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RESEARCH ARTICLE

**An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

BATHYMETRIC ANALYSIS OF LYSTAD BAY, HORSESHOE ISLAND BY USING HIGH RESOLUTION MULTIBEAM ECHOSOUNDER DATA*

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ABSTRACT

In this study the compatibility between high resolution multibeam echosounder data of Lystad Bay, Horseshoe Island obtained during Turkish Antarctic Expedition-III and the soundings of British Admiralty (BA) 2974&3213 nautical charts produced by United Kingdom Hydrographic Office (UKHO) was investigated. The bay was charted in 1960, first, by Lieut.C.J.C. Wynne-Edwards (Royal Navy)'s survey data and no chart has been produced with any new measurements since then. BA charts were created by means of single beam echosounder data. The comparison of the newly gathered data in the surveyed area (6.9km^2) which covers half of the Lystad Bay indicate that soundings on the nautical charts of BA2974 & BA3213 are shallower and coastlines are not compatible. Additionally, the data from February 2019 depicts depths as varying between 2.8-94.6 meters. Dense multibeam echosounder data made 3D analyzes achievable, which shows that the sea bottom topography has not only trenches but also shoals that should be considered in order to navigate safely in the bay. Moreover, modern satellite-based positioning systems provide more accuracy than terrestrial positioning systems. The sound velocity is measured as 1446.5 and 1447.5 m/s at the surface and decreasing with increasing depth.

Keywords: *Horseshoe Island, Lystad Bay, Multibeam Echosounder Data, Bathymetry.*

YÜKSEK ÇÖZÜNÜRLÜKLÜ ÇOK BİMLİ İSKANDİL VERİLERİ İLE HORSESHOE ADASI, LYSTAD KÖRFEZİ'NİN BATİMETRİK ANALİZİ

ÖZ

Bu çalışmada Üçüncü Ulusal Antarktika Bilim Seferi'nde Horseshoe Adası, Lystad Körfezi'nde toplanan çok bimli iskandil verileri ile Birleşik Krallık Hidrografi Ofisi tarafından üretilen BA2974 & BA3213 numaralı seyir haritalarındaki derinlik değerleri arasındaki uyumluluk araştırılmıştır. Söz konusu körfez ilk kez 1957 yılında Yüzbaşı Wynne-Edwards (Kraliyet Donanması) tarafından toplanan verilerle 1960 yılında haritalandırılmıştır ve bu zamandan beri yeni ölçümlerle hiçbir harita üretilmemiştir. Söz konusu İngiliz haritaları tek bimli iskandil verisi kullanılarak oluşturulmuştur. Lystad Körfezi'nde mesahası yapılan ve yaklaşık yarısını kapsayan sahada (6.9km2) toplanan batimetrik verilerden elde edilen sonuçlar BA2974 & BA3213 numaralı seyir haritalarındaki iskandil değerlerinin Şubat 2019'daki ölçümlerden daha sığ değerlere sahip olduğunu ve sahil hatlarının uyumlu olmadığını göstermektedir. İlaveten Şubat 2019 verileri 2.8-94.6m arasında değişken derinlikler göstermektedir. Yoğun çok bimli iskandil verileri körfezde güvenli seyir icra etmek için dikkate alınması gereken hem çukurları hemde sığlıkları olan deniz tabanı topografyasını gösteren 3 boyutlu analizlerin yapılmasını mümkün kılmıştır. Ayrıca modern uydu tabanlı konumlandırma sistemleri kara tabanlı konumlandırma sistemlerinden daha fazla doğruluk sağlamaktadır. Ses hızı yüzeyde 1446.5 ve 1447.5m/s olarak ölçülmüştür ve artan derinlikle birlikte azalmaktadır.

Anahtar Kelimeler: *Horseshoe Adası, Lystad Körfezi, Çok Bimli İskandil Verisi, Batimetri.*

1. INTRODUCTION

A bathymetric measurement is a complex process since sailors/mariners always demand reliable value on nautical charts. An accurate map of the sea floor is not only vital to the safety of navigation in nautical chart production but also critical for other purposes such as ocean circulation models (i.e. HYCOM, MOHID, ROMS, NEMO, POM) used in physical, chemical, biological oceanography. Seafloor topography has a crucial role in understanding climate change effects since they can deliver significant information about sea-level rise, potential changes in shoreline, sediment transport, benthic habitat mapping and distribution of clay minerals on the surface sediments (Kenny et al., 2003; Bart et al., 2016; Jung et al., 2021). Also, depth information is of great importance for understanding ocean circulation dynamics, patterns and Earth’s structure. The previously made studies in the Antarctic region validate the above-mentioned cases.

The understanding of the Antarctic ecosystem and ocean circulation could be improved with more accurate and high-resolution bathymetric data. Especially the western part of the Antarctic Peninsula, which is ice-free, gets people’s attention from all around the world since many bases in Antarctica (%30) are situated in this specific region. Due to its advantages (being close to mainland, being ice-free etc.) scientists focus more on the South Shetlands Islands for their research. However, studies in the southern part of the Antarctic Peninsula are rare as opposed to the South Shetlands Islands and especially bathymetric data are still sparse.

Accurate, reliable and up-to-date depth information is imperative to navigate in the bay, especially along shipping routes for carrying camping and scientific equipments in Antarctica where limited depth information is available. Strong winds prevail outside the bay and there is no pier/port for vessels to take shelter. High resolution bathymetric data are needed to navigate safely and as closely as possible to the Turkish Scientific Research Camp so that wind effect can be minimized. Another necessity is to ensure the right place for anchoring.

Hydrographers and oceanographers have used different methods and tools to collect and process data during survey. In the past, depth was measured by placing weight on the rope. After that echo sounding systems have been used for measuring depths by transmitting acoustics pulses in seafloor mapping since the beginning of 20^{th} century. A variety of techniques including visual, mechanical, acoustic methods can be used to obtain bathymetric data however most common tools and methods known today are quantitative ones such as single beam and multi beam echosounders.

In general, single beam echosounder which makes a single depth measurement has been used until 1960s (L-3 Communications SeaBeam Instruments, 2000). It is most basic echo sounding device and has some limitations that make it not appropriate. It falls short of producing depth measurements for well-defined locations and conducting a survey in a reasonable time (not a time-sufficient tool). That device cannot provide detailed sea bottom mapping and may miss valuable depth information such as seamounts, wrecks and covers a limited area with low spatial resolution data. A single beam measures the range at a point below the ship and could give better results for flat bottom however for irregular sea floor it cannot produce an accurate detailed depth measurement. On the other hand a new technique uses multiple depth sounding beams allow surveyors to produce higher spatial resolution with less endeavors (Parnum et al., 2009). Multibeam echo sounders that have their transducers mounted to the hull of the ship has become available to scientific community for about four decades and can map larger areas with multiple beams and swath width (Clarke, 2018). Multibeam echosounders send many beams and have the ability to measure different locations simultaneously. The received signal is a complicated pulse since it is strongly influenced by shape of bottom and sediment type. For bathymetry, unique characteristics and superior capabilities of multibeam echosounder make it more common to use for depicting ocean bottom mapping (Brissette and Clarke, 2015; Zhao, 2015).

South Shetland Islands located in Antarctic Peninsula (northwestern part of Antarctica) is the region where a large percentage of bases are located due to its ideal conditions like mentioned before. Horseshoe Island in which Turkish Scientific Research Camp established is close to South Shetland Islands as displayed in Figure 1. The closest base to Turkish Scientific Research Camp is located 46km western side of the Rothera Base (belongs to UK) on the Adelaide Island (Figure 2) in the Marguerite Bay. The detailed information regarding the boundaries and co-ordinates of Lystad Bay are presented in Table 1.

The existing British Admiralty (BA) charts, BA2974 and BA3213, were produced by means of single-beam echosounder data gathered in 1957, and are pretty old. They house low resolution data with the scales of 1:150000 and 1:50000, respectively. BA3213 was produced in 1960 by using 1957's survey data. In 2012, BA2974 covering the area of Marguerite Bay was published and updated however survey data of 1957 was used for the region of Lystad Bay. Despite the high attention towards the region, only those charts shown in Figure 3 are at sailors's service. Apart from the surveys made for the production of the before said charts, unfortunately, no studies or surveys have been carried out for hydrographic purposes, until 2019.

The Horseshoe Island where Turkish Scientific Research Camp is established covers an area of 60km2, has one bay and two coves, most part of its coastline is ice-free, just 23 km (36%) of it being ice-covered (Yıldırım, 2019). The archipelago of Marguerite Bay, where the Lystad Bay is located was covered by sheet of ice at ca. 20ka ago (Bentley et al., 2011). However, the ice-sheet was removed with the effects of climatic events by ca. 9.5ka (Çiner et al., 2019). The geomorphology of the Horseshoe Island shows that it is still under the influence of glaciers (Yıldırım, 2019). That indicates coastlines and surroundings of the island continue interacting with ice, so topography of it will continue changing over a long-term time scale. Glaciers can transport material beneath them and carry rocks far away from their original locations (Spellman, 2021). Moreover they can reshape the seafloor with respect to their weight over hundreds or thousands of years (Spellman, 2021). So it could be stated that ice reshapes the bathymetry of the region in the long term and gives the idea to the geologists about the historical change of geological formation.

The aim of the study is not only to obtain bathymetry of the area but also to compare with BA charts. The scope of the area is the Turkish Scientific Research Camp in Antarctica. That's why this study is crucial for the reach of achievement of future scientific research in Antarctica.

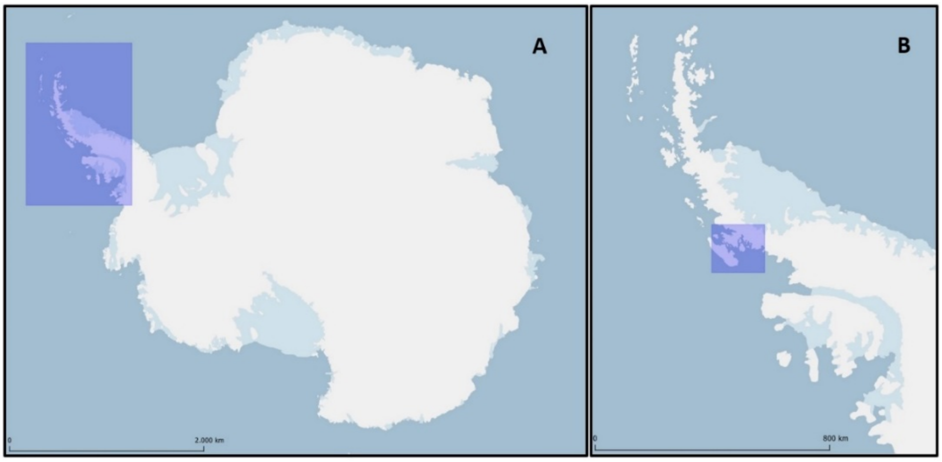

Figure 1. Location map of Antarctica (A) and Antarctic Peninsula (B).

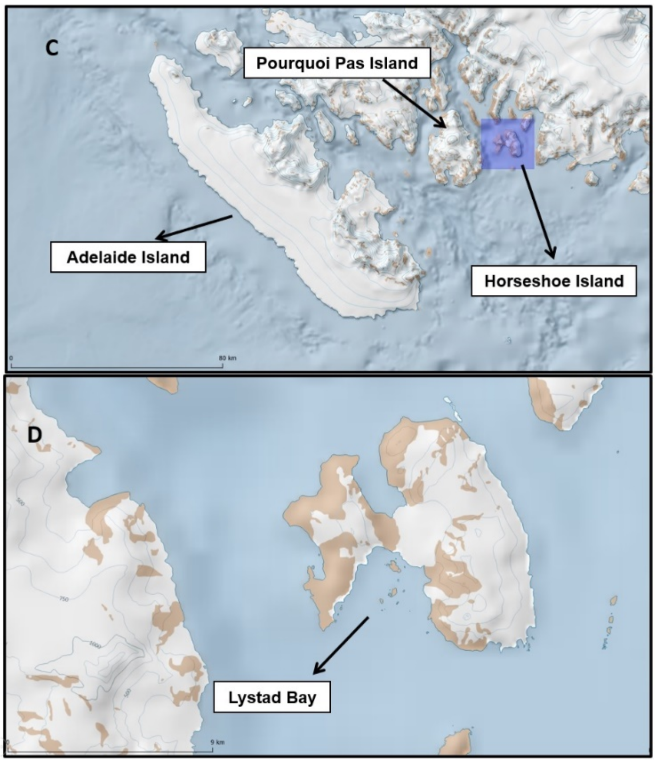

Figure 2. Surroundings of Horseshoe Island (C) and Lystad Bay (D).

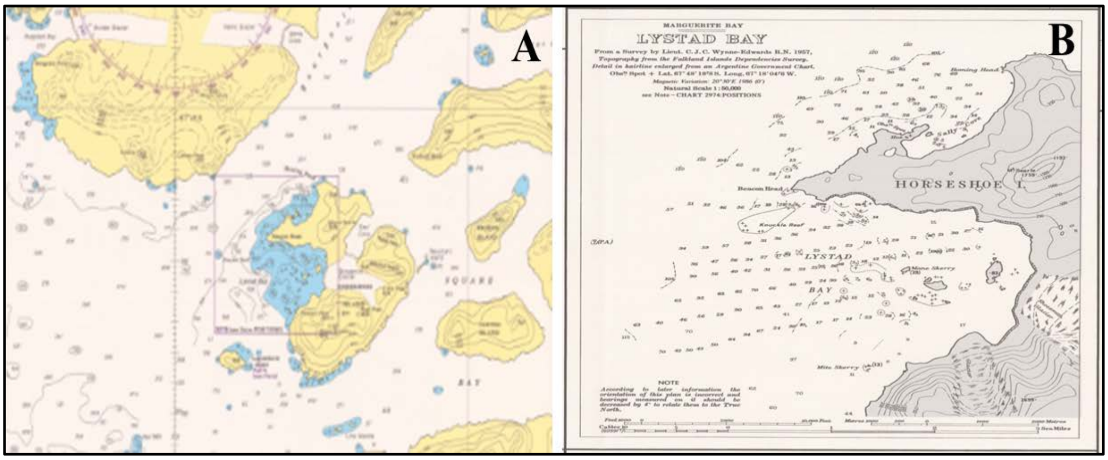

Figure 3. The charts of BA2974 (A) with scale of 1:150000 & BA3213 (B) with scale of 1:50000.

Table 1. Boundaries of Lystad Bay.

Corners	Latitude	Longitude
Northwestern	67°49’22.40’’ S	067°20’47.63’’ W
Northeastern	67°49’33.33’’ S	067°14’25.24’’ W
Southeastern	67°50’52.22’’ S	067°14’04.21’’ W
Southwestern	67°52’05.59’’ S	067°18’21.76’’ W

The remainder of this paper is organized as follows: Section 2 describes the data, equipments and methods, Section 3 presents the results and Section 4 concludes the study with a summary.

2. MATERIAL AND METHODS

Sound velocity in the environment during data collection period is of great importance for accurate hydrographic surveying and calculations (Alkan et al., 2006). Sound can travel in water more easily than air and has the ability to move great distances in water environment (L-3 Communications SeaBeam Instruments, 2000). Sound speed is a function of the parameters of salinity, temperature and pressure. In general, typical sound velocity of seawater under the nominal condition (0 °C, 35 psu) is 1500 m/s and calculated as shown below;

Sound Speed=Frequency x Wavelength

Low frequency sound is attenuated slowly while high frequency can travel impeded throughout the sea since attenuation of sound is based on the frequency (L-3 Communications SeaBeam Instruments, 2000). During depth measurement, the amount of energy reflected or scattered depends on the characteristics of the material and the angle of incidence. The name of the returning signal is “echo”.

Passive sonars that just listen and active sonars that both listen and produce sound waves are two basic types of sonars. With respect to definitions it is clear that active sonar principle is used for bathymetric measurements. The idea depends on the time delay between transmitted and received signals, where depth information is obtained by using time delay and velocity of echo. In other words echo time is the time of round trip. Speed of sound in water column is obtained from portable CTD equipment in this survey. After getting all those parameters range (depth) could be calculated as shown below;

Depth=1/2*Velocity*Echo Time

Tide is another parameter that should be taken into account. Soundings are reduced to chart datum which refers to lowest astronomical tide or mean sea level in order to include tide on the measurements. If there is not a tide gauge in the survey area, tide measurements should be specifically done or tide gauge can be installed. Fortunately, in the study region there is a permanently installed tide gauge in Rothera which used to obtain the depth values to be reduced to chart datum. Using the tide data of previously established tide stations is also advised by IHO M-13 document.

All those parameters are processed and used to create reliable bathymetric datasets. For data quality control and processing of bathymetric data CARIS HIPS & SIPS software is used. Interpolation technique (angle cube etc.) is not applied to data since interpolated points do not reveal realistic values.

Total vertical uncertainty is calculated with the formula shown below. In this formula, the parameter of "a" represents the rate of the uncertainty that does not change with depth, "b" is the rate of the uncertainty that varies with depth and "d" means the depth value (IHO S44). In accordance with these calculations, maximum errors of the depth measurements with increasing depth are displayed in Figure 4.

$$error = \pm\sqrt{\mathrm{a}^2 + (\mathrm{b} + \mathrm{d})^2}$$

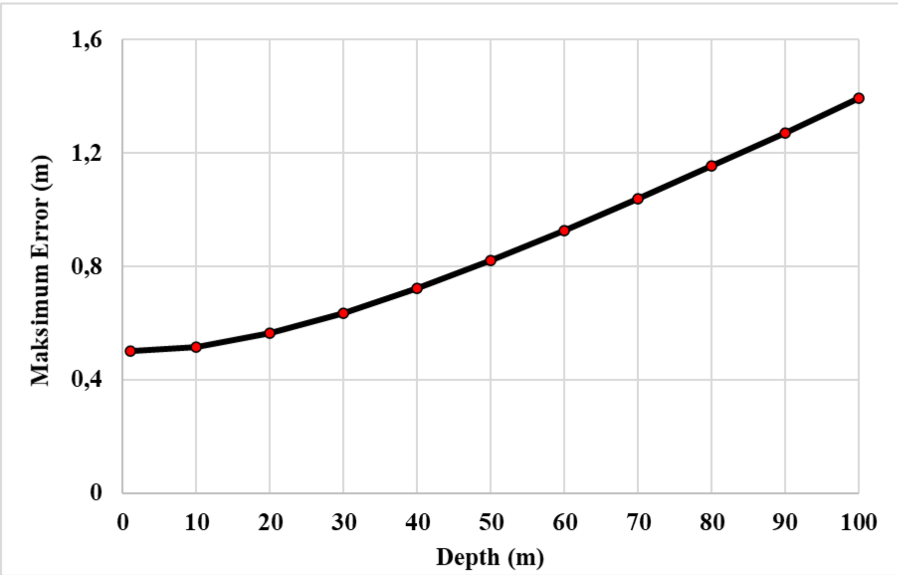

Figure 4. Graph of maximum errors for Order 1a.

High resolution bathymetric data gathered during the Turkish Antarctic Expedition-III in February 2019 and the survey area is located in the south-central part of the Antarctic Peninsula and focuses on Lystad Bay. During data process and collection period, International Hydrographic Organization (IHO) Standards-44 are applied to bathymetric data. Accuracy of data is “Order 1a” in accordance with minimum bathymetry standards for safety of navigation hydrographic surveys of IHO S-44 at 95% confidence. WGS 84 Datum and UTM 19S Projection are used for all co-ordinates and the resolution of the surveyed data is 1m.

Accurately mapping is the paramount for getting accurate solutions and analyses in evaluations. In this study bathymetric data that consist of three parameters named as *.xyz (latitude, longitude, sounding) are obtained by the R2SONIC 2022 multibeam echosounder (Figure 5) that uses acoustic waves. Details about the equipments and softwares utilized in this study are shown in Table 2. All those materials and data belong to Turkish Navy Office of Navigation, Hydrography and Oceanography. The instrument of R2SONIC 2022 has 256 beams and 400kHz (1*1 degree beam width). Main components of an echo sounder are transducer, transmitter, receiver and recorder. Survey speed was around 5kts. Coastline measured with TOPCON GR-3 GNSS (Global Navigation Satellite System) refers to the line where coast and water meet (IHO S32). Additionally, a free GIS package for research, education and operation in Antarctica which is called Quantarctica V3 is used too.

Table 2. Information about the equipments and softwares.

Purpose	Equipment
Hydrographic Surveying	R2SONIC 2022 400 Khz
Temperature, Salinity, Sound Speed	Valeport CTD
Coastline	TOPCON GR-3 GNSS
Data process / analysis	CARIS HIPS and SIPS
Tide	Rothera Station Tide Gauge (UK)

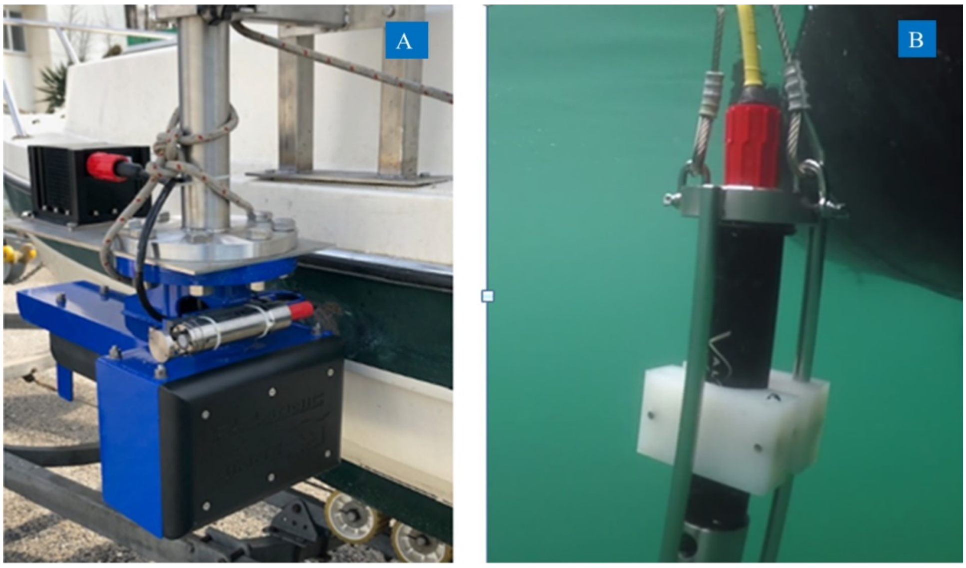

Figure 5. Equipment of R2SONIC 2022 400 Khz Multibeam Echosounder (A) and Valeport CTD (B).

3. RESULTS

Horseshoe Island, the third largest island in the Marguerite Bay, has the dimensions of approximately 9km by 10 km, covers an area of 64.29km^2 and its coastline is 53.75km long. The survey area is located in the Lystad Bay which is in the southern part of the Horseshoe Island and covers an area of 13.62 km^2 with some small islands. The numbers found in the study of Yıldırım (2019) are compatible with our calculations.

Lystad Bay of Horseshoe Island is first charted in 1960 by using Lieut. C.J.C. Wynne-Edwards's survey data and neither a new chart has been produced with new measurements nor a new survey has been carried out since 1957. For the updated version of BA2974, Lieut. C.J.C. Wynne-Edwards's data were used again in 2012. Since this survey conducted six decades ago when terrestrial methods were used, the data of it needs to be corrected and revised with respect to new satellite-based positioning systems. Terrestrial methods used in the past to minimize positioning errors with mechanical, optical, electronic means are sextant, triangulation/intersection, visual, range-azimuth (IHO M-13). Sextant positioning that performed by simultaneous measurement of two horizontal angles between three position-known objects is not considered accurate today. Recently the other technique called visual position method that used for structures of navigation aids is very little used (IHO M-13). Range-Azimuth Positioning, based on the generation of a position through the perpendicular intersection between lines of locations, once was a very common and most used method (IHO M-13).

Availability of Global Positioning System (GPS) positioning methods make it become the worldwide and take place of the all-previous techniques after 1990s (IHO M-13). GPS positioning devices used in this new study can provide better accuracy for positioning than terrestrial positioning methods with the advantages of satellites (IHO M-13).

CTD is used before gathering hydrographic data since sound speed is needed to apply the instrument of R2SONIC 2022. Sound speed is the final and crucial product which depends on salinity, temperature and pressure and calculated by those parameters. The locations of portable CTD measurements and sound velocity profile are presented in Figure 6. With respect to Figure 6, it could be said that sound velocity ranges from 1446.5 to 1447.5 m/s at the surface and decreases from surface to deeper parts. When sound speed values of this study are compared with Mediterranean Sea, annual horizontal distribution sound speed at 50m in Mediterranean Sea is clearly greater than Southern Ocean with values between 1506 and 1527 (Salon et al., 2003) due to its warmer waters. During the data process session, critical sound speed data are strictly applied to surveyed data since those regions have unique characteristics with low temperature and hence low sound velocity data. Sound travels faster with higher temperature which strongly influences the sound speed. In other words, sound propagates slower in cold water than warm water (Fofonoff and Millard, 1983).

As mentioned in material and methods, sea level measurements of Rothera Station are used since it was the closest station to the bay. According to Figure 7, mean sea level values of the dates of 20-24 February 2019 vary from about 0.48m to 1.97m. Tide values during the survey time subtracted from measured data in order to reduce soundings to chart datum.

In the Turkish Antarctic Expedition of 2019, the proportion of surveyed area (6.9 km^2) to the total area of the bay is approximately %50. For the surveyed area, Bathymetry of the bay has sharp changes and the depth from the coastline to Marguerite Bay increases from 2.8 m to 94.6m as depicted in Figure 8.

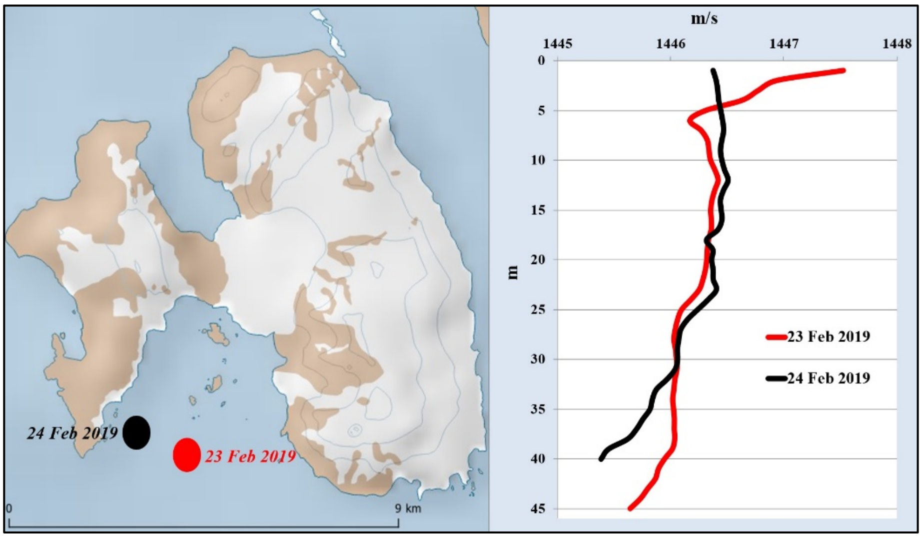

Figure 6. Location of CTD measurements and sound velocity profile of Lystad Bay.

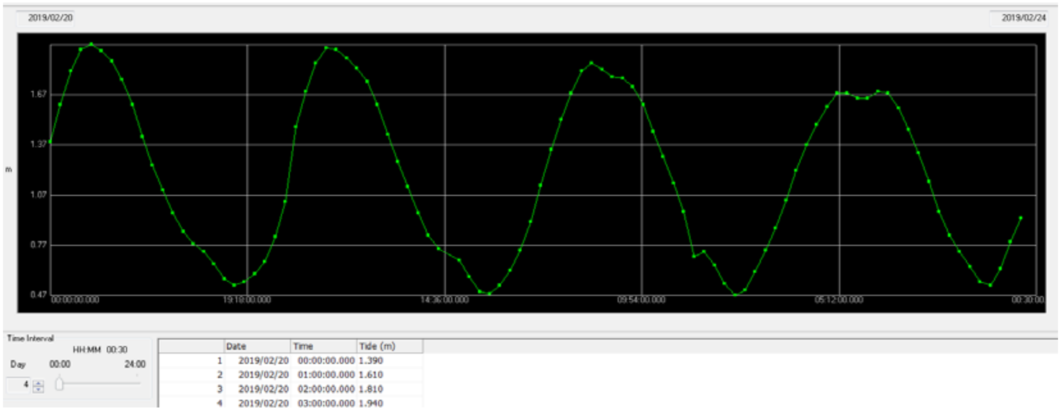

Figure 7. Sea level measurements of Rothera Station (20-24 February 2019).

Modern multi-beam echo sounders provide very detailed full seafloor coverage. By the help of that high resolution bathymetric data, 3D picture of the sea floor can be visualized with all features such as seamounts, trenches. That is why 3D Picture of the surveyed area is created. Depth is changeable with trenches and shallow areas in the bay. The deepest point is 94.6m (67º 49’ 45.22’’S, 067º 19’ 38.15’’W) and the shallowest point is 2.8m (67º 49’ 53.77’’S, 67º 15’ 26.92’’W) as shown in Figure 8. The unnamed trench/deep in the bay is dedicated to prominent Turkish cartographer Piri Reis. On the other hand the resolution and accuracy of old data were not good enough to draw a 3D picture of seafloor.

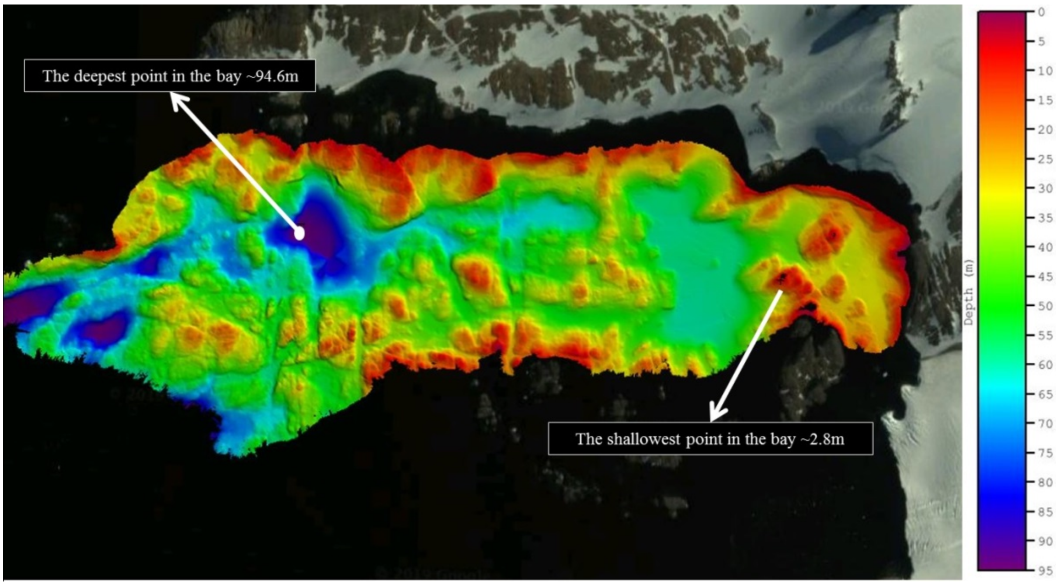

Figure 8. 2D Picture of the surveyed area.

The new survey data gives the advantage to see all features of bottom topography and provides detailed examination. For instance, two selected shallow areas examined whether those locations are obstacle to navigational safety. These analyses represent that the point located in the central part does not need to be considered as a problem for ships that have draft lower than 8m however the point closes to the camp is shallow (2.8m) and has risks for safety of mariners (Figure 10).

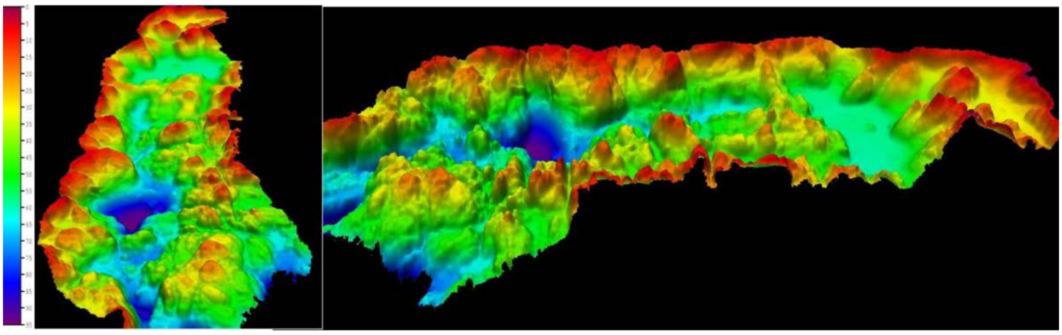

Figure 9. 3D Picture of the surveyed area.

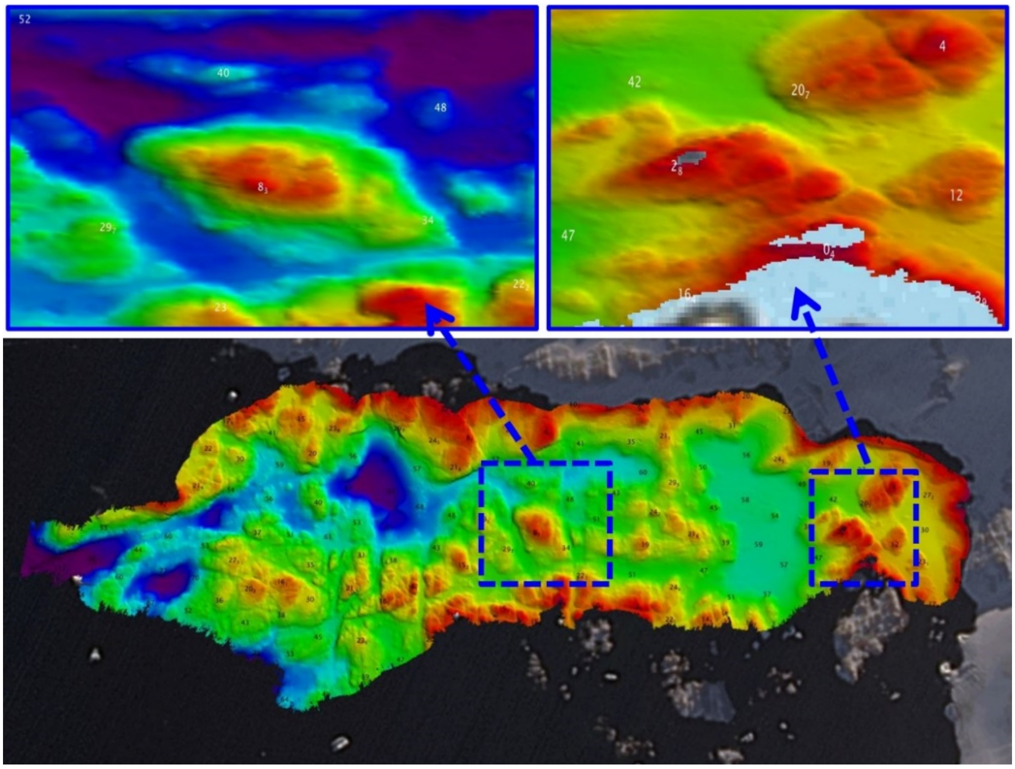

Figure 10. Detailed analyses of critical positions.

In general, the analyses of the comparisons discussed herein indicated highly differences of coastline and depth for new and old survey. The point-to-point comparisons with visual inspection confirm that there is a clear difference between depth information (Figure 11-12). Figure 11-12 present that soundings in BA2974 and BA3213 are shallower than the new survey data and the positions of the coastline data are shifted 70m in east and west direction due to differences in sensitivity of past & recent technologies.

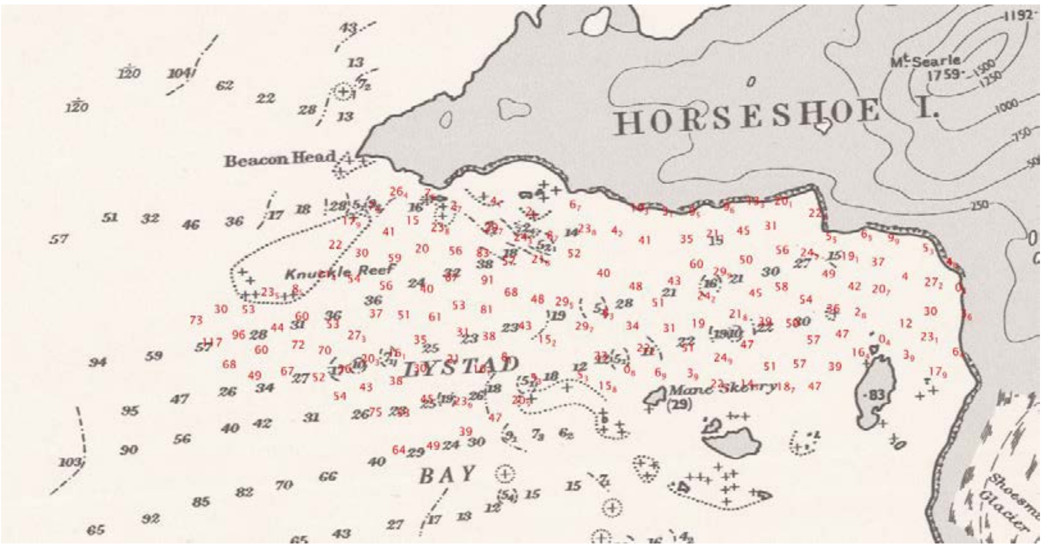

Figure 11. Comparison of BA3213 (black coloured) and survey data of February 2019 (red coloured).

Coastline of new data is not following the same pattern with BA charts. The differences between soundings and coastline of BA charts with new survey are due to modern techniques and technology used in 2019 not the glaciers since influences of glaciers over sea floor topography take more than hundreds or thousands of years. Additionally, to see the variations and glaciers effect not only long time period but also high-resolution data are needed. In the light of that information old data do not meet the requirements to understand the glaciers impact on sea floor.

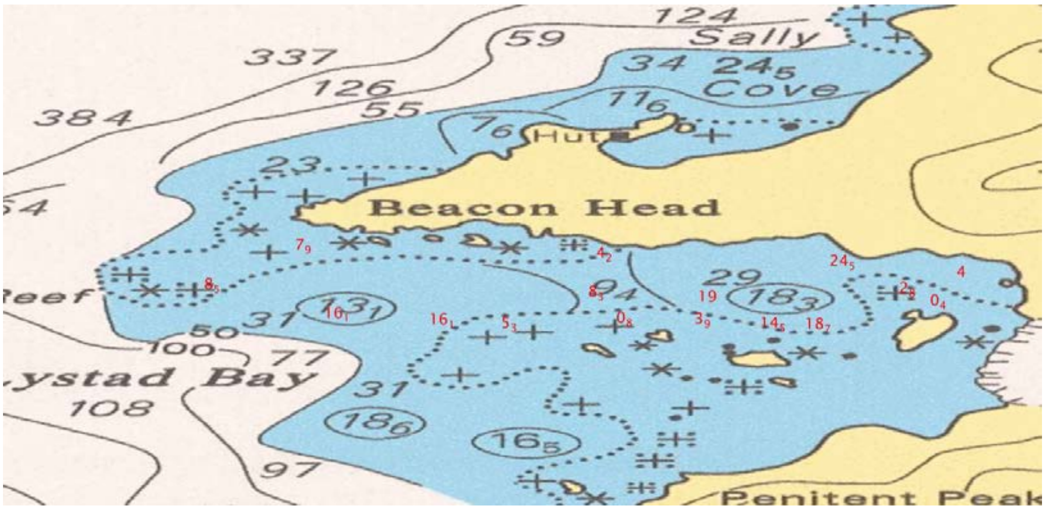

Figure 12. Comparison of BA2974 (black coloured) and survey data of February 2019 (red coloured).

4. CONCLUSION AND DISCUSSION

The focus of this study lies on Lystad Bay where data is most needed for following Turkish Antarctic Expeditions. In this study the values obtained with new survey conducted in 2019 and comparisons of BA charts with high resolution data were presented. The results give useful preliminary information on bathymetric characteristics in Lystad Bay. The collected data shows variation of depth information between 2.8m to 94.6m and the overall bathymetric data of Lystad Bay reveals differences between new & old survey data. It is discovered that multibeam echosounder data are significantly deeper than single beam data of BA charts. The differences observed for the region are due to techniques and technology not the glaciers since it takes more than hundreds or thousands of years to mention about the impact of glaciers.

Single-beam echo sounders just provides one line of depth information along the survey vessel route so missed features (trench, wreck etc.) could be found in port and starboard sides of the track. However multi-beam echo sounders can compute both port/starboard and fore/aft at the same time and provides seafloor coverage with more soundings than single-beam echo sounders. In this survey portable multibeam echosounder (R2SONIC 2022, 400 Khz) is used to gather depth information. Another advantage of this new study is that GNSS services are being used to derive positions. Satellite-based positioning equipments provide higher accuracy than land-based positioning systems. All new technology tools increase the accuracy of the data and give confidence to hydrographers during producing nautical charts.

Our data comparison shows that multibeam echosounder data have a great potential for Antarctica for following years. In order to support safety of navigation BA2974 and BA3213 charts should be updated with respect to new data gathered by Turkish Navy-Office of Navigation, Hydrography and Oceanography since no points in the charts are matching with new data.

Lastly the remaining unsurveyed part (%50) of the bay should be surveyed in the near future. The data gathered in old techniques should be replaced with new high-resolution data since low resolution data may miss all features. Sidescan sonar is another way for getting detailed data from the sea floor and it can display a mosaic map of topography.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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