Study 1 – Relative Performance of Surface vs. Bottom-Mounted Hydrophones in a Tidal Channel

FINAL REPORT

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Executive Summary

Passive Acoustic Monitoring (PAM) technologies are commonly used to monitor echolocating marine mammals around tidal energy devices. However, the detection efficiency of PAM instruments can be hindered by a variety of factors (e.g., signal attenuation, flow noise, ambient noise) inherent to high flow environments that can vary with deployment depth, and can impede monitoring efforts. While previous work indicated that conventional hydrophones that record raw pressure time series data may be preferrable for monitoring harbour porpoise in tidal channels, where these technologies should be deployed for effective monitoring (i.e., at the sea surface or on the sea floor) remains an unresolved issue.

In partnership with the Pathway Program, Sustainable Marine Energy Canada Ltd. and the Fundy Ocean Research Center for Energy assessed the relative performance of a surface deployed and bottom-mounted conventional hydrophone to understand whether deployment location impacted the detection range of the instrument. An icListen HF hydrophone was deployed about 2 m below the surface from a floating tidal energy platform (i.e., PLAT-I) and bottom-mounted on an autonomous subsea platform 65 m from the PLAT-I in Grand Passage, NS. A series of passive drifts were then conducted from a vessel over the platform and in the vicinity of the PLAT-I across a range of tidal flow conditions while playing synthetic harbour porpoise clicks ('pseudo clicks') emitted from an icTalk. The drifts measured by the surface deployed hydrophone occurred in August 2020; the drifts measured from the bottom-mounted hydrophone occurred in January 2020.

We found that it was possible to detect pseudo-clicks and real harbour porpoise clicks from both hydrophone locations. However, data from the surface deployed hydrophone contained audible interference from waves and the broadband, impulsive, bursting of bubbles associated with wave action that is difficult to differentiate from echolocation clicks. This ambient noise will negatively affect automated porpoise click detectors and could lead to increased rates of false-positive detections. The surface-deployed hydrophone also had substantial electrical noise in the data which could affect automated detectors. The drifting vessel had to stay clear of the PLAT-I whereas it could pass directly over the bottom-mounted hydrophone. These differences in drift geometry made the comparison of detection ranges challenging. Pseudo clicks were detected at greater distances from the bottom-mounted than the surface deployed hydrophone. However, it is important to bear in mind that these results were generated using synthetic clicks generated by an icTalk (nearly omnidirectional), and that real harbour porpoise emit a stronger echolocation click using a directional beam. Further, understanding the effects of current velocity on the quality of the icTalk signal could help with interpretation of results.

The choice of which PAM instrument to use and where to deploy it depends on the scientific question being asked. A primary objective of the Pathway Program is to define, test and validate an environmental effects monitoring solution that can be used by tidal energy developers for monitoring the near-field (0 - 100m) region of their tidal energy device at the FORCE demonstration site. Both hydrophone mounting locations were able to detect low-

power pseudo-clicks close to or longer than 100 m, and thus satisfy the near-field monitoring requirement. While it is possible to detect harbour porpoise clicks using a surface deployed hydrophone, the detection range for automated detectors may be smaller than a bottom-mounted hydrophone due to impulsive ambient noise associated with wave action at the surface. Moreover, harbour porpoise clicks are directional and are typically produced while diving and foraging at depth and are less likely to be detected by a surface deployed hydrophone. However, for a surface-deployed turbine, such as the PLAT-I, having the monitoring hydrophone close to the turbine depth may provide more relevant data than a bottom mounted hydrophone. An important consideration in selecting a monitoring technology is whether near-real-time data are required or if archival results provided several months after collection is sufficient. For real-time data, a hydrophone mounted on the turbine platform is much more economically sustainable than a separate monitoring platform with its own power and data cable. For archival data analysis and reporting, especially for bottom mounted turbines and for prototyping programs, a separate bottom mooring for the monitoring equipment may be a better solution based on cost and performance.

Given these considerations, the results of these measurements did not provide sufficient evidence to strongly prefer one hydrophone position over another. Rather, developers are encouraged to demonstrate that they are able to detect pseudo-clicks in the turbine's near-field using a drifting projector. When cabled hydrophones are to be used, developers need to safeguard against acoustic and electronic contamination from equipment on their tidal energy devices.

Introduction and Objectives

Passive Acoustic Monitoring (PAM) technologies are frequently used to monitor echolocating marine mammals (primarily porpoise and dolphin) in high flow environments that are the focus of instream tidal power development (Adams et al., 2019; Malinka et al., 2018). However, the detection efficiency of PAM instruments for monitoring vocalizing marine mammals in tidal channels is impacted by several factors, including the vocalizing bandwidth for the target species and the potential masking of these sounds by flow noise and ambient sound (e.g., sediment transport on the seafloor), as well as the propagating environment, reverberation, sensor placement and sensor deployment methodology (Hasselman et al., 2020a). A recent comparative study of PAM technologies revealed that conventional hydrophones (i.e., those that record raw pressure time series data) may be preferable to 'stand alone' click detectors for monitoring harbour porpoise in tidal channels; particularly if appropriate sensitivity settings for the instrument are coupled with a suitable click detector and classifier (Hasselman et al., 2020b). However, where conventional hydrophones should be deployed (i.e., surface deployed or bottom-mounted) for effective monitoring of harbour porpoise remains an unresolved issue.

Although monitoring of instream tidal turbines (typically bottom-mounted devices) has frequently involved the deployment of instruments on the seafloor (either mounted on an autonomous or cabled subsea platform, or integrated into the device substructure), deploying and recovering such instruments involves considerable costs (i.e., specialized vessels and complex marine operations) and risks for monitoring (e.g., instrument malfunction and loss of data, loss of the instrument itself). While floating tidal energy platforms provide several advantages for monitoring (i.e., easy access to instruments and monitoring data) that may offset some of these aforementioned risks, monitoring from the sea surface in tidal channels has its own inherent challenges. For instance, the acoustic detection range of PAM instruments is known to vary with deployment depth (Sostres Alonso & Nuuttila, 2015), and their ability to detect harbour porpoise echolocation clicks may be impacted by signal attenuation and interference from waves and turbulence near the sea surface in tidal channels (Hasselman et al., 2020a).

Sustainable Marine Energy Canada Ltd. ('Sustainable Marine') operates a floating tidal energy platform (i.e., 'PLAT-I' – PLATform for Inshore Energy; Figures 1 and 2) at its tidal demonstration site in Grand Passage, Bay of Fundy. Sustainable Marine conducts a series of monitoring activities using surface deployed instruments, including the use of a conventional hydrophone (OceanSonics icListenHF) for monitoring harbour porpoise (*Phocoena phocoena*) activity. Thus, the PLAT-I provides an excellent opportunity to conduct an *in-situ* assessment of the relative performance of a surface deployed and bottom-mounted conventional hydrophone for detecting harbour porpoise in a tidal channel. To that end, the primary objective of this study was to evaluate the relative performance of a surface deployed and bottom-mounted conventional hydrophone to understand whether deployment location impacts the detection range of synthetic harbour porpoise clicks.

Figure 1: a)The PLAT-I moored in Grand Passage (photo credit: www.oceannews.com/news/energy/sustainable-marine-energy-reveals-plans-for-tidal-energy-project); b)a

This study constitutes the final component of comparative tests for PAM technologies under Phase 3 ('Technology Validation') of The Pathway Program[1]. A primary objective of the Pathway Program is to define, test and validate an environmental effects monitoring solution that can be used by tidal energy developers for monitoring the near-field (0 – 100m) region of their tidal energy devices at the FORCE tidal demonstration site in the Minas Passage. This work serves to determine whether the relative performance of a PAM device used for detecting harbour porpoise vocalizations is impacted by the deployment location (i.e., surface vs. bottom) so that an informed decision can be made about the deployment location for PAM devices for future monitoring efforts.

Sea Mammal Research Unit Consulting North America Ltd. (SMRU) conducted the data analyses component of this work, and their final report is included herein as an Appendix. The body of this report outlines the field components of this project, and only reflects the main points of the results contained in the SMRU report. For a more thorough understanding of the results and interpretation of the data, readers are encouraged to review the Appendix.

Methodology

Although collaborative in spirit, this project was conducted under contract between Sustainable Marine and the Offshore Energy Research Association (OERA) under the Pathway Program and

[1] https://oera.ca/research/pathway-program-towards-regulatory-certainty-instream-tidal-energy-projects

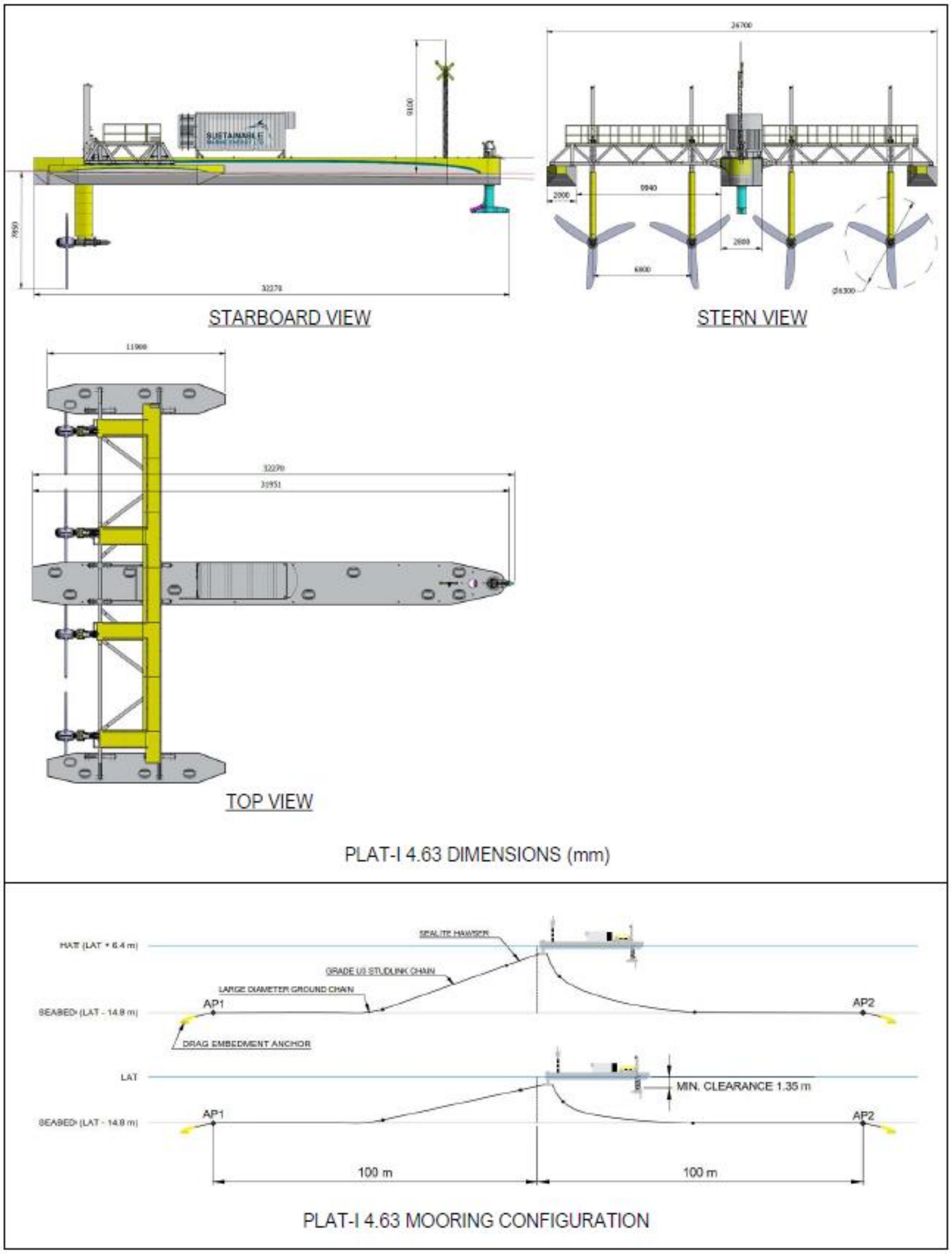

Figure 2: Schematic of the PLAT-I 4.63 showing starboard, stern and top views along with mooring configuration.

utilized the PLAT-I deployed in Grand Passage, NS. Sustainable Marine sub-contracted the Fundy Ocean Research Center for Energy (FORCE) to conduct the field trials and data collection, and FORCE sub-contracted SMRU to conduct the data analyses and reporting aspects of the project. The relative performance of a PAM instrument deployed at the surface vs. on the seabed was assessed across a range of tidal flow conditions experienced in Grand Passage by playing synthetic harbour porpoise clicks (hereafter 'pseudo clicks') emitted by an Ocean Sonics Ltd. icTalk (a positive control for signal detections) during a series of passive drifts from a vessel (i.e., 'SMEagol') in the vicinity of the PAM instruments (Figure 3).

For the purposes of this study, the icListen HF served as a surrogate for PAM devices and was justified on the grounds that this project was not designed to address questions about the performance of any given hydrophone *per se* (a topic previously addressed; Hasselman et al. 2020b), but rather the potential effects of signal interference inherent to the deployment location on the performance of PAM technologies in general. Thus, we make the assumption that any potential signal interference associated with waves and turbulence near the surface has an approximately equal effect on hydrophone performance across the suite of conventional PAM technologies that are available, and that might be used for monitoring harbour porpoise in tidal channels.

Field trials

The surface deployed icListen HF was pole-mounted 2m below the surface near the bow of the port outer hull of the PLAT-I and was cabled to provide power supply and data storage to an external hard drive connected to a laptop. The bottom-mounted icListen HF was connected to an Ocean Sonics SmartRecorder that extended the data storage capacity of the hydrophone as required for the duration of the deployment. Both the bottom-mounted hydrophone and SmartRecorder were integrated into one of FORCE's FAST (Fundy Advanced Senor Technology) subsea platforms and deployed in Grand Passage approximately 65m (from center spread) north of the PLAT-I at 17m depth (high water) (Figure 4).

Both the surface and bottom-mounted hydrophones were deployed over two periods (January 7-17, and August 12-21, 2020) to record pseudo clicks during the passive drift trials and real harbour porpoise in the area over a range of tidal flow conditions. Passive drifts were conducted on January 14 and August 19 over the FAST platform and near the PLAT-I from the SMEagol, with the icTalk deployed over the side of the vessel at approximately 5 m depth (water depth was 15-30 meters in the drift area). During the August 19th drifts, the orientation of the icTalk was alternated between an upward and downward facing orientation to ensure both hydrophones could adequately detect pseudo clicks. These drifts were conducted over an entire tidal cycle (i.e., ebb and flood tide) to determine the ability of the surface deployed and bottom-mounted hydrophones to detect this positive control signal across a range of flow conditions experienced in Grand Passage. The center frequency of the pseudo clicks from the icTalk was 130 kHz, with pseudo clicks produced every 0.3 seconds at peak-to-peak sound pressure levels of 130 dB re 1µPa at 1 m from the projector. A handheld GPS (Garmin Oregon

600) recorded the vessel tracks during the passive drifts. Tidal current velocity data for Grand Passage was obtained using open source software based on the FVCOM model (Chen & Beardsley, 2011) and provided to SMRU for analysis.

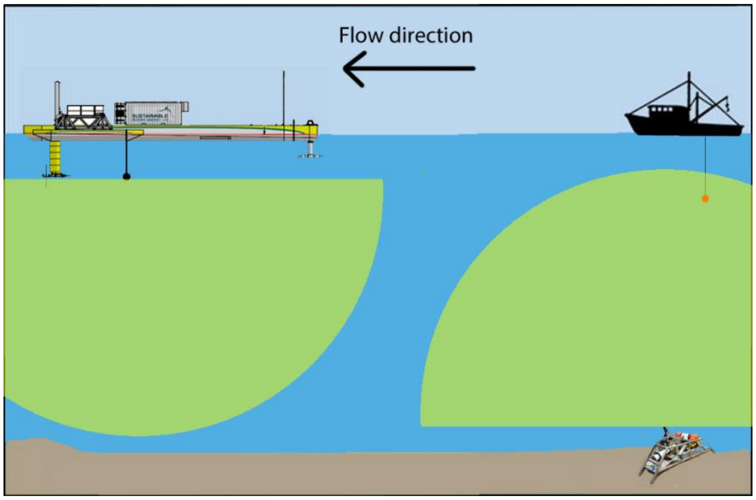

Figure 3: Schematic of the study design in Grand Passage, showing the icTalk (red dot) suspended from a vessel, and the icListen hydrophones deployed on the seabed and near the surface from the PLAT-I (not to scale).

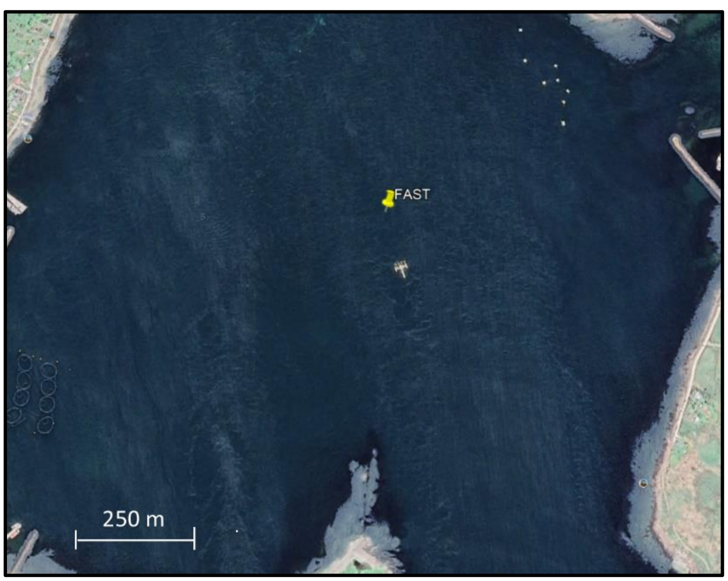

Figure 4: Satellite image of Grand Passage showing the location of the PLAT-I (center) on flood tide and the approximate position of the bottom-mounted hydrophone deployed on the FAST platform (image credit: Google Earth).

Upon completion of the data collection in January, it was discovered that electrical interference from a power inverter on the PLAT-I had contaminated the data from the surface deployed hydrophone, making it unusable. However, the data from the bottom-mounted hydrophone was suitable for analyses (Figure 5). Conversely, upon completion of the data collection in August, it was discovered that the Smart Recorder on the bottom-mounted hydrophone failed to store data, whereas the PLAT-I mounted data was suitable for analyses. Following discussions with SMRU, the decision was made to proceed with analyses using the bottom-mounted hydrophone data collected in January with the surface deployed hydrophone data collected in August. Although not ideal, analyses of detection range and the development of detection functions to understand relative performance of surface deployed and bottom mounted hydrophones can still be accomplished using this approach.

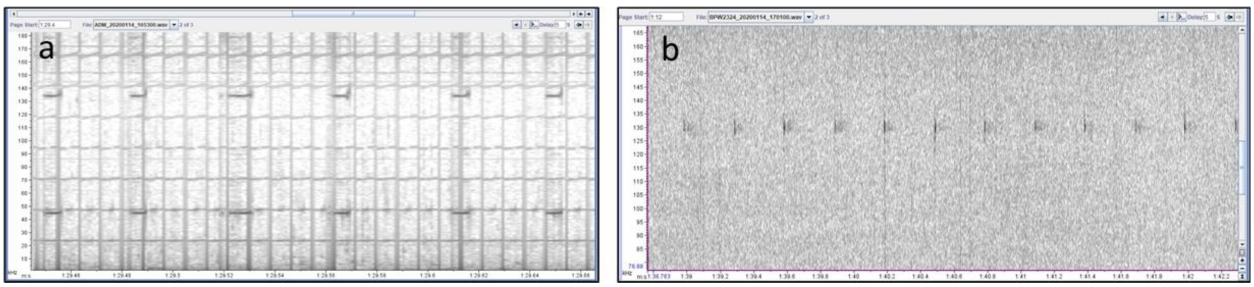

Figure 5: Spectrograms showing a) electrical interference for the surface deployed icListen hydrophone mounted on the PLAT-I in January 2020, and b) pseudo clicks from the bottom-deployed icListen hydrophone.

Data analysis

Upon platform recovery, data from both hydrophones were downloaded and provided to SMRU for standard QA/QC procedures and analyses. The project plan called for the use of automated detectors to identify the pseudo-clicks. Automated detectors differentiate signals (in this case pseudo-clicks) from noise in the data. To improve signal detectability, processing can be applied to remove noise or enhance the signal before comparing to a threshold value. For harbour porpoise clicks, the signal is very short but relatively narrowband, and in this instance the only good enhancement is to filter out energy at frequencies above and below those of the echolocation click, followed by summing the energy over a short period of time. Once processed, a click can be identified when the short-time energy exceeds the average energy. However, if the signal-to-noise ratio (SNR) remains low despite these measures, then a detection cannot be made (B. Martin, pers. comm. 2021). In this case, processing to improve signal detectability was not applied to the data. A low signal to noise ratio (SNR) for the surface deployed hydrophone (due to either ambient noise, or range between the icTalk and the PLAT-I mounted hydrophone during drifts) prevented the use of automated click detectors to find pseudo clicks in the data. Thus, all detections were made manually by trained analysts, and only drifts where at least one pseudo click was detected were included in analyses. The relative performance of the surface deployed and bottom-mounted hydrophone was assessed by constructing detection functions that describe the probability of detecting pseudo clicks by each hydrophone and evaluating the detection range for the surface deployed and bottom-mounted hydrophone. Details are provided in the Appendix.

Results

A total of 9,098 pseudo clicks were annotated from the bottom-mounted hydrophone across the 58 passive drifts conducted during the January 2020 deployment. The potential for collision between the drifting vessel and the PLAT-I prevented close approaches to the surface deployed hydrophone except during high-water and low-water slack periods when current and vessel movement were low. As such, only four of the 35 passive drifts during the August 2020 deployment approached within 100m of the PLAT-I, and 368 pseudo clicks were annotated in the dataset collected by the surface deployed hydrophone. Instances where pseudo clicks were not recorded during some passive drifts were likely due to the low source level of the icTalk, flow noise, ambient noise, and the passive drift not passing close enough to the hydrophones, or some combination thereof.

Pseudo clicks were generally detected during drifts over the bottom-mounted hydrophone, with pseudo clicks at the beginning and end of the drifts (when the icTalk was furthest away) being less detectable. This is consistent with the findings of previous drifting experiments using bottom-mounted hydrophones (Hasselman et al., 2020b). However, this pattern was not observed for the surface deployed hydrophone, as pseudo clicks were sporadically detected throughout the drifts in no definitive pattern. The median and 3rd quartile sound pressure levels of the surface-deployed data were ~2 dB lower than for the bottom mounted data (Figure 6), however, the surface mounted data contained substantially more short impulsive noise (comparing Figures 6 and 7), which could have made detecting the clicks more difficult for the analysts.

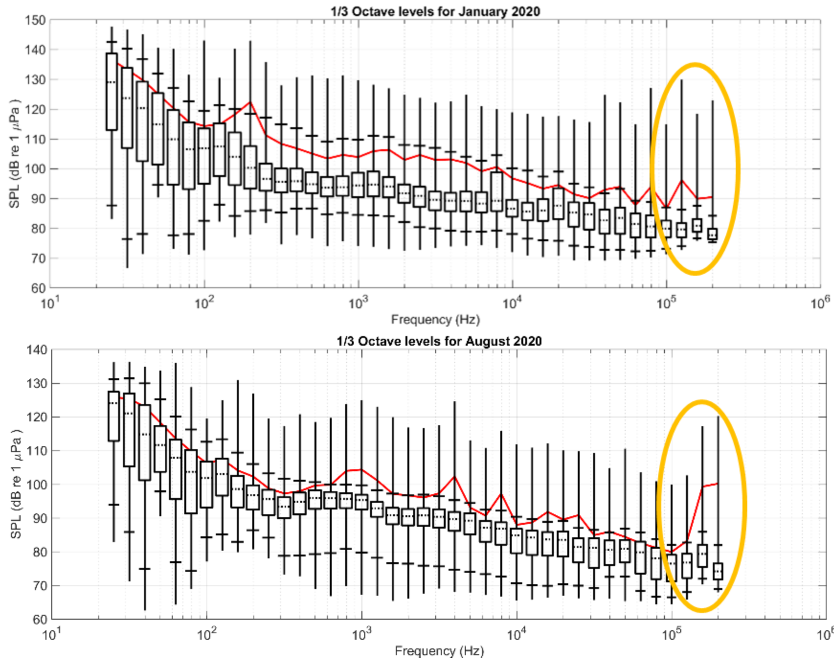

Figure 6: Decidecade sound pressure levels recorded for the bottom-mounted hydrophone (top panel) and the surface deployed hydrophone (bottom panel). Data is represented by box and whisker plots (minimum, Q1, median, Q3, maximum) and mean values are represented by a solid red line. Orange circles highlight the frequency range of harbour porpoise clicks and pseudo clicks generated by the icTalk.

The data collected from the PLAT-I mounted hydrophone contained interference from wave action and the broadband, impulsive, bursting of bubbles associated with waves that is particularly challenging to differentiate from echolocation clicks (Figure 7). Impulsive noise like that detected in this study for surface deployed hydrophones will negatively affect automated porpoise click detectors and may lead to an increased rate of false-positive detections. In contrast to the surface deployed hydrophone, interference in the bottom-mounted hydrophone dataset was predominantly characterized by occasional boat noise (from the drifting vessel re-positioning itself for the next pass), which was comparatively easy to differentiate from pseudo clicks (Figure 8) and does not impede the use of porpoise click detectors.

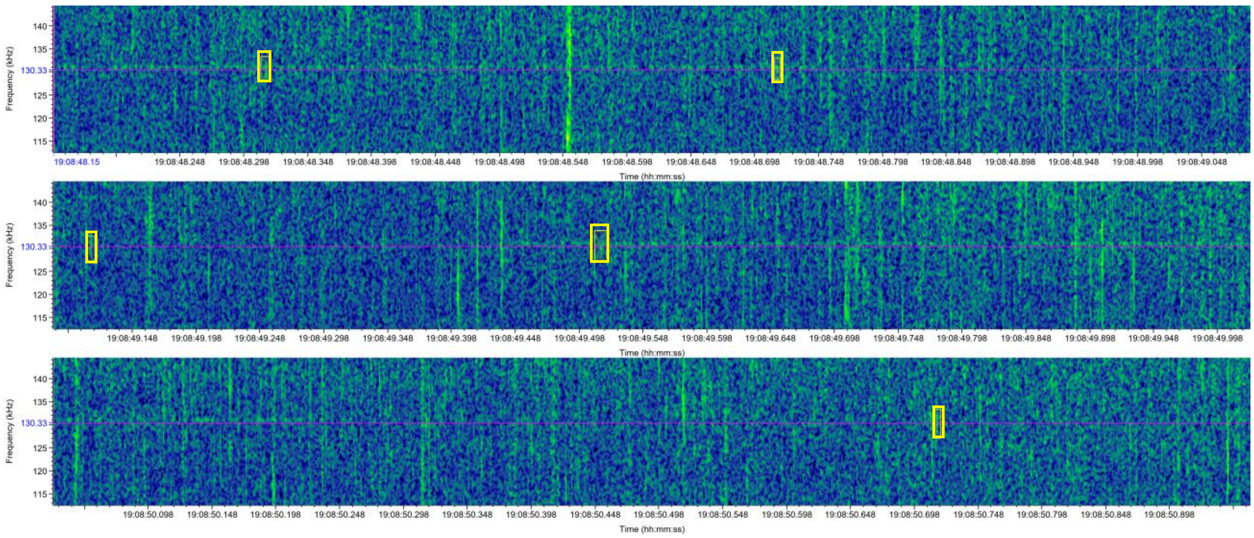

Figure 7: Spectrogram (FFT = 2048, 50% overlap, 512 kHz sample rate) from the PLAT-I mounted hydrophone during passive drifts showing received pseudo clicks (yellow boxes), and a 130 kHz reference line (purple) used for aiding in the click detection process. Vertical lines throughout the spectrogram indicate noise likely generated by bubbles near the surface.

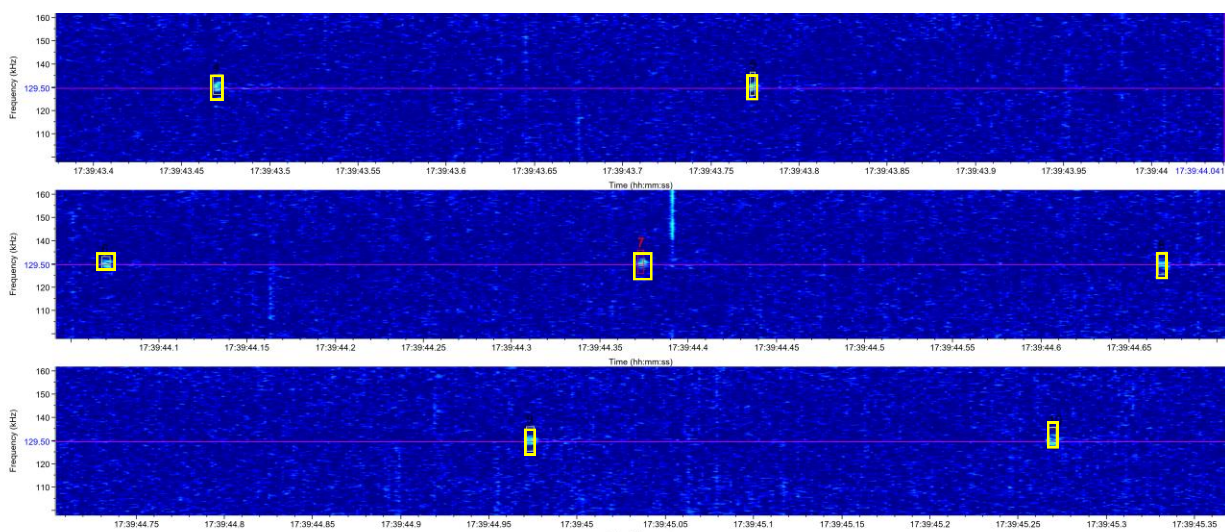

Figure 8: Spectrogram (FFT = 2048, 50% overlap, 512 kHz sample rate) from the bottom-mounted hydrophone during passive drifts showing received pseudo clicks (yellow boxes), and a 130 kHz reference line (purple) used for aiding in the click detection process. Lack of impulsive sounds facilitated easier detection of pseudo clicks.

The generation of detection functions from the drift data revealed that the proportion of pseudo clicks detected by the surface deployed hydrophone was considerably lower than that detected by the bottom-mounted hydrophone (Figure 9). The maximum detection range for pseudo clicks from the surface deployed hydrophone was 88m compared to 135m for the bottom-mounted hydrophone. Assuming the source level of real harbour porpoise clicks is ~60dB greater than the icTalk (Villadsgaard et al., 2007), but with a penalty of 30 dB for off-axis clicks, the 50% detection range for the surface deployed and bottom-mounted hydrophones is approximately 170m and 310m, respectively. These values are based on manual annotations of the spectrograms and represent over-estimates of the detection range for automated detectors, especially for the surface deployed hydrophone where interference made the use of the available automated click detectors of little value. However, it is important to recognize that more data was collected by the bottom mounted hydrophone than that mounted on the PLAT-I (i.e., pseudo clicks detected during 58 and 4 drifts, respectively). Data compatibility issues between the surface deployed and bottom mounted hydrophone made the comparison of detection ranges challenging, and these results should be considered preliminary.

The modelled tidal current velocity for both the surface deployed and bottom-mounted hydrophone ranged from 0-2 m/s. Maximum flow values were higher at surface than at the sea bottom. When taking flow rate into consideration, these preliminary analyses suggest that even under similar current velocities, the detection probability range may be greater for the bottom-mounted hydrophone than the surface deployed hydrophone. Additional work is required to explore this further.

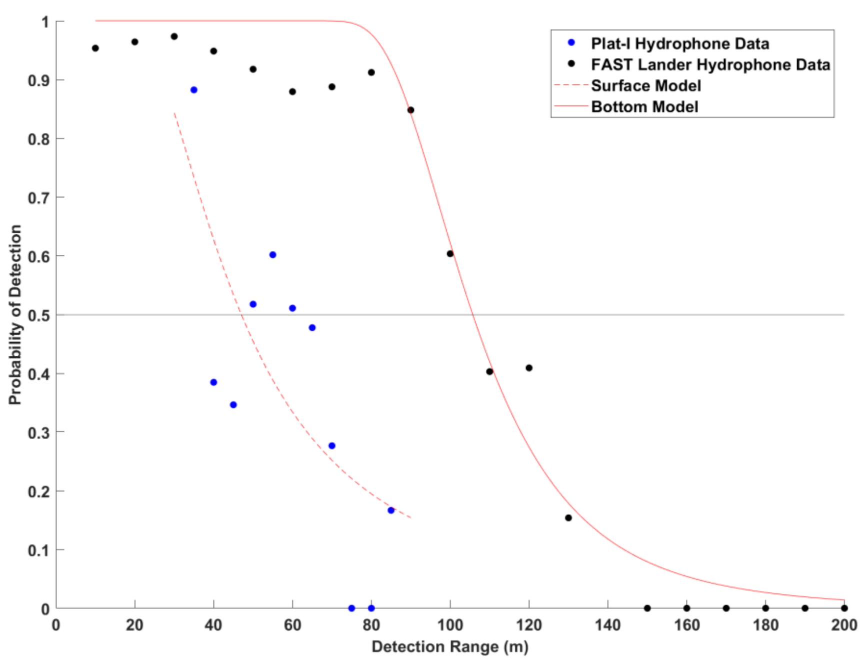

Figure 9: Detection functions for surface deployed and bottom-mounted hydrophones showing reduced detection range for the hydrophone mounted on the PLAT-I. The 50% detection probability is shown by the horizontal line.

Conclusions and Recommendations

Using PAM technologies to monitoring echolocating marine mammals in tidal channels dominated by high current velocities is inherently challenging. The choice of which instrument to use and where it should be deployed depends on the scientific questions being asked; particularly those by regulatory agencies if the monitoring is related to industry. A primary objective of the Pathway Program is to define, test and validate an environmental effects monitoring solution that can be used by tidal energy developers for monitoring the near-field (0 – 100m) region of their tidal energy devices at the FORCE tidal demonstration site in the Minas Passage.

Previous work under the Pathway Program evaluated multiple PAM technologies and revealed that conventional hydrophones that record raw pressure time series data may be preferable for monitoring harbour porpoise in Minas Passage (Hasselman et al., 2020b). This study sought to evaluate the relative performance of a surface deployed and bottom-mounted conventional hydrophone to understand whether deployment location impacts instrument detection range.

While it is possible to detect harbour porpoise clicks from a surface deployed hydrophone, the detection range appears smaller than bottom-mounted hydrophones and sufficient care must be taken to avoid acoustic and electrical contamination from other equipment on floating tidal energy platforms. However, it is important to bear in mind that the results of this study are based on a relatively small number of pseudo clicks collected from the PLAT-I mounted hydrophone in Grand Passage. Conditions may differ at the FORCE site and additional data would help to further refine expectations about the utility of a surface deployed hydrophone for monitoring harbour porpoise. These preliminary results suggests that the reduced detection range for the surface deployed hydrophone was not attributed to differences in flow velocities (flow noise) over the surface of the hydrophones, but rather short impulsive noise at the surface from wave action and air bubbles that is similar to porpoise clicks. These impulsive sounds masked many of the pseudo clicks generated by the icTalk during the passive drift trials and interfered with the click detection process. These factors influenced the data collected using the specific configuration and mounting of the surface deployed hydrophone, and it is possible that these issues could be partially addressed through an alternative mounting configuration.

It is important to note that harbour porpoise clicks are directional, and are typically produced while diving and foraging at depth (Sørensen et al., 2018). As such, harbour porpoise are less likely to produce clicks while directed at the surface, and are less likely to be detected by surface deployed hydrophones. However, porpoise also employ clicks to image their environment, and for surface deployed turbines having a hydrophone at the same depth as the turbine may provide more relevant detection information than would be provided by a bottom mounted hydrophone offset from the turbine location. For foraging porpoise, the directionality of clicks will have a negative effect on the median detection range, as an elevated proportion of the clicks reaching the surface hydrophone will be off-axis. While the inclusion of additional covariates (variation in drift speed, tidal current, sound profiles) may help to refine the detection model, the large disparity in the impulsive noises suggest they would be unlikely to result in a different interpretation of the data collected in this program.

Given the various considerations listed above, the results of this work suggests that PAM monitoring for harbour porpoise in high flow environments can be conducted using surface mounted hydrophones, but more work is required to refine detection ranges in tidal channels. While surface deployed hydrophones may be used, developers need to implement safeguards against acoustic and electrical contamination from equipment on their tidal every devices, and need to be aware of the potentially smaller detection range that a surface deployed hydrophone might provide. Measurement of in-situ detection ranges using a drifting projector, similar to the drifts performed in this program, should be considered to verify that hydrophones are able to detect porpoise in the turbine's near-field (100 m).

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Appendix – SMRU Final Report

Acoustic Detection Probabilities in Surface and Bottom Mounted Hydrophones

Prepared for FORCE

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Acoustic Detection Probabilities in Surface and Bottom Mounted Hydrophones

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1 Executive Summary

In support of the Pathways program an assessment of the relative acoustic detection range of harbour porpoise was undertaken. The primary goal of this study is to determine whether the relative performance of a PAM device used for detecting harbour porpoise vocalizations is impacted by the deployment location (i.e., surface vs. bottom) so that an informed decision can be made about the deployment location for PAM devices for future monitoring efforts. Two hydrophones were deployed during this study. One was affixed to the Sustainable Marine Energy (SME) Plat-I floating platform in Grand Passage, NS and suspended 4 m below the surface. The second was deployed on a Fundy Advanced Sensor Technology (FAST) bottom lander 17 m below the surface. An icTalk projected porpoise-like clicks (pseudo-clicks) while drifting freely in the current past the two hydrophones. Due to technical difficulties, data from drifts were not collected simultaneously on both surface and bottom hydrophones. Therefore, data from January 14, 2020 were used for the bottom hydrophone analyses and data from August 19, 2020 for the surface hydrophone analyses.

Pseudo clicks recorded from both hydrophones were manually annotated (N = 9,098 in bottom recordings, N=368 in surface recordings) and we estimated the proportion of clicks missed by the analyst based on known inter-click-intervals of the icTalk.

Our key findings are as follows:

1) Pseudo-clicks could be detected by instruments in both locations.
2) The maximum detection range for pseudo-clicks recorded by the surface-mounted hydrophone was 88 m and 135 m for the bottom mounted hydrophone. Similarly, the range at which the detection probability dropped to 50% was 46 m for data collected by the surface mounted recordings and 104 m for the bottom mounted recordings.
3) The difference in detection range between the surface and bottom could primarily be attributed to elevated high-frequency noise at the surface hydrophone.
4) Despite the lower detection range at the surface, the surface-mounted hydrophone did opportunistically record wild harbour porpoise.

Given these findings we recommend the use of bottom-moored hydrophones where economically feasible.

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2 Introduction

To meet Canadian and Nova Scotian regulations, Tidal Instream Energy Converters (TISECs) installed in Nova Scotian waters have been required to institute marine mammal Environmental Effects Monitoring Plans (EEMPs). Much of this effort has focused on using echolocation click detectors to detect the presence of harbour porpoise (*Phocoena phocoena*). Early TISEC projects in Nova Scotian waters were bottom mounted devices and testing sites lacked surface infrastructure from which to mount click detectors. As a result, harbour porpoise monitoring has mostly been done by deploying click detectors on the seafloor. However, SME's TISEC technology is a floating platform (Plat-I) with attached Schottel turbines. This provides the option of mounting click detectors from the Plat-I instead of on the seafloor.

Deploying and recovering instruments from the seafloor (bottom) represents considerable cost and risk for monitoring activities. Deployment and recovery typically require vessels equipped with davits and loss of bottom mounted instruments does occur. As such, deploying instruments from the floating Plat-I could represent cost savings if successful. However, changing the deployment depth of an acoustic recorder is known to have large impacts on acoustic detection range (Sostres *et al.* 2015). Any successful surface deployment would need to prove the ability to detect harbor porpoise in the near field.

Here we seek to determine first if it possible to detect harbor porpoise from the Plat-I and second if the detection range is similar to detection ranges obtained from bottom mounted instruments. To achieve this, we measure how the detection ranges of simulated harbour porpoise clicks are impacted by the deployment location (i.e., surface vs. bottom). This information will allow managers to make informed decisions about the utility and limitations of various deployment options.

3 Methods

3.1 Data Collection

This project is a collaborative effort between FORCE, OERA and SMEC and utilized the Plat-I floating tidal energy platform deployed in Grand Passage, NS. The relative performance of a Passive Acoustic Monitoring (PAM) device deployed at the surface and on the bottom was assessed across the range of tidal flows experienced in Grand Passage using synthetic harbour porpoise click-trains emitted from an Ocean Sonics icTalk. Here we investigate whether it is possible to detect harbor porpoise clicks in the near field range (>100 m) of the Plat-I as well as the mid-field range (100-1000 m) of the Plat-I.

For the purposes of this project, Ocean Sonics icListen hydrophones served as a surrogate for PAM devices in general. This can be justified on the grounds that this study is not designed to address questions pertaining to the performance of any given hydrophone per se (a topic already addressed in a prior study), but rather the potential effects of signal interference inherent to the deployment location(i.e., near the surface or bottom) on the performance of PAM devices in this application. Thus, we make the assumption that any potential signal interference associated with waves and turbulence near the surface has an approximately equal effect on hydrophone performance across the suite of PAM technologies that are available and might be used in EEMP monitoring.

3.1.1 Hardware

An icListen HF hydrophone was mounted on a FAST lander at a depth of 17m during high water (i.e., 'bottom-mounted'), approximately 65m North of the Plat-I. The Plat-I (i.e., 'surface-deployed') had a pole-mounted icListen HF near the bow of the platform at a depth of 4m. Upon completion of the passive drift tracks, the icListen hydrophones remained deployed for a few days to gather opportunistic data from harbour porpoise transiting the area. Upon completion of the study, the icListen hydrophones were recovered and the data were downloaded and sent to a SMRU Consulting for analysis.

3.1.2 Drift Experiments

Passive drifts in the vicinity of the FAST lander and Plat-I platform were made from a vessel while playing synthetic click trains using the icTalk. These passive drifts occurred on January 14, 2020, and again on August 19, 2020 over the course an entire tidal cycle (ebb and flood stages) to determine the ability of the icListen hydrophones to detect this signal across the range of flow conditions. Lightbulb implosions were used to validate the ability of the systems to detect loud implosive sounds and a SoundTrap was deployed with the intent to synchronize recordings across Plat-I and FAST lander. However, since data were ultimately derived from different time periods, synchronization was not possible.

The icTalk transducer is reported to be nearly omni-directional, however marginal beam patterns can result in large variations in detection ranges. To account for the downward, and more on-axis, orientation of icTalk with respect to the bottom-mounted hydrophones, we changed the orientation of the projector during the summer drifts. For these experiments we implemented two orientations of the icTalk. For half of the drifts, the hydrophone was oriented downward and for the other half the icTalk was inverted on the cable such that the element was facing upward. The passive drift tracks were recorded using a handheld GPS unit and used later for analyses.

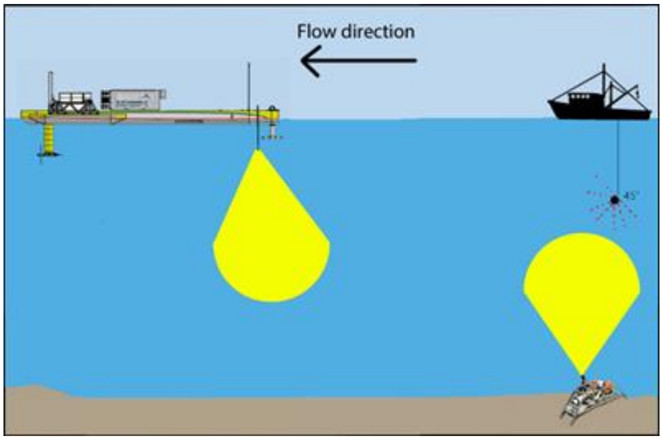

Figure 1: Schematic of study design for Grand Passage indicating the locations of the two hydrophones on the Plat-I floating platform and the FAST bottom lander as well as the icTalk suspended from the vessel.

Technical challenges prevented data collected from the Plat-I from being used during the winter drifts. These issues were resolved during the intervening months before August when the trial was re-run. However, data from the FAST lander could not be recovered from the summer drifts. As such, we were limited in our analysis to comparing the bottom mounted hydrophone data collected in the winter to the surface monitored hydrophone data collected in the summer.

3.2 Detecting Pseudo-Clicks

Because of the low signal to noise ratio (SNR) for the pseudo-clicks detected by instruments attached to the Plat-I, it was not possible to use automated-detectors to find pseudo-clicks. Thus, all annotations were made by trained analysts using Raven Lite software. For both surface and bottom data, analysts identified the start and end time of each passive drift and manually searched for pseudo-clicks matching the 130 kHz center frequency, 5 kHz bandwidth and .01 s duration and 0.3 s inter-pulse-interval. When SNR values were low either because of the range between the vessel and the sensors or high ambient noise levels the inter-pulse-interval was used to estimate the expected arrival time for the pseudo-clicks. The section of the spectrogram including the expected arrival time was then searched for potential pseudo-clicks. Only drifts where at least one pseudo-click could be manually detected in the data were included in the range analysis.

3.3 Range Estimates

The start time of each drift was estimated by using the first GPS position provided for each of the drifts. The continuous range between the vessel GPS and the bottom lander was obtained by interpolating the GPS coordinates from each drift. For the surface comparison, the distance between the drifting vessel and the position of the Plat-I were continuously monitored and the range between the two were again interpolated.

3.4 Comparing Detection Ranges

3.4.1 Signal Measurements

We calculated the signal to noise ratio (SNR) of each signal using (Equation 1) where peak is the peak pressure of the pseudo-click within the detection window and rms is the root-mean squared pressure of the 0.78 ms surrounding each peak.

$$SNR = 20 * log10\left(\frac{Peak}{RMS}\right) \qquad \text{Equation 1}$$

It is not possible to perfectly center manual annotations around each pseudo-click. Therefore, custom Matlab scripts were used to calculate SNR from the region of the annotation. To estimate the exact arrival time of the pseudo-click, a 0.04 s selection of the raw sound recordings was extracted from the data based on the midpoint of each annotation. This section of data contained both the click and a sample of the background noise.

The exact arrival time of the click was obtained by first bandpass filtering the signal between 128 and 132 kHz (i.e. the 1/3 octave band centered on 130 kHz). The peak time of the filtered signal was used to estimate the exact arrival time of each pseudo-click.

This same process was repeated for 'missed clicks'. Here we estimated the arrival time of the missed annotation based on the inter-pulse-interval of the received clicks. For example, if received pseudo-clicks were observed at 0.0s, 0.3s, 0.6s and 0.12s, we assumed a missed pseudo-click at 0.9 s.

Following Miller and Whalberg (2013), data for noise level metrics were filtered using a band filter centered on 130kHz for noise and received level measurements. This resulted in a bandpass filter between approximately 115 and 145 kHz.

Ambient noise levels in all cases were measured in rms over the 115-145 one third octave band measured over 1.6µs.

3.4.2 Detection Functions

Detection functions describe the probability of detecting an animal as a function of range between the source and the 'observer' (Equation 2). Distance sampling methods are typically used to estimate the proportion of data missed as a function of range. However, in this study the ranges between the sound source and observer were known for both detected and missed clicks.

$$Detection\ Probability \propto g(SNR)$$ Equation 2

In acoustics, the observers are hydrophones, and the acoustic detection represents the source. Factors affecting the detection probability are characterized by the sonar equation (Equation 3). Equation 3 where SL is the source level of the signal of interest (here pseudo-clicks), NL is the ambient noise level at the arrival time of the signal and TL is the transmission loss over the range between the source and receiver. All values are measured in decibels (dB) and measured across the same bandwidth.

$$SNR = SL - TL - NL$$ Equation 3

Here we assume that the detection function is described by a hazard rate function (Equation 4) where σ and *b* are the unknown parameters describing the shape of the function, *r* is the range between the source and receiver (in meters), and SNR is the signal to noise ratio of each detection as measured from the data.

$$P(r) = 1 - exp^{(-(r/\sigma)^{-b}))}$$ Equation 4

To estimate σ and *b,* the proportion of pseudo-clicks detected was calculated for 10m bins. Initial values of σ and *b* were chosen at random and an optimization function (mean squared error) was used to refine the values. Parameters σ and *b* were obtained for both surface and bottom experiments.

Finally, using the sonar equations we extrapolated our findings of the detection range of pseudo-clicks estimate the 50% detection range for wild harbour porpoise (Equation 5). Here we assumed consistent noise regimes, source levels of 130 dB re 1μPa for the icTalk (SL1) and 160 dB re 1μPa^{2}s for the porpoise (SL2; Teilmann et al., 2002). Transmission loss is the sum of spherical spreading ($20 \bullet \log_{10}(r)$) and molecular absorption ($38 \bullet \log_{10}(r)$), and r1 is the observed 50% detection range, and r is the estimated 50% detection range given the new source levels.

The system of equations was used to estimate the range at which real harbour porpoise would be detected under similar conditions where *r1* is the observed range and estimate range for wild porpoise clicks and ranges are measured in kilometers.

$$SNR = SL1 - TL - NL = 130 - NL - 20 * log_{10}(r1) - 38 * log_{10}\left(\frac{r1}{1000}\right)$$

$$SNR = SL2 - TL - NL = 160 - NL - 20 * log_{10}(r) - 38 * log_{10}\left(\frac{r}{1000}\right)$$

Equation 5

3.5 Current Effects

Tidal current velocity data were obtained using open source software (Chen and Beardsley 2011) and provided to FORCE and SMRU Consulting for analysis. The current model estimated the tri-axial current velocity on a 10 min scale for the seabed and surface and the magnitude of the tri-axial current velocity was used for each experiment. For the FAST lander experiment we used the current velocity modelled for the seabed and surface models for the Plat-I.

Modelled current velocity were matched with each pseudo-click arrival. Because drifts typically lasted less than 5 minutes, the maximum being 9 min, this resulted in each drift being associated with one velocity estimate.

To determine what, if any, effect tidal current had on the analysis, a subset of the drifts for the surface and bottom mounted recorders were selected and the detection functions were compared to each other. Here we sought to identify whether differences in the observed detection function for the entire data sets could be attributed to flow noise. If so, we would expect that the surface and bottom detection functions would be nearly identical for the data subset.

4 Results

4.1 Drift Data

The Plat-I hydrophone data from the January drifts was contaminated by electronic noise which was traced to a power supply issue and these data could not be used. During the August drifts, the FORCE lander hydrophone did not collect data. As such, we did not have simultaneous acoustic data from both the platform and lander and had to analyze the two data set separately.

The FORCE crew undertook a total of 58 drifts on January 14, 2020 and 35 drifts on August 19th 2020. The Plat-I rotates freely in the current creating a navigational hazard which precluded close approaches to the hydrophone mounted on the Plat-I except when current and vessel movement was extremely low. Because of this, only three of the 35 drifts on August 19th approached within 100m of the Plat-I mounted hydrophone. Pseudo-clicks from the icTalk were observable in data from these drifts.

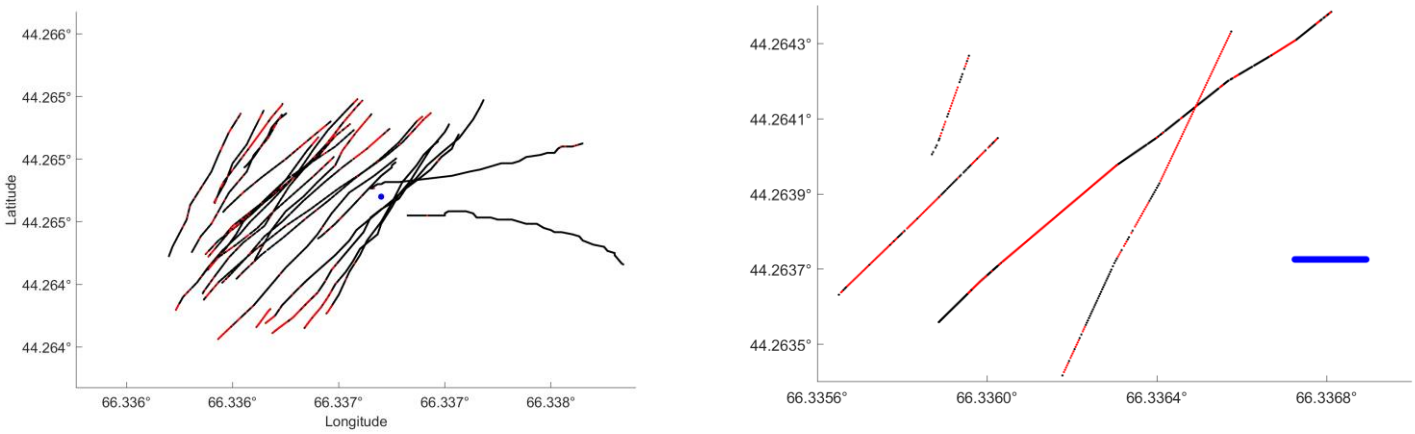

Figure 2 Survey data included in the analysis. Overhead view of the vessel drifts with respect to the bottom lander in January (left panel) and Plat-I surface platform in August (right panel). Black points represent pseudo-click annotations and red points indicate detections missed by the analyst. Blue point represents the hydrophone location on the FAST Lander or mobile Plat-I.

For each drift past the bottom lander, pseudo-clicks were generally detected throughout the drift with pseudo-clicks at the beginning and end of the drift (when the icTalk was furthest away) being less detectable. This pattern was not as obvious in the few observable drifts past the surface platform. In these later drifts, pseudo-clicks were masked by ambient noise within ranges where the clicks would otherwise be detectable.

Table 1 Summary table for drift, annotations, noise levels and detection ranges at the two study sites. Values in parentheses represent 95% confidence intervals.

	Surface Plat-I	**Bottom FAST Lander**
Total Drifts	35	58
Drifts Annotated	4	27
Number of Annotations	368	9,098
Median Noise Level (dB re 1uPa) in the 130 kHz octave band	76.4 (70.8-83.6)	73.9 (71.1-78.5)
SNR (dB)	5.3 (3.3-10.3)	3.8 (1.8-14.1)
Maximum Detection Range (m)	88	135

4.2 Noise Levels

One third octave, also known as decidecade bands, noise levels throughout the recording survey periods were measured (Figure 3). Surface recordings had lower low frequency noise than recordings from the bottom lander. However, above 100 kHz, noise levels were considerably higher in data collected by the hydrophone mounted to the Plat-I (Figure 3).

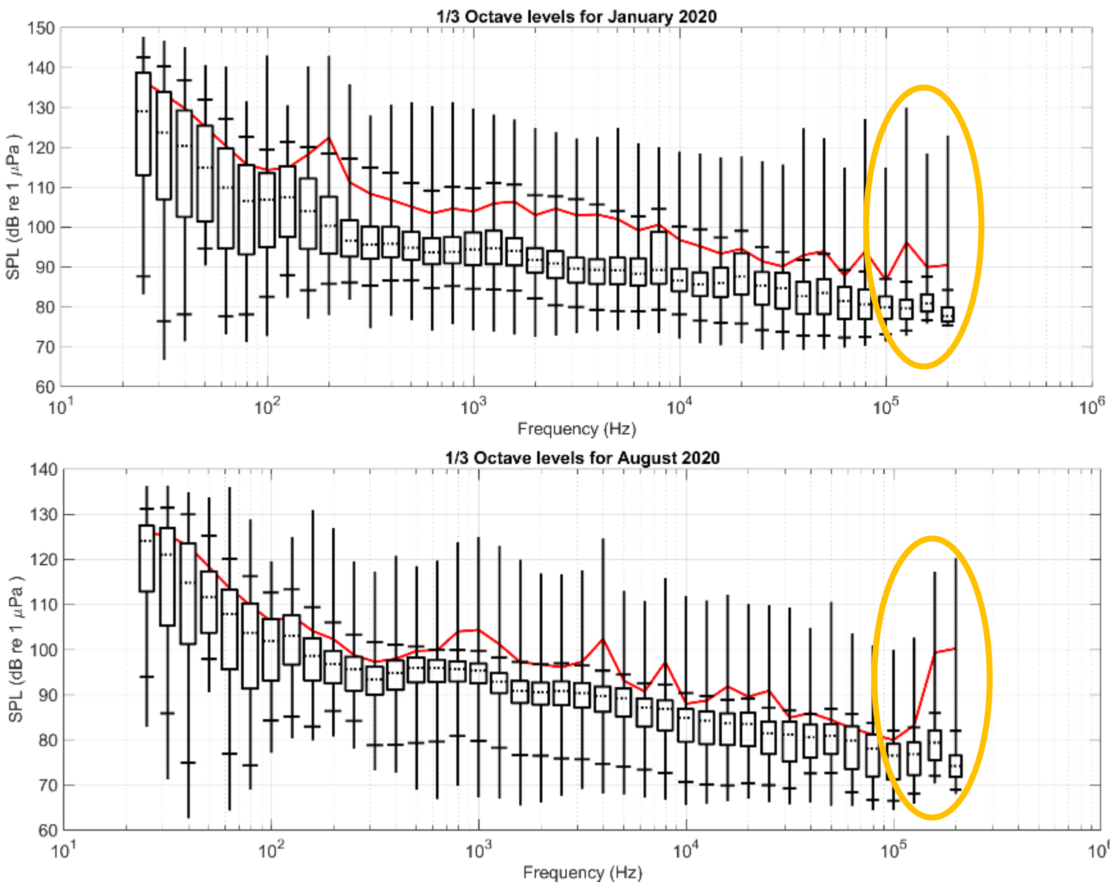

Figure 3 One third octave sound pressure levels recorded at the bottom lander site (winter, top panel) and at the Plat-I (surface, bottom panel). Orange circles indicate frequency range of harbour porpoise clicks and icTalk pseudo-clicks.

The rms noise level in the one third octave band including the130 kHz pseudo-clicks was measured during all drifts, regardless of whether they were included in the detection analysis. The median band during the drifts at the bottom platform was 73.9 dB and 76.4 re 1µPa at the surface location. Noise levels associated with the bottom lander were normally distributed ranging from 70-80 dB_{rms} re 1µPa across the 115-145 kHz band.

However, noise levels recorded at the surface platform were multi-modally distributed with peaks at 72, 79, and 83 dB_{rms} re 1µPa measured over 1.6 µs (Figure 4). Transient increases in ambient noise levels during the drifts resulted in considerable interference in our ability to detect pseudo-clicks and depressed the maximum detection range. Increased noise levels, necessarily, result in a reduction of the detection range of clicks produced at a constant amplitude.

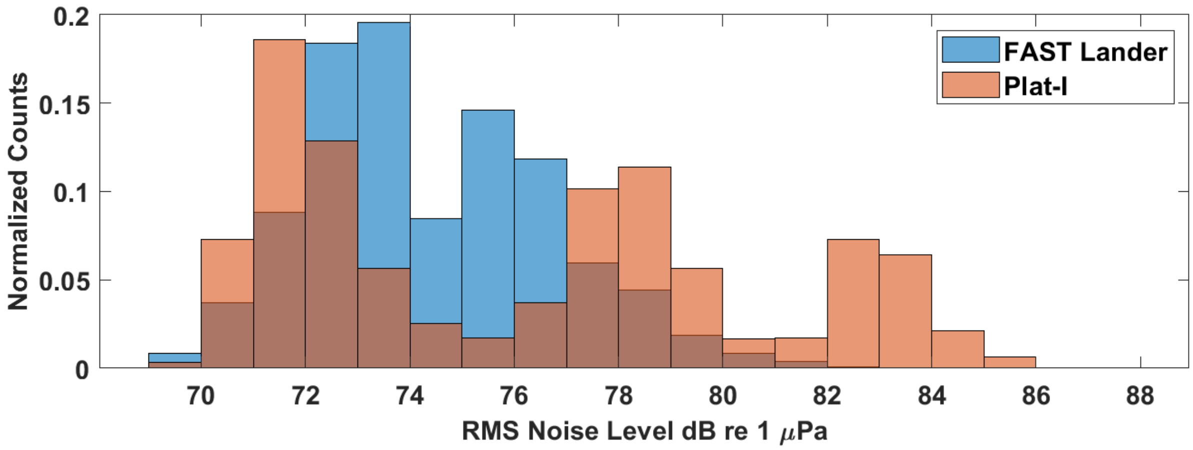

Figure 4 Noise level rms SPL distribution in the 130 kHz octave band associated with the drifts.

The quality of the noise regime in the 130 kHz band also differed significantly between the two surveys. Data collected at the surface contained audible interference from wave action and the broadband, impulsive, bursting of bubbles associated with waves. This type of noise is particularly challenging to differentiate from the impulsive nature of echolocation clicks (Figure 5). Impulsive noise also adversely affects porpoise detectors through the same mechanism, confounding impulses from noise increase the number of false positive detections. Identifying pseudo-clicks in these data required a significant amount of time and near continuous spectrogram parameter tuning.

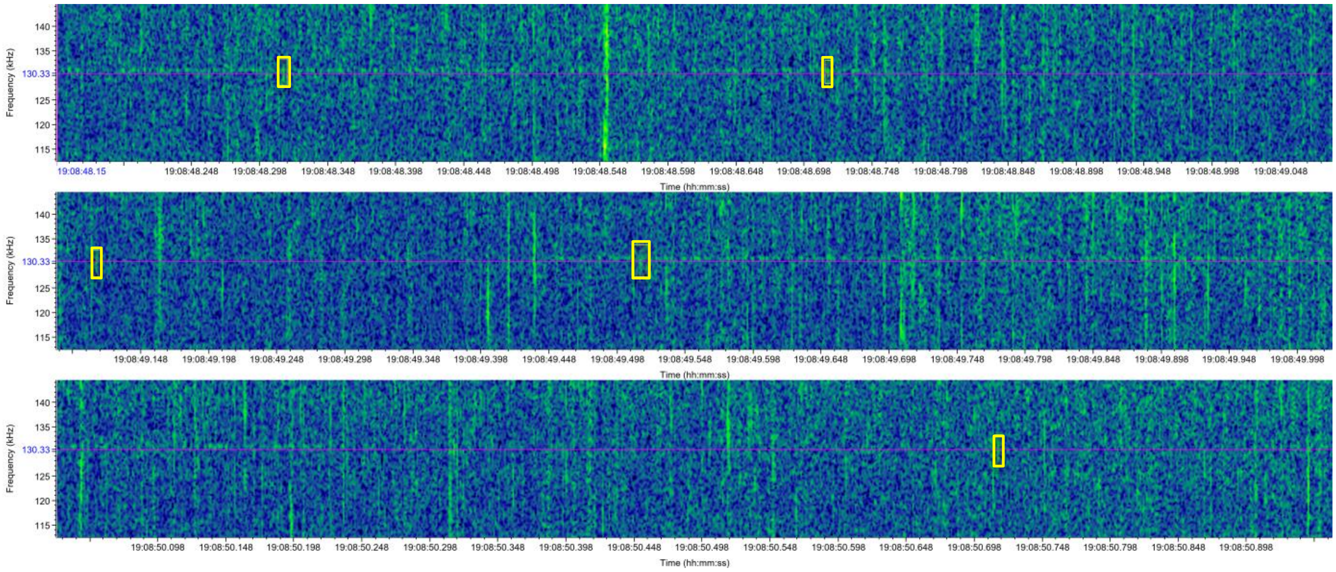

Figure 5 Spectrogram (FFT = 2048, 50% overlap, 512 kHz sample rate) of surface drift showing received pseudo-clicks (yellow boxes) a 130kHz reference line (purple line) used for aiding in the detection process. Vertical lines throughout indicate likely bubble action.

In contrast to the surface recordings, the interference in the recordings from the bottom mounted hydrophone was predominantly characterized by occasional boat noise (Figure 6). There was considerably less energy in the higher frequency data. In these data, the scope of the analysis (e.g., number of drifts annotated) was limited not by the ability to detect pseudo-clicks but by time. Noise in the data collected by the bottom mounted hydrophone was characterized by continuous gaussian noise in which it was easy to identify pseudo-clicks. Figure 6 shows a representative sample of data containing pseudo-clicks collected by the bottom mounted hydrophone.

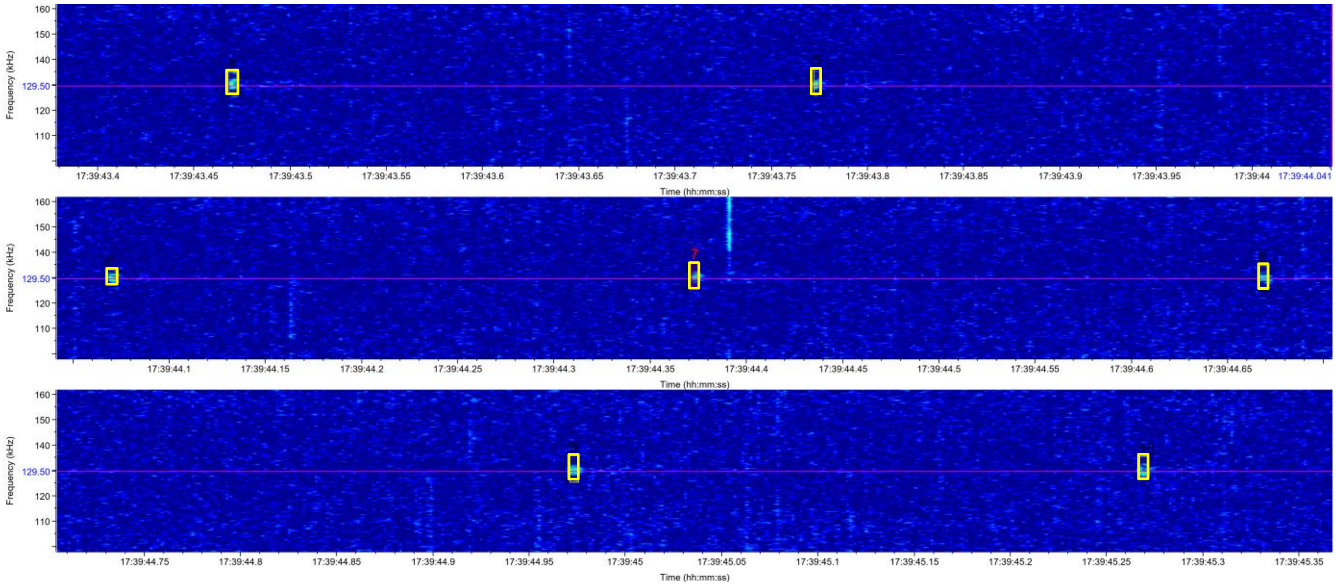

Figure 6 Spectrogram (FFT = 2048, 50% overlap, 512 kHz sample rate) of FAST lander data showing received pseudo-clicks (yellow boxes) a 130kHz reference line (purple line) used for aiding in the detection process. Lack of impulsive sounds allowed for easier detection of pseudo-clicks and will facilitate automated detection.

4.3 Detection Functions

The proportion of pseudo-clicks detected at the surfaces was markedly lower than pseudo-clicks detected by the bottom-mounted hydrophone (Figure 7). The maximum pseudo-click detection range at the surface deployment was 88 m as compared to 135 m for the bottom lander. The 50% detection range for the surface hydrophone was 46 m and 104 m for the bottom mounted hydrophone. Assuming the harbor porpoise source levels are ~30 dB higher than the icTalk, Equation 5 is used to solve for the expected detection range of 'real' harbor porpoise clicks. Using these values, we estimate 50% detection range of 144 m at the surface and 342 m at the bottom. Again, these values were calculated using human observers, and as such represent over-estimates of the detection range especially at the surface where interference made the use of automated detectors impossible.

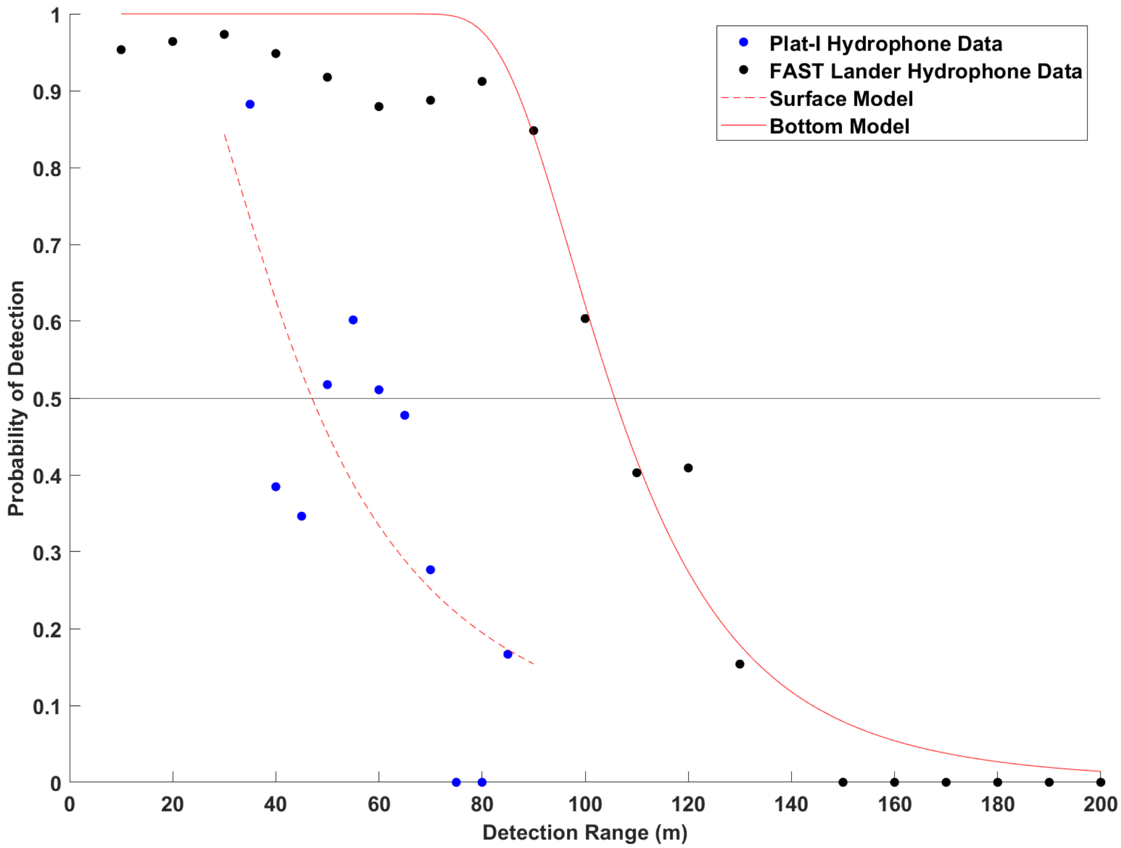

Figure 7 Proportion of pseudo-clicks detected and modeled detection function for data collected by bottom mounted instruments (black points) and instruments deployed at the surface (blue points). Horizontal line indicates 50% detection probability.

4.4 Current Effects

For both Plat-I and FAST Lander the modelled current velocity ranged from 0 to 2 m/s (Figure 8). Maximum flow velocities were higher at the Plat-I location and minimum flow velocities (<1 m/s) were observed at the FAST Lander. Data associated with current velocities between 0.5 and 1.25 m/s were selected for the flow analysis. This resulted in two drifts from each experiment being included with a total of 637 pseudo-click arrivals at the FAST Lander and 635 at the Plat-I.

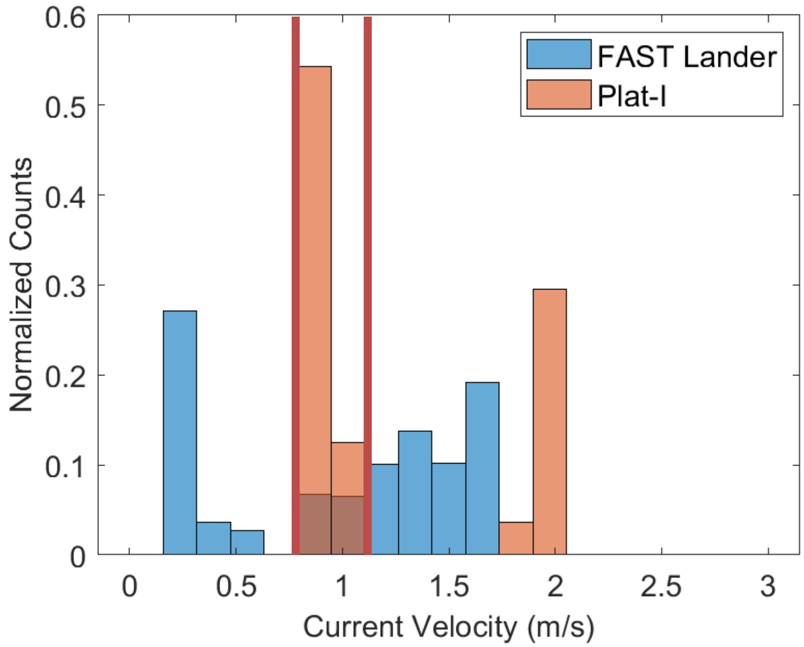

Figure 8 Normalized histogram of the modelled current velocities associated with all drift trials included in the analysis. Modeled values for the FAST lander were derived from the seabed models and surface model for the Plat-I. Red lines indicate data collected from periods with similar flow velocities and selected for the flow analysis.

With two drifts from the each of the Plat-I and FAST lander data sets included in the flow analysis, there were insufficient data to create meaningful detection functions. However, the pattern in the proportion of pseudo clicks detected vs. range were consistent with the observations from the whole dataset. This indicates that under similar current velocities, the detection probability range is still considerably greater at the FAST lander location than from a hydrophone mounted at on the Plat-I (Figure 9).

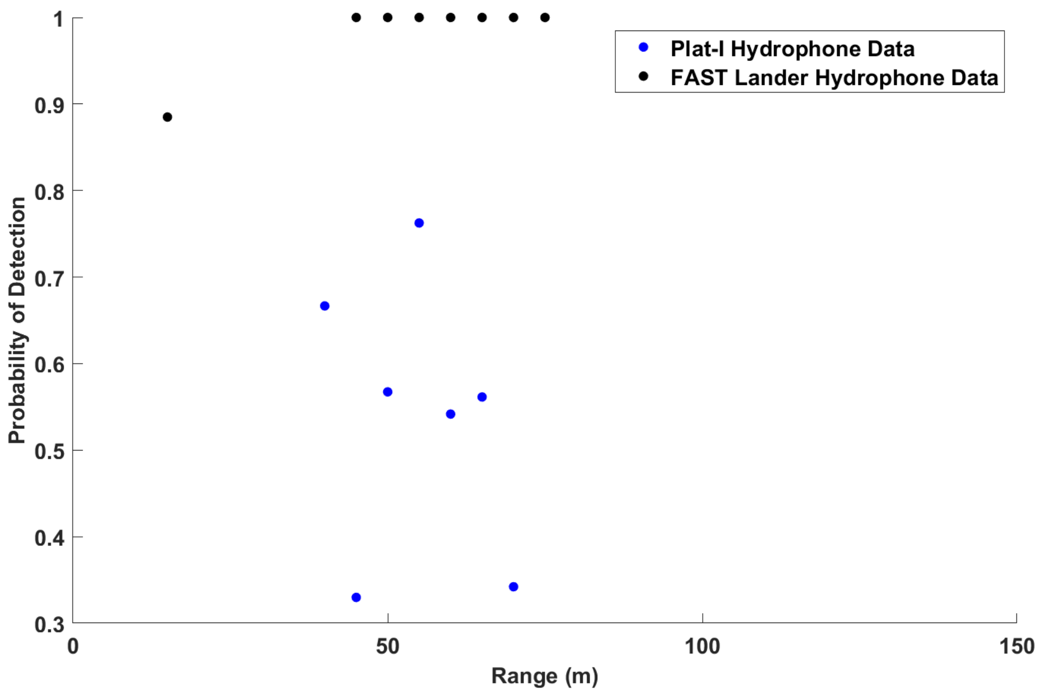

Figure 9 Observed detection probabilities for the flow experiment (modelled flow velocity greater than 0.5 m/s and less than 1.25 m/s). As with the full data set, the detection probability was consistently higher for recordings made at the FAST lander.

4.5 Opportunistic Sightings

FORCE staff noted the presence of harbour porpoise in the waters surrounding the Plat-I during the August 19th drift experiments. Staff removed the icTalk from the water during this time and noted the approximate range between the wild porpoise and the surface hydrophone. SMRU Consulting staff investigated data from the Plat-I and were able to confirm the presence of echolocation clicks in the acoustic recordings consistent with staff observation (Figure 10).

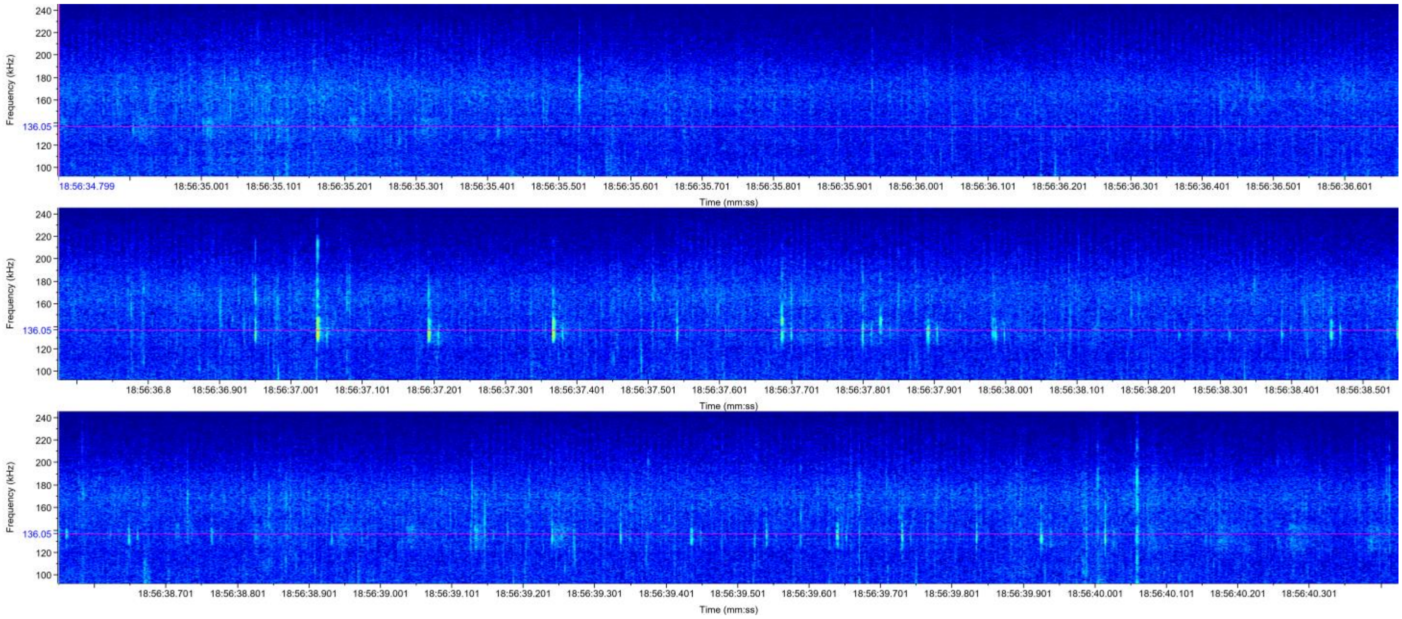

Figure 10 Spectrogram (FFT = 2048, 50% overlap, 512 kHz sample rate) of wild harbour porpoise clicks recorded by the surface-mounted hydrophone.

5 Discussion

This study demonstrates that it is possible to detect harbour porpoise clicks from hydrophones mounted on either bottom moored landers or the Plat-I floating platform *if* sufficient care is taken to avoid acoustic contamination from other equipment on the Plat-I platform. Pseudo-clicks produced by the icTalk were observed in both data sets and wild harbour porpoise echolocation clicks were detected in both data sets.

The estimated detection range at the surface hydrophone was considerably smaller than that for the bottom hydrophone. The difference in detection ranges could be attributable to any aspect of the sonar equation (SL, TL, NL). While the source level of the icTalk was fixed throughout the study, high frequency sounds are necessarily directional and the beam pattern of icTalk is not completely uniform. We also investigated whether current speed between the two disparate experiments could drive the difference in detection ranges. For a small subset of data consisting of limited current velocities we found similar detection ranges as the full data set. This suggests noise induced by current flow over the hydrophones did not drive the differences we found in detection range between the bottom and surface mounted hydrophones.

Transmission loss characteristic also varies between the two sets of drifts. Clicks, or pseudo-clicks arriving at the surface mounted hydrophone are subjected to interference from wave action under normal conditions. The presence of thermoclines can also ‘trap’ sounds in shallow or deep water depending on the direction of the thermocline. However, we do not expect this to have had a major impact on the current study given the extensive tidal mixing in the area.

The biggest contributor to the variation in detection range between the two hydrophone locations was ambient noise. The increased noise at the surface masked many pseudo-clicks and interfered with the detection process.

Potential covariates that we did not directly account for included water depth, wind speed, direction relative to the instrument, and vessel speed. Windspeed is a major contributor to ambient noise levels in moderate to high frequencies and could contribute to disparities in the noise regime between the two sites. However, historical records indicate similar windspeeds (1-14 km/hr; < Beaufort 2) during the winter and summer drift experiments (https://climate.weather.gc.ca/). While windspeed is not typically thought to impart noise in high frequencies that assumption is limited to deep water deployments. Hydrophones are not typically placed near the surface because the impulsive nature of wave action and bubbles bursting is necessarily broadband. The nature of high frequency noise is not well characterized for surface deployed hydrophones, but bubble and spray action caused by breaking waves can induce broadband noise and interference into the high frequency components of the noise regime, regardless of the source (Macaulay et al., 2017).

It is also important to note that harbour porpoise clicks are directional, and animals preferentially produce them while diving and foraging at depth (Sørensen *et al.* 2018). This is not the case with the icTalk which more closely resembles and omni-directional transducer. In doing so, animals are on, average, less likely to produce clicks while directed at the surface. The directionality of the clicks will have limited effects on the maximum detection range as that is determined by clicks received on-axis of the porpoise. However, the median detection range will decrease as a greater proportion of the clicks reaching the surface hydrophone will be off-axis.

Ideally the data from this study would have been derived from a single day of drifts which would have provided consistency across the covariates of interest including tidal flow, wind speed, depth etc. This would limit some of the confounding factors that are not easily addressed in the present study. These include variation in drift speed, tidal currents, sound speed profiles etc. Regardless, the large disparity in noise levels in the 130 kHz band suggests that additional covariates would help refine the detection models but are unlikely to result in different interpretations of the data.

With the considerations above, we recommend that EEMPs focused on harbour porpoise around TISECs use bottom mounted-hydrophones wherever possible. Where there is a need for real-time or near-real time monitoring surface mounted hydrophones can be used, but only with careful design and monitoring to avoid acoustic contamination from other equipment and consideration of a smaller detection range.

6 Conclusions

This report sought to 1) determine whether it is possible to detect harbor porpoise in the near field with hydrophones deployed at or near the surface and 2) compare the detection range of a hydrophone deployed at the surface with one deployed on the seafloor.

We found that it was possible to detect both pseudo-clicks and real harbor porpoise clicks from a surface mounted hydrophone. Therefore, maintaining a hydrophone from the Plat-I can provide some insight into the presence of harbor porpoise very near the platform, assuming the mechanical and electrical noise emanating from the machinery is limited as it was in the latter part of the summer. Platform mounted hydrophones provide potential for real time monitoring of harbor porpoise and expeditious knowledge of instrument malfunction issues whereas this is not possible for bottom-moored archival instruments.

In comparing detection ranges there were considerable issues with data compatibility between the surface and bottom drifts. With the data that were collected, we found that the detection range for pseudo-clicks was considerably greater for the hydrophone moored to the seafloor than the one at the surface. Though the discrepancy in data collection limits the generalization of this finding, for the converse to be true and average detection range to be as large or larger at the surface than at the bottom, it would require one or both of the following conditions to be true. Harbor porpoise would need to produce clicks while on-axis with the surface hydrophone more often than while they were on-axis with the bottom mounted hydrophone. This would require that click production be greater at the surface or when oriented upward than at depth or oriented towards the seafloor. Second, noise levels and interference the surface would need to be lower than those at the bottom. We do not believe these hypotheses are likely. Thus, while acknowledging the considerable limitations of these data, we believe that under similar environmental conditions, the detection range for hydrophones mounted at the surface will likely be smaller than bottom mounted hydrophones in nearly all instances.

Acknowledgements

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