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BATHYMETRIC ANALYSIS USING MULTIFREQUENCY MULTIBEAM ECHOSOUNDER

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Abstract. Making a nautical chart for safe navigation is a bathymetric survey's primary goal. Multifrequency MBES have been developed over the last few decades, and their introduction has dramatically improved the efficiency, accuracy, and spatial resolution of coastal and ocean mapping. The goal of multifrequency MBES is to increase the subsurface's detection resolution. To obtain an accurate picture of the seabed, the user can lessen the impact of this subsidence by running surveys in three different modes at once. With the help of multifrequency MBES, this study will analyze bathymetry in shallow coastal waters. The digital bathymetric model's (DBM) frequencies are remarkably close. The depth value of the study site ranges from –20 m to –70 m with reference to lowest water surface (LWS) based on the produced DBM. Generally, the difference between 100 kHz, 200 kHz, and 400 kHz is as small as 0–30 cm, and a small part is 30–60 cm. The volume between frequencies for an area of 1 ha is between 90 m^3 to 440 m^3. If the thickness of the dredged sediment is 1 m, then the difference in volume between frequencies is less than 5%. The bathymetry difference between 100 kHz and 400 kHz frequencies to –10 cm is dominated by the region of 0 cm. Dredging volume inter frequency ranges from 0.042 m^3/m^2 to 0.068 m^3/m^2.

Keywords: nautical chart, digital batymetric model, multifrequency MBES, dredging volume.

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1. Introduction

Hydrography's primary objective is to measure water depth at sea and on land (rivers, reservoirs, lakes). According to (International Hydrographic Organization, 2005), a hydrographer must possess a technical understanding of media, underwater acoustics, depth measuring tools, and procedures to adhere to worldwide and nationally established standards. A lead line and sounding pole are mechanical equipment that can measure depth. Electromagnetic waves, lidar, and remote sensing techniques can be used to measure the water depth. Acoustic equipments can also be utilized, including single-beam echosounder (SBES) and multibeam echo sounder (MBES). Since it may penetrate up to thousands of meters, the acoustic approach is the most popular. At the same time, there are depth-related restrictions with the mechanical, light detection and ranging (LiDAR), and remote sensing approaches.

With SBES and MBES, acoustic technology for gauging water depth begins to take shape. The effectiveness, accuracy, and spatial resolution of coastal and ocean mapping have significantly improved over the last 20 years with the introduction of MBES (Hell, 2011). The water column and seafloor are frequently observed and mapped using MBES, another acoustic method (Lecours et al., 2015; Lurton & Lamarche, 2015; Cui et al., 2021). Applications for bathymetric surveys can be found not only in seawater but also in lakes, dams, and rivers (Huizinga, 2016; Ierodiaconou et al., 2018). Making a nautical chart for use in navigational safety is the main goal of an MBES survey (Amirebrahimi et al., 2019; Brown et al., 2019). Bathymetric data from MBES is used by some researchers and communities to meet their objectives, including those related to planning (Menandro & Bastos, 2020), modeling (Gula et al., 2015), tourism (Šiljeg et al., 2022), drawing maritime boundaries in accordance with national and international maritime legislation (Blondel, 2012) and marine resources management (Lamarche & Lurton, 2018; Lurton & Lamarche, 2015).

The development of MBES has led to the performance of ultra-high resolution (cm) underwater seafloor mapping (Ierodiaconou et al., 2018) and remote sensing of the terrestrial environment (Huizinga & Heimann, 2018) at the exact same spatial resolution. MBES can also be utilized to find subsurface objects. Depending on the type of soil and the grazing angle, Fonseca et al. (2002) predicted that the subsurface would only be accessible to MBES in 95 kHz of frequency in the upper few decimeters to possibly 1 m. MBES single frequency (95 kHz) was utilized by Fonseca et al. (2002) and no other frequencies were examined. In a different investigation, Feldens et al. (2018) found that the penetration depth for 600 kHz for sandy sediments is just 1 cm, but 200 kHz may penetrate 8 cm into the subsurface. Feldens et al. (2018) asserted that the research only slightly discussed subsurface depth penetration and only discussed sand-based materials. Other sediments, including mud, clay, and rocks, have not been covered in this study. In addition, rather than on a ping-by-ping basis, Feldens et al. (2018) utilized MBES multifrequency.

Using multifrequency MBES, Gaida et al. (2020) discovered that in muddy places, the bathymetric difference between the lowest (90 kHz) and highest (450 kHz) frequencies might reach a value of up to 60 cm. The bathymetric discrepancies between 700 kHz and 170 kHz, which can be up to 20 cm, were shown by Menandro et al. (2022) to be consistent with the expected responses of substrate frequency and the kind of sea bottom in the research area. Utilized MBES on a multifrequency ping-by-ping basis in accordance with Gaida et al. (2020), with a single survey directly obtaining data at the appropriate frequency. To reduce survey errors, our survey is quicker and generates data concurrently. Yet, each frequency's data density is 1/the total number of frequencies. Only the highest and lowest frequencies 450 kHz to 90 kHz for Gaida et al. (2020) and 700 kHz to 170 kHz for Menandro et al. (2022) – are covered in both studies of subsurface penetration.

Since 1965, the seafloor has been mapped using single-frequency data obtained with an MBES. In the past seven years, multifrequency MBES has evolved as the most recent generation of MBES. To provide multifrequency data with a single survey platform pass, multifrequency MBES allows the frequency to be changed on a ping-by-ping basis. Multifrequency bathymetry is designed for higher subsurface detection resolution. Layers of suspended sediment provide noise that makes it difficult to resolve the subsurface precisely and accurately (R2Sonic, 2019). The user can lessen the impact of this subsidence to obtain an accurate picture of the seabed by running surveys at various high frequencies simultaneously (for instance, 100 kHz, 200 kHz, and 300 kHz).

Currently, hydrography surveyors can use multifrequency MBES to obtain depth data with several frequencies at once in one survey. However, the surveyors' question which frequency depth will be used to create navigation charts and other applications. Therefore, to answer the question, this study aims to analyze the differences in bathymetric results from different frequencies with multifrequency MBES.

2. Materials and methods

2.1. Research area

The data set was gathered in Patricia Bay, British Columbia, a location that has already undergone extensive seafloor mapping and acoustic characterization research (Biffard, 2011). The multispectral study was carried out at a location in the middle of the bay (Figure 1). It is well known that Patricia Bay's general vicinity has a diverse bottom with a variety of depths, seabed slopes, and seabed kinds. From northeast to southwest, the depth of the site rose, and halfway down the survey area, two shoals extended into the site from either side. Previous tests of acoustic seabed classification techniques at the site (Biffard, 2011) produced findings that were compared to the VSC classification from this study.

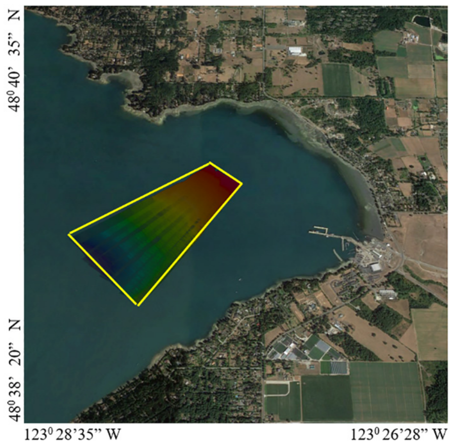

Figure 1. Research are using MBES in Patricia Bay, North Saanich, British Columbia, Canada

2.2. Bathymetric multifrequency MBES acquisition

A multifrequency MBES collection can offer highly detailed bathymetric data on the seafloor. Using an R2Sonic 2026 MBES with the sonar head deployed through a moon pool in the side-mounted survey vessel, this investigation collected bathymetry. The MBES system gathers data in a series of five pings at operating frequencies of 100, 200, and 300 kHz in equiangular mode. The user can adjust the system settings, including transmit power, gain, and pulse length, or they can be specified in automatic acquisition modes. The R2Sonic 2026 MBES's technical specs are displayed in Table 1, along with a few acquisition-related metrics. To process the raw data further, separate software is used to extract it from the .gsf files (Eiva Navi Scan). For measuring the ship's attitude (pitch, roll, and yaw), the inertial motion unit (IMU) sensor and differential GNSS are used in this system. It is additionally outfitted with sound velocity profiler measurements at the start, middle, and conclusion of the survey as well as tidal observations throughout the survey to acquire a correction for the underwater sound wave speed.

Table 1. R2Sonic 2026 multifrequency MBES technical specification (R2Sonic, 2019)

Frequency	170–450 kHz. Optional 90 kHz and 100 kHz
Number of soundings	Up to 1024 soundings per ping
Beam width (Ω_{tx} and Ω_{rx})	0.45°×0.45° at 450 kHz 1°×1° at 200 kHz 2°×2° at 90 kHz & 100 kHz (optional)
Selectable Swath sector	10° to 160° User selectable in real-time
Nominal pulse length τ_n	15 µs–2 ms
Pulse type	Shape CW
Sounding pattern	Equiangular Equidistant single / double / quad modes Ultra High Density (UHD)
Ping rate	up to 60 Hz
Bandwidth	up to 60 kHz
Sounding Depth	up to 800 m+

Bathymetry datasets were processed to generate a bathymetric surface for each of the line survey areas. Bathymetry data were cleaned for erroneous soundings. Furthermore, the data is separated based on frequencies, namely 100, 200 and 400 kHz. Bathymetric surfaces were generated at 1 m resolution for visual inspection, and bathymetric sounding data were subsequently exported for each area as ACSII (x, y, z) files for subsequent analysis.

3. Result and discussion

3.1. Digital Bathymetric Model (DBM)

The ship's attitude was corrected using raw data from the MBES R2Sonic 2026 bathymetry by computing the test patch values for each rotation against the x-axis (pitch), y-axis (roll), and z-axis (yaw). The data were then processed to remove noise from reflections from features like fish, seaweed, and other non-seabed items. depth data is corrected using tidal observation data to the lowest water surface (LWS), the vertical datum. To create a digital bathymetric model with a 1 m of spatial resolution, the depth data is gridded using Kriging interpolation technique, as shown in Figure 2.

The seabed in the survey area is depicted at each frequency in Figure 2, the appearance at 100 kHz, 200 kHz, and 400 kHz is nearly identical. This identical DBM is due to the survey being carried out simultaneously (once a survey) with multifrequency MBES on a ping-by-ping basis. Thus, the error between a ping with the next ping or between a frequency with the following frequency has a uniform error. The survey region has a depth range of –20 m LWS to –70 m LWS. The coastal side section in the northeast part is shallow, less than –30 m LWS (orange to red color). The more to the middle of the area sea survey, the deeper the depth. The southwestern part of the survey area has a depth of –60 m to –70 meters (light blue to dark blue).

3.2. Depth difference inter frequency

Although the seabed appearance is similar, it will look different if the image is cross-sectional. Figure 3a shows a cross-section sketch from northwest to southeast (cyan) and southwest to northeast (purple). Figure 3b describes that Profile A generally shows that sea depths between 100, 200, and 400 kHz frequencies have almost the same depth. However, in some segments (distance 70–130 m), there is a reasonably decent depth difference, approximately 0.5 m. In addition, the frequency of 400 kHz is shallower than the depth of 200 kHz and 100 kHz. The 400 kHz frequency is higher than the 100 kHz and 200 kHz frequencies, so the penetration of the 400 kHz frequency is minor compared to the 100 kHz and 200 kHz frequencies. Figure 3c shows Profile B, which indicates the profiles between frequencies. It could be that this suggests that seafloor features along profile B are hard layers (rocks or gravels), so frequencies of 100 and 200 kHz do not reach penetration into the bottom layers of the seabed. It needs to be checked with its backscatter intensity value.

Table 2 shows the difference in depth between frequencies, where the smallest difference is the difference in depth between 100 kHz and 400 kHz which is –0.656 m. The maximum difference between a depth of 100 kHz and 200 kHz is 0.001 m. The average difference between depths ranges from –0.019 to –0.092 m.

Table 2. Measured depth difference between used frequencies in profile A and B

Depth difference	Minimum (m)	Maximum (m)	Average (m)
$d_{100\ kHz}–d_{200\ kHz}$	–0.573	0.001	–0.019
$d_{100\ kHz}–d_{400\ kHz}$	–0.656	–0.012	–0.034
$d_{200\ kHz}–d_{400\ kHz}$	–0.488	–0.051	–0.092

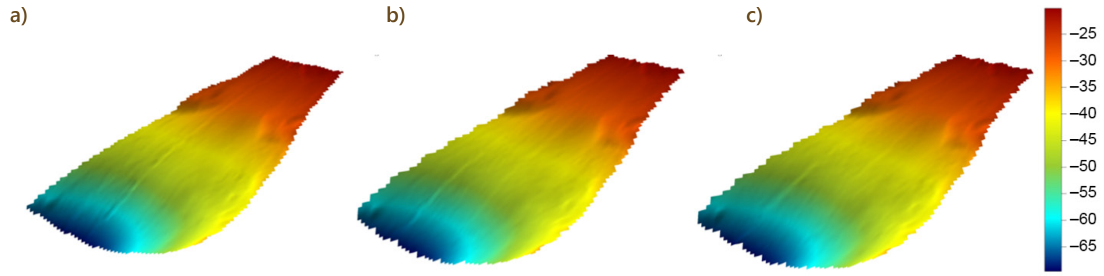

Figure 2. Digital bathymetric model of area survey: a – 100 kHz; b – 200 kHz; c – 400 kHz

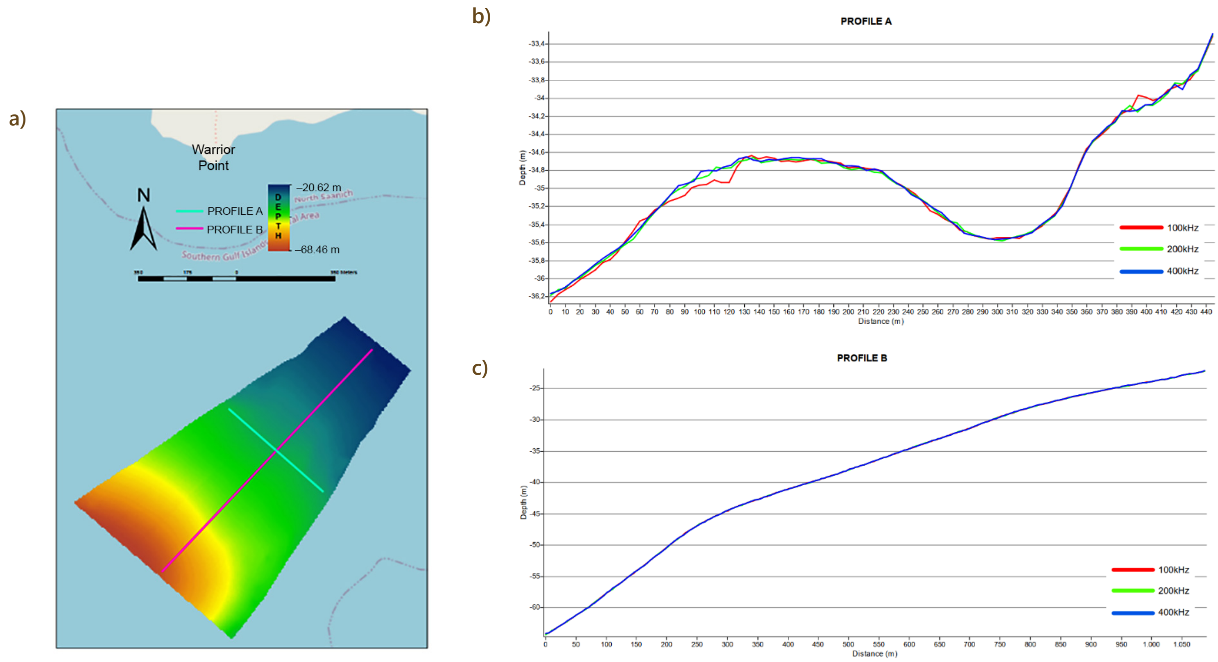

Figure 3. a – Cross section's line over depth; b – Northwest to Southeast; c – Southwest to Northeast

Figure 4 illustrates the difference in depth between frequencies. The depth difference between frequencies of 100–200 kHz and 100–400 kHz is dominated by differences of 0–0.1 m and 0.1–0.2 m, respectively. While the difference between 200–400 kHz ranges from 0–0.3 m. A small part of the area (green – light blue and dark blue) whose depth difference is more than 0.3 m to less than 0.7 m.

3.3. Volume analysis

Furthermore, the volume is used to calculate the depth difference between frequencies. Cut and fill volumes describe the quantity of fill or excavation material required for dredging projects. This study calculated the influence of depth difference using triangular irregular networks or digital terrain models to compute the cut and fill volumes. This calculation aims to determine how much depth variation across frequencies affects volume while using multifrequency MBES. The difference in depth volume per area between frequencies of 0.009 m^3/m^2 and 0.044 m^3/m^2 is displayed in the table. That implies that there is a discrepancy in volume of roughly 90 m^3 to 440 m^3 at each 1 ha surveyed area. It indicates that the variation in dredging volume is merely 0.9% to 4.44%. Suppose dredging is done in a 1 ha area at a depth of 1 m. The percentage of the difference between frequencies decreases with increasing silt thickness that needs to be dredged. This result shows no appreciable variations in volume computations between frequencies.

Table 3. Volume difference between frequencies

Depth difference	Area (m^2)	Volume (m^3)	Volume / area (m^3/m^2)
$d_{100\ kHz}$–$d_{200\ kHz}$	1325952.022	12591.343	0.009
$d_{100\ kHz}$–$d_{400\ kHz}$	1316961.369	21670.336	0.016
$d_{200\ kHz}$–$d_{400\ kHz}$	1373314.343	60119.185	0.044

4. Conclusions

The depths range from –20 m to –70 m LWS in the MBES multifrequency 3D bathymetry model for each frequency (100 kHz, 200 kHz, and 400 kHz). Between 0 and 30 cm dominates all depth differences inter-frequencies. A small part of the area shows a depth difference between 30 to 60 m. An inter-frequency dredging volume differential range from 0.009 m^3/m^2 to 0.044 m^3/m^2. With a dredge

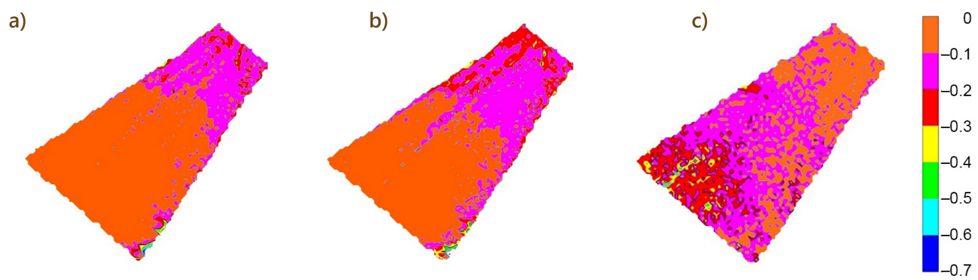

Figure 4. Depth difference inter frequencies: a – 100–200 kHz; b – 100–400 kHz; c – 200–400 kHz

thickness of 1 m and an area of 1 ha less than 5%, this figure is insignificant compared to the entire dredging volume.

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