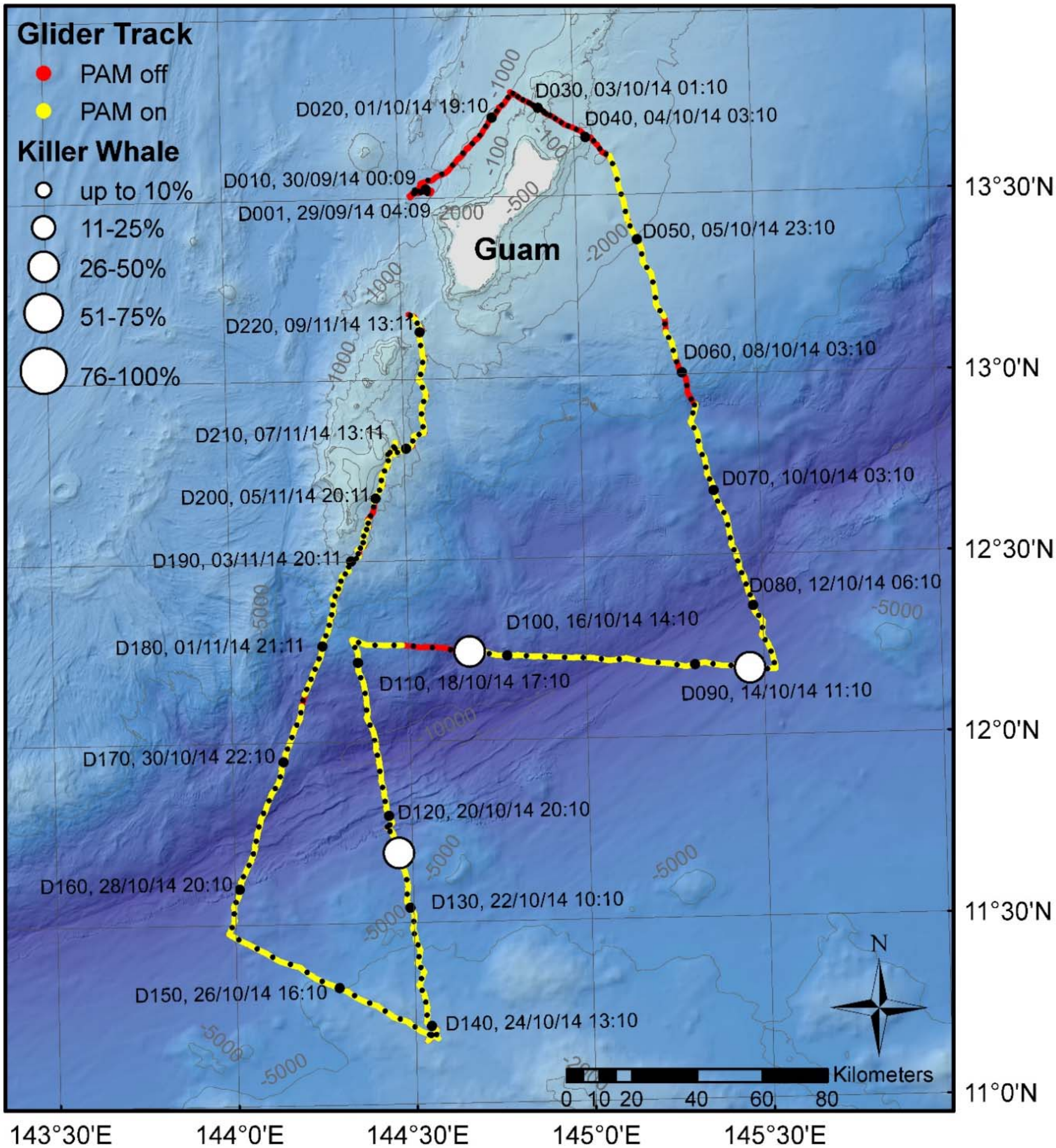

Figure 17: SG178 killer whale encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.3 Risso's dolphins

SG178 recorded two Risso's dolphin encounters during two dives. An example of the recorded echolocation clicks is shown in **Figure 18**. The LTSA (upper panel) depicts the characteristic peaks and notches at specific frequencies (Soldevilla et al. 2008). Similar to the killer whale detections, Risso's dolphin encounters occurred in deep offshore waters (**Figure 19**).

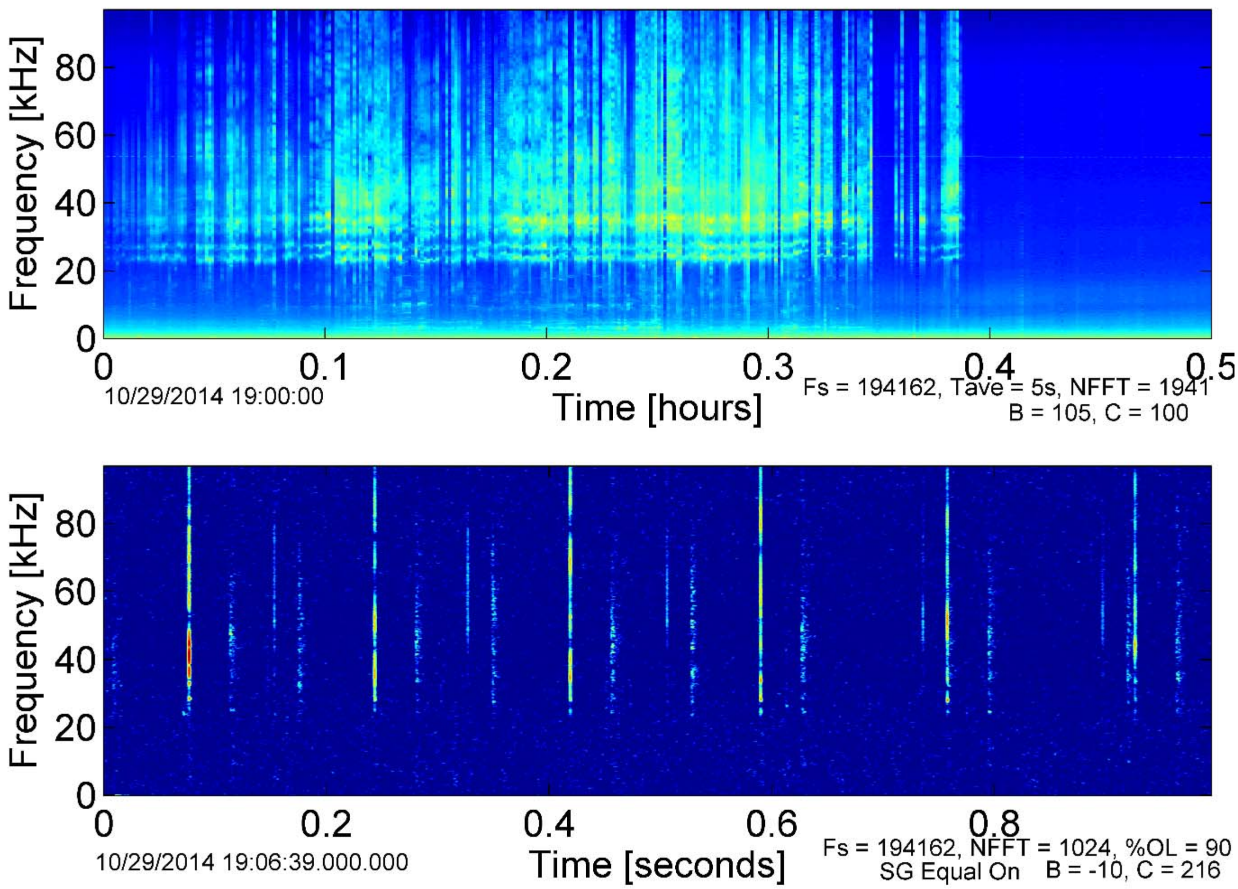

Figure 18: Risso's dolphin echolocation clicks recorded with SG178 on 29 October 2014.

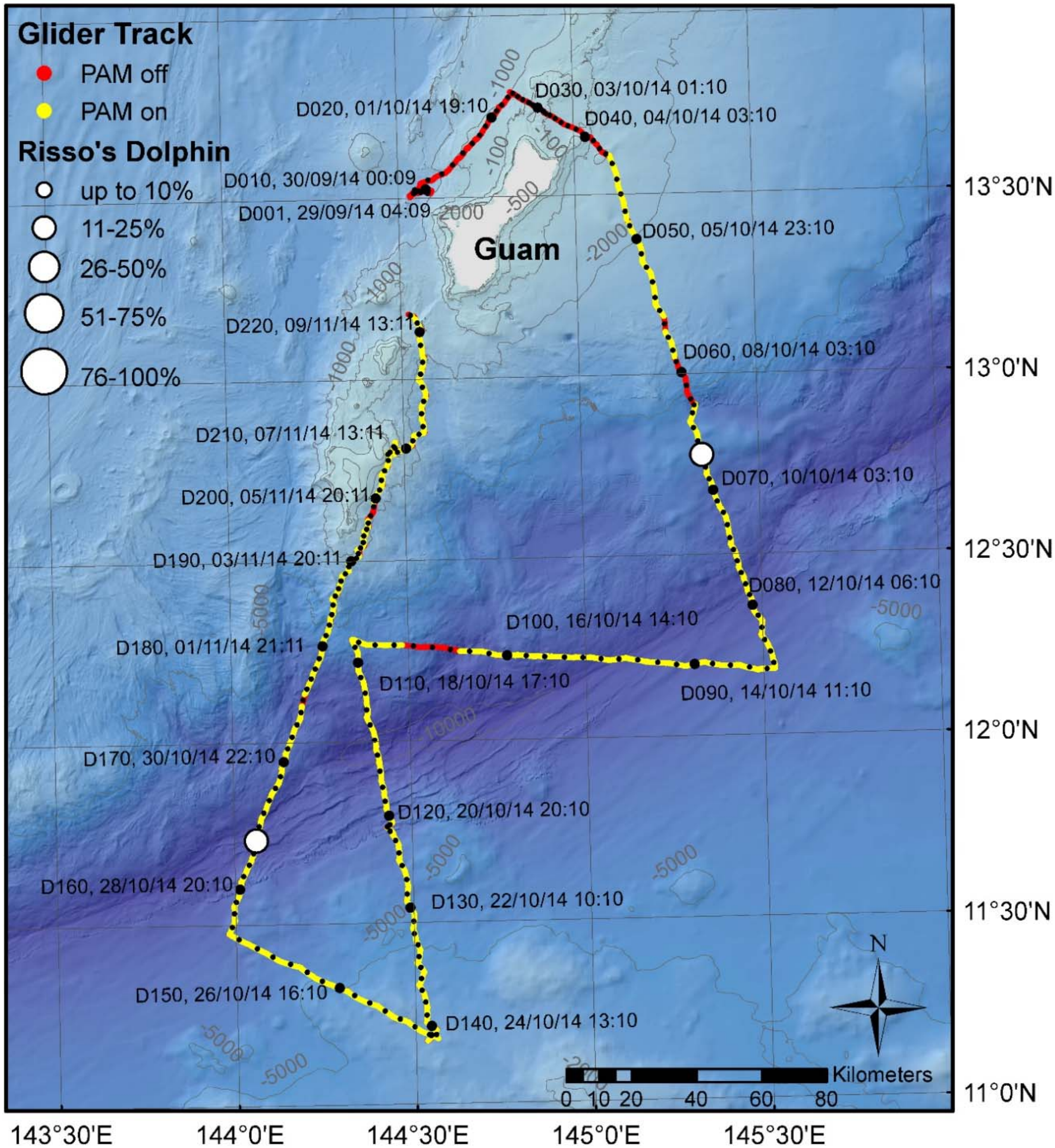

Figure 19: SG178 Risso's dolphin encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.4 Sperm whales

Sperm whale echolocation clicks (**Figure 20**) were detected 20 times throughout the survey, on 17 individual dives (**Appendix A**). The locations of the dives with sperm whale detections are show in **Figure 21**.

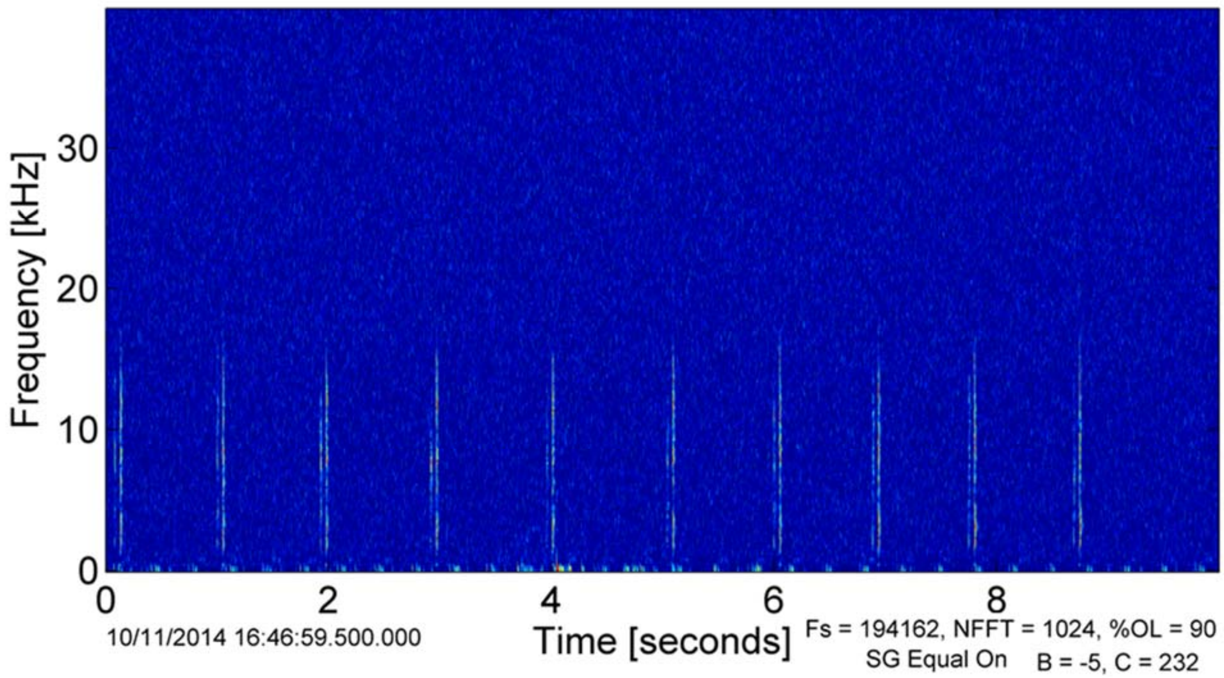

Figure 20: Sperm whale echolocation clicks recorded with SG178 on 11 October 2014.

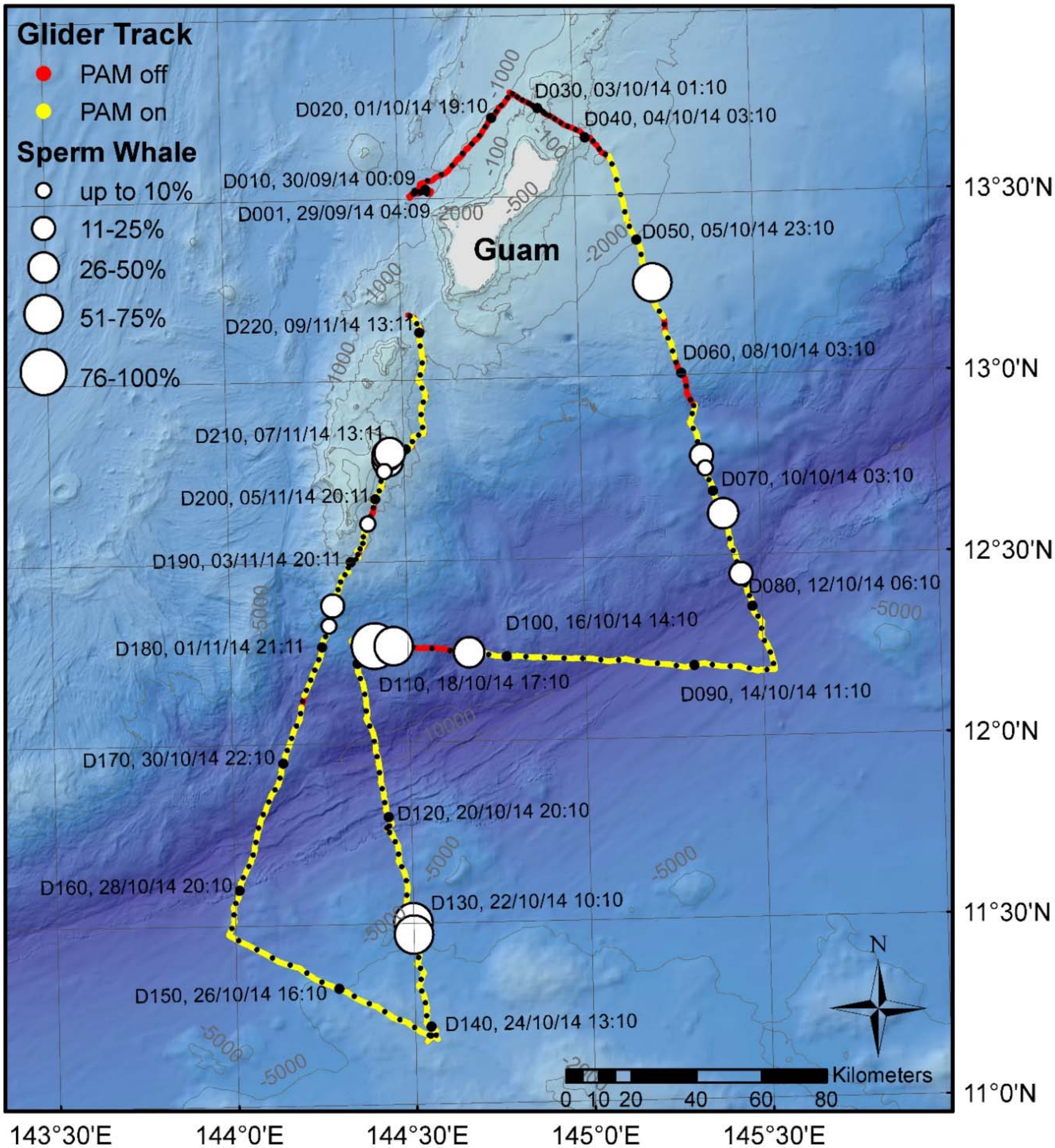

Figure 21: SG178 sperm whale encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.5 Other odontocetes - low-frequency whistles

Eight encounters of low-frequency whistles were recorded on seven glider dives. An example of a low-frequency whistle is shown in **Figure 22**. These encounters are likely associated with one of the following species: false killer whale, short-finned pilot whale, melon-headed whale, pygmy killer whale, or rough-toothed dolphin. Dive locations are shown in **Figure 23**. The longest encounter (approximately 4 h, **Appendix A**) was recorded during dive 126. Calls were recorded in water 1,000 to 10,000 m deep.

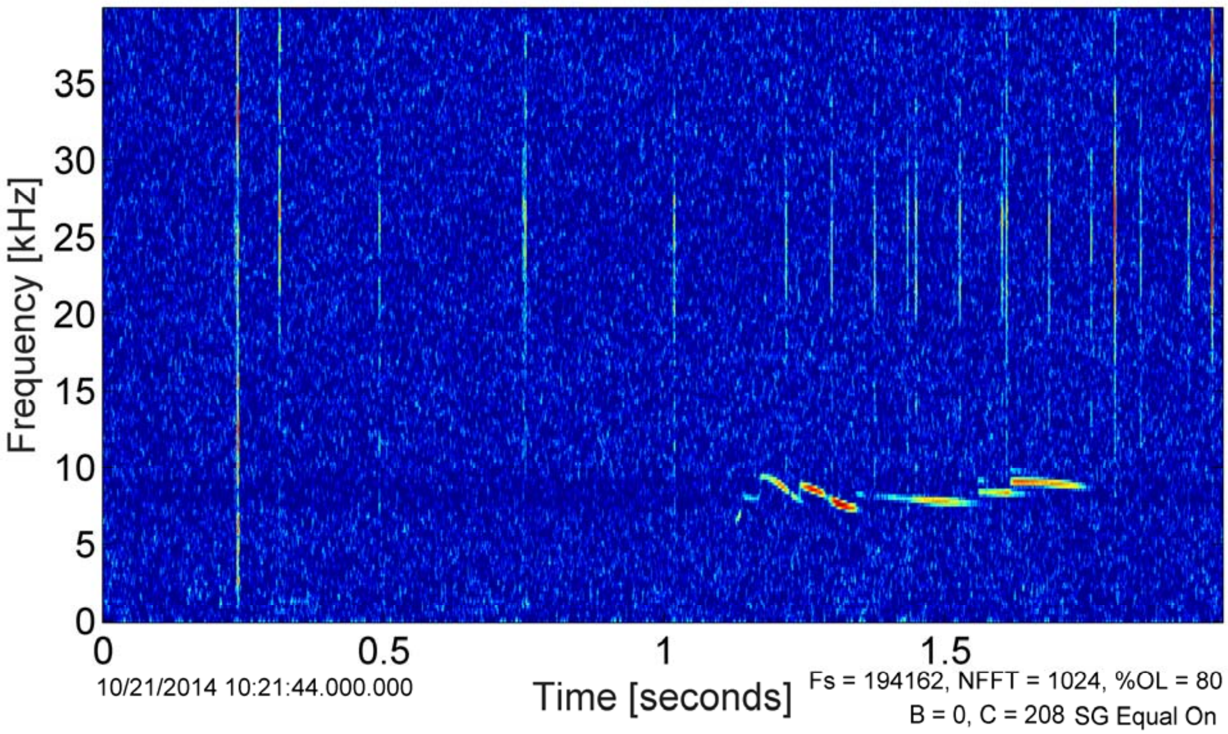

Figure 22: Low-frequency whistles recorded with SG178.

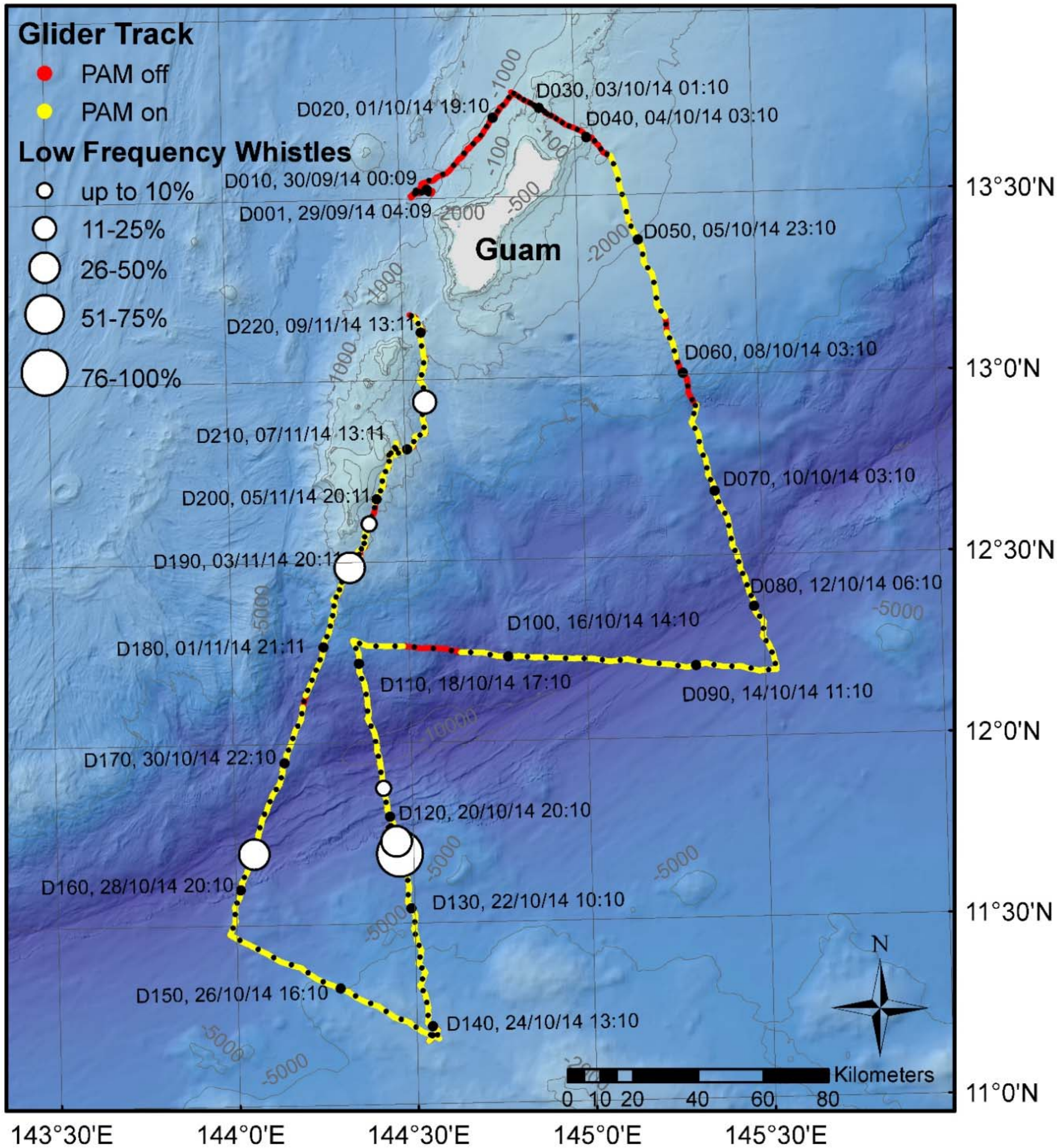

Figure 23: SG178 low-frequency whistle encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.6 Other odontocetes – high-frequency whistles

Detections of high-frequency whistles likely represent the presence of one or more of the following species: bottlenose dolphin, pantropical spotted dolphin, short-beaked common dolphin, spinner dolphin, striped dolphin, and Fraser's dolphin.

An example of a high-frequency whistle is given in **Figure 24**. No high-frequency whistle encounters were detected by SG178 during the first eighty dives of the survey. The majority of the twenty-one encounters (**Appendix A**) occurred between dives 100 and 140. Some of the encounters spanned across two dives. These whistles were recorded in relatively shallow but also deep water (**Figure 25**).

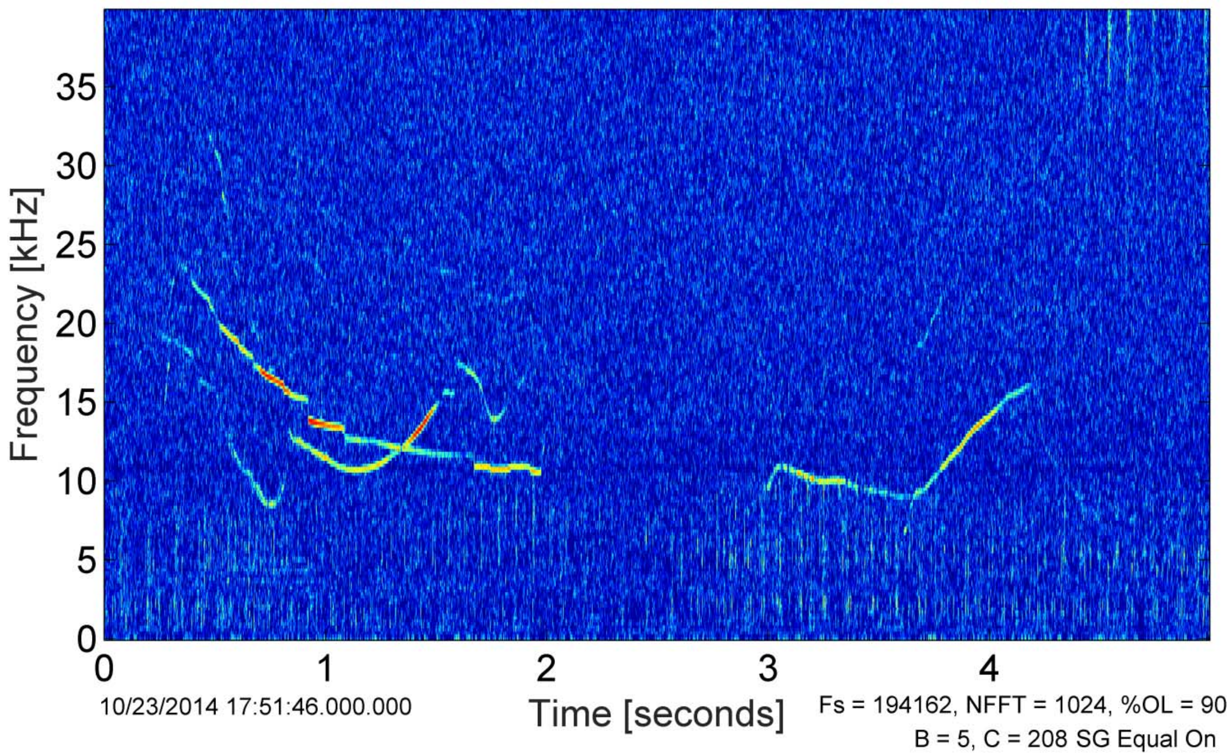

Figure 24: High-frequency whistles recorded with SG178 recorded on 23 October 2014.

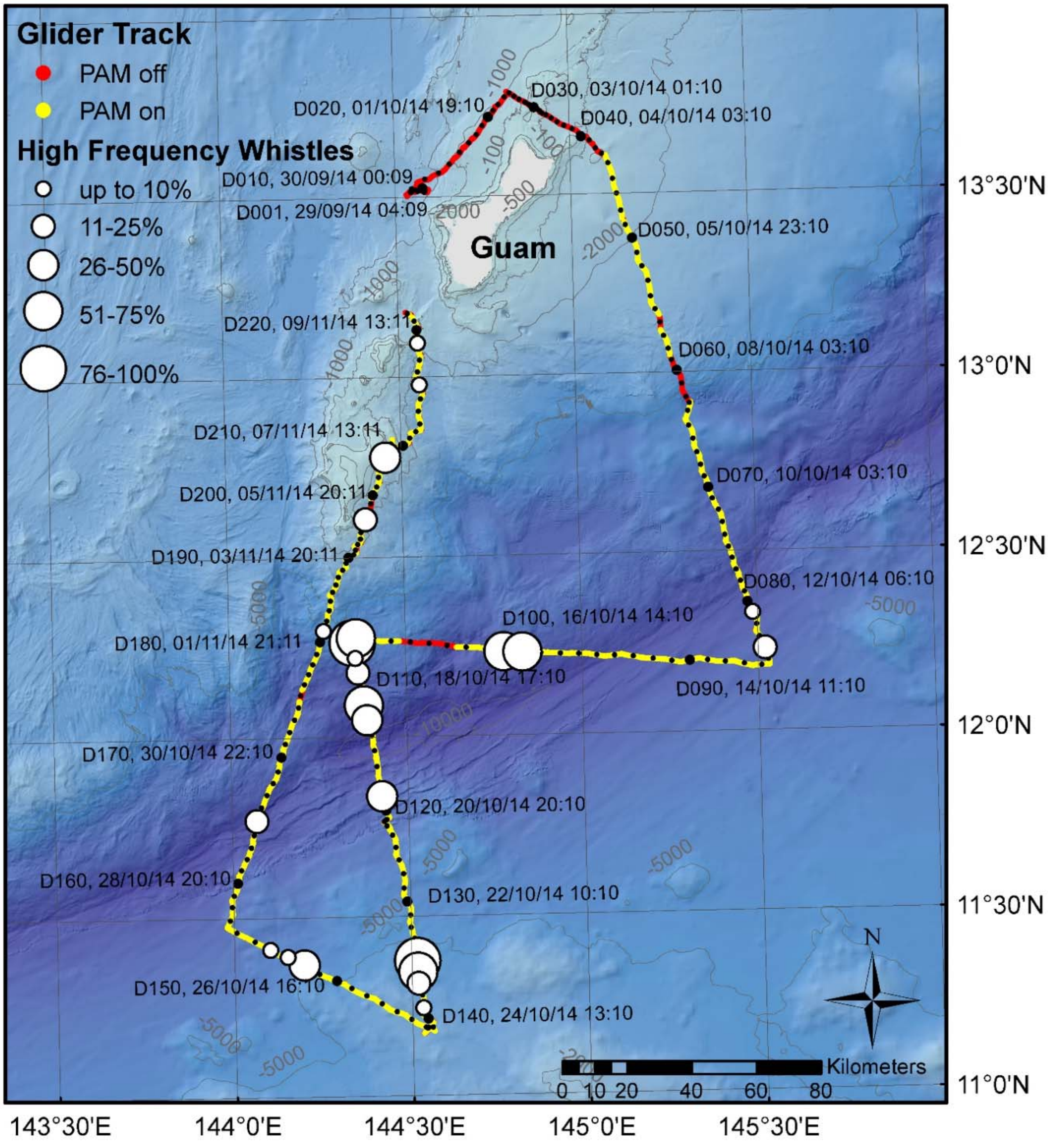

Figure 25: SG178 high-frequency whistle encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.7 Other odontocetes - low- and high-frequency whistles

Nine encounters included either low- and high-frequency whistles, or whistles that covered a wide frequency range with equal energy above and below 10 kHz. An example of a low- and high-frequency whistle encounter is shown in **Figure 26.** These encounters spanned 13 dives, as four of the encounters occurred across two dive consecutive dives. The majority of encounters (**Appendix A**) occurred between dives 86 and 100 (**Figure 27**) and in deep water (>5,000 m). These encounters could include any of the above species listed for the low- and high-frequency whistle classes.

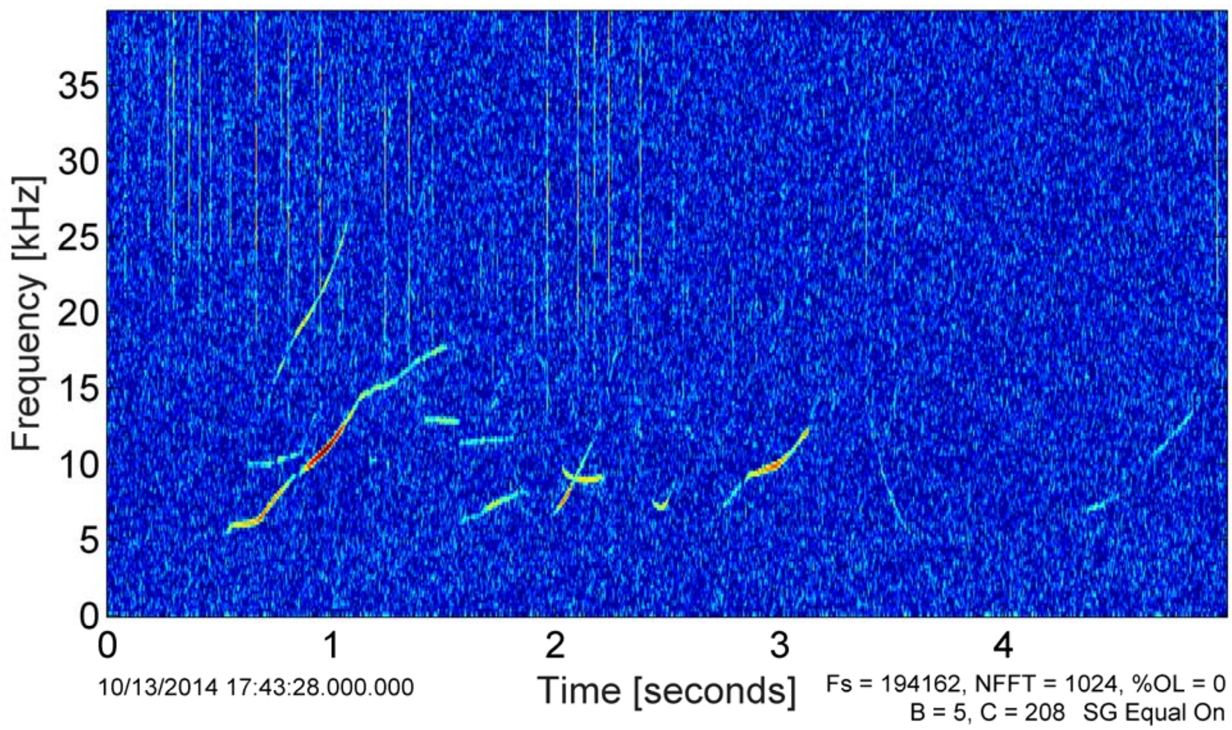

Figure 26: Low- and high-frequency whistles recorded with SG178 on 13 October 2014.

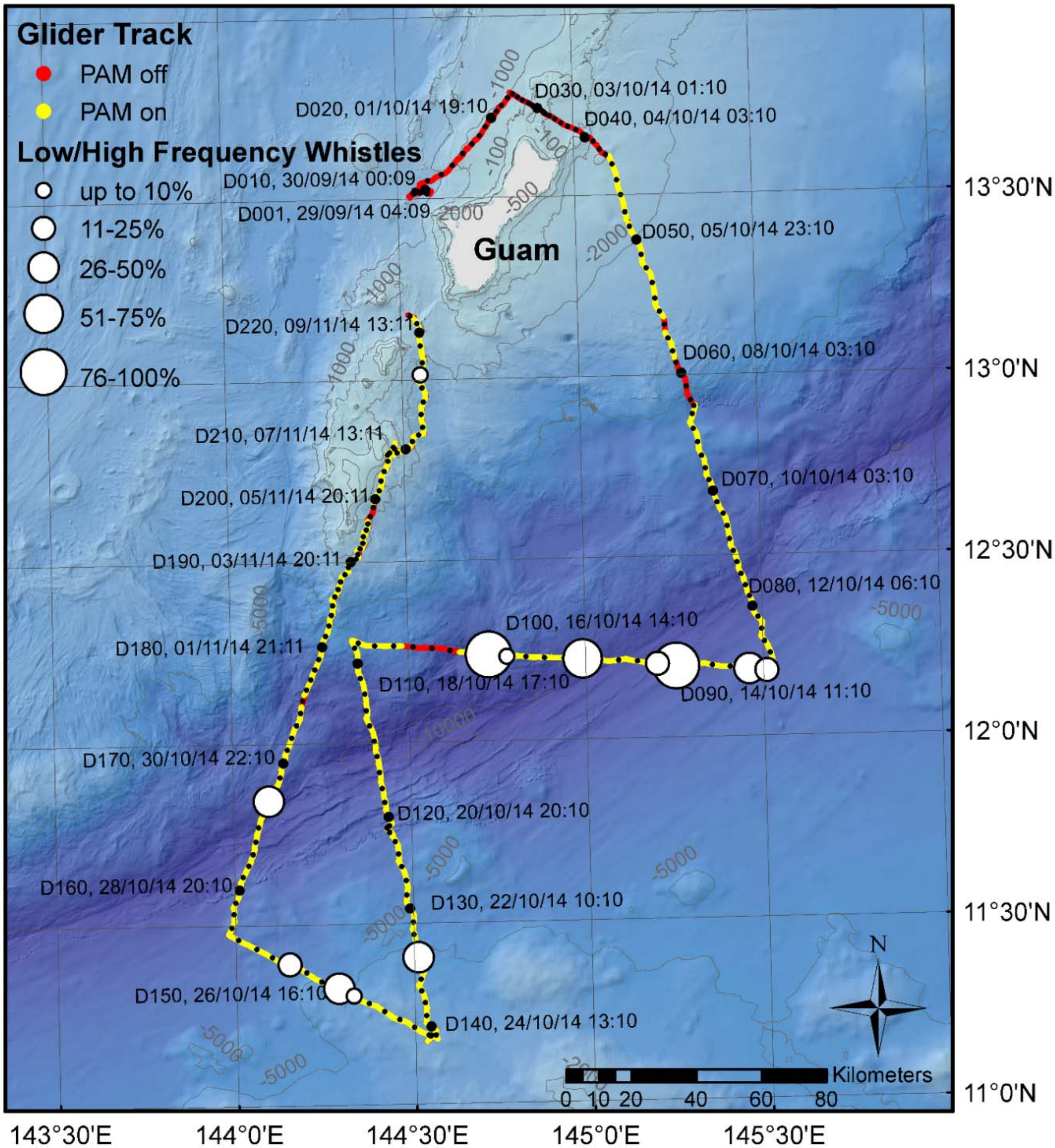

Figure 27: SG178 low- and high-frequency whistle encounters. The circle size indicates percentage of recording time per dive with target signals.

3.2.8 Echolocation clicks and burst pulses

The last group, "echolocation clicks and burst pulses," describes the 35 encounters with only transient signals present (no whistles, **Appendix A**). An example is shown in **Figure 28**. These clicks did not show characteristic spectral features which allowed a species identification. This group could potentially include any of the following species: false killer whale, short-finned pilot whale, melon-headed whale, pygmy killer whale, and rough-toothed dolphin, bottlenose dolphin, pantropical spotted dolphin, short-beaked common dolphin, spinner dolphin, striped dolphin, and Fraser's dolphin. Dives during which these clicks were recorded are shown in **Figure 29**.

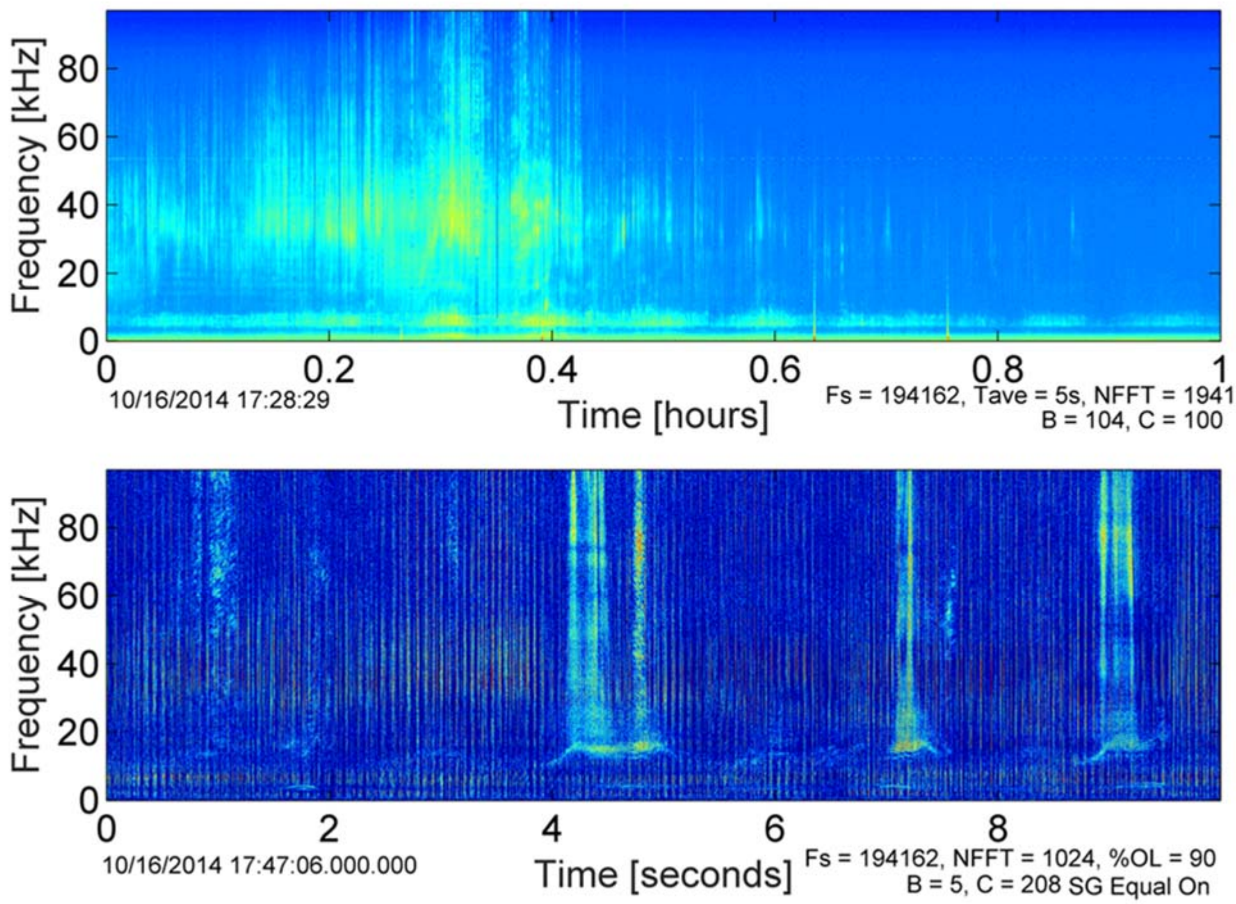

Figure 28: Echolocation click and burst pulses recorded with SG178 on 16 October 2014.

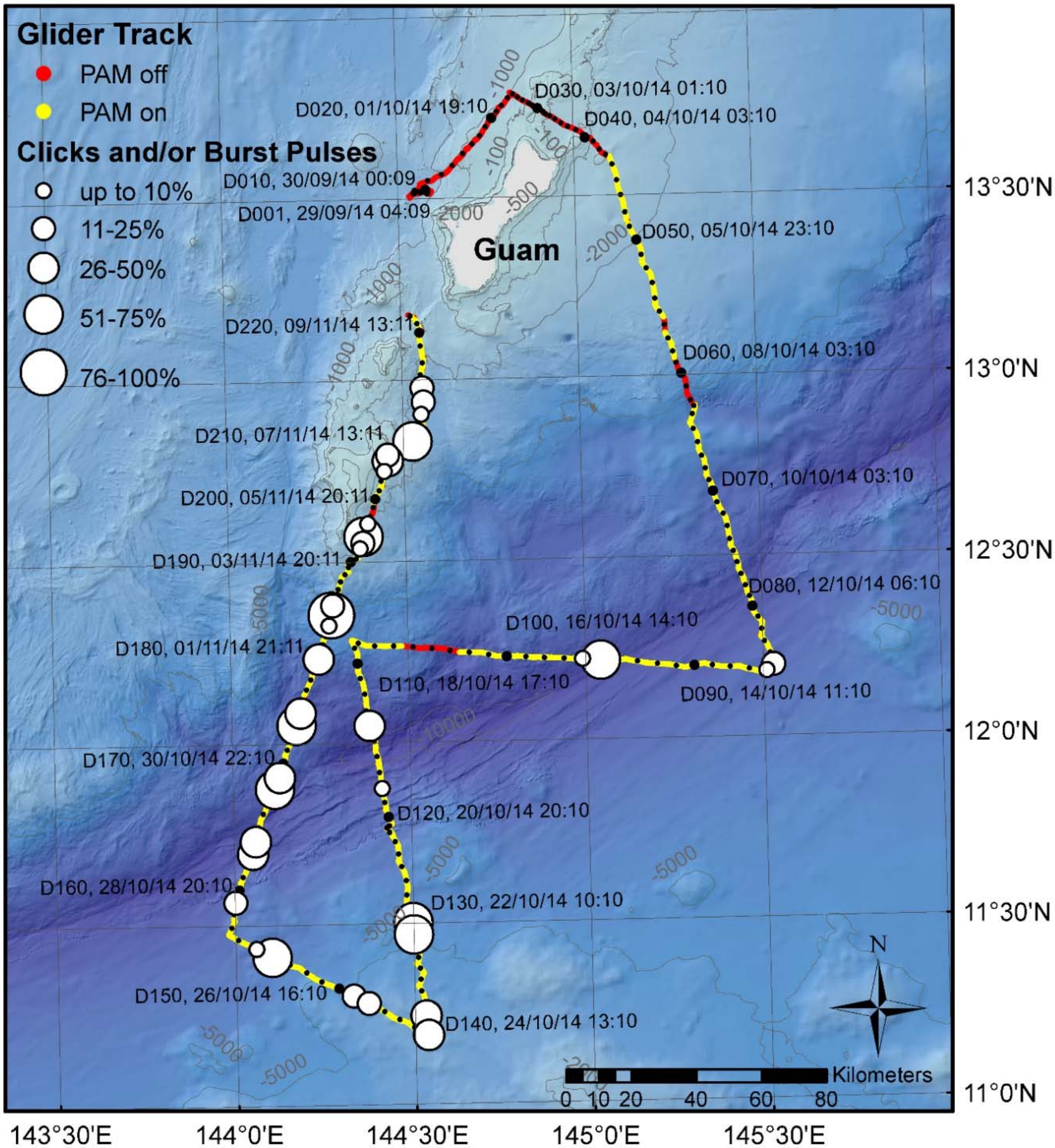

Figure 29: SG178 echolocation clicks and burst pulses encounters. The circle size indicates percentage of recording time per dive with target signals.

3.3 Mysticetes

3.3.1 Humpback whale

Screening of the low- and mid-frequency data from SG178 revealed calls from two species of cetaceans. Sounds from at least one humpback whale (**Figure 30**) were recorded on 22 October 2014 in offshore waters (**Figure 31**). There were two encounters two hours apart, on two subsequent dives. Most of these were up- and down-sweeping sounds below 500 Hz, typical for this species. The recorded sounds were likely partial song. As the calls never overlapped this was likely a single animal encounter.

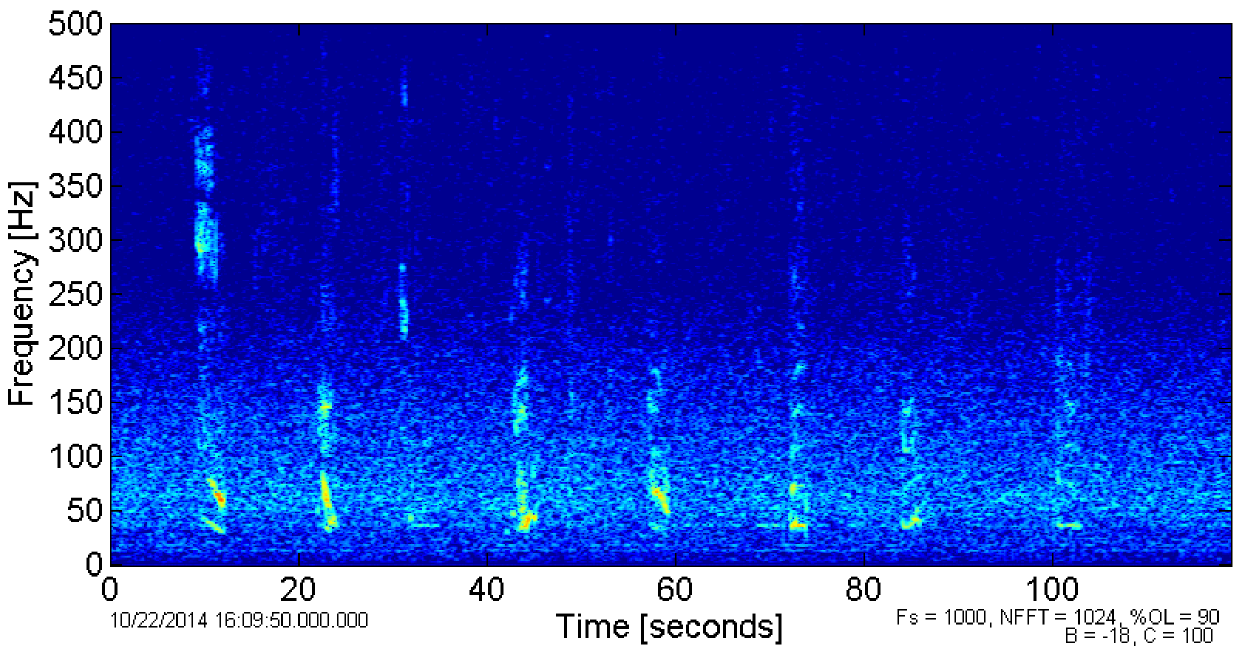

Figure 30: Humpback whale vocalizations recorded with SG178 on 22 October 2014.

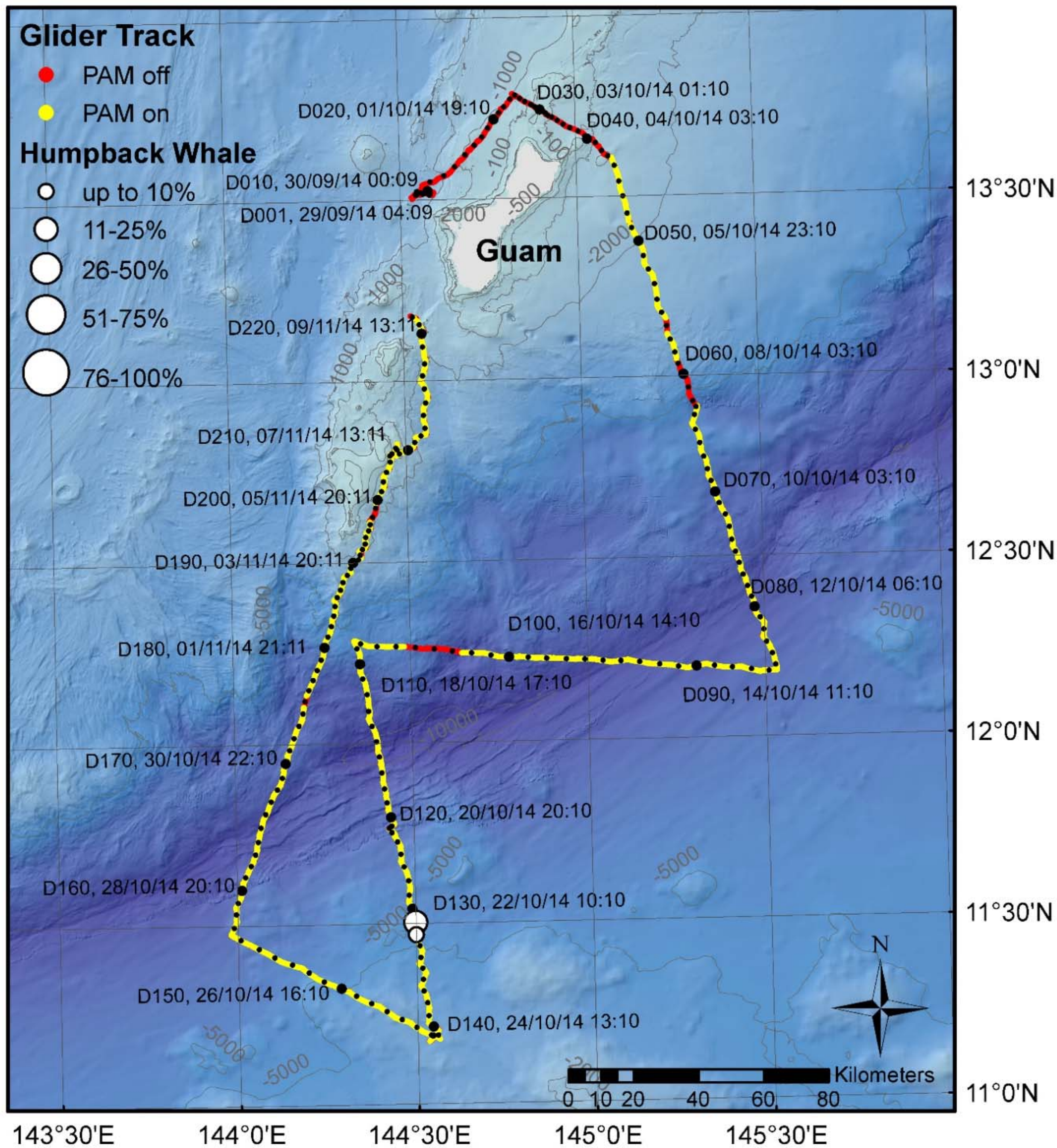

Figure 31: SG178 Humpback whale encounters. The circle size indicates percentage of recording time per dive with target signals.

3.3.2 Unidentified mysticete

A second sound, which we classified as being produced by an unidentified baleen whale, was recorded more often. This was a complex, multi-part call lasting 3 to 5 seconds, started with a low-frequency moan with a fundamental frequency at approximately 38 Hz and ended with a quick sweep up to approximately 7.5 kHz (**Figure 32**). This call, to our knowledge, has not been described in the literature but resembles the minke whale "star wars" call described by Gedamke et al. (2001) and also has some characteristics of the minke whale "boing" vocalization (Rankin and Barlow 2005). This sound was recorded on 45 encounters between 14 October and 06 November 2014 (**Appendix A**). Calls were typically 1 minute apart and often occurred in long sequences: on 14 October 2014 we recorded a continuous series of calls for over 7 hours. Dive locations for the 36 dives with encounters are shown in **Figure 33**.

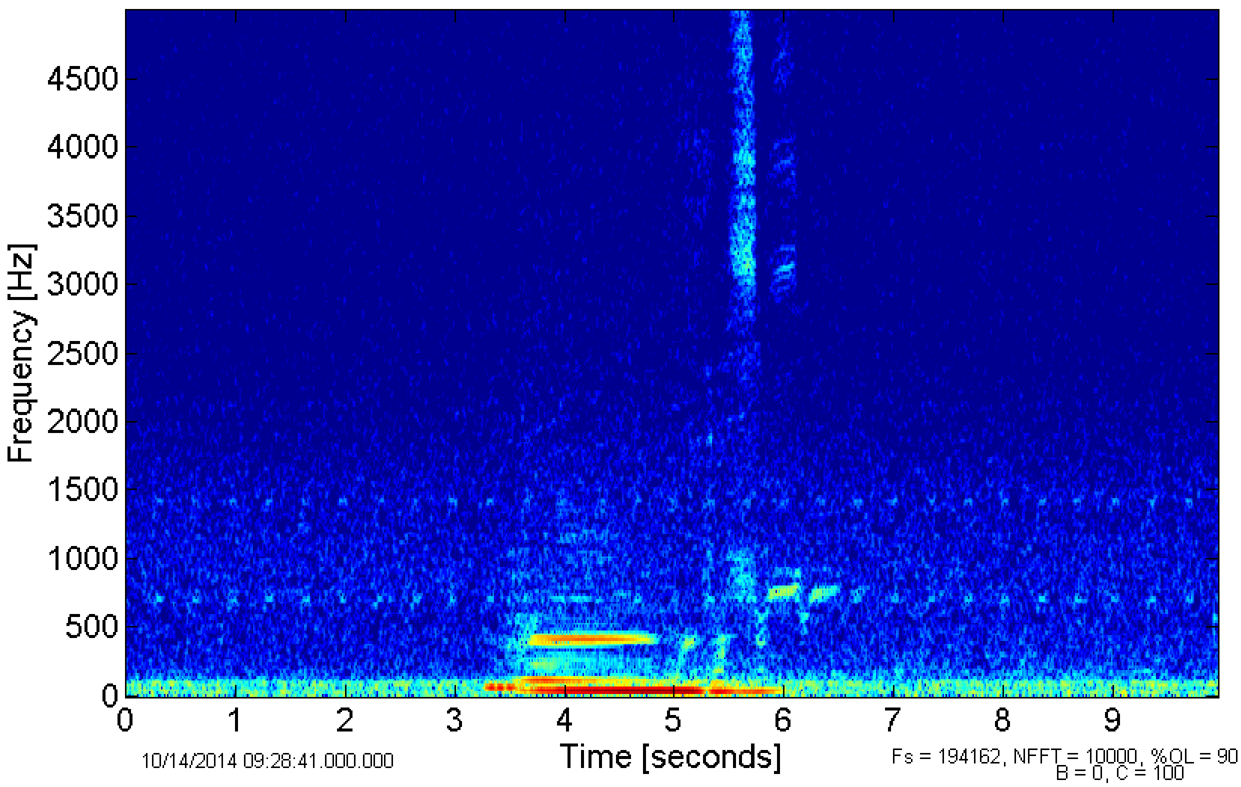

Figure 32: Unidentified mysticete call recorded with SG178 on 14 October 2014. This call consist of a tonal part at about 38 Hz and sweeps up to >7.5 kHz. The periodic signal at approximately 750 and 1,500 Hz is a glider produced noise.

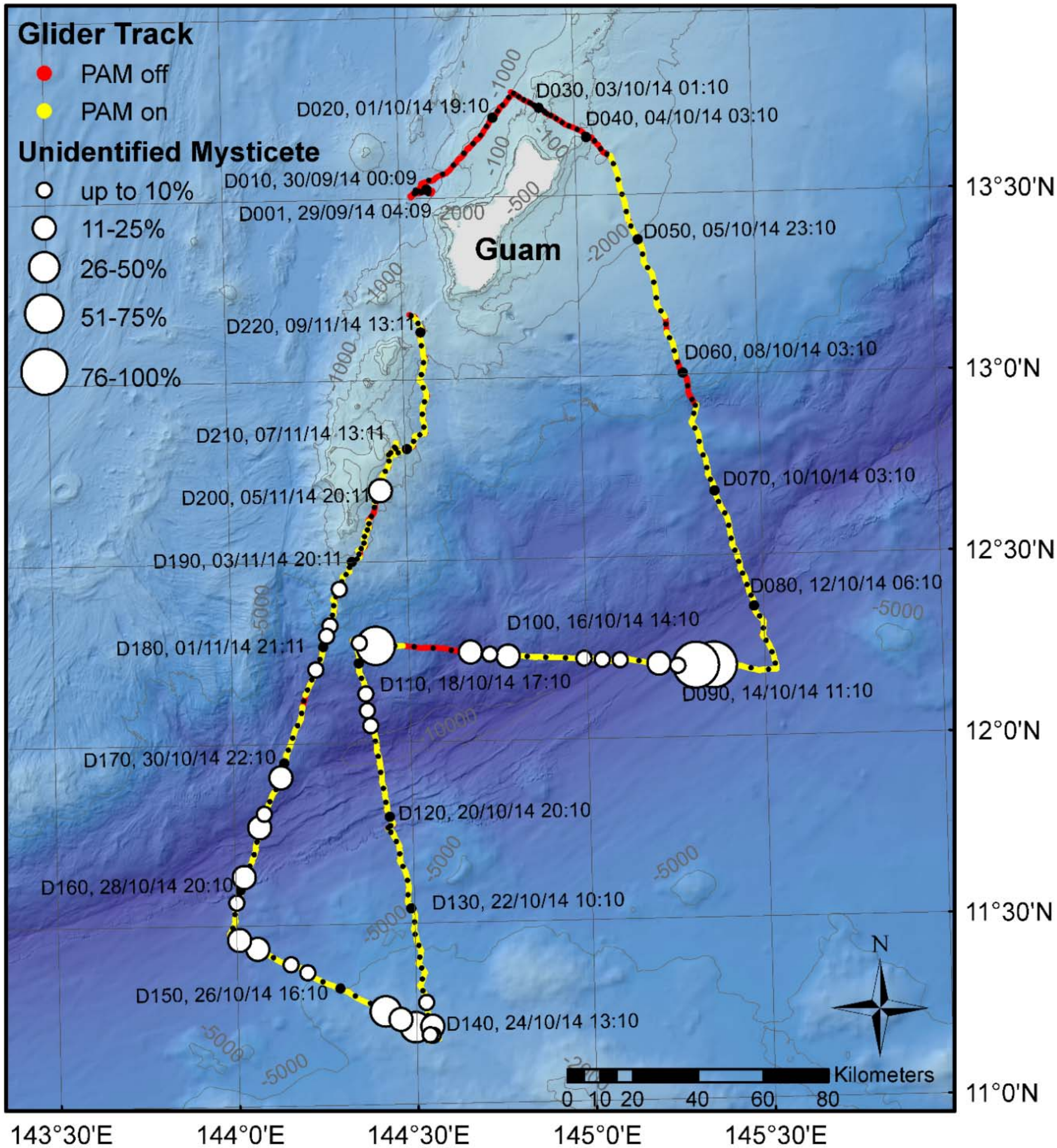

Figure 33: SG178 unidentified mysticete encounters. The circle size indicates percentage of recording time per dive with target signals.

3.4 Mid-Frequency Active Sonar (MFAS)

Two MFAS encounters were recorded by the SG178 glider (**Figure 34**). Encounters 1 and 2 occurred during dive 45 (N13.585, E145.108) and dive 46 (N13.541, E145.120) and lasted for 164 minutes and 73 minutes, respectively (**Figure 35**).

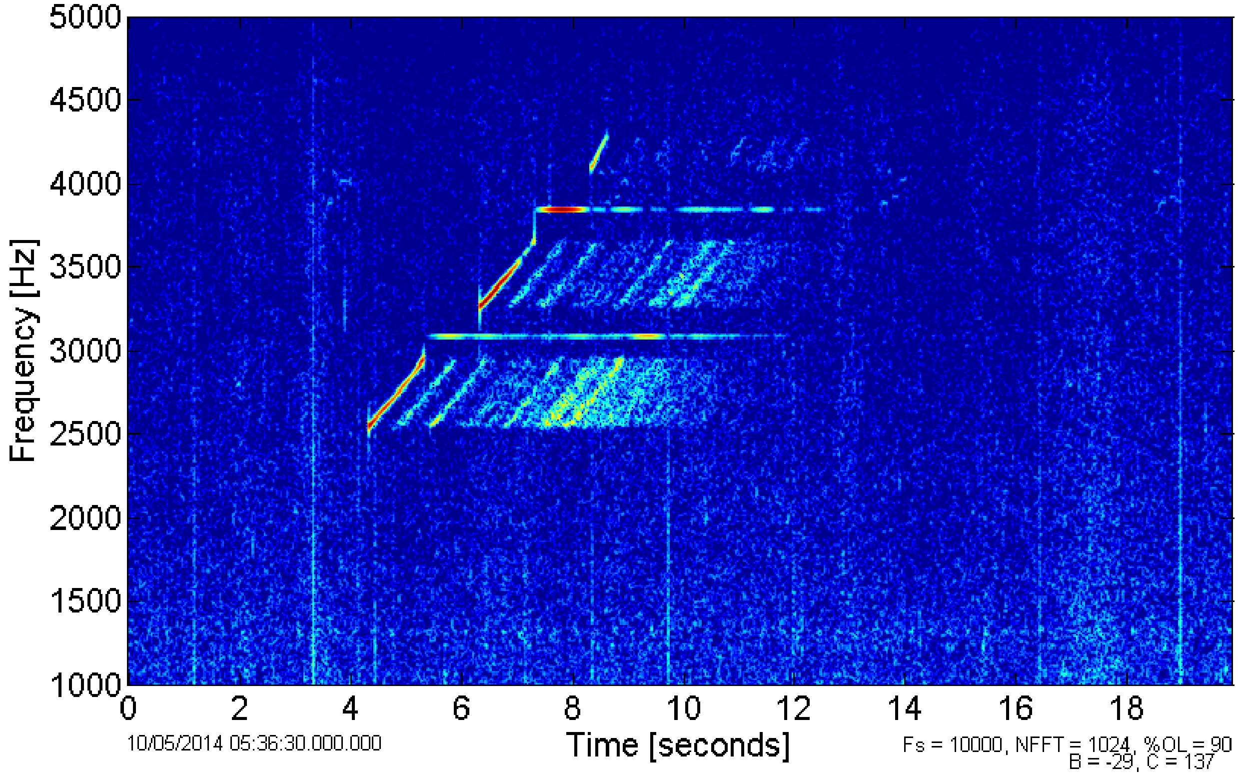

Figure 34: MFAS signal recorded with SG178 on 05 October 2014.

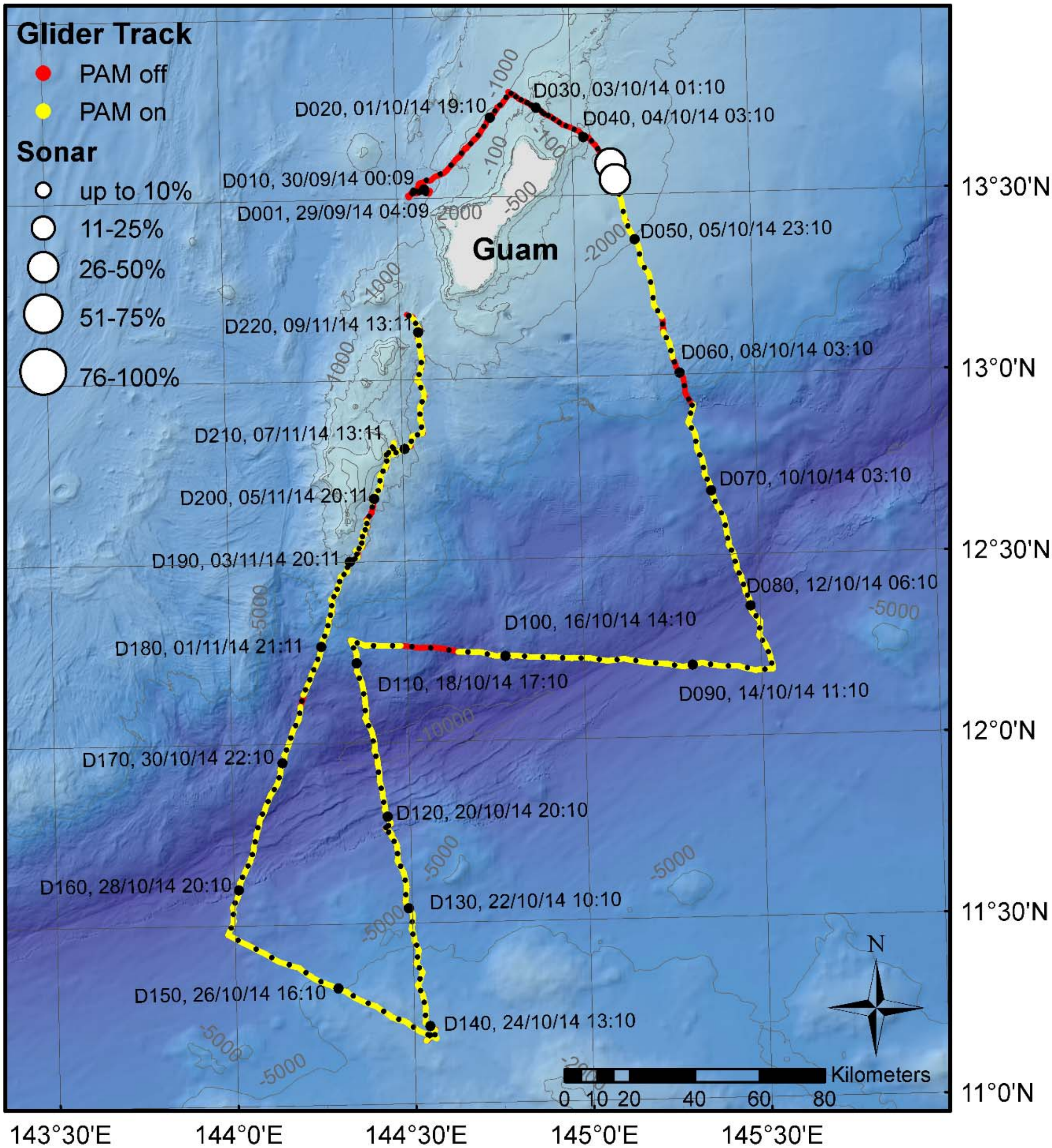

Figure 35: SG178 sonar encounters. The circle size indicates percentage of recording time per dive target signals.

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4. Discussion

Glider performance

Even though one of the two gliders experienced a malfunction and didn't record usable acoustics data, the MIRC acoustic glider survey was successful. SG178 recorded a total of 749 h (approximately 31 days) of acoustic data during this survey which was the longest passive-acoustic glider survey APL-UW and OSU conducted to date. Even though the 6.4 level PAM board has been extensively tested on the bench and in short-duration trials, this was the first survey which exceeded 1 month in duration. These long-duration trials are invaluable for improving these systems and are crucial for further development efforts. The long-term goal is to further extend the deployment duration to allow for 2 to 3 months continuous acoustic data collection.

This survey also demonstrated that once gliders are deployed, changes to the flight path can be made in near real-time. This was extremely helpful when an unexpected waterspace management issue came up. In addition, the offshore areas east of Guam, Rota and Saipan are characterized by frequent rough weather conditions which make it difficult to survey these areas with traditional survey methods. Furthermore the Marianas Trench is very deep and thus deploying moored recording systems is extremely involved and costly.

In summary, this survey proved that autonomous underwater vehicles are useful tools to conduct acoustic monitoring efforts in these remote areas cost efficiently. However, it also proved that no matter how well and careful instruments are being prepared and tested, malfunctions can occur as was the case with SG179.

Environmental Data

An additional benefit in using gliders for marine mammal surveys is the collection of environmental data. The measured depth-averaged currents indicated that the glider can be safely operated in this part of the MIRC. The current information as well as the temperature profiles are useful for additional future analysis efforts on occurrence patterns of cetacean species in the MIRC. The in-situ measured sound-speed profiles can be used to describe the sound propagation conditions in the study area in detail. These data will be used in an ongoing project funded by the Office of Naval Research to develop and evaluate a framework for density estimation of cetacean species using slow-moving underwater vehicles including gliders and floats.

The Seaglider can be equipped with a suite of additional environmental sensors. For example, active acoustic sensors would provide information on prey fields, which would be helpful for more comprehensive ecosystem studies (e.g., how the occurrence of cetaceans related to the availability of prey and oceanographic conditions).

Monitoring questions

What species of toothed whales (and especially beaked whales) occur in the MIRC, and what is their spatial and seasonal distribution in offshore areas adjacent to Guam, Rota, Tinian, and Saipan?

Over 15 different species of toothed whales occur in MIRC, including at least three beaked whale species. Recordings included both low- and high-frequency whistles, echolocation clicks, and burst pulses. Some encounters consisted of a single call type, while many contained both clicks and whistles, and a few contained all three. There were relatively few detections of beaked whale vocalizations. Out of seven encounters, three were identified as Blainville's beaked whales and four as potential beaked whales. The low detection rates are consistent with the few beaked whale detections reported for a recording package (EAR) moored south of Guam (Munger et al. 2014). Other acoustically identified species included sperm whales, killer whales, and Risso's dolphins. Most acoustic encounters recorded by the glider could not be classified to the species level, but were likely small and medium-sized delphinid species.

The variety of high-frequency acoustic encounters indicates there are numerous species present offshore of Guam in the fall. Relatively few detections of odontocetes (and mysticetes) were made during the first ten days of the survey. It is unclear if this was due to spatial (animals are not common in this area) or temporal (animals are not common in this area during fall) reasons. Previous surveys also had relatively few sightings of odontocetes southeast of Guam (Fulling et al. 2011, Norris et al. 2012). However, those efforts have typically taken place in the spring. Data collected during the spring 2015 glider deployment will help address some of the spatio-temporal questions.

What species of baleen whales occur in the MIRC, and what is their spatial and seasonal distribution in offshore areas adjacent to Guam, Rota, Tinian, and Saipan?

Seven species of baleen whales are thought to inhabit the waters around the Marianas Islands (Department of the Navy 2005) yet there is little information on species distribution and seasonal habitat use patterns for this region. All of these whales are thought to be migratory species and thus would be present in this area seasonally. To date, visual (boat based and aerial) surveys in the area have identified Bryde's, sei, humpback and minke whales during the January-mid-April survey period (MISTCS; Fulling et al. 2011, DoN 2005, 2007). Minke, humpback and possibly sei whales were detected acoustically and visually in offshore areas in February and April 2010 (Norris et al., 2012). Additional passive acoustic data have recorded the calls of minke and humpback whales (EAR data; Munger et al. 2014) and blue whale D and central Pacific tonal calls, sei, minke, humpback, fin whale and possibly Bryde's whale calls (HARP data; Hill et al. 2015, Oleson et al. 2015).

During the glider survey, we recorded relatively few sounds from baleen whales, most likely because this effort occurred during the fall. The passive acoustic system worked well and the method of analysis (visually inspecting time aligned spectrograms) insured species were unlikely to be missed. Sounds from a humpback whale were recorded on 22 October 2014 in offshore waters and were likely partial song or from an animal transiting through the area. Given this small sample size very little information can be gleaned on temporal and spatial use of this area by humpbacks. It is likely the glider recorded more humpback song and additional encounters during the glider survey in spring 2015.

Sounds from a second, to date unidentified species, were more numerous in the acoustic record. Other studies in the area have also recorded “unknown” or novel low-frequency calls. Norris et al. (2012) reported more than 6 previously unreported calls recorded in the presence of sei whales; most of these calls were short, 600 to 1,200 Hz sounds. Oleson et al. (2015) report numerous instances of short, unknown 50 Hz and 38 Hz tonal sounds that bear some resemblance to Bryde’s whale calls but did not provide details or a spectrogram of these calls. The calls reported here are different than these other “atypical” baleen whale calls. The tremendous frequency range (30 Hz to 7.5 kHz) resembles the minke whale “star wars” call described by Gedamke et al. (2001) and also has some spectral and aural characteristics of the minke whale ”boing” vocalization (Rankin and Barlow 2005). However, the low-frequency component of this call (**Figure 36**) does resemble the unknown call reported by Hill et al. (2015). Of special note is the fact that when the analyst reviewed the low-frequency and mid-frequency data independently she did not connect the two parts of this call. Upon inspection of a particularly loud call, a second component was noticed that exceeded the upper limit of the low-frequency data, so the analyst examined the mid-frequency data and then realized this was more than just an unusual low-frequency tone. This is one of the reasons the analyst began time aligning the low- and mid-frequency data when annotating calls. SG178 recorded these unknown calls in numerous areas during the survey, at both onshore and offshore locations, but not during the initial nine days of survey, north of N12.75°. Temporal and spatial trends in the presence and absence of this call are difficult to tease apart given this single survey and no previous reports of this call in the study area.

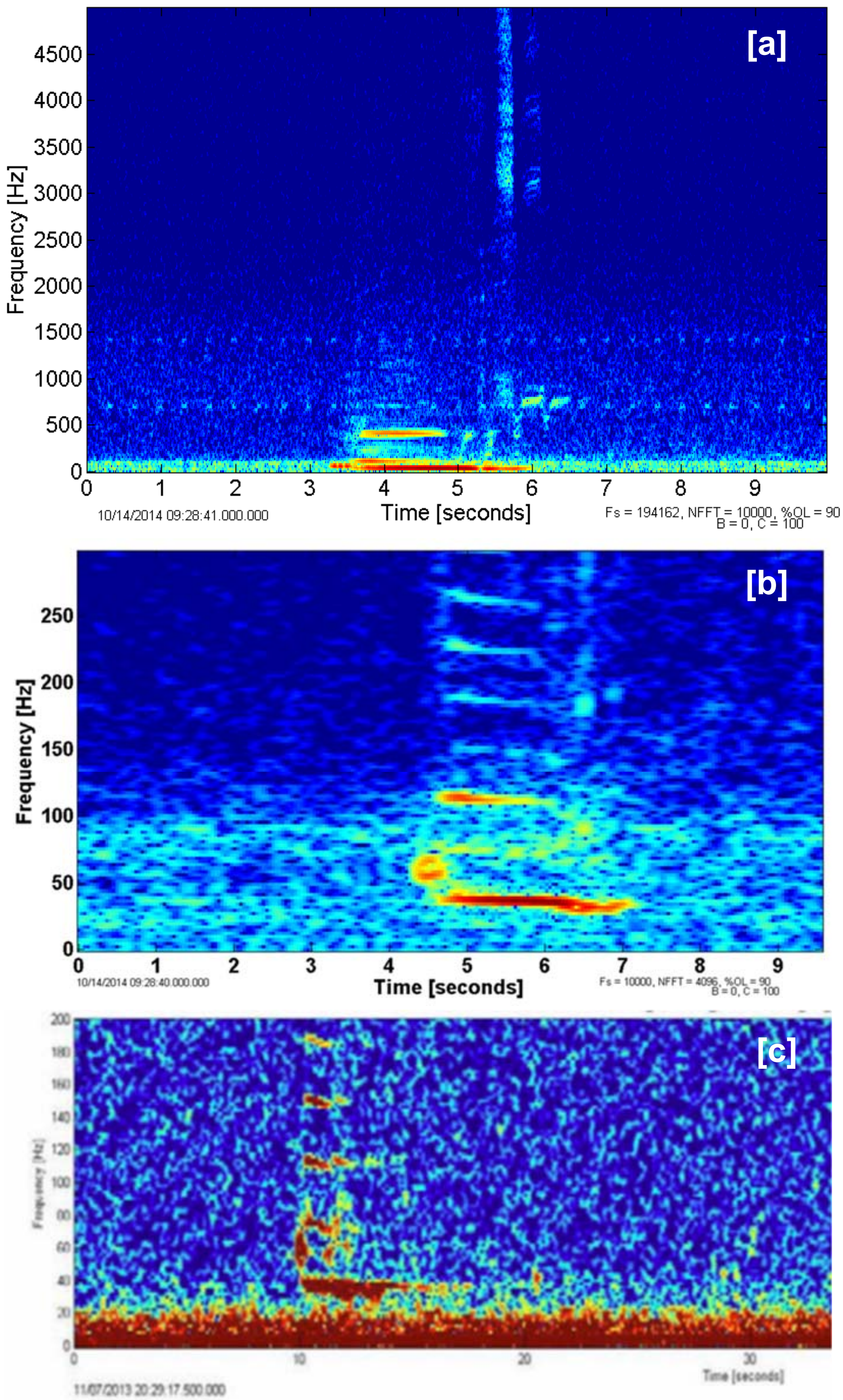

Figure 36: Unidentified mysticete call with both high (panel a) and low (panel b) frequency components recorded by SG178 on 14 October 2014. Panel c shows spectrogram of unknown call recorded via 2013-14 Tinian HARP on 7 November 2013 (Hill et al. 2015, Figure 16, p. 57).

4.1 Conclusions

Even though one of the two gliders experienced a malfunction and didn't record usable acoustics data, the MIRC acoustic glider survey was successful. SG178 recorded a total of 749 h (approximately 31 days) of acoustic data during this survey. The glider covered a distance of 833 km (695 km with the PAM system active) over ground. This was the longest passive-acoustic glider survey APL-UW and OSU conducted to date.

Because of the slow instrument speed, flow noise at the hydrophone is minimal in comparison to a towed array and does not hinder the detection of low-frequency baleen whale calls. Therefore gliders can be used to monitor both baleen and toothed whales effectively with improved spatial and temporal resolution.

The deployment and recovery of the instruments can be performed from a small vessel (even a RHIB) and doesn't require special equipment such as an a-frame or a winch. Gliders also don't need to be deployed exactly in the area of interest. After being launched, the glider pilot can fly the instrument to the desired survey area before activating the sensors. Because deployment and recoveries can be executed close to shore, the associated costs are much reduced compared to the deployment of moored recorders.

Ongoing development efforts aim to increase the deployment duration of the passive-acoustic Seaglider by a factor of 2-3. Long-duration deployments such as this MIRC survey are invaluable for these development efforts and provide valuable information on necessary improvements of the system.

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A

Details of All Acoustic Encounters Recorded by Glider SG178

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A.1 ODONTOCETES

Beaked whale encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	54	06/10/2014 18:15:23	06/10/2014 19:54:49	Md	13.2114	145.2188
2	58	07/10/2014 15:37:45	07/10/2014 15:38:04	PBW	13.0647	125.2662
3	108	18/10/2014 06:35:15	18/10/2014 07:03:07	PBW	12.2766	144.3606
4	110	18/10/2014 19:29:03	18/10/2014 19:56:08	Md	12.2199	144.3573
5	118	20/10/2014 08:27:57	20/10/2014 08:34:51	PBW	11.8735	144.4194
6	119	20/10/2014 16:58:19	20/10/2014 16:58:30	PBW	11.8349	144.4256
7	219	09/11/2014 09:46:58	09/11/2014 10:38:39	Md	13.0937	144.5332

*Md = Blainville's beaked whale, PBW = possible beaked whale

Killer whale encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	87	13/10/2014 19:27:02	13/10/2014 20:54:17	Oo	12.1846	145.4593
2	102	17/10/2014 02:09:16	17/10/2014 03:35:43	Oo	12.2450	144.6724
3	126	21/10/2014 11:54:19	21/10/2014 14:20:13	Oo	11.6921	144.4612

*Oo = Killer whale

Risso's dolphin encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	67	09/10/2014 13:12:15	09/10/2014 14:22:41	Gg	12.7757	145.3401
2	164	29/10/2014 18:23:35	29/10/2014 19:23:51	Gg	11.7325	144.0614

*Gg = Risso's dolphin

Sperm whale encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	53	06/10/2014 12:53:52	06/10/2014 15:10:22	Pm	13.2553	145.2133
2	53	06/10/2014 15:47:32	06/10/2014 16:02:45	Pm	13.2553	145.2133
3	67	09/10/2014 13:12:15	09/10/2014 14:22:41	Pm	12.7757	145.3401
4	68	09/10/2014 18:26:40	09/10/2014 18:28:21	Pm	12.7400	145.3498
5	72	10/10/2014 13:10:25	10/10/2014 15:07:51	Pm	12.6141	145.3966
6	77	11/10/2014 16:32:33	11/10/2014 17:11:43	Pm	12.4472	145.4429
7	102	16/10/2014 23:09:06	17/10/2014 01:18:20	Pm	12.2450	144.6724
8	106	17/10/2014 20:54:47	18/10/2014 00:09:16	Pm	12.2664	144.4597
9	107	18/10/2014 01:46:32	18/10/2014 05:26:58	Pm	12.2675	144.4066
10	131	22/10/2014 14:55:22	22/10/2014 20:19:00	Pm	11.5036	144.4990
11	182	02/11/2014 06:38:38	02/11/2014 06:54:35	Pm	12.3257	144.2791
12	182	02/11/2014 07:40:02	02/11/2014 07:42:24	Pm	12.3257	144.2791
13	184	02/11/2014 15:35:04	02/11/2014 16:11:56	Pm	12.3807	144.2909
14	192	04/11/2014 04:44:24	04/11/2014 04:45:39	Pm	12.5219	144.3652
15	197	05/11/2014 04:30:42	05/11/2014 04:38:42	Pm	12.6056	144.3942
16	197	05/11/2014 06:43:23	05/11/2014 06:44:02	Pm	12.6056	144.3942
17	203	06/11/2014 11:01:58	06/11/2014 11:02:23	Pm	12.7493	144.4440
18	204	06/11/2014 14:25:12	06/11/2014 17:38:05	Pm	12.7773	144.4546
19	205	06/11/2014 18:09:16	06/11/2014 18:35:18	Pm	12.7945	144.4547
20	206	06/11/2014 22:14:50	06/11/2014 23:14:12	Pm	12.8002	144.4606

*Pm = Sperm whale

Low-frequency whistle encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	118	20/10/2014 10:20:43	20/10/2014 10:22:26	LFW	11.8735	144.4194
2	125	21/10/2014 09:46:43	21/10/2014 11:12:07	LFW	11.7268	144.4527
3	126	21/10/2014 11:54:19	21/10/2014 15:44:44	LFW	11.6921	144.4612
4	163	29/10/2014 09:28:19	29/10/2014 10:50:49	LFW	11.6977	144.0525
5	172	31/10/2014 05:54:50	31/10/2014 05:54:52	LFW	12.0177	144.1672
6	189	03/11/2014 14:36:32	03/11/2014 16:54:24	LFW	12.4855	144.3369
7	197	05/11/2014 04:30:42	05/11/2014 04:38:42	LFW	12.6056	144.3942
8	215	08/11/2014 13:46:34	08/11/2014 14:40:49	LFW	12.9391	144.5588

*LFW = Low-frequency whistle

High-frequency whistle encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	81	12/10/2014 11:28:25	12/10/2014 11:51:59	HFW	12.3273	145.4870
2	84	13/10/2014 05:17:02	13/10/2014 06:25:00	HFW	12.2279	145.5196
3	100	16/10/2014 09:07:54	16/10/2014 15:57:51	HFW	12.2300	144.8319
4	108	18/10/2014 06:35:15	18/10/2014 07:03:07	HFW	12.2766	144.3606
5	109	18/10/2014 07:53:09	18/10/2014 15:47:13	HFW	12.2629	144.3502
6	111	18/10/2014 23:04:24	19/10/2014 00:10:53	HFW	12.1789	144.3649
7	113	19/10/2014 08:39:49	19/10/2014 13:09:00	HFW	12.0893	144.3793
8	119	20/10/2014 13:09:45	20/10/2014 14:58:09	HFW	11.8349	144.4256
9	135	23/10/2014 10:01:46	23/10/2014 13:55:35	HFW	11.3758	144.5160
10	136	23/10/2014 15:50:45	23/10/2014 19:00:52	HFW	11.3449	144.5177
11	137	23/10/2014 19:58:48	23/10/2014 20:50:07	HFW	11.3128	144.5181

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
12	139	24/10/2014 07:28:58	24/10/2014 07:37:02	HFW	11.2440	144.5306
13	152	27/10/2014 03:13:59	27/10/2014 04:41:56	HFW	11.3686	144.1970
14	153	27/10/2014 10:37:21	27/10/2014 11:09:21	HFW	11.3908	144.1504
15	165	29/10/2014 21:25:49	29/10/2014 22:05:36	HFW	11.7712	144.0701
16	181	02/11/2014 01:12:04	02/11/2014 01:37:08	HFW	12.2967	144.2686
17	197	05/11/2014 04:30:42	05/11/2014 05:23:42	HFW	12.6056	144.3942
18	204	06/11/2014 12:33:14	06/11/2014 14:11:48	HFW	12.7773	144.4546
19	215	08/11/2014 15:40:15	08/11/2014 16:06:48	HFW	12.9391	144.5588
20	218	09/11/2014 05:59:02	09/11/2014 06:11:20	HFW	13.0467	144.5586

*HFW = High-frequency whistle

Low- and high-frequency whistle encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	87	13/10/2014 16:01:34	13/10/2014 18:47:18	LHFW	12.1846	145.4593
2	91	14/10/2014 14:48:03	14/10/2014 19:45:23	LHFW	12.1966	145.2540
3	96	15/10/2014 16:47:51	15/10/2014 19:14:38	LHFW	12.2219	144.9910
4	101	16/10/2014 17:03:15	16/10/2014 22:09:41	LHFW	12.2384	144.7271
5	134	23/10/2014 07:22:10	23/10/2014 08:55:12	LHFW	11.4057	144.5115
6	150	26/10/2014 13:54:36	26/10/2014 16:23:30	LHFW	11.3230	144.2875
7	153	27/10/2014 08:49:52	27/10/2014 10:00:59	LHFW	11.3908	144.1504
8	167	30/10/2014 08:05:20	30/10/2014 09:59:30	LHFW	11.8432	144.1002
9	217	09/11/2014 00:10:37	09/11/2014 00:12:41	LHFW	13.0138	144.5519

*LHFW = Low- and high-frequency whistle

Echolocation clicks and/or burst pulses encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	85	13/10/2014 08:18:09	13/10/2014 09:15:20	ECBP	12.1959	145.5287
2	86	13/10/2014 13:55:45	13/10/2014 14:25:12	ECBP	12.1797	145.5086
3	95	15/10/2014 10:30:54	15/10/2014 11:14:24	ECBP	12.2171	145.0418
4	95	15/10/2014 13:34:17	15/10/2014 15:45:39	ECBP	12.2171	145.0418
5	114	19/10/2014 13:38:18	19/10/2014 15:33:41	ECBP	12.0473	144.3876
6	118	20/10/2014 08:27:58	20/10/2014 08:34:51	ECBP	11.8735	144.4194
7	131	22/10/2014 14:55:23	22/10/2014 20:19:49	ECBP	11.5036	144.4990
8	139	24/10/2014 08:16:25	24/10/2014 10:48:39	ECBP	11.2440	144.5306
9	144	25/10/2014 08:51:08	25/10/2014 11:10:40	ECBP	11.1906	144.5365
10	149	26/10/2014 08:11:19	26/10/2014 09:54:27	ECBP	11.3021	144.3286
11	154	27/10/2014 13:00:27	27/10/2014 16:20:08	ECBP	11.4113	144.1019
12	159	28/10/2014 14:52:41	28/10/2014 16:00:21	ECBP	11.5641	144.0019
13	163	29/10/2014 12:06:02	29/10/2014 14:41:20	ECBP	11.6977	144.0525
14	164	29/10/2014 15:35:33	29/10/2014 16:13:20	ECBP	11.7325	144.0614
15	164	29/10/2014 16:53:28	29/10/2014 17:33:18	ECBP	11.7325	144.0614
16	168	30/10/2014 11:16:03	30/10/2014 11:47:56	ECBP	11.8760	144.1181
17	168	30/10/2014 12:41:44	30/10/2014 16:39:55	ECBP	11.8760	144.1181
18	173	31/10/2014 10:59:56	31/10/2014 12:50:02	ECBP	12.0515	144.1823
19	174	31/10/2014 13:20:42	31/10/2014 16:42:35	ECBP	12.0847	144.1944
20	179	01/11/2014 15:35:50	01/11/2014 17:47:33	ECBP	12.2335	144.2485
21	182	02/11/2014 06:38:38	02/11/2014 06:54:35	ECBP	12.3257	144.2791
22	182	02/11/2014 07:40:02	02/11/2014 07:42:24	ECBP	12.3257	144.2791
23	183	02/11/2014 08:46:56	02/11/2014 13:39:57	ECBP	12.3542	144.2862

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
24	184	02/11/2014 15:35:04	02/11/2014 16:11:56	ECBP	12.3807	144.2909
25	192	04/11/2014 04:44:24	04/11/2014 04:45:39	ECBP	12.5219	144.3652
26	193	04/11/2014 11:50:49	04/11/2014 12:12:16	ECBP	12.5367	144.3714
27	194	04/11/2014 15:53:00	04/11/2014 19:49:26	ECBP	12.5521	144.3793
28	197	05/11/2014 06:43:23	05/11/2014 06:44:02	ECBP	12.6056	144.3942
29	203	06/11/2014 08:50:38	06/11/2014 09:15:54	ECBP	12.7493	144.4440
30	203	06/11/2014 11:01:58	06/11/2014 11:02:23	ECBP	12.7493	144.4440
31	204	06/11/2014 14:25:12	06/11/2014 17:38:05	ECBP	12.7773	144.4546
32	211	07/11/2014 17:23:13	07/11/2014 19:48:04	ECBP	12.8303	144.5253
33	214	08/11/2014 10:04:25	08/11/2014 10:39:56	ECBP	12.9049	144.5522
34	215	08/11/2014 14:42:50	08/11/2014 15:31:45	ECBP	12.9391	144.5588
35	216	08/11/2014 17:54:31	08/11/2014 18:54:34	ECBP	12.9780	144.5558

*ECBP = Echolocation clicks and/or burst pulses

A.2 MYSTICETES

Humpback whale encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	131	22/10/2014 15:25:26	22/10/2014 16:11:59	Mn	11.5036	144.4990
2	132	22/10/2014 18:37:48	22/10/2014 18:40:33	Mn	11.4693	144.4997

*Mn = Humpback whale

Unknown mysticete encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	89	14/10/2014 03:42:58	14/10/2014 11:57:19	UMY	12.1971	145.3554
2	90	14/10/2014 12:50:23	14/10/2014 13:22:26	UMY	12.1972	145.3051
3	91	14/10/2014 14:03:17	14/10/2014 14:25:32	UMY	12.1966	145.2540
4	92	14/10/2014 20:24:46	14/10/2014 20:55:00	UMY	12.2033	145.2015
5	94	15/10/2014 09:52:00	15/10/2014 09:57:00	UMY	12.2152	145.0925
6	95	15/10/2014 10:34:20	15/10/2014 10:38:23	UMY	12.2171	145.0418
7	95	15/10/2014 13:35:00	15/10/2014 13:35:05	UMY	12.2171	145.0418
8	96	15/10/2014 20:02:57	15/10/2014 20:03:57	UMY	12.2219	144.9910
9	100	16/10/2014 14:41:00	16/10/2014 15:14:57	UMY	12.2319	144.7773
10	100	16/10/2014 16:11:03	16/10/2014 16:30:41	UMY	12.2319	144.7773
11	101	16/10/2014 17:55:03	16/10/2014 18:02:25	UMY	12.2384	144.7271
12	101	16/10/2014 22:13:19	16/10/2014 22:40:42	UMY	12.2450	144.6724
13	102	17/10/2014 00:22:49	17/10/2014 01:07:50	UMY	12.2450	144.6724
14	102	17/10/2014 01:47:39	17/10/2014 01:47:45	UMY	12.2450	144.6724
15	102	17/10/2014 03:10:34	17/10/2014 03:33:30	UMY	12.2450	144.6724

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
16	107	18/10/2014 02:22:03	18/10/2014 05:09:04	UMY	12.2675	144.4066
17	108	18/10/2014 05:56:58	18/10/2014 06:02:04	UMY	12.2766	144.3606
18	112	19/10/2014 01:53:00	19/10/2014 01:53:05	UMY	12.1353	144.3758
19	114	19/10/2014 11:13:33	19/10/2014 12:00:02	UMY	12.0473	144.3876
20	138	24/10/2014 05:15:00	24/10/2014 05:15:05	UMY	11.2804	144.5282
21	140	24/10/2014 12:06:00	24/10/2014 12:42:00	UMY	11.2140	144.5440
22	141	24/10/2014 16:35:00	24/10/2014 16:35:05	UMY	11.1892	144.5447
23	144	25/10/2014 11:16:00	25/10/2014 11:16:05	UMY	11.1906	144.5365
24	145	25/10/2014 14:00:00	25/10/2014 15:47:00	UMY	11.2128	144.4962
25	146	25/10/2014 20:13:00	25/10/2014 20:55:00	UMY	11.2351	144.4552
26	147	26/10/2014 01:26:00	26/10/2014 02:33:00	UMY	11.2578	144.4131
27	152	27/10/2014 00:44:00	27/10/2014 00:44:05	UMY	11.3686	144.1970
28	153	27/10/2014 06:18:00	27/10/2014 06:18:05	UMY	11.3908	144.1504
29	155	27/10/2014 18:36:00	27/10/2014 19:41:00	UMY	11.4359	144.0576
30	156	27/10/2014 21:42:00	27/10/2014 22:09:00	UMY	11.4611	144.0073
31	156	27/10/2014 22:49:00	27/10/2014 22:55:00	UMY	11.4611	144.0073
32	159	28/10/2014 13:52:00	28/10/2014 14:16:00	UMY	11.5641	144.0019
33	161	29/10/2014 01:05:00	29/10/2014 01:46:00	UMY	11.6344	144.0237
34	161	29/10/2014 02:19:00	29/10/2014 02:46:00	UMY	11.6344	144.0237
35	165	29/10/2014 22:26:00	29/10/2014 22:26:05	UMY	11.7712	144.0701
36	166	30/10/2014 04:14:00	30/10/2014 04:14:05	UMY	11.8083	144.0839
37	169	30/10/2014 16:26:00	30/10/2014 16:56:00	UMY	11.9084	144.1324
38	178	01/11/2014 13:25:00	01/11/2014 13:25:05	UMY	12.2042	144.2363

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
40	181	02/11/2014 02:54:17	02/11/2014 03:07:05	UMY	12.2967	144.2686
41	182	02/11/2014 04:38:00	02/11/2014 04:38:05	UMY	12.3257	144.2791
42	182	02/11/2014 06:16:00	02/11/2014 06:29:00	UMY	12.3257	144.2791
43	186	03/11/2014 00:25:00	03/11/2014 00:25:05	UMY	12.4252	144.3073
44	187	03/11/2014 07:25:00	03/11/2014 07:25:05	UMY	12.4468	144.3144
45	201	06/11/2014 01:07:00	06/11/2014 02:07:00	UMY	12.6960	144.4291

*UMY = unidentified mysticete

A.3 MID-FREQUENCY ACTIVE SONAR (MFAS)

Mid-frequency active sonar (MFAS) encounters*

Encounter [no.]	Dive [no.]	Start date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label	Latitude [degrees N]	Longitude [degrees E]
1	45	04/10/2014 21:49:05	05/10/2014 01:34:42	Sonar	13.5847	145.1080
2	46	05/10/2014 04:28:53	05/10/2014 05:41:48	Sonar	13.5408	145.1200

*Sonar = MFAS

B

Lessons Learned.

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Water space management:

- Because of a water space management issue, SG178 had to be flown around the northern tip of Guam and not as initially planned around the southern tip. This significantly extended the transit time to the start point of the acoustic transect line and ultimately resulted in unanticipated battery consumption.

  Proposed solution: Improve communication between all involved parties (OSU, APL-UW, HDR, NAVFAC, and operational Navy personnel).

Glider technical issues:

- During the transit to the survey area, APL-UW detected a sudden and uncharacteristic drop in SG179's battery voltage (24-volt battery pack) shortly after the start of the acoustic survey. The transmitted engineering data indicated that acoustic data was being collected. However, as raw acoustic data is not being transmitted, we were not able to remotely derive the quality of the collected data. In the following days after the issue was detected, we continued to carefully monitor the battery voltage. The intention was to keep the glider flying for as long as possible to continue collecting acoustic data. However, because the 24-volt battery pack powers, among other things the buoyancy pump of the glider, the glider pilot had to adjust the transect line on 22 October 2014, and fly straight back to the recovery location off Guam. The battery voltage dropped to a level where the risk of losing the vehicle outweighed the potential of adding another few days of acoustics recordings.

  After an inspection of SG179 in the lab, APL-UW believes that the battery issue may have been caused by an external connector failure. Unfortunately, it was not possible to derive the exact cause of the malfunction. The failure resulted in significant ground fault currents flowing through the ocean and hull and resulted in substantial damage (pitting and other corrosion) to the hull which almost caused an instrument loss. The review of the acoustic data collected with SG179 revealed that the recordings were not usable for any kind of bioacoustics analysis. The electronic noise contamination of the data is related to the mechanical failure described above.

  Proposed solution: This failure could not have been prevented. The deployment team conducted a thorough test of SG179 (including the PAM system) hours before the deployment and closely monitored its behavior during the first dives while the deployment vessel was still in the vicinity. These tests did not reveal any issues.

  Other remarks: Malfunctions can (and eventually will) happen. Other instruments (e.g., EARs and HARPs) regularly used for passive acoustic monitoring have failed too. This is simply the nature of oceanographic research and there will never be a 100% success guarantee. As an example, OSU/NOAA-PMEL has deployed and operated moored hydrophones for over 25 years. We deployed literally hundreds of moored hydrophones around the globe and our success rate is approximately 95%. This means that during 5 out of 100 deployments something doesn't go according to plan - sometimes even a complete instrument loss. If the data to be collected is absolute indispensable, two gliders should be operated in the same area for redundancy and risk reduction.

Glider operational issues:

- Because SG179 had to be recovered as soon as possible after the second issue was identified, the transect line of SG178 had to be slightly modified as well to facilitate a recovery of both gliders at the same time. The current budget did not provide enough funding to conduct two separate recovery trips.

  Proposed solution: Consider a contingency budget when flying multiple gliders to cover expenses related to a separate recovery of the instruments.