ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

3D SEAFLOOR MODEL DETERMINATION AND CHANGE DETECTION WITH MULTITEMPORAL MULTI BEAM ECHO SOUNDER BATHYMETRY

M.Sc. THESIS

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Geomatics Engineering Programme

JANUARY 2017

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

FARKLI ZAMANLARDA ALINAN ÇOK BİMLİ İSKANDİL VERİLERİ İLE 3 BOYUTLU YÜZEY MODELİNİN OLUŞTURULMASI VE YÜZEY DEĞİŞİM ANALİZİ

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To my spouse and child,

FOREWORD

This thesis marks the finale of my Master of Science degree in The Department of Geomatics Engineering at the Istanbul Technical University (ITU), Istanbul, Turkey. The research in this study was executed as a contracted measurement project within 'The Northern Cyprus Water Supply Project'. The General Directorate of State Hydraulic Works is participated as client and my previous company Denar Ocean Engineering S.A. is participated as contractor company.

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November 2016

Eray ZİREK
Survey Engineer

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ABBREVIATIONS

TRNC	: Turkish Republic of Northern Cyprus
IHO	: International Hydrographic Organization
MBES	: Multi Beam Echo Sounder
SBES	: Single Beam Echo Sounder
SDB	: Satellite Derived Bathymetry
LiDAR	: Light Detection and Ranging
ALB	: Airborne Laser Scanning
GPS	: Global Positioning System
GNSS	: Global Navigation Satellite System
DGPS	: Differential Global Positioning System
THU	: Total Horizontal Uncertainty
TVU	: Total Vertical Uncertainty
IMU	: Inertial Measurement Unit
SONAR	: Sound Navigation and Ranging
AUV	: Autonomous Underwater Vehicle
SVS	: Sound Velocity Sensor
PPS	: Pulse-Per-Signal
MRU	: Motion Reference Unit
CTD	: Conductivity Temperature Depth
LINZ	: Land Information New Zealand
USACE	: United States Army Corps of Engineers
CHS	: Canadian Hydrographic Service
SHODB	: Turkish Naval Forces Office of Navigation, Hydrography and Oceanography

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SUMMARY

Topography is the term that indicates the study of various landforms that exist on or below the Earth and a detailed knowledge of topography is required to understand the most Earth processes. In the oceans, sea floor topography refers the geographic features of the sea floor including the configuration of a surface and the position of its natural and man-made features; and detailed nautical charts are fundamental for many sciences such as physical oceanography, biology and marine geology. Besides, it is significant for navigational requirement. This revealed the necessity of hydrographic measurements and measurement systems.

For this purpose, many techniques developed and used to create the map of the seafloor. From the first primitive technique which involved lowering a weighted line into the water to satellite derived altimetry many systems used for determination of seafloor. After the development of electronic and computer technology, the modern systems become more accurate and effective. An echo sounder system is one of the modern techniques that use the sound waves to determine the depth which is also called ‘sounding’. Echo sounders are classified with the capability of producing sounding in one time. Single beam echo sounder (SBES) system can produce single sounding in each measurement. Besides, multi beam echo sounder (MBES) system can produce hundreds of sounding in each measurement sets and provide 100% seafloor coverage.

The hydrographic offices, which use the Multi Beam Echo Sounder (MBES) system for the establishment of nautical charts, have their own set of accuracy standards for hydrographic surveys, which generally comply with the standards defined by the International Hydrographic Organization (IHO). MBES systems include multiple measurement systems such as sonar head, positioning system, motion sensor that

work in a synchronized manner. Therefore, the system components are installed and established to each other in 3D space of vessel. Before the measurements, the ‘Patch Test’ is required to eliminate the systematic errors due to instrumental synchronization and installation. In this test, signal delay test (latency), Y-axis rotation (roll), X-axis rotation (pitch), Z-axis rotation (yaw) errors are calculated. Besides, the effects of the sound velocity measurement through water column and the sea level changes need to be taken into consideration especially in the multi-temporal data analysis and 3D modeling.

In this thesis, the seafloor of the Anamur -TRNC Drinking Water Pipeline route in the ‘Northern Cyprus Water Project’ is selected as a study area. This project, a unique in the world, is an international water diversion project designed to supply water for drinking and irrigation from southern Turkey to Northern Cyprus via pipeline under Mediterranean Sea. The dredged channels for pipe laying in the Anamur and TRNC shores are considered in this study and two MBES surveys are conducted in different periods to determine the surface differences. Multi temporal multi beam echo sounder measurements are used in the change analysis and surface modeling and the efficiency of this system is outlined together with its limitations.

FARKLI ZAMANLARDA ALINAN ÇOK BİMLİ İSKANDİL VERİLERİ İLE 3 BOYUTLU YÜZEY MODELİNİN OLUŞTURULMASI VE YÜZEY DEĞİŞİM ANALİZİ

ÖZET

Topografya yeryüzü üzerinde ve altında bulunan çeşitli yer şekillerini detayları ile inceleyen çalışmaların tanımlanmasıdır. Yeryüzündeki hareketlerin anlaşılması için detaylı topografik bilgiye ihtiyaç vardır. Okyanuslarda deniz tabanının yapısı, taban yüzeyinin özellikleri ile doğal oluşumlar ve insan yapılarını içeren coğrafi nitelikler topoğrafyanın kapsamına girmektedir. Bu kapsamda detaylı deniz haritalarının hazırlanması, fiziksel oşinografi, biyoloji, deniz jeolojisi ve jeofiziği gibi bilimler açısından önem arz etmektedir. Bunun yanında seyir haritalarının oluşturulması, deniz ulaşımı açısından da kritik öneme sahiptir. Bu ise hidrografik ölçümlerin ve ölçüm sistemlerinin gerekliliğini vurgulamaktadır.

Deniz tabanının haritalanması için birçok teknik geliştirilmiştir. En ilkel tekniklerden birisi olan bir ipin ucuna bağlanmış ağırlığın suya daldırılması yoluyla yapılan el iskandili yönteminden, uydu tabanlı altimetrik sistemlere kadar birçok yöntem kullanılmıştır.

Elektronik ve bilgisayar teknolojilerinin gelişmesi ile birlikte, modern ölçüm sistemleri daha hassas ve etkin hale gelmiştir. Günümüzde deniz ölçümleri için etkin kullanılan optik ve sonar sistemler bulunmaktadır. Optik sistemler içerisinde teknolojisi hızla gelişen Lidar sistemleri yeşil lazer ışını kullanarak su içerisine gönderdiği sinyallerin saçılımlarını derinlik verisi olarak değerlendirir. Görünebilirliğin yüksek olduğu sığ sularda etkin çalışan bu sistem, derinlik arttıkça ve görünürlük azaldıkça hassasiyetini ve etkinliğini kaybeder. İskandil sistemi 'su yüksekliği' olarak adlandırılan derinlik verisini üretebilmek için ses dalgasını kullanan modern tekniklerden birdir. Ses dalgası ile ölçüm yapan sistemler basitçe sesin suda gidiş ve dönüş hızını hesaplayarak derinlik verisi elde ederler. İskandiller bir seferde ölçebildikleri derinlik verisi sayısına göre sınıflandırılmıştır. Tek bimli iskandil (TBİ) sistemi bir seferde aletin nadiri doğrultusunda tek bir derinlik verisi üretir.

Bunun yanında, çok bimli iskandil (ÇBİ), bir seferde yüzlerce derinlik ölçümü sağlayarak deniz tabanında %100 kaplama sağlamaktadır.

Deniz haritası üretimi için çok bimli iskandil sistemleri kullanan hidrografi kurumları/şirketler hidrografik ölçüm standartlarına uygun olarak ölçüm yapmalıdırlar. Bu standartlar genellikle Uluslararası Hidrografi Örgütü (IHO) standartları ile uyumludur. Bazı örgütler doğrudan bu standartları kullanırken, bazıları ise bu standartlardan daha sıkı olan standartlar geliştirilmiştir. Çok bimli iskandil sistemleri; iskandil, konumlandırma sistemi ve hareket sensörü gibi senkronize bir şekilde çalışması gereken birçok ölçüm aletini içermektedir. Bundan dolayı sistem elemanlarının iyi bir kurulum ile tekneye monteleri gerçekleştirilmeli ve ölçüm teknesinin 3B uzayı içerisinde birbiriyle olan ilişkileri tanımlanmalıdır. Ölçümler öncesinde 'patch testi' olarak adlandırılan kalibrasyon prosedürü, kurulum ve aletlerin senkronizasyonundan kaynaklanan hataların giderilmesi için gerekmektedir. Bu test kapsamında, sinyal gecikmesi testi (latency), Y ekseni dönüklüğü (roll), X ekseni dönüklüğü (pitch) ve Z ekseni dönüklüğü (yaw) hataları hesaplanmıştır. Bunlarla birlikte, özellikle zamansal veri analizi ve 3B yüzey modellemesi için su kolonu boyunca gerçekleştirilen ses hızı ölçümleri ve su seviyesi değişimleri göz önünde bulundurulmuştur.

Bu tezde göz önüne alınan çalışma bölgesi KKTC (Kuzey Kıbrıs Türk Cumhuriyeti) 'Su Temini Projesi' içerisinde yer alan, Anamur – KKTC ishale boru hattı güzergâhını kapsayan alandır. Bu proje, Türkiye'den Kuzey Kıbrıs Türk Cumhuriyeti'ne, Akdeniz'de deniz altından boru hatları ile içme ve sulama suyu temini amacı ile gerçekleştirilmiş olup, özellikleri bakımından dünyada benzeri bulunmayan uluslararası bir su iletim hattı projesidir. Proje 4 bölümden oluşmaktadır. Bu bölümlerden birincisi Anamur Alaköprü Barajı'ndan, Ören kasabasına kadar olan iletim hattı, ikincisi boru hatlarının kazı gemisi tarafından oluşturulmuş kanal içerisinde deniz ile buluştuğu bölüm, üçüncüsü projeyi bu boyutlarda yapılmış tek proje özelliğini kazandıran Akdeniz geçiş kısmı ve dördüncüsü ise KKTC kıyılarından Geçitköy barajına su taşınması kısmıdır. Akdeniz geçiş kısmını önemli yapan özelliği ise 500m uzunluğundaki yekpare boruların su seviyesinin 250m kadar altında askıda kalıp, çelik halatlar ile deniz tabanına monte edilmiş olmasıdır.

Proje kapsamında boru hatlarının 0 m yüksekliğinden, -30 m su derinliğine kadar olan bölümünde su borusu, proje kapsamında kazılmış olan kanal içerisine serilmiştir. Bu dünyanın en büyük kazı gemilerinden birisi ile tek seferde açılmış olup, borular yerleştirilene kadar açık bırakılmıştır. Bu tez çalışmasında kazı sonrası ve boruların döşenmesinden önce çok bimli iskandil yöntemi ile yapılan deniz ölçüm verileri ile değişim saptama analizi gerçekleştirilmiştir. Anamur ve KKTC taraflarında ikişer kez ayrı zamanlarda gerçekleştirilen ölçüm çalışmaları, ölçümlerin değerlendirmesi ve veri analizleri ile 3B modeller oluşturulmuş ve bu modeller kullanılarak yüzey değişim analizleri ve kullanılan sistemlerin etkinliği tüm ayrıntılarıyla belirtilmiştir.

1. INTRODUCTION

The World's oceans are covering almost 75% of total surface area. This fact alone indicates how important oceans and ocean geography for all life forms on the Earth. Same as the landside of the Earth, ocean floor contains slopes, geological contents, shelves, sub marine canyons etc. Hence, a detailed knowledge of sea floor topography is fundamental to the many sciences such as physical oceanography, biology and marine geology. Therefore, the seafloor measurements need to be carried on all activities which provide extended information of geological, geographical and geophysical features of the seafloor. Hence, it is necessary to constitute hydrographic activities which provide adequate information. [1] In brief, hydrography, as defined, is the science of determination of the sea floor topography by using proper and acceptable techniques. Many different measurement systems are being used to determine sea floor topography.

In general, there are two main systems used for this purpose. First one is the classical manual measurement system like a rope and a Secchi disc that can be used for very shallow water. This system is a rapid method to gather depth information. In some circumstances without vertical positioning, the lead line measurements would be used for depth information. Due to its inaccuracy for more than 5m water depth, this method is used favorably to check approximate depth value for more accurate systems as a supportive method. The second one is the modern measurement systems such as LIDAR (Light Detection and Ranging), radar altimeters and the acoustic systems, which are faster and more accurate.

The technique wherein the elevation or shallow water depth is calculated by the reflection time delay between the transmission of a pulse and its return signal is known as LIDAR and it is becoming increasingly popular for the depth measurements in recent years. With good water clarity, a LIDAR system can reach 50m water depth by using green laser beams. [2] The one other technology used to measure water depth is the estimation of bathymetric data by using satellite altimetry. Dense satellite altimetry measurements can be used in combination with sparse measurements of seafloor depth to generate a uniform resolution map of seafloor topography. The maps constituted from this method don't have sufficient accuracy and resolution to be used for navigational or underwater constructions. However, they are useful to gather brief information about the seafloor topography. Among the modern methods, the acoustic systems, both single-beam sounders and multi beam echo sounder systems, are the most preferable ones. Single beam and multi beam echo sounder systems use SONAR (SOund Navigation and Ranging) to send sound beam from transducer to seafloor and read reflected sound data. Depth can be calculated by the time difference between transmitted and reflected data. From the 1930s, single-beam echo sounders were mostly used to create bathymetric charts. [3]

Today, multi beam echo sounder (MBES) is used to get a more precise description of the bottom topography with hundreds of very narrow adjacent beams arranged in swath degrees across track line. These new survey data sets are extremely dense in comparison to traditional surveys, and basically provide total coverage of the bottom. To capture and store bathymetric data from these datasets for subsequent analysis and modeling, some basic approaches such contours and grid models are used. A three dimensional model of the sea floor created by these approaches is very important for environmental monitoring such as bed shear stress, erosion rates, etc., and also for modeling and simulations. [4]

In this thesis, it is focused on; the importance of hydrographic measurements and systems, the detailed usage of Multibeam Echo Sounder Systems with all limitations, the Drinking Water Pipeline Project between Turkey and Turkish Republic of Northern Cyprus (TRNC), the comparison of two depth data, which surveyed in different time periods on the channel dragged along the water pipeline project route.

It is aimed to monitor the changes along the shallow parts of the pipeline route, which are crucial for the marine geology and the pipeline risk assessments such as sea floor erosion, sediment deposition, etc. by using proper processing techniques such as, data acquisition, data analysis, seafloor modeling and change detection analysis.

2. HYDROGRAPHY

The development of a National Maritime Policy for a country requires a well-developed capability to conduct all researches, which allows obtaining basic knowledge of the geographical, geological and geophysical features of the seafloor and coastal areas, as well the ocean currents, tidal changes of the seawater. In addition to these, all data must process properly to describe the geographical relationship with the land and the dynamics of the ocean, which should be accurately depicted in all zones of national shipping.

In this context, hydrography is the science of describing the physical features of water body and seafloor by measurements. There are numbers of descriptions in hydrography made by hydrographic authorities from the beginning of hydrographic surveys. Most definitions focused on general interest of hydrographic surveys like water depth as the common data type for all hydrographic surveys. Additional concern of many surveys is the nature of the seafloor material (i.e. rock, mud, sand, silt, clay) due to implications for anchoring, dredging, structure construction, pipeline and cable routing, and fisheries habitat. [5]

Besides, hydrography is the key to progress on all maritime activities, having a great influence on nation's economy. To adequately address the areas such as maritime traffic control; coastal zone management; exploration and exploitation of marine resources; environmental protection and maritime defense, the hydrographic service needs to be existed. The hydrographic service, through systematic data collection carried out on the coast or at sea, produces, and disseminates the information to support the maritime navigation safety and marine environment preservation, defense and exploitation.

2.1 Definitions and Brief History

The word 'hydrography' comes from the ancient Greek, 'water' and 'to write'. Many authorities have made the definition of hydrography. These definitions are revised for many times regarding to technological and technical improvements of the science. [6]

2.1.1 Definitions

The term and concept of hydrography are subject to constant change due to developing science, technology and objectives. In other words, the term ‘hydrography’ today means most likely something different than 20 years ago when it was used first time. Today international organizations developed their definitions on hydrography in time.

The definition produced by the United Nations (UN) has discussed in 1977 by a group of experts. This definition published in 1978 in English as, “Hydrography may be defined as the science of measuring and depicting those parameters that are necessary to describe the precise nature and configuration of the sea-bed, its geographical relationship to the landmass, and the characteristics and dynamics of the sea. The parameters encompass bathymetry, geology, geophysics, tides, currents, waves and certain other physical properties of sea water” [7]

Although this definition gained wide recognition, the UN has written a new one after 28 years. The new definition published in a Training Manual in 2006 is given below;

“Hydrography is the discipline dedicated to describe the precise nature and configuration of the sea-bed, its geographical relationship [to] the land mass and the characteristics and dynamics of the sea. It is the total set of spatial data and information and the applied science of its acquisition, maintaining and processing, necessary to describe the topographical, physical and dynamic nature of the hydrosphere and its borders to the solid earth, and the associated facilities and structures”. [7]

In this definition, it is observed that the fundamental things have changed. When these two definitions are compared, it could be seen that, the hydrography is not only a “science of measuring and depicting” anymore, but it is a “discipline” that turned to an “applied science of its acquisition, maintenance and processing” denoting “the total set of spatial data and information”.

One of the different definitions described by ‘The National Oceanic and Atmospheric Administration (NOAA)’ provides a different view on hydrography given in the fourth edition of the Hydrographic Manual. Unlike the UN, the NOAA colligates the hydrography not generally under the applied science and defines as;

"Hydrography is that branch of physical oceanography dealing with the measurement and definition of the configuration of the bottoms and adjacent land areas of oceans, lakes, rivers, harbors, and other water forms on Earth. Hydrographic surveying in the strict sense is defined merely as the surveying of a water area; however, in modern usage it may include a wide variety of other objectives such as measurements of tides, currents, gravity, Earth magnetism, and determinations of the physical and chemical properties of water". [7] As seen in this definition, the hydrography is presented unfamiliarly as a "branch of physical oceanography".

The International Hydrographic Organization (IHO) has published a definition of Hydrography in the fifth edition of the Hydrographic Dictionary in 1994. The definition is given as below;

"That branch of applied science which deals with the measurement and description of the physical features of the navigable portion of the EARTH's surface and adjoining coastal areas, with special reference to their use for the purpose of NAVIGATION". [8] In time this definition has revised many times but IHO made a final definition in Hydrographic dictionary in 2009 as below;

"Hydrography is that branch of applied sciences which deals with the measurement and description of the features of the sea and coastal areas for the primary purpose of navigation and all other marine purposes and activities including (inter alia) offshore activities, research, protection of the marine environment and prediction services" [8]. According to this definition, hydrography exclusively deals with the sea and coastal areas and not anymore exclusively for navigation purposes. [7]

2.1.2 Brief history

Exploration of the sea floor surface and shallow subsurface has fascinated mankind for centuries. Hydrography is the oldest science of the sea; hence the history of hydrography is nearly as old as sailing. Today the oldest navigational chart known as the Carte Pisane was drawn towards the end of the 13th century on an animal skin and known as 'portolans'.

In the early hydrographic surveys, the sounding pole and hand lead lines were used for the depth measurements.

In 1904, weighted wire-drag surveys were used in hydrography, wherein a wire fixed at a certain depth having an arrangement of weights and buoys which were attached to two vessels and then was dragged between two points. When the wire came across to any barrier, it would become tense and a 'V' shaped, showing the position of all barriers and depth. (Figure 2.1). [2]

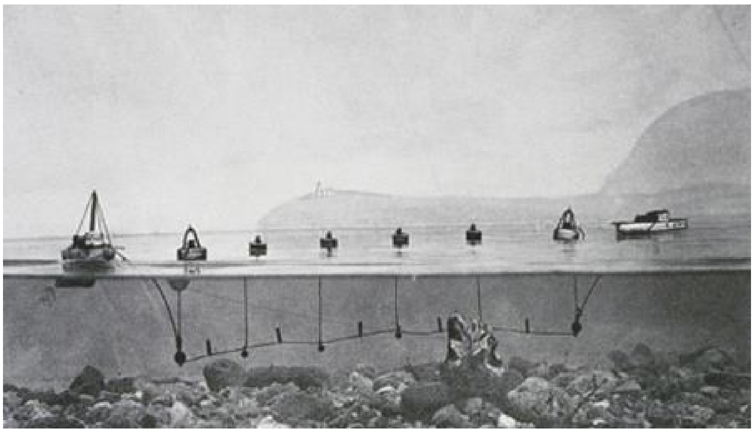

Figure 2.1 Wire-drag survey method. [9]

In the1930's, the development and implementation of single-beam echo sounders were seen and sound waves were used to measure the distance of the sea floor directly below a vessel. By running a series of lines at a specified spacing, single beam echo sounders and fathometers greatly increased the speed of the survey process by allowing more data points to be collected. However, this method still left gaps in quantitative depth information between survey lines. [2]

From 1950s to the end of 1970s, numerous evolutionary concepts were advanced. Side scan sonar technology offered a qualitative means of obtaining the sonic equivalent of an aerial photograph and improved the ability to identify submerged wrecks and obstructions. Multibeam swath systems made it possible to obtain quantitative depth information for 100% of the bottom in a survey area. [10]

Improvements in transducer technology and timing accuracy made possible to introduce transducers which provides precise soundings, which has 30° - 60° beam width that only made it possible to create large-scale maps of the seafloor. The purpose of swath bathymetry is to measure the depth with as many points as possible to extend to distance on one or both sides of the ship, instead of measuring only nadir direction of the ship. Swath bathymetry systems can be characterized according to the main criteria's like; across-track coverage, accuracy of depth measurements, confidence in seabed classification method(s) and the density of bottom sampling. The first researches on multi beam sonar showed up in the International Hydrographic Review around 1960. [11]

Today, in parallel with the development of computer technology and digital processing methods, sonar systems produce more accurate and better precision measurements. Besides sonar measurements, LiDAR and satellite derived measurements are used in many hydrographic applications.

2.2 Hydrography Associated Fields

2.2.1 Maritime transport

More than 80% of international trade in the world is carried by sea. Maritime commerce is a basic element for a nation's economy. However, many areas and ports in the world do not have accurate nor adequate nautical chart coverage. Therefore, modern nautical charts are required to provide information for safe navigation at sea. The shipping industry needs efficiency and safety. Poorly charted areas and the lack of information can cause voyages to be longer than necessary, and may prevent the optimum loading of ships, thus increasing costs. The saving of time and money resulting from the use of shorter and deeper routes produce important economies for national industry and commerce. Hence, the quality of maps and charts produced and continually updated and distributed by a Hydrographic Service are so important. Modern charts also provide information required to create the routing systems established by international conventions and to meet the economic interests of the coastal state. [1]

2.2.2 Coastal zone management

Adequate coastal zone management includes many items such as construction of new ports and the maintenance and development of existing ones; dredging operations for the maintenance of charted depths and for the establishment, monitoring and improvement of channels; control of coastal erosion etc. Precise large-scale surveys that provide the primary data are essential for projects involving all items mentioned above. Due to the rapid changes that might occur in shorelines, these surveys must be updated with the frequency dictated by the monitoring and analysis process. The information collected by Hydrographic Offices about the coastal zone provides essential input to coastal zone GIS (Geographic Information Systems) which are increasingly being used for better overall management and decision-making with regard to conflicting uses within the coastal region. [1]

2.2.3 Exploration and exploitation of marine resources

The extensive data-bases collected over the years by Hydrographic Offices, together with their various products and services, are used primarily to support safety of navigation. However, they are of considerable economic value in assisting the management and exploitation of natural marine resources. In recent years, it has become more evident that inadequate hydrographic services not only restrict the growth of maritime trade but also lead to costly delays in resource exploration. Coastal and offshore sedimentary areas may contain mineral deposits, in particular hydrocarbons, which require adequate surveys in order to be identified. Bathymetric, tidal and meteorological data provided by a Hydrographic Service is a fundamental element in the development of a hydrocarbon industry. The fishing industry, a source of national wealth, needs marine information not only for the safe navigation of their vessels but also for safe deployment of their fishing gear, which will prevent costly losses. Therefore, oceanographic charts, compiled and produced by Hydrographic Offices, are being extensively used in the fishing industry. [1]

2.2.4 Environment protection and management

An essential factor for the protection of the environment is safe and accurate navigation. Accidents and pollution caused by wrecks and oil spills, have a negative impact on the industries such as tourism and fisheries sectors which are mostly dependent on coastal resources, and leads to long-term economic effects. In this context, the value of navigation services for the protection and management of the marine environment has been internationally recognized. [1]

2.2.5 Marine science

Marine science depends largely on bathymetric information. More clearly, global tide and circulation models, local and regional models for a wide variety of scientific studies, marine geology/geophysics, and the deployment/placement of scientific instrumentation and many other aspects of marine science depend on the bathymetric measurements done by hydrographic services. [1]

2.2.6 National spatial data infrastructure

Good quality and well managed spatial data is an essential component to economic and commercial development, and to environmental protection. In this context, many nations are establishing national spatial data infrastructures, together with the services and data sets of major national spatial data providers, for example topography, geodesy, geophysics, meteorology, and bathymetry. Hence, the hydrographic service is an important part of the national spatial data infrastructure. [1]

2.2.7 Maritime boundary delimitation

High quality hydrographic data is essential for the delimitation of the maritime boundaries properly as detailed in the Convention on the Law of the Sea adopted by the United Nations. Countries make hydrographic surveys to determine maritime boundaries for their maritime safety. Maritime boundaries exist in the context of territorial waters, contiguous zones, and exclusive economic zones; however, the terminology does not cover lake or river boundaries, within the context of land boundaries. The delineation of maritime boundaries using nautical charts has strategic, economic and environmental implications. [1]

2.2.8 Maritime defense

The marine data and information provided by national hydrographic offices reinforce diverse products used in naval operations, such as surface, submarine, anti-submarine, mine hunting and air sea naval operations. In this context hydrographic and oceanographic data are crucial for the preparation of such products. [1]

2.2.9 Tourism

Good quality nautical charts are particularly important to the development of the economically important industry of tourism. Especially the potential of the cruise ship industry is so important for the developing nations. If the safe navigation to remote touristic landscapes is prevented or limited by a lack of adequate charts, the tourism sector will be influenced negatively. [1]

2.2.10 Recreational boating

The recreational boating community often does not update their charts; however, updated chart information readily available along with many types of value added information such as marina locations, etc. is so valuable for them. This development is likely to result in the recreational leisure sector becoming a significantly larger user of the hydrographic data. Besides, the volumes of maritime trade are growing continuously and, in the future, the exploitation and sustainable development of the national maritime zones will become a major pre-occupation of government and industry. [1]

2.3 Hydrographic Measurement Systems

From past to today, many different hydrographic measurement systems are used depending on the technological developments. In the past, many marine structures built at convenient locations base on environmental observations, or nautical charts created with simple surveying methods. In time, hydrographic surveys, also known as a bathymetric survey, has become essential for all marine activities to make correct decisions. In addition to this, choosing the convenient system for a survey has a vital importance for the application. Accuracy of survey, size of survey area, general depth information, feature of water and seafloor are the primary factors which effect the survey equipment and measurement system.

Hydrographic surveying systems are mainly divided into four groups as conventional, satellite based, laser and sonar systems. [12]

2.3.1 Conventional systems

These systems are known as the oldest and simplest bathymetric measurement technics. The systems are based on the direct measurement of sea floor depth by using a sounding pole or lead line from a ship. These technics are used to create nautical charts and shallow water bathymetric data. [13]

The first evidence that man was measuring the depths is found in tomb paintings of ancient Egypt dating from 1800 B.C. (Figure 2.2).

Figure 2.2 Egyptian carving on sounding pole. [14]

This ancient ‘Sounding Pole’ technic involves the use of a long straight pole to measure water depths, but limited in use to very shallow water. This system generally is used in near coast or rivers to practically see the water depth for navigation of small vessels and ships (Figure 2.3). [15]

Figure 2.3 The sounding pole technique used to measure depths. [16]

The sounding pole technique was then replaced with the traditional lead-weighted line. For the deployment to the bottom when lowered over the side of a vessel, the ropes or lines with depth markings attached to lead weights are used in the lead line survey (Figure 2.4). In the survey, each depth measurement had to be taken manually and recorded. Besides, the correct positioning information of each depth had to be determined regarding to the reference points fixed by three-point sextant. While taking every single depth measurement the position must be determined at the same time to avoid position error because of the vessel movement due to dynamic sea surface. [15]

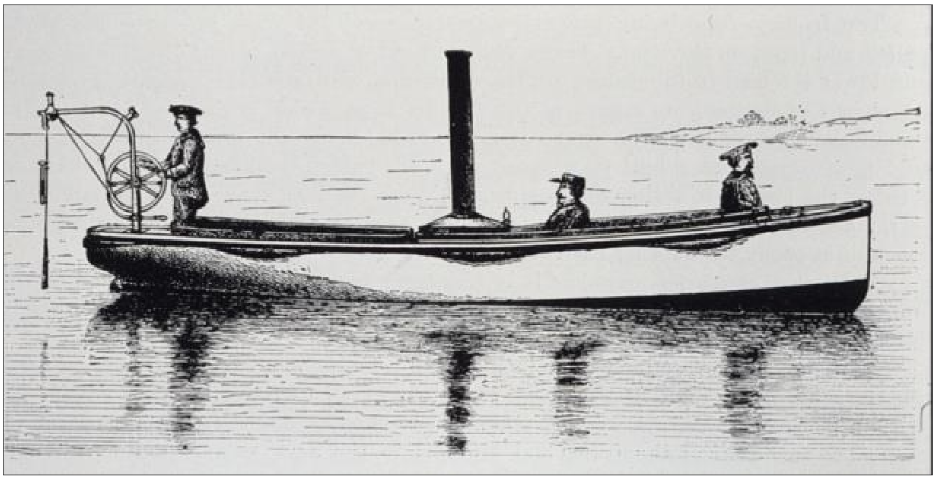

Figure 2.4 Lead-line depth measurement. [17]

2.3.2 Satellite systems

Satellite derived bathymetry (SDB) systems was developed in the late 1970s, but recent advances in satellite technology, such as improved resolution and multi-spectral bands, have increased its potential as a source of hydrographic data. The use of SDB data is increasing throughout the hydrographic industry as a low cost source of data and wide coverage (within depth and image limitations). However, since the depth measurements that the system provides, is not as good as Multi-beam echo sounder (MBES), some objects or seafloor information might be missing. Even so, the object detection capacity is better than lead-line survey and single beam echo sounders (SBES) alone, but not as good as SBES used with side scan sonar that provides 100% area coverage or MBES. The satellite derived bathymetry systems collect depth data with horizontal positional accuracy which is similar to MBES and SBES and better than historic lead line survey. However vertical positioning accuracy is lower than any other measurement systems.

There are two types of satellite based bathymetry technics. The first one is the bathymetry by using altimeter. Ocean surface height is measured by satellite radar altimeters and time duration of the radar pulse needed for a round-trip from the satellite to sea body surface and then back to satellite is calculated. The ocean floor consisting of huge mountains affects the Earth's gravity field. Its effect can be seen as more water around them and bulges at the outward of the ocean surface. This method of depth estimation is known as 'Altimetric Bathymetry'. In this method, the mountains under the ocean floor need to have a mile high and several miles wide for the formation of the sufficient surface bump in the sea level to be recognizable for the radar altimeter satellites. For this reason, the echo sounding bathymetry aboard ships is more accurate and detailed than altimetric bathymetry. Even so, the combination of conventional echo sounding with altimetric bathymetry provides best coverage to produce the best global bathymetric models. (Figure 2.5). [18]

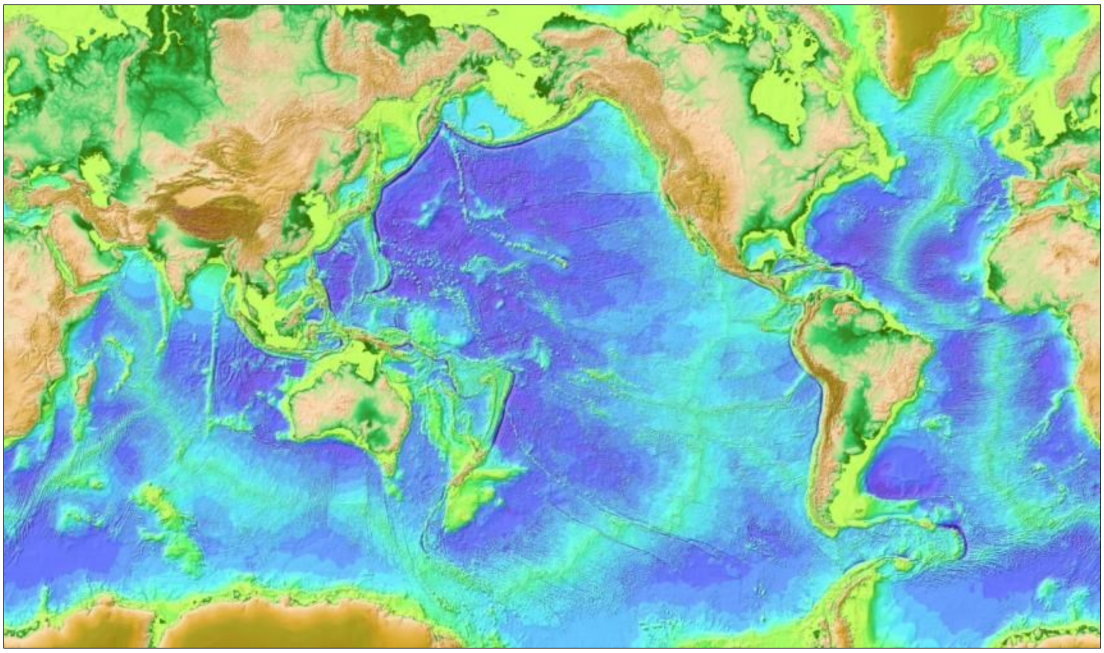

Figure 2.5 World ocean map created with satellite altimetric bathymetry and echo sounding combination. [19]

The other satellite derived bathymetry technic is the optical remote sensing bathymetry. Over the shallower areas, in optically shallow waters, the water reflectance is used to derive the bottom depth. In this scope, successive methods have been developed for research or operational purposes. [20]

The accuracy of the map produced by this approach depends on water turbidity and bottom composition changes that are expected to occur inside the survey area. Also, it is constrained by the spatial coverage of the field data. However optically derived bathymetry from airborne and satellite-borne (multispectral and hyperspectral) sensors is gaining popularity due to being cost effective alternative to other techniques for near shore/shallow water environments. [20]

2.3.3 Laser systems

A LiDAR is active remote sensing equipment that uses time delay between a laser pulse and its reflected signal by the target to determine the distance of the latter. LiDAR is used in two types of airborne systems, namely topographic and bathymetric. Topographic systems are used for measuring terrain heights, whereas bathymetric systems are used for determining depths in water. The systems are made up fundamentally the same components. The airborne laser scanning (ALB) system can measure depths up to 50 m, in particular uses of green laser (Figure 2.6). The ALB system can be mounted on a suitable aircraft. This technique can be used to map very shallow waters and surf zones. It can also map the topography of the near shore (beaches and dunes). The major components of an ALS system are Laser Range Finder, Scanner, Global Navigation Satellite System (GNSS), Inertial Measurement Unit (IMU) and computer. [21]

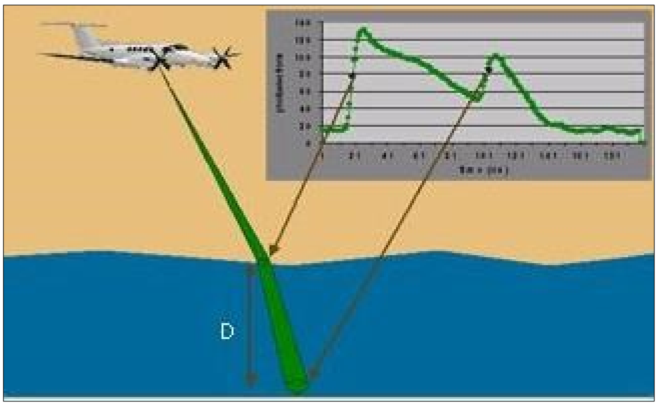

Figure 2.6 LiDAR bathymetry. [22]

ALB systems have many advantages like the ability to survey the combined features and constructions, both above and below the waterline in a single scan. In addition, detailed digital images are recorded to allow for visual analysis and use with digital terrain models. Besides, in shore areas where it would be dangerous or inaccessible to boats, the ALB systems are safe to survey. ALB Systems are also able to survey without consideration of environmental conditions such as extreme weather or ice coverage or when natural disasters occur. The ability to survey large areas in relatively short time frames in a cost effective manner.

However, there are several disadvantages of this system. The amount of energy required to transmit a green laser pulse is much higher than that of an infrared laser pulse. The higher power laser pulses result in a lower frequency of generated pulses for green laser (1 kHz) than infrared laser (8 kHz), and therefore a lower point density is achieved. Due to system using green laser, the scan beam needs to be expanded to make it eye safe at the surface to safely operate. This reduces the amount of energy which returns to the sensor, in addition to the scattering in the water column limits the maximum achievable depth. The most important disadvantage is the measurements are dependent on water clarity. Another factor is the surface foam which can make water penetration difficult due to the added refraction. To overcome these problems, additional flight lines need to be scanned. Also LiDAR data must be corrected and patch tested by using Multibeam sonar system to be sure about data. [23]

2.3.4 Sonar (echo sounding) systems

Since the sound can travel over such great distances, remote sensing can be used as a tool in a water environment. Devices that use sounds in such an application are known as sonars. SONAR is the sound navigation and ranging system that uses sound pulses to communicate or determine objects under the surface of the water. There are two different kinds of sonar technology having the same title. The first one is known as passive sonar and it is used to listen for the sound dispersed from other objects. This kind of sonar systems are generally used for navigational purposes by ships and submarines. The other one is the active sonar which is propagates pulses of sounds and listens for echoes. These systems are also being used for the navigational purposes, besides for measurements of seafloor and water dynamics. [24]

The sound moves quite efficiently through water, far more easily than it does through air. The signal travels through the water until it is reflected by the seabed or an object in the water column. Parts of the reflected signal are received by the transducer. Range can thus be calculated by multiplying the time taken to receive the reflected signal and the speed of sound in water. Since the sound beam has travelled twice the range distance, the result needs to be divided by two.

$$\text{Range} = 1/2 * \Delta t * v_w \qquad 2.1$$

Δt - Time difference between the transmitted and the received signal
v_w - Speed of sound in water [25]

2.3.5 Basic acoustic theory

The main concern of using echo sounder is the behavior of sound in water. Once the acoustic transmitter sends the sound pulse into the water, many factors influence the sound. The major impact to sound is the velocity (Figure 2.7). [26]

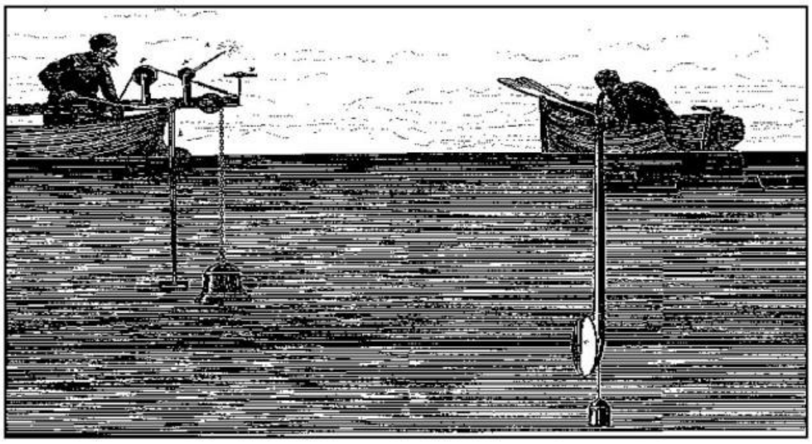

Figure 2.7 Sound velocity measurement technique used in 1822. [26]

As the acoustic pulse passes through the water column, the velocity of the wave front will vary based on the sound velocity; this is called as refraction (Figure 2.8). If the sound velocity is not accounted for in the data collection software, the depths will be in error, therefore for multi beam echo sounder system, the sound velocity through the water column is a vital factor.

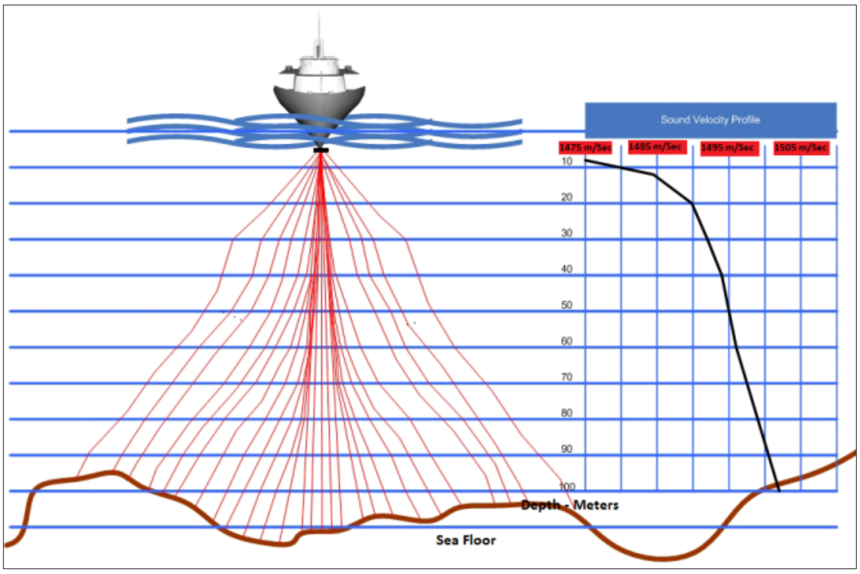

Figure 2.8 Concept of refraction due to different sound velocities in the water column. [26]

The velocity of sound in water varies both horizontally and vertically. It cannot be assumed that the velocity of sound in the water column remains constant over large areas or throughout the day in a more local area. The main influences on sound velocity are: conductivity (related to salinity), temperature and depth (related to pressure). The Table 2.1 shows the effect of variables to sound velocity.

Table 2.1 Change in velocity regarding to variables. [26]

Variables	Change in velocity
1 ° C change in Temperature	4.0 m/sec
1 ppt change in Salinity	1.4 m/sec
100 m change in Depth (10 atm's pressure)	1.7 m/sec

Wrong sound velocity profile determination through water column can cause refraction errors. This error increases from nadir to side beams on multi beam systems whereas in the single beam systems, it directly affects the single sounding data that sent from the nadir of echo sounder. The visual effect is that the swath will curl up like a smile or curl down like a frown. The actual representation is that the soundings are either too shallow or too deep (Figure 2.9). [26]

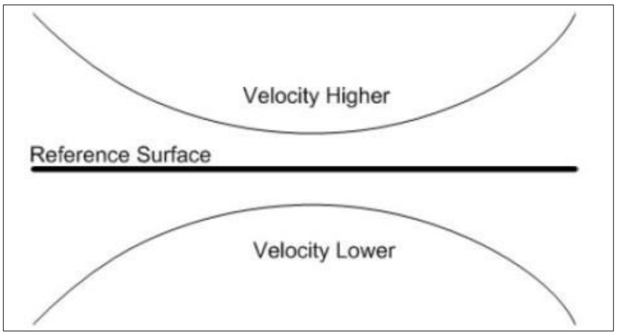

Figure 2.9 Indication of refraction error. [26]

The transmission of an acoustic pulse which is called 'ping' while reflecting from sea bottom upward, it faces with transmission losses. There are other physical influences that affect the travel of pulse and cause loss of signal. In general there are two kind of signal loss. First one is the spreading loss which doesn't represent a loss of energy, but refers to fact that the propagation of the acoustic pulse is such that the energy is simply spread over a progressively larger surface area, thus reducing its density. Spreading loss is not frequency dependent. The other signal loss is absorption which is frequency dependent and refers to the conversion of acoustic energy to heat when it strikes chemically distinct molecules in the water column. Absorption is one of the key factors in the attenuation of the acoustic energy based on frequency; the higher the frequency, the greater the absorption. The higher the sonar operating frequency, the more rapid the vibration (or excitement) of the particles in the water and this leads to the greater transference of acoustic energy; thus, the attenuation of the acoustic wave. This is the reason why lower frequencies are used to obtain deeper data. [26]

2.3.5.1 Single beam echo sounder system

In the configuration of the single-beam bathymetry systems, there is a transceiver (transducer/receiver) mounted to the hull or side mount, to the ship. Hull mount is the installation of the transducer to down side and as close as the gravity center to avoid the system from motion errors, whereas side montage is the installation of the transducer to port or starboard of the vessel. Both has limitations and advantages which will be detailed in the chapter 3.3. These systems measure the water depth directly beneath the vessel. The transceiver contains a transmitter, which controls pulse length and provides electrical power at a given frequency. [27]

The SBES transceiver uses a high-frequency acoustic pulse in a beam directly downward into the water column

Figure 2.10). The resolution is the acoustic energy that reflected off the sea floor beneath the vessel and received at the transceiver. To this respect, system collects depth information along the vessel direction i.e., high resolution along-track data obtained in the sampling interval. The continuous recording of water depth below the vessel yields high-resolution depth measurements along the survey track. [27]

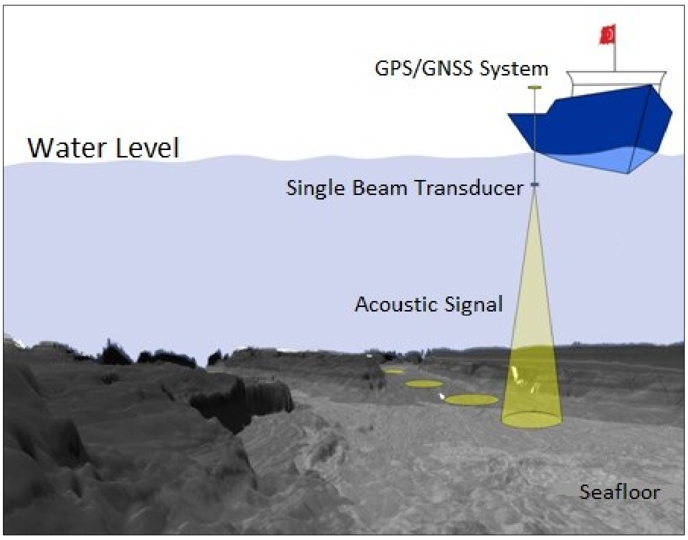

Figure 2.10 Single beam echo sounding.

Across-track resolution of single beam echo sounder depends on the gap between survey lines. In this system, across – track resolution is generally lower than along-track resolution.

The transmitting and receiving the signal is a repeating cycle at a fast rate, on the order of milliseconds. Additional information such as heave of the vessel can also be measured with a heave sensor, and used to "correct" the depth measurements in the processing. [27]

Initially, the system uses two-way travel time to calculate depth (Figure 2.11) using an assumed sound velocity in water; usually sound velocity measurements are done before and after the survey to avoid data from velocity error.

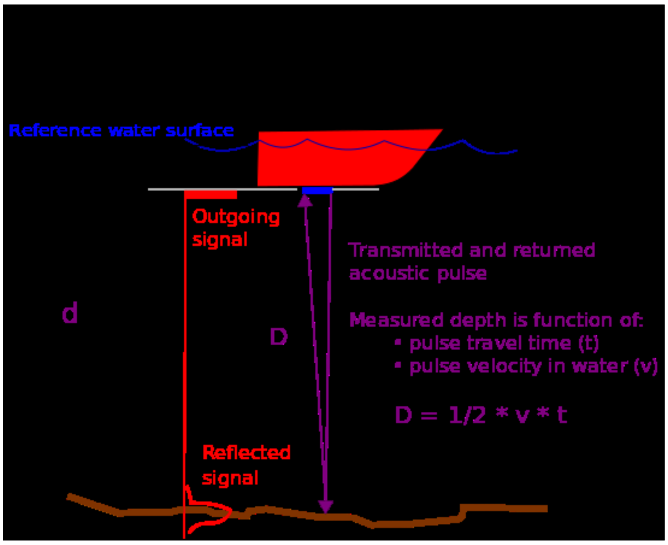

Figure 2.11 Depth calculation in the single beam echosounder system. [28]

Although having some limitations versus more technological hydrographic measurement systems, there are some advantages which still make this system preferable against them. The system is cost efficient comparing with other electronic systems. It has fewer data points and therefore it is easy to handle them in the process. This limitation provides faster response for results of survey. Besides, the system has less complicated system requirements that provide the user easier mobilization and installation opportunity. The system is compatible for the use with motion sensor which can collect high accuracy data and interpolation opportunity. Thus, these advantages make the SBES is still one of the most prevalent depth measurement system in global market for the depth measurements or navigational purposes. [29]

2.3.5.2 Multibeam echo sounder system

Multibeam bathymetry is basically an extension of the single beam echo sounder. It can be simply defined as a number of single beam transducers aligned to form an array of beams. By precisely aligning the transducers, a swath of measurements can be surveyed. The swath is much wider than a single transducer beam and thus increases coverage and reduces operational costs. [30]

The system can sweep more than one location on the sea floor with a single ping and achieve higher resolution than conventional echo sounders. In other words, this system operation can be called as a narrow single-beam echo sounder due to being operated at several different locations on the bottom at once. These bottom locations are arranged such that they map a contiguous area of the bottom. The strip of points in a perpendicular direction to the track of the vessel is called a swath. The dimension of the swath in the across-track direction (perpendicular to the path of the vessel) is called the swath width, and it can be measured either as a fixed angle or as a physical size that changes with depth. The swath of multi beam sonar is illustrated in Figure 2.12.

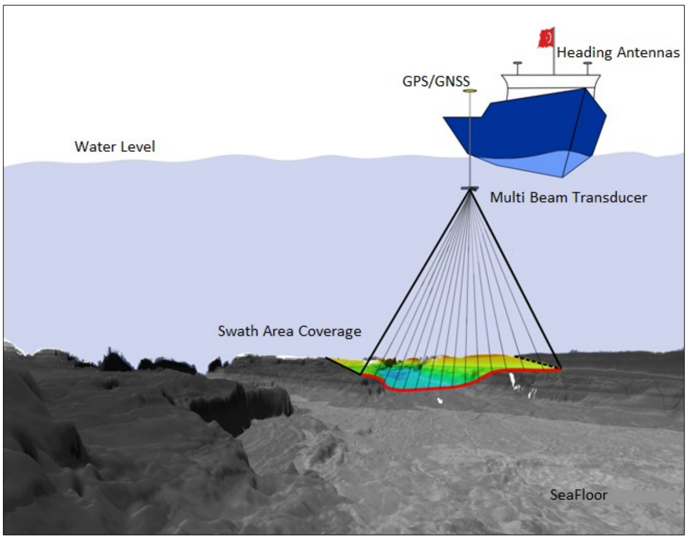

Figure 2.12 Multi beam echo sounder system.

A multi beam echo sounder transmits an acoustic pulse in a wide fan in the direction through the water column. This results in a wide footprint in that direction on the sea floor. The back scattered signal is received by a transducer which segments the above wide footprint into multiple smaller beams, as shown in Figure 2.13. The width of these beams is of the order of one to a few degrees, depending on the system. In this manner, a high number of depth soundings are generated for each pulse transmission. A lane of soundings is obtained from a single vessel's track, rather than a single line of soundings.

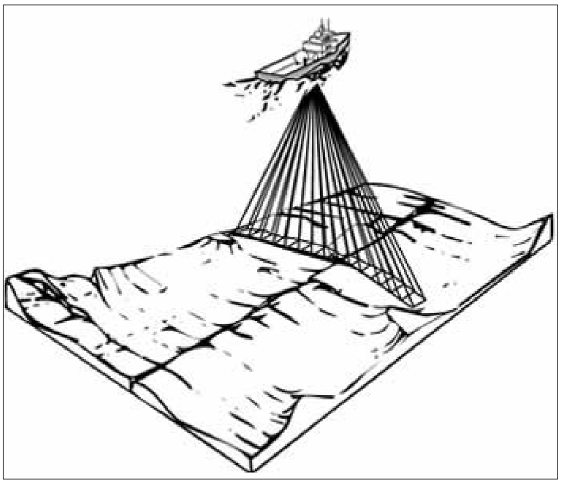

Figure 2.13 Footprint of MBES. [31]

The existing multi beam systems can be classified regarding to their depth measuring limits. The main factor for the reachable depth range for an echo sounder is related to frequency. Considering the frequencies, classes can be as shallow water, medium-depth water and deep-sea systems, and have some features outlined below:

- Shallow water multi beam sounders use the frequencies ranging from 200-400 of 700 kHz, which have a depth range from almost 0-100 meters below the transducer.
- Medium depth sounders use the frequencies between 30 and 90 kHz, which can measure at depths between 100-1500 m.
- Deep-sea systems, which are used to explore the bottom of the deep oceans, generally use frequencies below 10-15 kHz (Figure 2.14).

The higher the transmitted frequency of the sounding means better resolution, besides lower frequency means deeper survey capability. But today's technology can achieve high resolution in deeper waters by mounting the multi beam system on an Autonomous Underwater Vehicle (AUV).

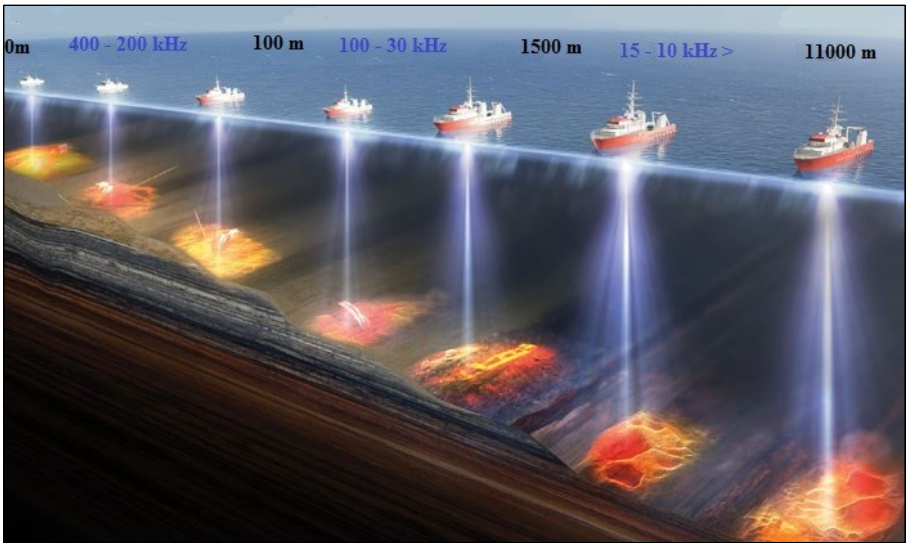

Figure 2.14 Depth ratings regarding to frequencies. [32]

The use of a multi beam echo sounder has many advantages. The major one is 100% coverage of the bottom can be achieved in a relatively cost effective manner. This is important for harbor and constricted waterway applications. Besides, since the MBES is a united system which different kinds of equipment are working together as synchronized, the errors and error sources are more than simpler systems. The most important ones are:

- Measurement errors of the system derived from system's electronics.
- Depth measurement error due to beam width.
- Effect of beam angle error, due to the system's electronics; the effect of this error increases with the swath angle.
- Acoustic propagation errors: these errors increase with the swath angle due to the ray bending effect and are similar in concept to radio frequency propagation in the atmosphere.
- Effect of motion errors (Roll, Pitch and Yaw); these errors increase with swath angle and side beams are more affected from this error.
- Beam steering error due to surface sound speed error
- Transducer misalignment error.
- Heave, dynamic draught and water level errors which are directly affect the depth data.
- System calibration errors; the error caused by wrong patch test procedure and results.
- Tides and/or other water level effects.

To avoid the survey from these errors above, they must be corrected with specific correction measurements and patch test. [33]

System corrections

Positioning corrections

To position the MBES data, Differential GPS technique is generally used to fix echo sounder position during measurements. The differential corrections should be controlled by comparison with a known control point on land. GPS receivers should be configured to output positions in the desired datum (normally WGS84) with quality tags. The quality of the position fixes (number of tracked satellites, horizontal and position dilution of precision, etc.) should be monitored during survey through navigation software or over GPS receiver screen. Also it is recommended a real-time comparison with a second positioning system. Post-processed differential is an alternative solution to real time kinematic (RTK) where a high accuracy positioning solution is required. Users can navigate with a Satellite Based Augmentation Service

(SBAS) such as WAAS or EGNOS while logging raw GPS aboard and simultaneously at a reference (control) station ashore. [34]

Real time kinematic GPS offers increased precision of the horizontal position. If the beam width is large, an increase in depth will increase the footprint on the seabed and degrade the actual positioning of the soundings. This is, potentially, more of a problem with SBES as MBES beam width is usually much smaller. Additionally, the accuracy of position of the soundings will be improved with the use of motion sensor equipment. [34]

Sound velocity correction

Sound velocity is an important factor for the accuracy of the depth measurement. It is used for two main purposes, the first one is the ‘Beam Steering Correction’ that is used to compute the effects on the angle from which signal comes or beam pointing angle. The second one is the ‘Ray Bending Correction’ that is used to compute the depth and position corresponding to the travel time measured. The accuracy of multi beam sonar system is dependent on these factors which related to sound velocity. This makes so important to know the speed of sound at the transducers head to give a start and finish orientation for the sonar head. Besides, it’s also necessary to know the sound speed profile from the transducer head to the sea floor which allows the sonar processor to calculate range and to correct for refraction (bending) of the acoustic beams. [35]

To avoid these errors, there are two kinds of sound velocity determination techniques that should be used during the surveys. The first one is the sea surface sound velocity determination technique. In this technique, a sound speed sensor should be mounted at the multi beam transducer head and sampled with every ping of the multi beam sonar. While the ship is sailing during the survey, it is possible to distinguish sudden changes in sound speed at the surface. Due to the possibility for rapid changes of sound speed, it is better to use a direct measuring sound speed sensor than to calculate sound speed from CTD data. The updated sound velocity value of sea surface is able to monitor on the multibeam software which allows a direct serial port connection of sound velocity sensor. The sound velocity sensor (SVS) measurement technique is depending on sending sound pulse to the plate which is mounted to a calibrated distance to the sensor (Figure 2.15).

Figure 2.15 Sound velocity sensor. [36]

The second sound velocity determination technique is used to profile the whole sound velocity through water column. Due to water dynamics, the sound velocity profile can be different. These differences occur as sound velocity errors and these errors are easily seen in the multibeam sonar data. As also referred in the Section 2.3.5, the acoustic path will bend upwards at the slower sound speeds but if the sound speed is faster at the surface then the path would bend down toward the bottom. This is also practically called as 'smiley face' for lower speed of sound and as 'sad face' for higher speed of sound.

The methodology of Sound Velocity Profiling (SVP) is used to deploy a CTD profiler by using a rope or a proper wire to send the sensor through water column till the sea floor (Figure 2.16). The equipment is able to measure sound velocity through the water column.

Figure 2.16 Sound velocity profiling. [37]

Tidal correction

The water level variations must be determined by using suitable methods across the entire survey area for the reduction of soundings to the necessary sounding datum. A local tide station can be used or a tide gauge close to survey area can be set up to log sea level data during the survey.[1] Another method to calculate water level is to usage of RTK GPS with centimeter precision in the vertical (Z) dimension. This method provides a total height measurement, including tide height, but the geoid separation must be accurately known, and the base station-rover range limitations must be clearly understood. The RTK tide usage together with a tide gauge can provide to see the sea level correlation between the different measuring methods. [34]

Motion corrections

The system requires detection of the vessel's pitch, rolling, heaving motions for the correction of the echo sounder beams. For this purpose, a motion sensor must be installed onboard to collect real-time motion data of the vessel (Figure 2.17). The standard type of 'Motion Reference Unit' (MRU) includes an accelerometer type of motion sensor. The correct installation and definition within the vessel reference frame are vital. Therefore the manufacturer's recommendations for installation must be taken into consideration. Also the lever arm relation between motion sensor and the other installed equipment is vitally important and must be determined by running the 'Patch Test' (system calibration) procedure. [34]

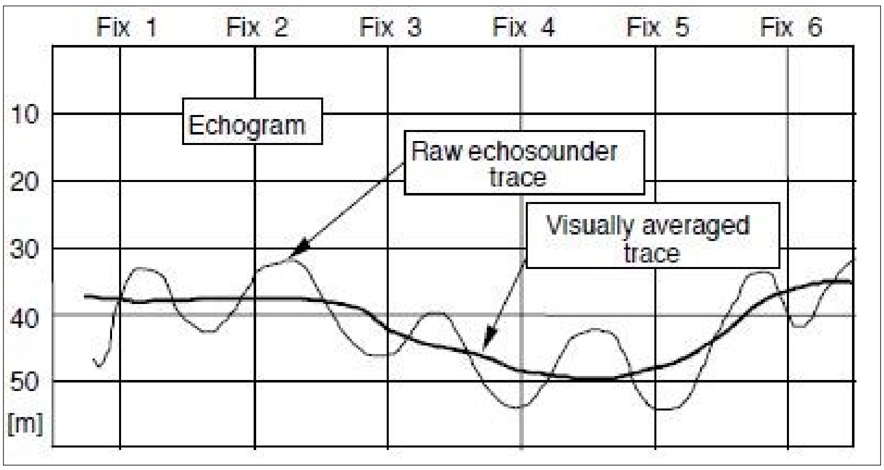

Figure 2.17 Heave compensation by using MRU. [34]

System calibration (patch test)

The patch test combines the hydrographic survey data collection procedures and the subsequent statistical analysis performed to determine angular misalignments and timing differences in the multi beam system hardware. The patch test or calibration survey is important and need to be performed carefully to ensure that the data collected is accurate and reliable. This test is a small survey of several lines that are run in order to check and correct the potential misalignment of survey equipment. There are four variables that are typically measured in the calibration process. These are time delay, pitch, roll and heading; and these variables also must be calculated in this order (Figure 2.18). A few seafloor features are needed in the measuring of the offsets between specific sensors, including a slope, flat bottom and a discrete object. [38]

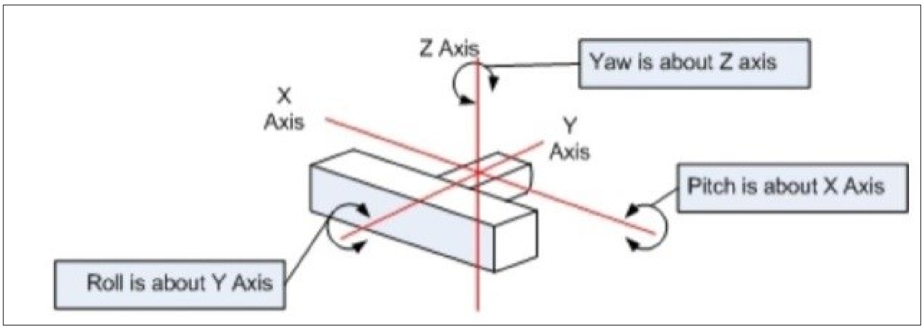

Figure 2.18 Calibration axis. [39]

Latency test (timing)

The latency test determines the time-synchronization differences between the time tagging of the multi beam soundings with respect to the time-tagging of the position records. The time-tagging for the motion and heading data needs to be synchronized with the rest of the data collected. Each test in a patch test is conducted over a specific bottom terrain, varying boat speeds and direction of the data collection. [40]

For the latency test, the surveyor should collect data over two same direction and overlapped lines, with significantly different speeds, over a sloped bottom. The speeds should vary by more than 50% from one another. For example first pass can be at 4 knots and the second pass at more than 6 knots speed (Figure 2.19). [39]

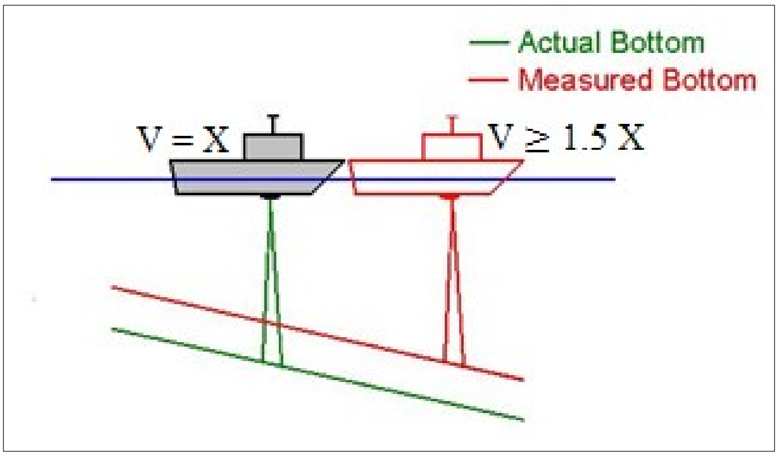

Figure 2.19 Latency error illustration. [15]

Latency test needs to be done the first, because the 'timing' for all of the data must be correct before you can perform any of the 'angular' tests. Today due to the PPS signal protocol used for data packaging, the latency test doesn't need to be done for most of the MBES.

Roll test

The roll test is performed to determine the offset or angular misalignment between the port/starboard orientation of the multi beam sonar head with respect to the motion reference unit (MRU) or inertial motion unit (IMU) (Figure 2.20). [40]

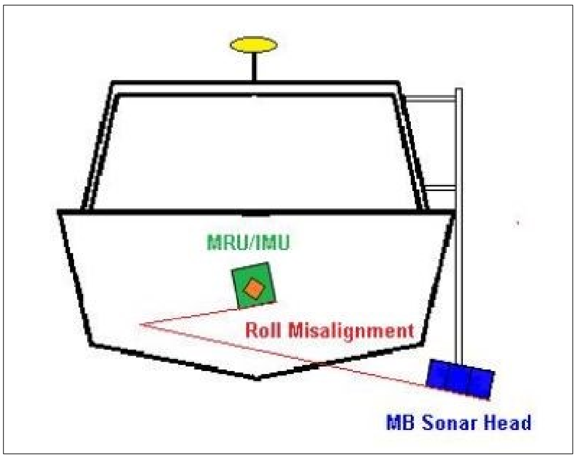

Figure 2.20 Roll misalignment. [40]

To determine the roll offset, the surveyor must collect two sets of data over a flat seafloor. This must be in the same survey line but in the opposite directions. Collecting data on reciprocal headings will result in the same depth at nadir, but different depths away from nadir which will be appear in a cross section as an "X", which displayed in Figure 2.21. [40]

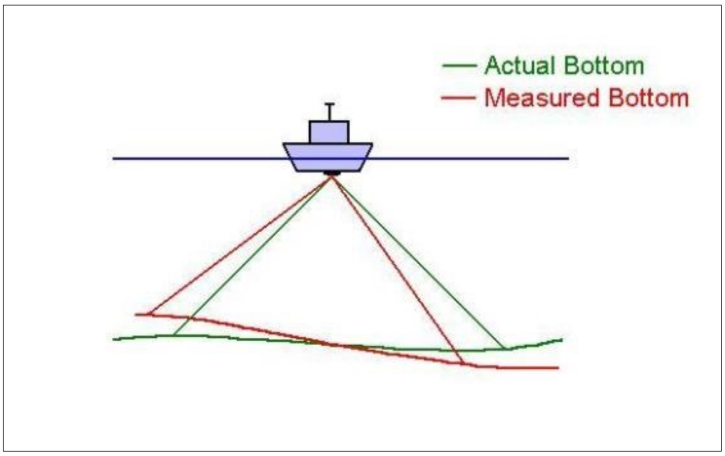

Figure 2.21 Roll error illustration. [41]

The roll misalignment determination is generally easy and consistent. However, roll may be the most critical value in the patch test routine that results an error in soundings directly. The graph in Figure 2.22 illustrates the roll error effect over depth data in 20 meters water depth. [20]

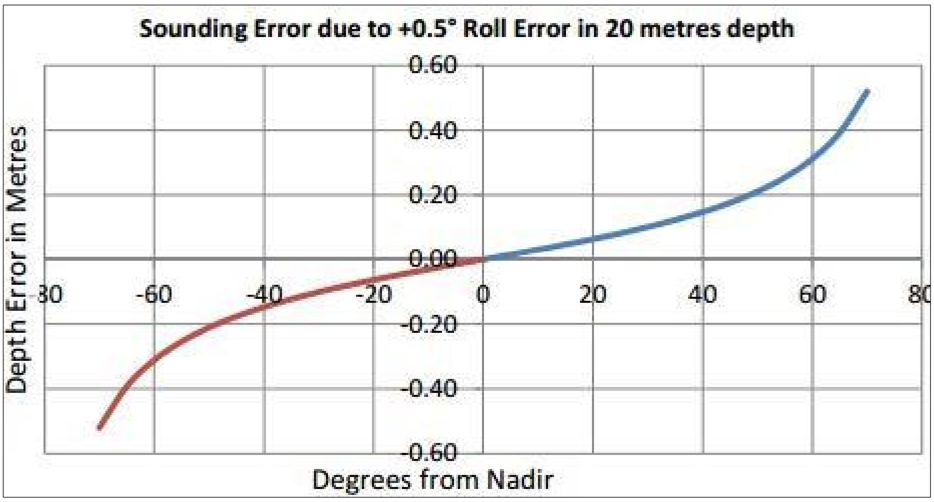

Figure 2.22 The depth errors due to inexact roll alignment. [39]

Pitch test

The pitch test is done to determine the offset or angular misalignment between the fore/aft orientation of the multi beam sonar head with respect to the motion reference unit (MRU) or inertial motion unit (IMU) (Figure 2.23).

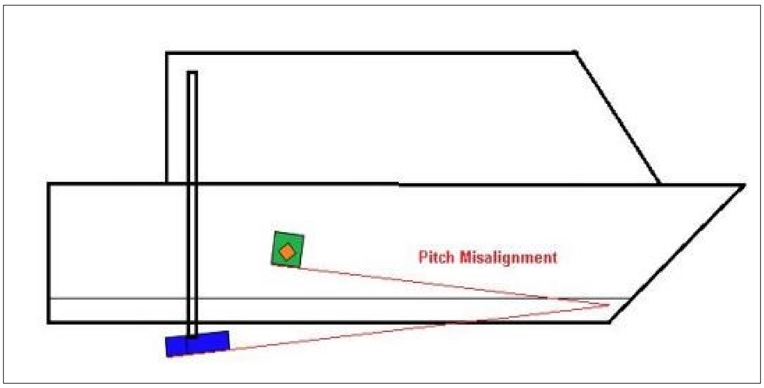

Figure 2.23 Pitch misalignment. [41]

The operator should collect two lines of survey data which are in opposite directions, along the same survey line track. Sailing speed should be the same for both survey lines. The area for data collection for this test should be over a sloped bottom. [40]

A profile, taken from the collected data will show two different slopes, which represent the reciprocal data collections (Figure 2.24). Through a number of iterations, the pitch angle corrections are done until the difference between the two surfaces reaches a null. Whatever the angle of correction, which results in the minima or null, that angle will be reported as the pitch misalignment. [39]

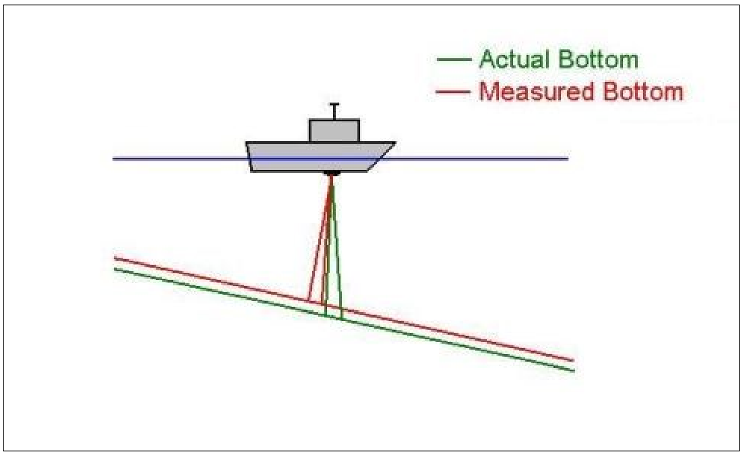

Figure 2.24 Pitch error illustration. [41]

The pitch error results in an along –track position error, which increases greatly with depth. The Figure 2.25 shows the position errors as a result of pitch misalignment. The error can be either negative or positive. [39]

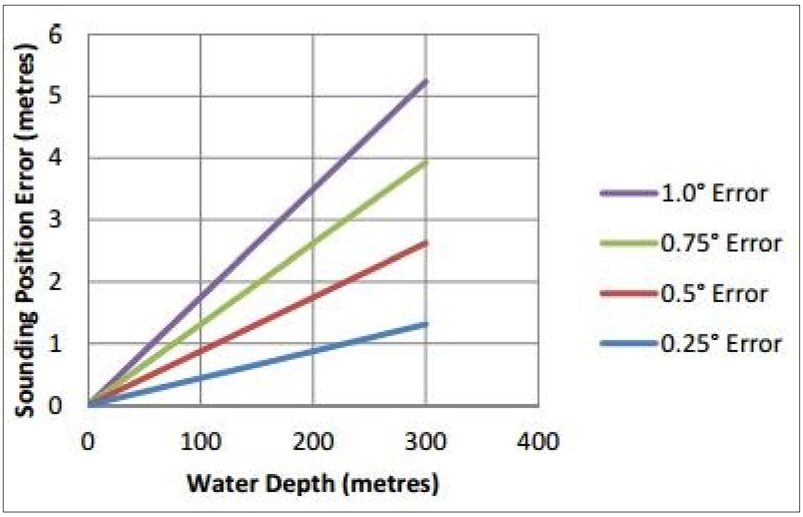

Figure 2.25 Position errors caused by wrong defined pitch alignment. [39]

Yaw test

The yaw test is carried out to determine the offset or angular misalignment between the orientations of the multi beam sonar head with respect to the heading sensor (Figure 2.26). [40]

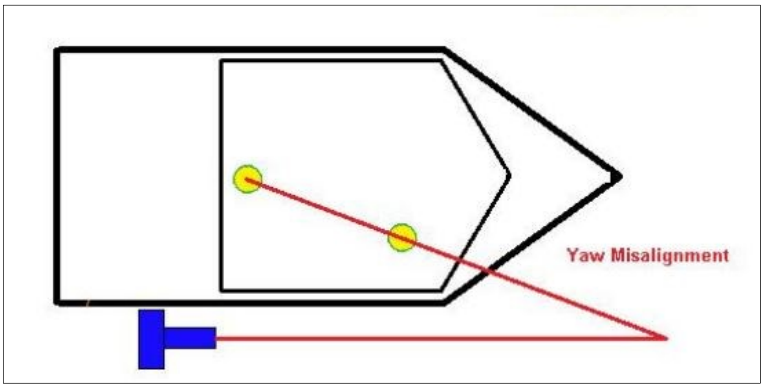

Figure 2.26 Yaw (heading) error illustration. [40]

The data collection and determination of yaw offset is usually the most difficult within four patch test procedure. Data collection over a slope or a sea bottom anomaly generally works for better yaw test computation. Because of this, the area that is used for the computation is not directly under the echo sounder, but in the outer beams and the slope may not be perfectly perpendicular in relation to the course of the vessel. For the yaw data collection two parallel lines are used, with the vessel surveying in the same direction on those lines. Generally, for second pass, sailing at the first pass data's edge will provide 50% overlap and better results. The lines are to be on either side of a sea floor feature or over a slope. This procedure allows visualizing the yaw error known as 'Ghost Image' (Figure 2.27). [39]

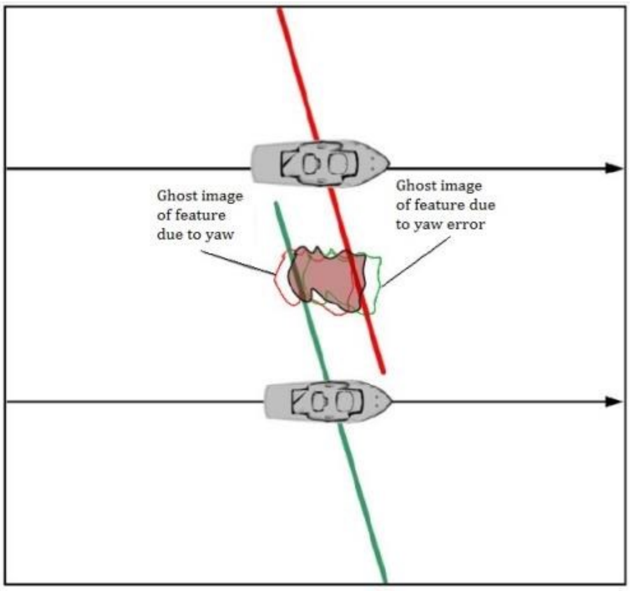

Figure 2.27 The ghost image caused by yaw error. [41]

The yaw error in MBES effects as position error, which increases on outer beams more than nadir beams of echo sounder. Figure 2.28 illustrates along track position error caused by 0.5 ° error in the yaw test. [39]

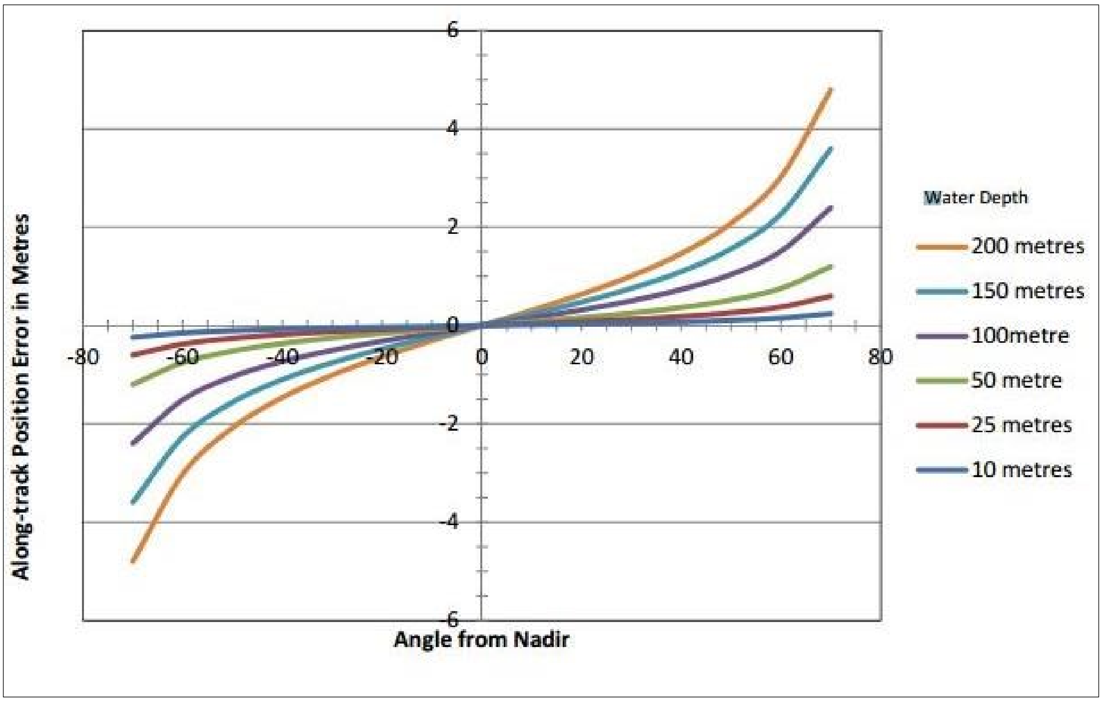

Figure 2.28 Position error caused by heading error of 0.50 °. [39]

2.4 Hydrographic Measurement Standards

As the measurement technology develops, the hydrographic surveying needs to have ongoing essential changes. The technological progression of satellite positioning systems, acoustic systems and advanced data processing systems have also changed the technics of hydrographic surveys. With these sophisticated technologies, the hydrographic services and contractors can collect data with better precision and quality. For this reason, it is necessary to update and create new standards, taking into considerations the needs. [42]

For this reason, the International Hydrographic Organization (IHO) has designed and published the series of standards to help and improve the safety of navigation. The name of the publication is the 'Standards of Hydrographic Surveys' (S-44) and the 1st edition published in January 1968. With an intense deliberation, a clearer guidance regarding to seafloor features, including numerous concerns such as system capabilities, the characteristics of features, etc., the 5th edition of S-44 is published in February 2008. This publication provides the minimum standards given in Table 2.2. In this study, all data are collected under IHO specifications. [8]

Today most of the hydrographic offices are using these standards directly. For example, the hydrographic office of Turkey, named as the 'Turkish Naval Forces Office of Navigation, Hydrography and Oceanography' accepted the IHO standards for hydrographic surveys. On the other hand, many countries have stricter version of the standards based on IHO. For example, LINZ (Land Information New Zealand), USACE (United States Army Corps of Engineers), CHS (Canadian Hydrographic Service) organizations have their own standards. [8,42,43]

Table 2.2 Minimum standards for hydrographic surveys. [8]

Order	**Special**	**1a**	**1b**	**2**
Description of areas	Areas where under-keel clearance is critical	Areas shallower than 100 meters where under-keel clearance is less critical but features of concern to surface shipping may exist	Areas shallower than 100 meters where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area	Areas generally deeper than 100 meters where a general description of the sea floor is considered adequate
Maximum allowable THU 95% confidence level	2 m	5 m + 5% of depth	5 m + 5% of depth	20 m+10% of depth
Maximum allowable TVU 95% confidence level	a* = 0.25 m b* = 0.0075m	a* = 0.5 m b* = 0.013	a* = 0.5 m b* = 0.013	a* = 1.0 m b* = 0.023
Full sea floor search	Required	Required	Not required	Not required
Feature detection	Cubic *features* > 1m	Cubic features > 2 meters, in depths up to 40 meters; 10% of depth beyond 40 meters	Not Applicable	Not Applicable
Recommended maximum line spacing	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 meters, whichever is greater For bathymetric LIDAR a spot spacing of 5 x 5 meters	4 x average depth
Positioning of fixed aids to navigation and topography significant to navigation. (95% confidence level)	2 meters	2 meters	2 meters	5 meters
Positioning of the coastline and topography less significant to navigation (95% confidence level)	10 meters	20 meters	20 meters	20 meters

3. APPLICATION

3.1 Study Area

As a Mediterranean island country, the Turkish Republic of Northern Cyprus (TRNC) with a typical Mediterranean climate is faced with draught for more than 40 years. This problem is affecting almost 300.000 people living in 3299 km² with limited natural clean water resources. The problem is not only related to water shortage but also its low water quality. Due to low-quality water resources, drinking water quality in most areas is below the world statistics. On the other hand, the country can only use less than 10% of the agricultural area for irrigational-based agriculture, besides these areas do not produce high quality crop yield because of the low quality, insufficient and irregular water supply. [44]

These adverse natural conditions experienced for long years have pushed TRNC and Turkey to produce projects for proper solutions. One of these projects is the Yayla Irrigation Project. The project took place in 1980's with the aim of building 65 wells for the irrigation of agricultural regions at the North-West of the island in Güzelyurt district. As a first step, the numbers of wells were brought down to 18 by canceling the wells close to the shore. Afterwards, only 11 wells were built in the area and started to pump water to fill the pools. The project has failed due to seawater intrusion observed from shore side to further inland areas. [44]

Another project is the Güzelyurt Derivation Channel Project which was realized in 1976. The project was aimed to avoid the surface water running to the sea during the short flowing period. For this purpose, diversion channels and the Güzelyurt water dam were built. However, the expected benefit from this project was not attained. [44]

Despite the problems in the earlier projects, a new project was brought forward in 1990's and aimed to transfer the drinking water to the island from the Manavgat watercourse by using water tankers. Turkish Republic General Directorate of State Hydraulics (DSI) built high-cost facilities for this purpose. However, transporting the water without decreasing the quality was only possible with high cost water tankers. For this reason, another solution came up to handle this problem in 1998 and water was transferred into large water balloons of 10.000 m³ – 40.000 m³ (Figure 3.1) in order to supply 4.1 million cubic meters of drinking water. The project was stopped in 2002 due to having some technical difficulties. [45]

Figure 3.1 Water transfer with balloons. [45]

After these projects faced limitations or/and terminated, a long term solution came up with the 'Turkish Republic of Northern Cyprus Water Supply Project' (Figure 3.2). With this project, first of its kind in the world, 75 million cubic meters drinking and irrigation water will be supplied to a severely water-deficient Northern Cyprus after it is completed.

Figure 3.2 The route of 'Turkish Republic of Northern Cyprus Water Supply Project'. [46]

The project consists of four stages. The first one is the Alaköprü water dam, having a capacity of 103 million cubic meters, built in 2014, July. The second stage is the transmission line between the Alakopru water dam and the Anamorium pumping station, which connects to underwater pipeline. The third stage of the project is the underwater part, which involves the most important part and makes the project unique in the world. This stage starts with the shore entrance part from land side to -30 meters water depth. The pipe is buried under the sea floor by a dredged channel. After this part, the pipe is laid on seafloor in -30 meters to - 280 meters water depth. This whole crossing is the most important section which is 80 km long. The pipeline is crossing the route from Anamur (Turkey) to Geçitköy (TRNC) at most 1430 meters and suspended in 280 meters below the sea surface (Figure 3.3). [46]

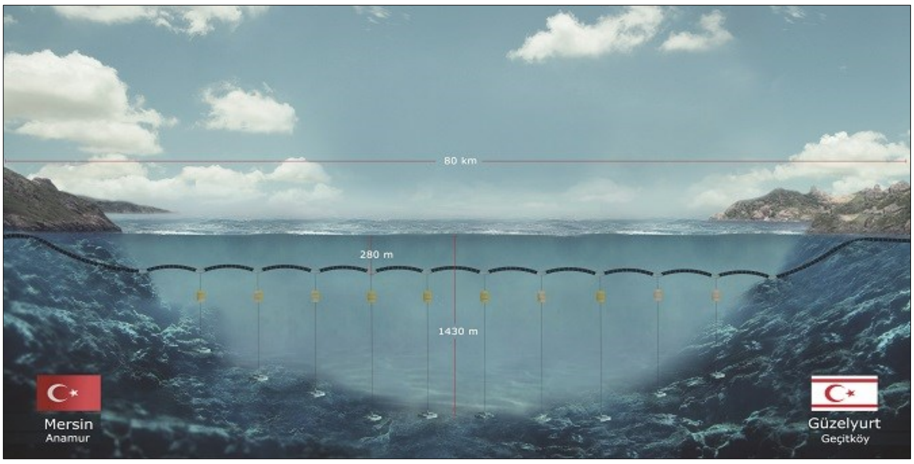

Figure 3.3 Sea crossing section of the project. [47]

One of the reasons for being unique is the size of the pipeline (1600mm diameter and 500 meters monolithic pipes). The final stage is the transmission line, all over the North Cyprus between the Geçitköy shores to Geçitköy water dam. The total project length will be 107 km from one water dam to another.

3.2 Equipment Used

In this study only multi beam echo sounder system is used in both the Turkish and TRNC shore side measurements. Since the system consists of multiple measurement devices, therefore each system should work accurately and complementary. For this reason, each equipment properties need to be known for accurate measurements.

3.2.1 Echo sounder

Echo sounder is one of the most important parts of the system, because it consists of transducer which sends the sound pulse and listen the reflected sound from the seafloor. In this study, R2 Sonic 2024 wideband high resolution shallow water multi beam echo sounder system is used. The system operates with selectable frequency option in real-time during the survey between 200 – 400 kHz. Beam width of the system is 1° along–track and 0.5° across-track which provides 50cm x 50 cm resolution in approximate 20m water depth. Besides, the echo sounder sweeps 4 or 5 times of water depth, that means it covers 80 m to 100 m sector coverage in 20m water depth. However, the coverage of the system is also related to the swath sector which is 10 to 160 degrees. This can be adjusted regarding to resolution needed in nadir of echo sounder. The use of smaller swath provides better resolution in nadir but smaller coverage. For the resolution, the number of beam factor is also substantial. The R2 Sonic 2024 equipment has 256 beams in across-track. The echo sounder is controlled by using a user interface over the survey computer, with the selectable parameters like electronically tilting option in control windows. Detailed equipment information is given in Appendix 1.

3.2.2 Motion sensor

Motion Sensor is the vital component of the system. Without motion sensor it is impossible to carry out an accurate swath bathymetric survey. The system calculates the pitch, roll, heave and heading motions during the survey. The motion sensor uses

GPS data to time and position tag for motion data and sends to software and echo sounder for a real-time data correction. In this study, PosMv Wave Master Motion sensor is used. The system measures pitch, roll and heave motions with fiber optical gyro and measures heading of the survey vessel with 2 antennas called dual antennas (primary and secondary). The system has high accuracy for shallow water measurements and dredging control surveys. With a proper installation, accurate offset measurement and good calibration progress, the system gives satisfactory data which can also be seen in survey monitor. The installation and calibration procedures are given in the Sections 3.3 and 3.4. The equipment has 0.02° for pitch & roll accuracy, 5cm or %5 of water depth heave accuracy and 0.015° of heading accuracy. The detailed equipment information is given in Appendix 2.

3.2.3 Positioning system

The system use positioning and position correction data to fix the depth data. There are different solutions for this purpose, but basically the system uses the global positioning system satellites to gather positioning data from primary GPS antenna together with an auxiliary antenna which gathers correction data for fixing. Differential GPS and RTK solutions are widely used to fix vessel position for hydrographic surveys. For this study, the Fugro Marinestar 9205 GPS/GNSS receiver is used for DGPS correction provided by Fugro Satellite Positioning B.V. The correction provides (±) 20 cm vertical accuracy during the survey. The correction data is entered as input to the sonar interface module to fix soundings. The system is preferred because it's easy installation and no base station requirements and also no distance limit from base station sourced by communication problems. Before the survey, the positioning accuracy is checked by using a land bench mark. Besides, on survey monitor, the accuracy and the correction solution are checked by setting a threshold. The detailed equipment information is given in Appendix 3.

3.2.4 CTD and sound velocity sensor

For multi beam surveys it is necessary to use two kinds of sound velocity measurement equipment as it given information in the Section 0. The first one is the RBR XR 620 series CTD logger. The equipment is used to deploy through water column to measure water parameters needed to calculate sound velocity profile through water column. The logged data is uploaded to survey software as a correction input during the survey. The detailed equipment information is given in Appendix 4. [37]

The second one is the Valeport Mini SVS which is mounted on transducer to measure sound velocity around it. The system enables to monitor sound velocity changes during survey. The real-time sound velocity data is observed during the survey and inputted to survey system. This is a very important variable for multi beam survey which needs to be monitored and updated during the survey since it is impossible to measure and correct it again. The detailed equipment information is given in Appendix 5.

3.2.5 Tide level measurement systems

For tidal measurements Taşucu and Girne Tide Stations provided by General Command of Mapping is used for all survey activities. These stations are close to both working areas in Turkish and TRNC side. For this reason, the mean sea level data is obtained from the General Command of Mapping simultaneously with the survey dates and used during the post processing.

3.2.6 Software used

For navigation, data acquisition, data process and charting purposes, the Hypack navigation software is used during the survey. Its HySweep module enables to monitor the measurements and all correction data together during the survey. While processing the data, same software is used to make all data corrections and noise cleaning of soundings. The soundings are controlled via R2 Sonic- Sonic Controller software in real-time. By using this software, sonar frequency, swath width, power and gain of sound pulse regarding to depth and surface and sound velocity form sensor are controlled by surveyor. To control positioning, positioning fixing and motion data, the PosMV Poswiev software is used. For this purpose, threshold values for real-time data set and changes are monitored. For 3D data evaluation and modeling, the Fledermaus IVS 3D software is used. The detailed equipment information is given in Appendix 6.

3.3 System Installation and Offset Measurement

Since the multi beam echo sounder system consists of multiple equipment, all system components must be installed efficiently and the offsets must be measured accurately for better survey results. Consequently, the choice of survey vessel has an importance for installation. For both Turkish and TRNC side surveys, wooden and stable vessels are selected. Although it's not preferred to make installation to wooden vessels due to impossibility of welding, however this problem is solved by using a proper aperture to mount echo sounder to side of the vessels. Multi beam sonar head is mounted to the starboard bulwark of the vessel in a way that fixed rigidly in one immovable position and away from any electrical and mechanical noise interference. This installation is crucial and required to prevent the sonar sound pulses from noises, which might be caused by vibrations come from the vessel engine. If there is any movement in the equipment seen during the survey or after the patch test, the patch test must be repeated; therefore, proper installation has a crucial importance. For this reason, the sonar head needs to be tided from both fore and aft sides of vessel by using a rope (Figure 3.4).

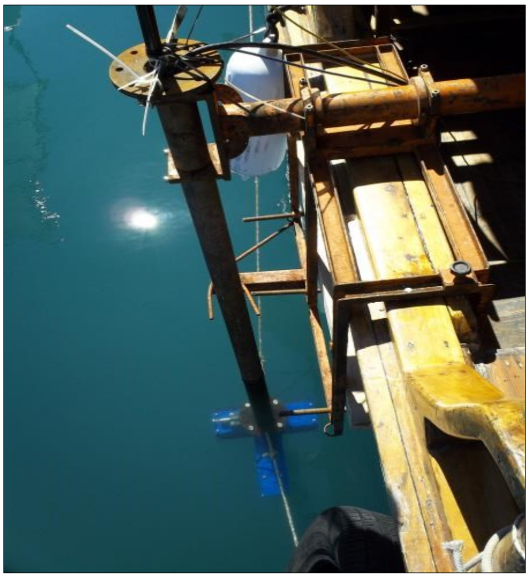

Figure 3.4 The installation of the multi beam transducer.

Other important component of the system is the motion sensor (IMU/MRU) mounted to the vessel's gravity center as close as possible. To find the gravity center, the blueprint of vessel is checked. The x axis of motion sensor represents the alignment of the keel of vessel and y axis represents the port and starboard sides of vessel.

Same as the echo sounder, the motion sensor's immovability is important; therefore the sensor needs to be mounted to the ground rigidly (Figure 3.5).

Figure 3.5 Motion sensor installation.

The dual antennas used to determine heading information are installed on the top of vessel across the vessel track direction. Antennas are mounted on a rod and the rod is mounted to the vessel rigidly to prevent from any movement during the survey (Figure 3.6).

Figure 3.6 The installation of heading antennas.

The aux GPS antenna is directly mounted on vertical alignment of sonar head to decrease the offset values against offset measurement errors (Figure 3.7).

Figure 3.7 The installation of auxiliary GPS antenna.

The process of physical alignment of the equipment on the vessel is referred to as offsets. The gravity center of vessel where the motion sensor is mounted is accepted as the reference point of all measurements. This point is determined by using the blueprints of each vessel used for both sides. As the offset measurement is crucial for accuracy of the survey data, measurements are referenced to the reference point of vessel. In this respect, offsets are measured using a metal tape and plumb bob. After making the first leg measurement, the second leg measurement is made in another direction to confirm the results. Usually a centimeter level disagreement is detected, and this error is compensated by averaging all measurements. As a next step, sonar head draft, which directly affects depth data, is measured. From the draft measurements, the water between sea surface and sonar head measurement plane is determined (Figure 3.8).

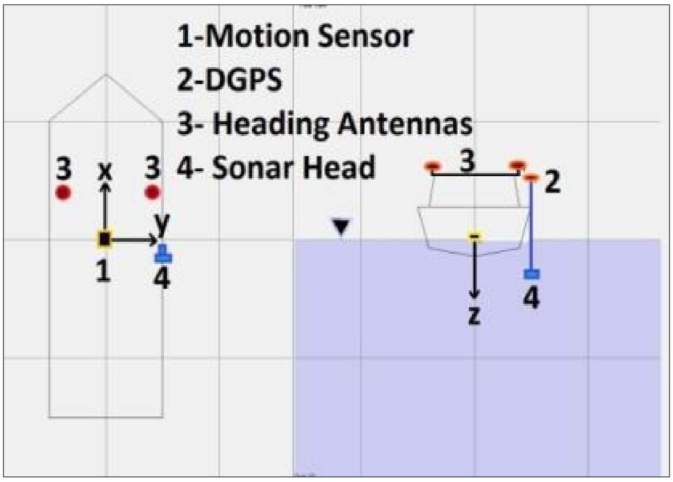

Figure 3.8 The system installation schema.

3.4 System Calibration

Before the measurements, the 'Patch Test' is required to eliminate the systematic errors due to instrumental synchronization and installation. In this test, Y-axis rotation (roll), X-axis rotation (pitch), Z-axis rotation (yaw) errors are calculated. For this purpose, ports, protocols, and services (PPS) cable is used for data flow. Since PPS which provides data packages in chosen time periods, is used in this study, the latency test was not performed.

For the patch test, the selection of the test area is important to determine not only the errors caused by installation, but also the angular misalignments and timing differences in the multi beam system hardware. To have better patch test results, some seafloor features such as slope, flat bottom and discrete objects (i.e. a pipe, driven pile, shipwreck, big concrete block or dredged channel) are required in the patch test area. Hence, matching and locating more observable features ensure better results in the patch test. In this study, the project area is selected as a patch test area because the dredged channel in the survey area is ideal for this purpose.

Before the patch test data acquisition, the updated sound velocity profile is determined and entered as an input to the system. Also the skipper is used to observe the patch test line directions and vessel speed. Three tests performed in this area and proper lines planned for each test (Figure 3.9).

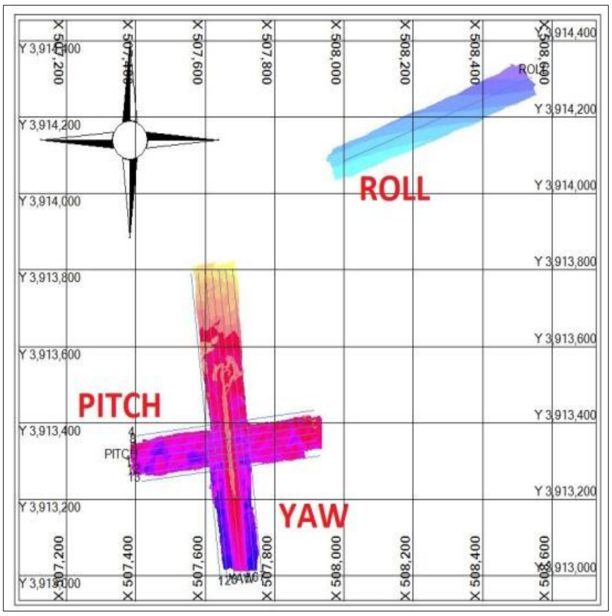

Figure 3.9 Patch test lines and areas (TRNC side).

All patch tests are carried out as described in the System Calibration Section. The test data is evaluated onboard after test survey is completed. A rapid overlook and noise cleaning are performed on data using the survey software; subsequently patch test is carried out with sections selected over the patch test data.

3.4.1 Pitch test application

For pitch test, the section is taken along the nadir of survey data respect to the alignment of lines (Figure 3.10).

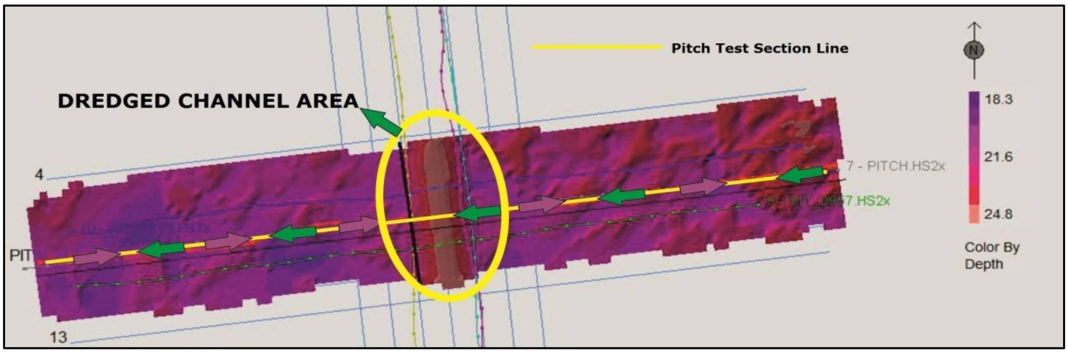

Figure 3.10 Pitch test section line.

In the test screen, angle step is set to 1° for DGPS positioning solution. At the beginning ‘coarse’, ‘medium’ and ‘fine’ level step sizes are selected in order. In error graph, practically having ‘U’ shape is preferred, but this is not always possible. However, it’s achieved in this study’s patch results (Figure 3.11).

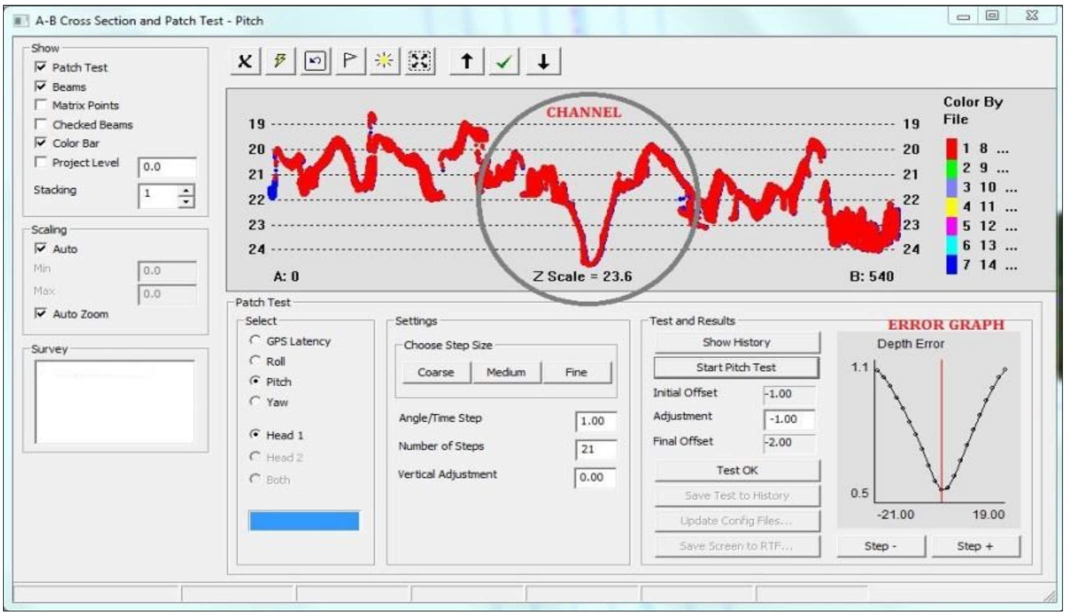

Figure 3.11 The pitch test results.

It is also seen that two data sets (blue and red) overlap perfectly after the test. Besides, it is also observed that the data over the channel matched rigidly. At the end of the test, ‘test ok’ button is clicked to save the test results.

3.4.2 Roll test application

For roll test, the section is chosen as being perpendicular to the survey lines (Figure 3.12). Since the roll error mostly affects the side beams, this section is selected to ensure a better visualization.

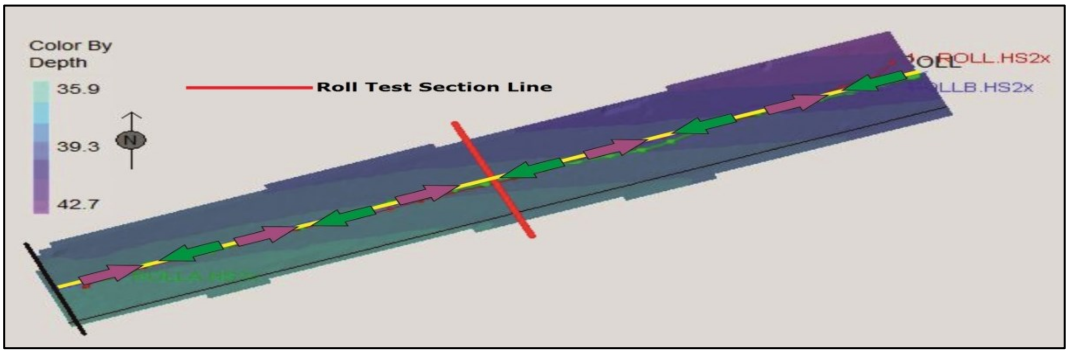

Figure 3.12 Roll test section line.

Same procedure is applied as done in the pitch test and the result screen is given below (Figure 3.13).

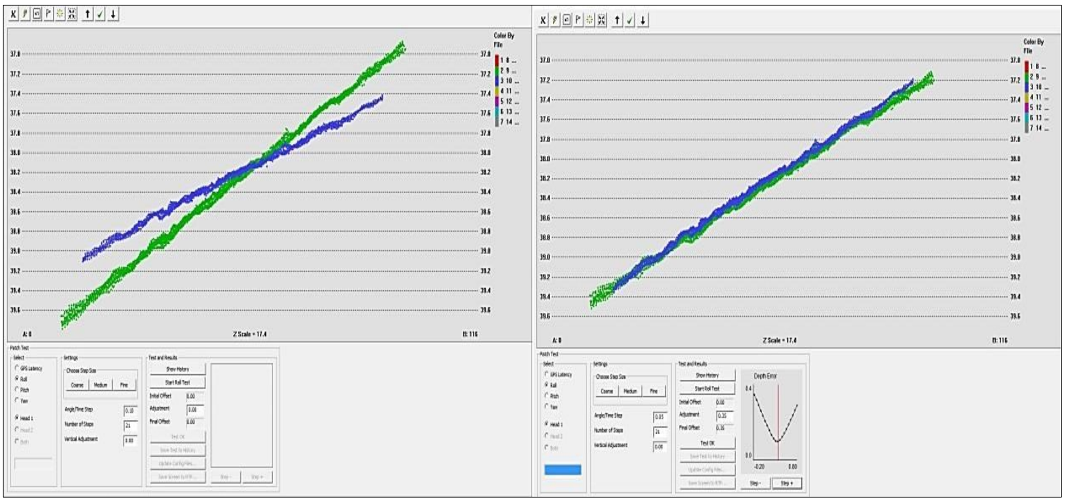

Figure 3.13 The roll test results.

The results show that the series of iterations made by the software has performed a better match between the overlapped data. The roll error is determined and eliminated afterwards.

3.4.3 Yaw test application

For yaw test, a cross section is taken between two survey lines. The lines are selected to cover the dredged channel on either side (Figure 3.14).

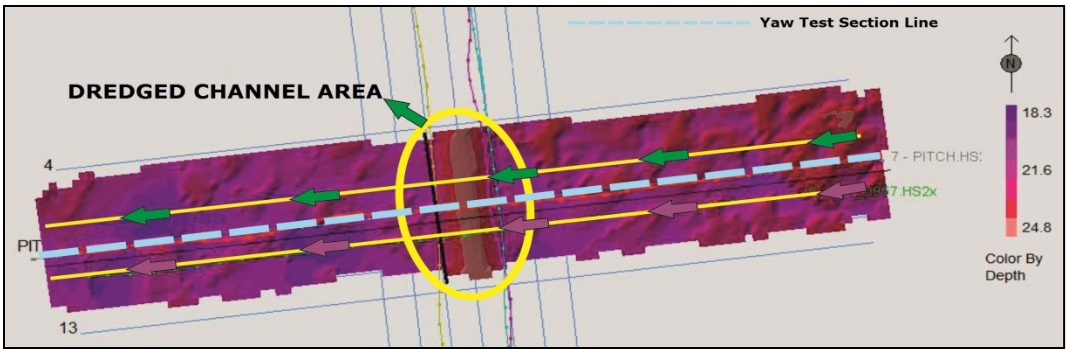

Figure 3.14 Yaw test section line.

The same patch test procedure is applied for this test too. Both survey data along the section has overlapped perfectly after the yaw test. The results are given in Figure 3.15.

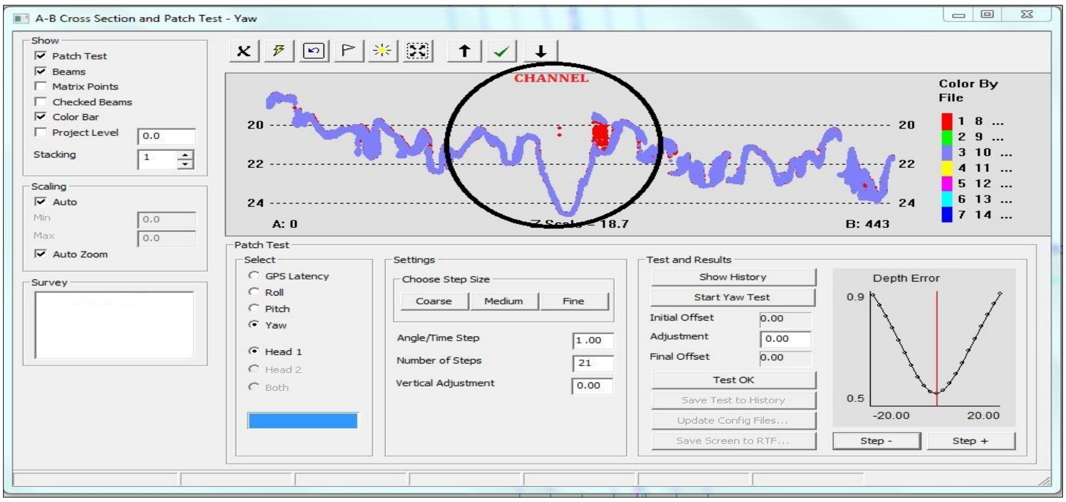

Figure 3.15 The yaw test results.

3.4.4 Patch test results

Patch test results are listed in the Table 3.1 for each survey.

Table 3.1 The patch test results of all surveys done in 2013 and 2014.

Survey	**Test Results**		
	Pitch	**Roll**	**Yaw**
Turkish Side June, 2013	-0.50°	0.10°	-1.00°
Turkish Side October, 2013	-1.00°	-0.90°	-1.00°
TRNC Side July, 2013	-1.00°	0.25°	-1.00°
TRNC Side March, 2014	-1.00°	0.35°	0.00°

Each survey couple is conducted by using the same vessels and the equipment installed almost at the same spots with close offset values. This enables to crosscheck the offsets and patch test results.

3.5 Data Acquisition

First the sound velocity data is collected by using CTD logger. Due to changes of water parameters during the survey, CTD data are logged twice during each survey, one at the beginning and another one at the end of the survey. Besides, sound velocity sensor data is monitored during the survey in case of any velocity changes. The sound velocity profiler needs to be deployed to the sea from the side of vessel, as slow as possible to reduce the sampling interval (Figure 3.16). Then the collected data is downloaded to the survey computer as an input to the survey software.

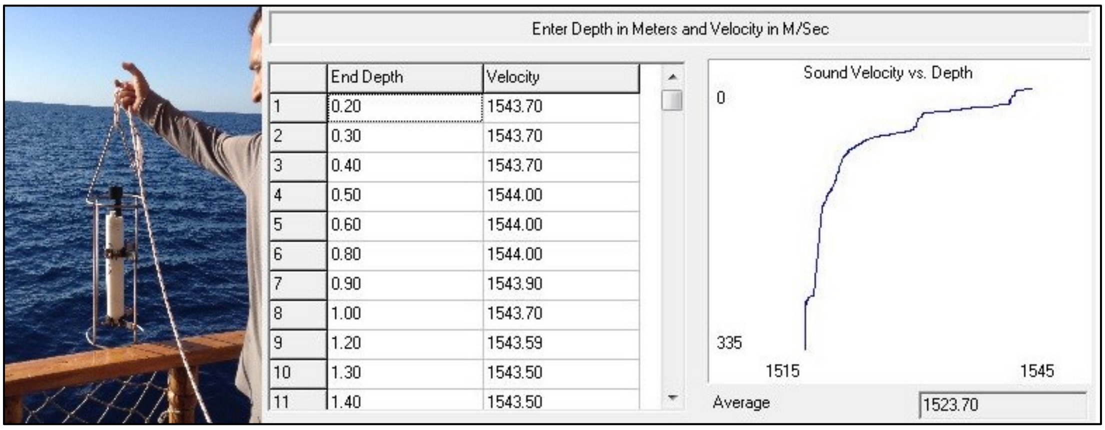

Figure 3.16 CTD deployment for sound velocity measurement and velocity graph.

Before starting to multibeam survey, the real-time depth value needs to be checked by using bar-check. For this reason, the vessel is tied to land side for stability and a calibrated rope which tied to a disk, is deployed near by the echo sounder and real-time depth value is checked simultaneously. This progress is repeated twice and only ±2cm difference is observed. After this progress, the system is accepted as ready for survey.

In this study, dredged channel area is covered for both sides and for all surveys in the specific route. All data is recorded in a log file as raw data. The recorded raw data includes all motion recordings of vessel (pitch, roll, yaw, and heave), 3D positioning information (X, Y, Z) and time tagging of survey data. Those survey data are collected along the survey lines, which configured by the skipper (Figure 3.17). Survey lines are defined taking the depth changes into consideration. According to the depth changes, the coverage is also changed relatively. Each survey line is tagged with a unique name for making easy to take notes about them. This helped to disable the lines which are not be used in the course of data processing section. During the trial, all return signals are recorded together with the corresponding GPS measurements to determine the exact location.

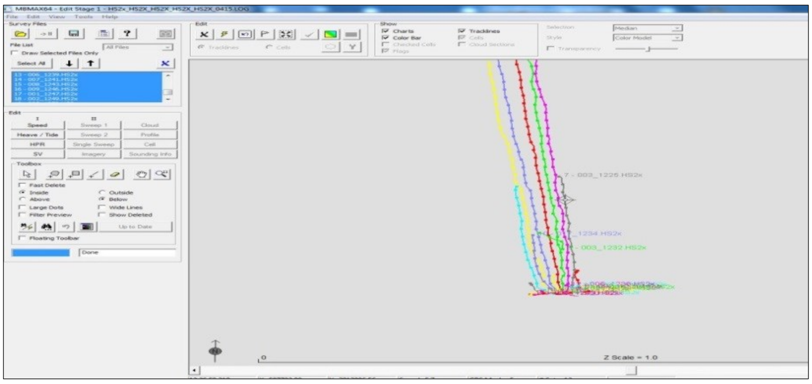

Figure 3.17 Tracks of survey lines.

In addition, the echo sounder draft is measured before and after the survey in case of any draft changes.

The whole survey activity is observed from the survey screen which is also shared with an extra monitor with skipper. The use of dual survey screen enabled to follow the whole survey activity. The first screen contains echo sounder control window, which makes possible to change signal gain, power and pulse length in real-time. This screen also includes raw and corrected depth information, beam pattern window and multibeam waterfall. These are developed to follow the seafloor topography during the survey (Figure 3.18).

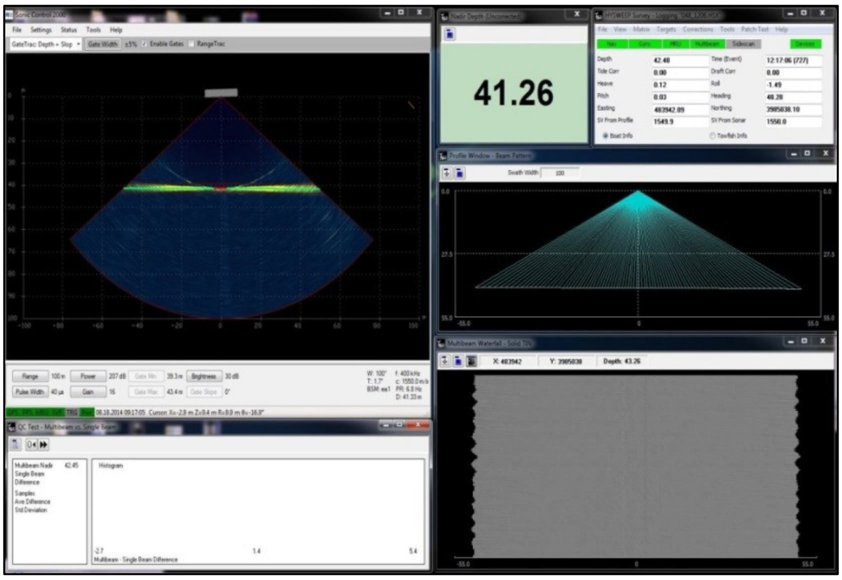

Figure 3.18 The first survey screen.

The second screen is shared together with skipper to direct the vessel easier. The screen includes the coverage illustration and survey line directions to steer the vessel regarding to this information. This screen also contents the information such as, distance to end of the line, heading, and the metadata of recorded file. The data coverage illustration ensures the %100 data coverage of the survey area (Figure 3.19).

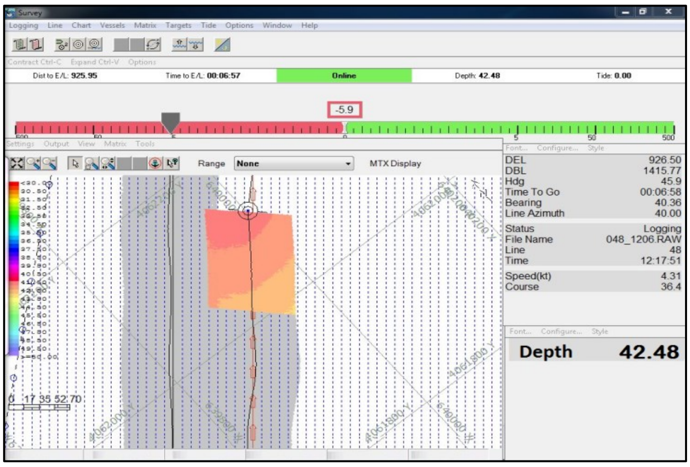

Figure 3.19 The second survey screen.

By the end of data acquisition, all collected data is stored on a hard drive for to prevent any data loss.

3.6 Data Processing

The aim of this step is to make ready all the data collected for the analysis. This is done by checking and cleaning it from the errors and noises (also called spikes). In other words, the navigation track lines, heave-pitch-roll, tide-and-draft and sound velocity profile information are reviewed while processing. The raw data is opened in the Hypack software editing tool. The tool provides to use filter option to automatically clean the noise data, however, some data loss can be occurred while cleaning operation, manual check and cleaning is preferred for this purpose.

It is also important to check irregular values from the motion sensor. Sometimes it is possible that the sensor records spike data and this can cause wrong compensated soundings. In this case, the motion data is checked and wrong data is cleared or interpolated.

Collected data is edited by using an area-based editing tool which groups points into ‘cells’ and applies statistical filters based on the distribution of z-values in each cell. Noise data, major flyers, blowouts or bad outer beam data are cleaned from each data set to not effect to final dataset (Figure 3.20).

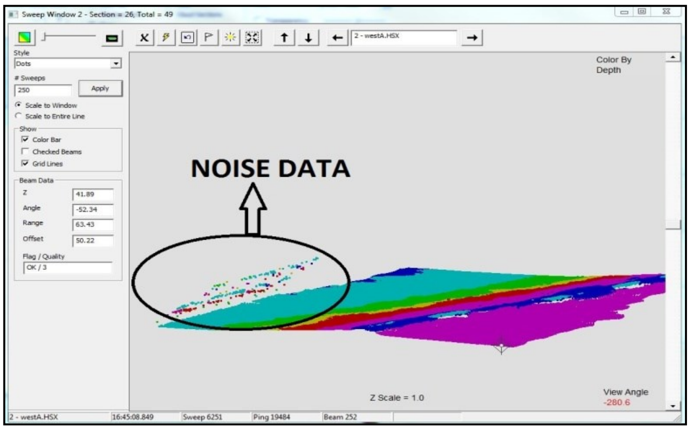

Figure 3.20 Noise cleaning process.

The tide information requested from tide station is used to reduce the depth data in order to reference leveling system. All process is completed with the editing tool of the Hypack. Improper survey lines are excluded from final data and data cell size is selected. Afterwards, soundings are exported as X, Y, Z file for 3D modeling.

3.7 3D Modeling and Surface Creation

The most exciting processing step for the bathymetric survey is the modeling of the seafloor and the comparison of multi-temporal multibeam bathymetric data sets. The bathymetric digital terrain models or DEMs are the real strength of multibeam sonar measurements providing an improved vision of the seafloor.

The demand for bathymetric digital terrain models or DEMs are growing rapidly with the increase in use of GIS and with an increase in the quality of information extracted using elevation data. These models are seen as a critical source of information for change detection analysis.

In this study, 3D surface modeling application is carried out with the Fledermaus software having features for the 3D visualization and for the analysis of elevation data. Hence, full resolution bathymetric and terrain models can be created and interacted with this software (Figure 3.21).

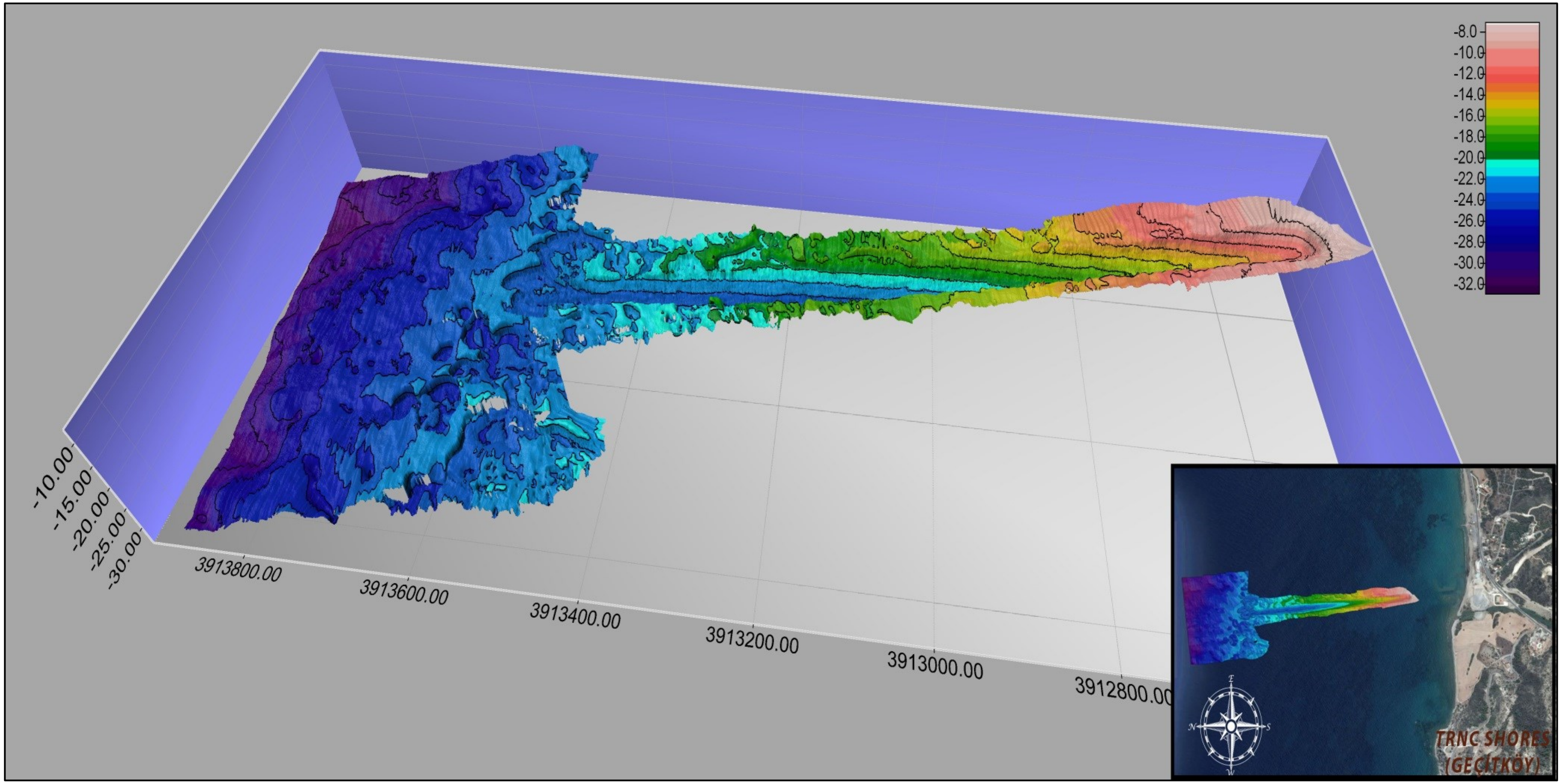

Figure 3.21 The 3D seafloor model with contour lines in the TRNC side.

The software operates to create 3D model with equidistant grid algorithm. The depth values are calculated for gridding with method of weighted moving average. This method analyses data points by creating a series of averages of different subsets of the full data set.

Since multibeam data files include millions of XYZ information, for visualizing, analyzing and modeling the multibeam echo sounder data in order to implement specific representation of seafloor, robust requires sufficient computer system and faster modeling algorithms are needed. The multibeam echo sounder system used in this study, provides equiangular and equidistance depth data. With the Equiangular swath measurement, it is possible to collect data in narrower intervals; hence the shallow water measurement has achieved approximate 0.20 m x 0.20 m resolution in nadir. Due to having huge data sets and also to prevent seafloor model from interval difference between nadir and side beams, a frequent type of filtering is used to increase the grid interval distance from approximate 0.20 m by 0.20 m to a grid of exact 0.5 m by 0.5 m. This grid calculation is made by using weighted moving average which is flexible for surface modelling.

Four different sets of XYZ data are exported and used to create 3D models. Due to each survey comprises different area coverages, all sets of data are cropped as not to overlap to each other. Multi beam echo sounder data collected along the dredged channel comprises depth information of shallow parts of the pipeline route (8-30 m water depth). Between these depths, there are two channels dredged by a dredging ship on each sides of this project route. Inshore entrance of pipeline in both sides is located in each of them. In the Turkish part, the first survey is completed in June 2013 and the second one is performed in October 2013, whereas in the TRNC part, surveys are completed in July 2013 and March 2014, respectively. Four 3D surface models (for two phase measurements from each side) are produced as an output for the model analysis. The data coverage of the Anamur side is specified as 2000m along the route and 150m widths and for TRNC side 1300m along the route and 125m widths. 3D seafloor models of each side are given in the following Figure 3.22, Figure 3.23, Figure 3.24 and Figure 3.25.

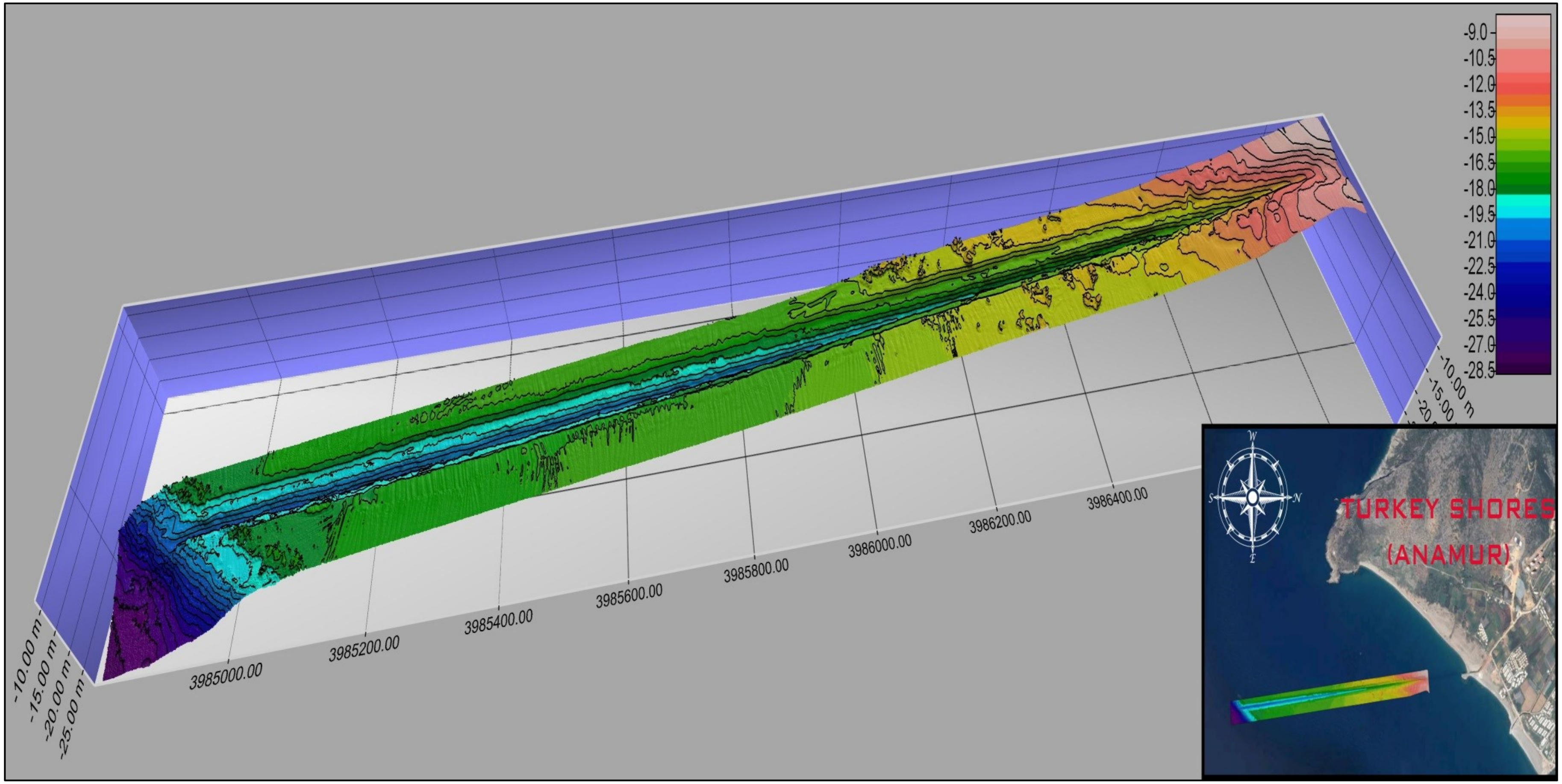

Figure 3.22 The 3D model of the survey conducted in the Turkish side on June, 2013.

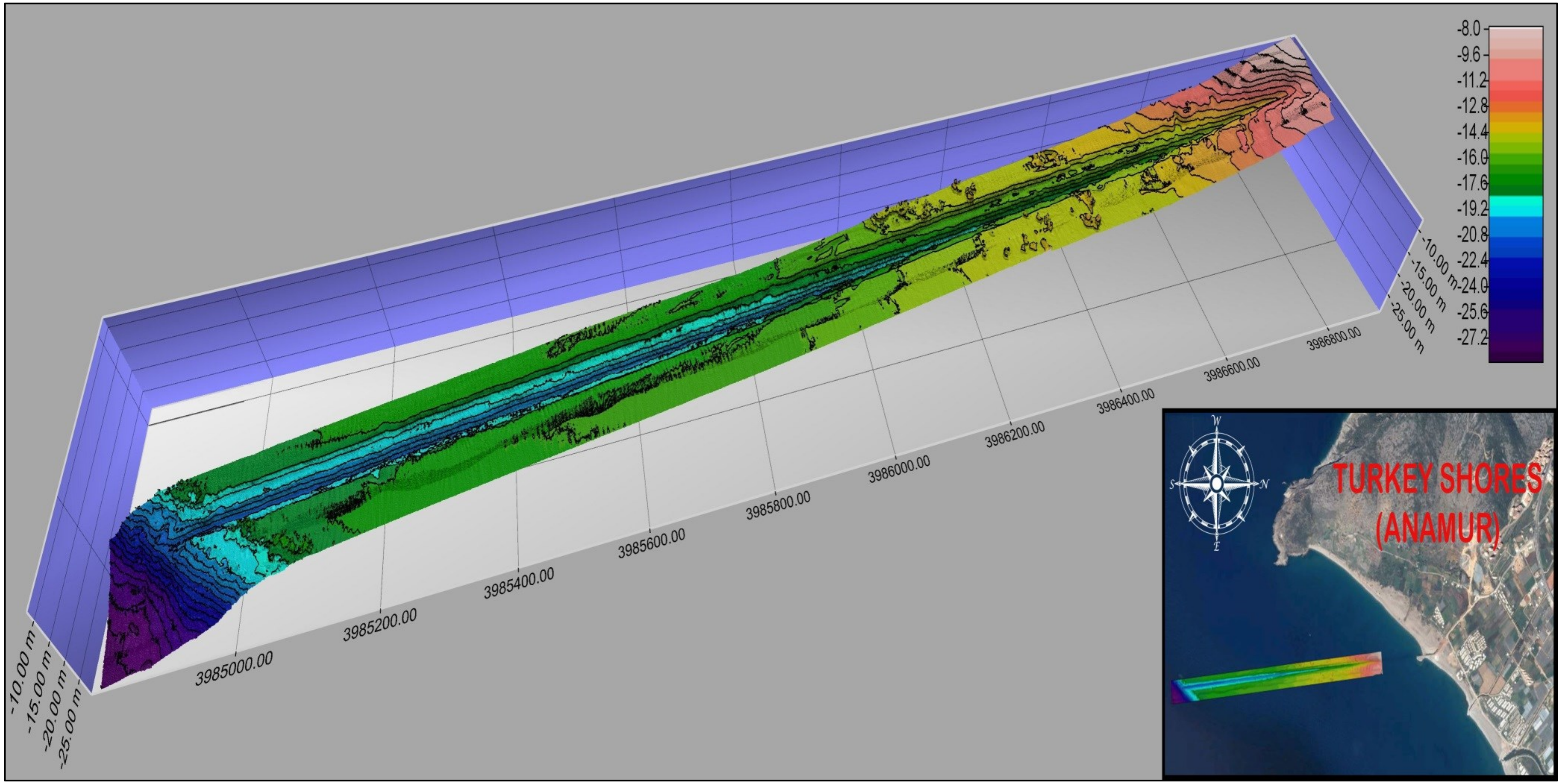

Figure 3.23 The 3D model of the survey conducted in the Turkish side on October, 2013.

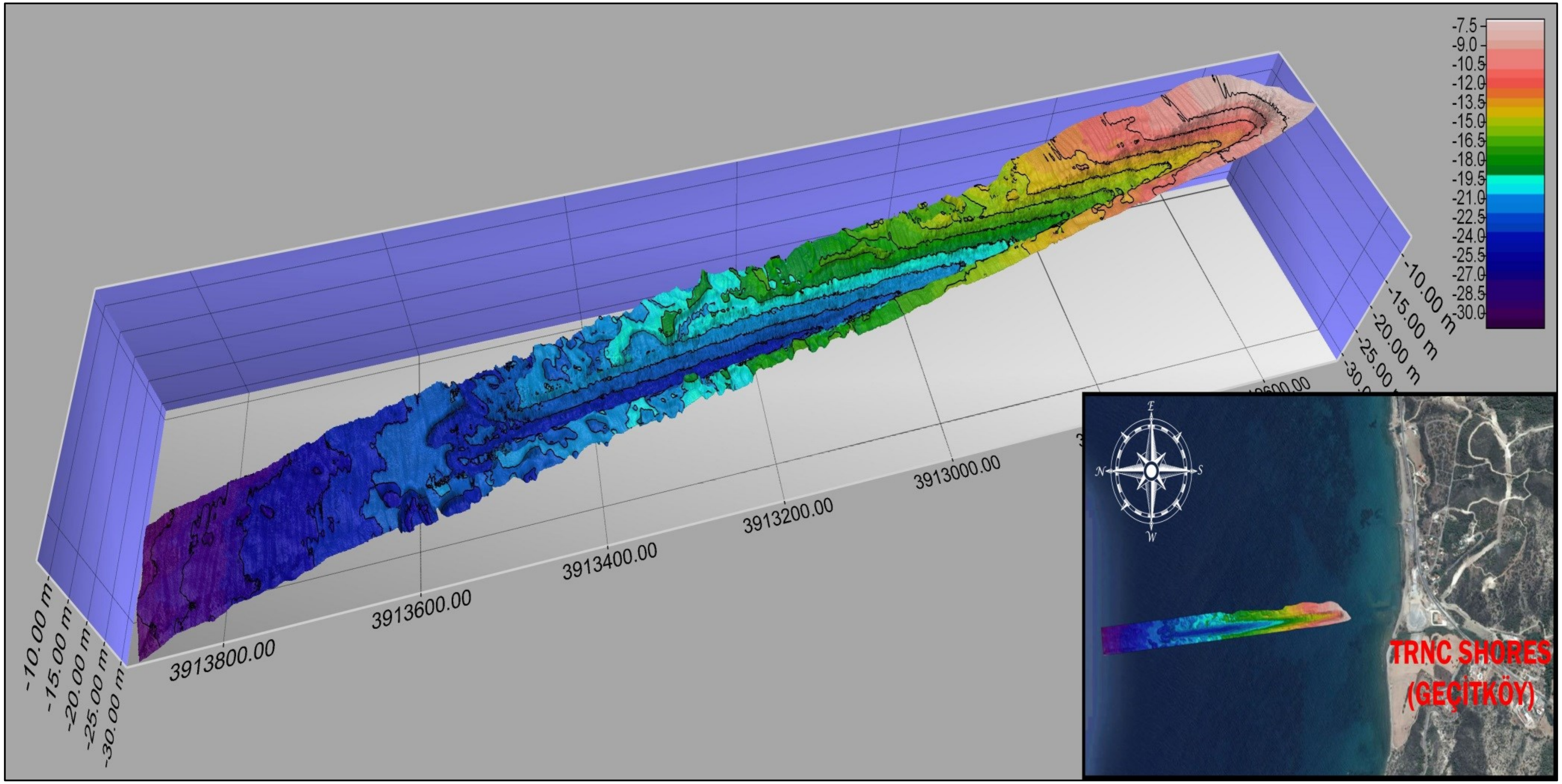

Figure 3.24 The 3D model of the survey conducted in the TRNC side on July, 2013.

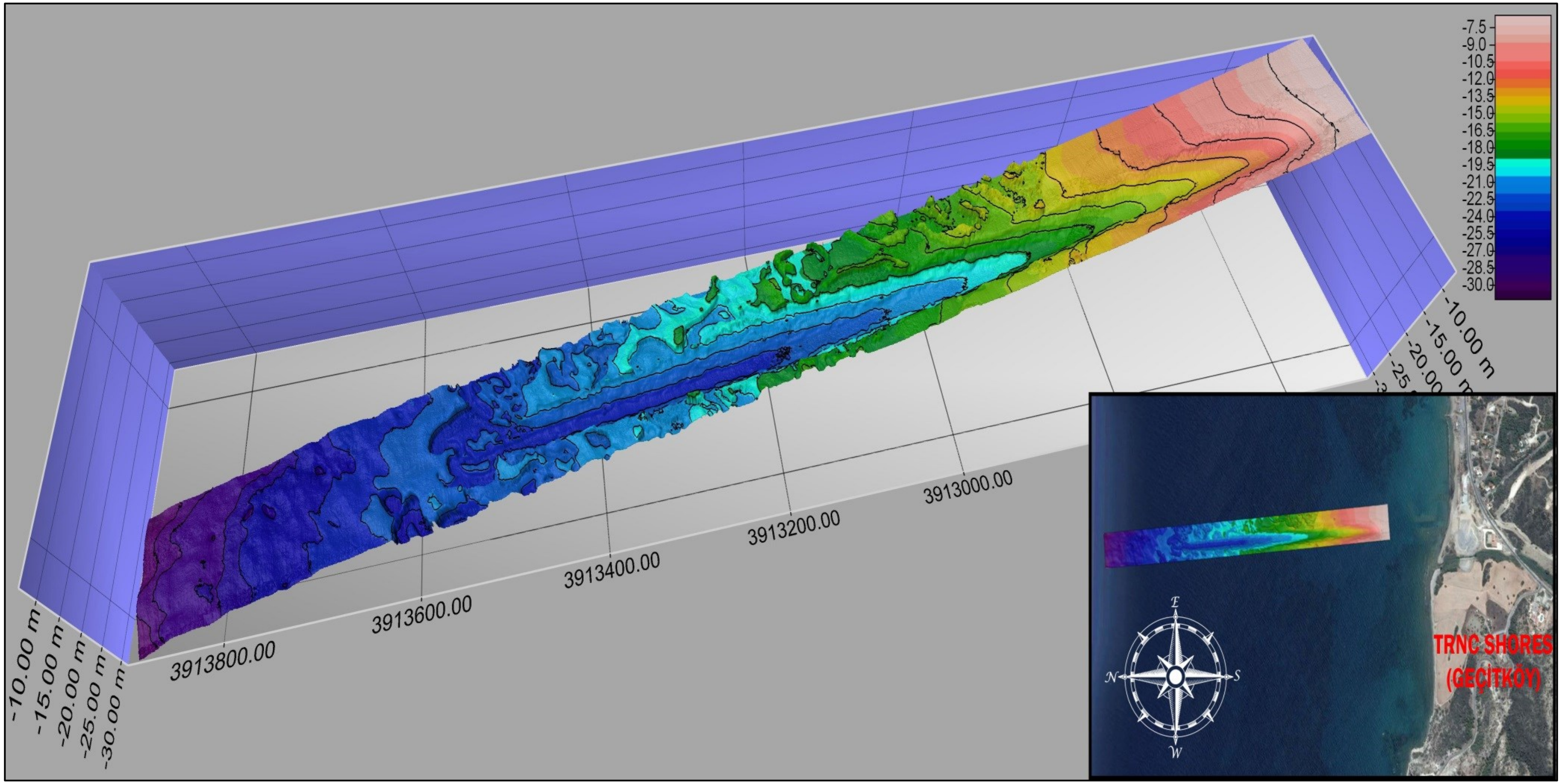

Figure 3.25 The 3D model of the survey conducted in the TRNC side on March, 2014.

3.8 Change Detection Analysis and Results

In this study, 'time' is used as a 4^{th} variable along with XYZ information to detect the changes in the multi-temporal survey data sets. By adding time as another dimension, it is aimed to create 4D high-resolution survey data couples for the analysis.

By using surface difference calculation tool, the differences between two seafloor surfaces are modelled as change. The algorithm determines the height at the bin center from the other surface using linear interpolation of the nearest bins at the point of interest. The determined surface differences from the two height values are recorded in the output file.

In order to calculate and create the models for the Anamur side, 0.50m x 0.50m resolution data sets are used. The analysis is carried out in the area having a size about 2100m long and 150m width.

After the Anamur side calculations, likewise 0.50m x 0.50m resolution data sets are used to create and analysis the change model. TRNC side analysis is carried out in the area having a size about 1300m long and 125m width.

As shown in the Figure 3.26 and Figure 3.27, the 4D high resolution data enable to detect and display significant dynamic information related to the sea dynamics and natural topographic features. Both survey areas have surface differences along and around the dredged channel. These changes are detected especially on the channel route due to deformation caused by dredged channel slopes, post dredge siltation and material convection depending on sea dynamics. As a physical condition, the dredged channel acts as a natural suspended solid material and siltation trap due to being deeper than the seafloor around the area. Both surface difference analyses show that the depth change is consisted in direct proportion to the time lapse between survey couples.

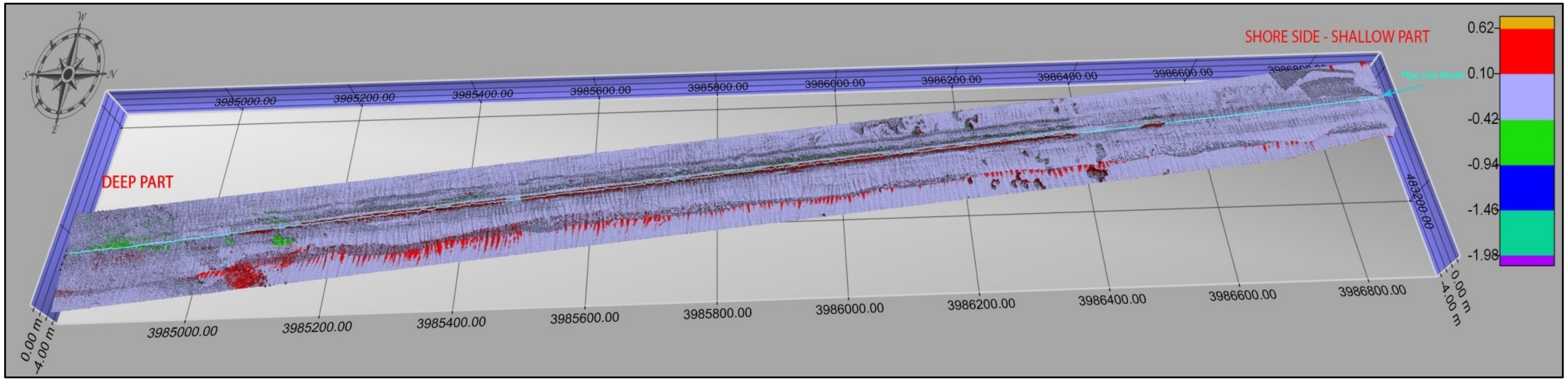

Figure 3.26 The change detection analysis in the Anamur side.

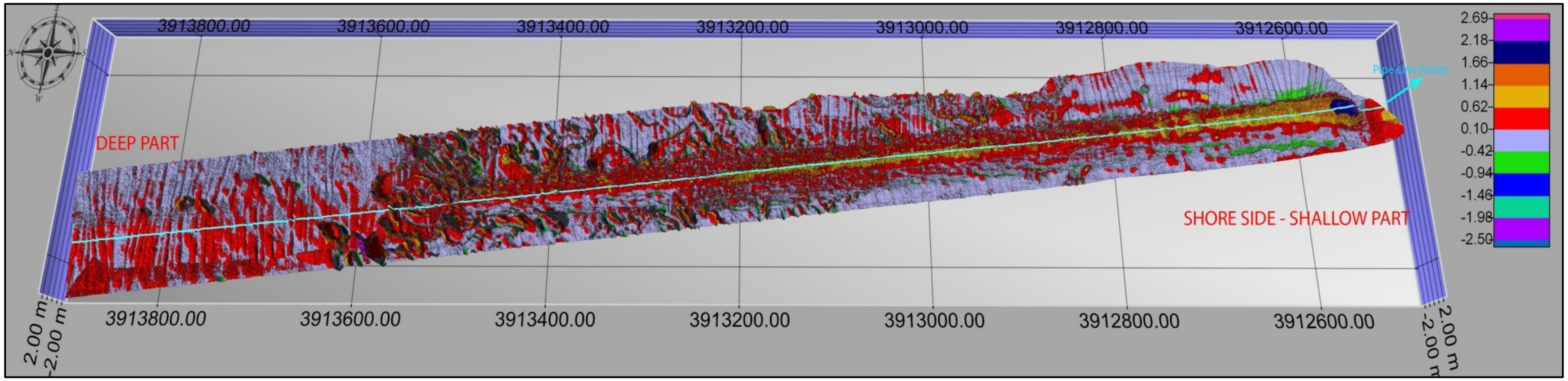

Figure 3.27 The change detection analysis in the TRNC side.

Change detection analysis is conducted in the Anamur side over 317.240 m² area. The results showed that 43.693 cubic meters material is filled the survey area. Besides, 4839 cubic meters material is disposed from the area. The results showed that the area has changed 38.854 cubic meters in four months after dredging according to the volume calculation. This implies a 0.12 m change per m² depth variations in the study area and the standard deviation of surface difference is calculated as 0.14m. The seafloor change is observed from channel slopes through center of the channel and around the dredging area. Slides are formed in depths in the outer part of the Anamur foreland alignment. Based on this observation, it is understood that the foreland has acted as a natural protector from coast to -18m water depths. The analysis in the Anamur side of study area is performed in four different parts. In each part, a cross section is created to observe the differences between the surfaces and for the comparison.

As it is shown in the Figure 3.28, the shallower parts of survey route stood are more stable than the middle and deeper parts. Because it is observed that the movement direction of the siltation is from shallow to deep. As of it, the shallower part is prevented from the material leak due to siltation, less than the deeper part of the survey area. Additionally, in some places, especially outside of the channel, the increased depth shows that some high density dredged material settled and thickened enough and resisted to leak into the channel.

The cross section of the middle part shows that the change is more visible on and around the channel. It is observed that the discharges left by dredging vessel nearby the dredged channel during the operation are slipped into the channel. Especially from the east side more material leaked into the channel. Most of the change is detected along this area since this part is out of foreland's protection. The change detected is approximately 30cm in that part of dredge as can be seen in the Figure 3.29. The difference between the models with regard to time is decreasing through the deeper stages of the channel. As it can be seen in Figure 3.30, the difference is being decreased.

The deeper part cross section shows almost the same results with the end of the middle part section. While the depth is decreasing at the end of the channel, the emission of soft materials is leaked to the deeper part of the area. The slope at the end of the dragged channel has also acted as another protector.

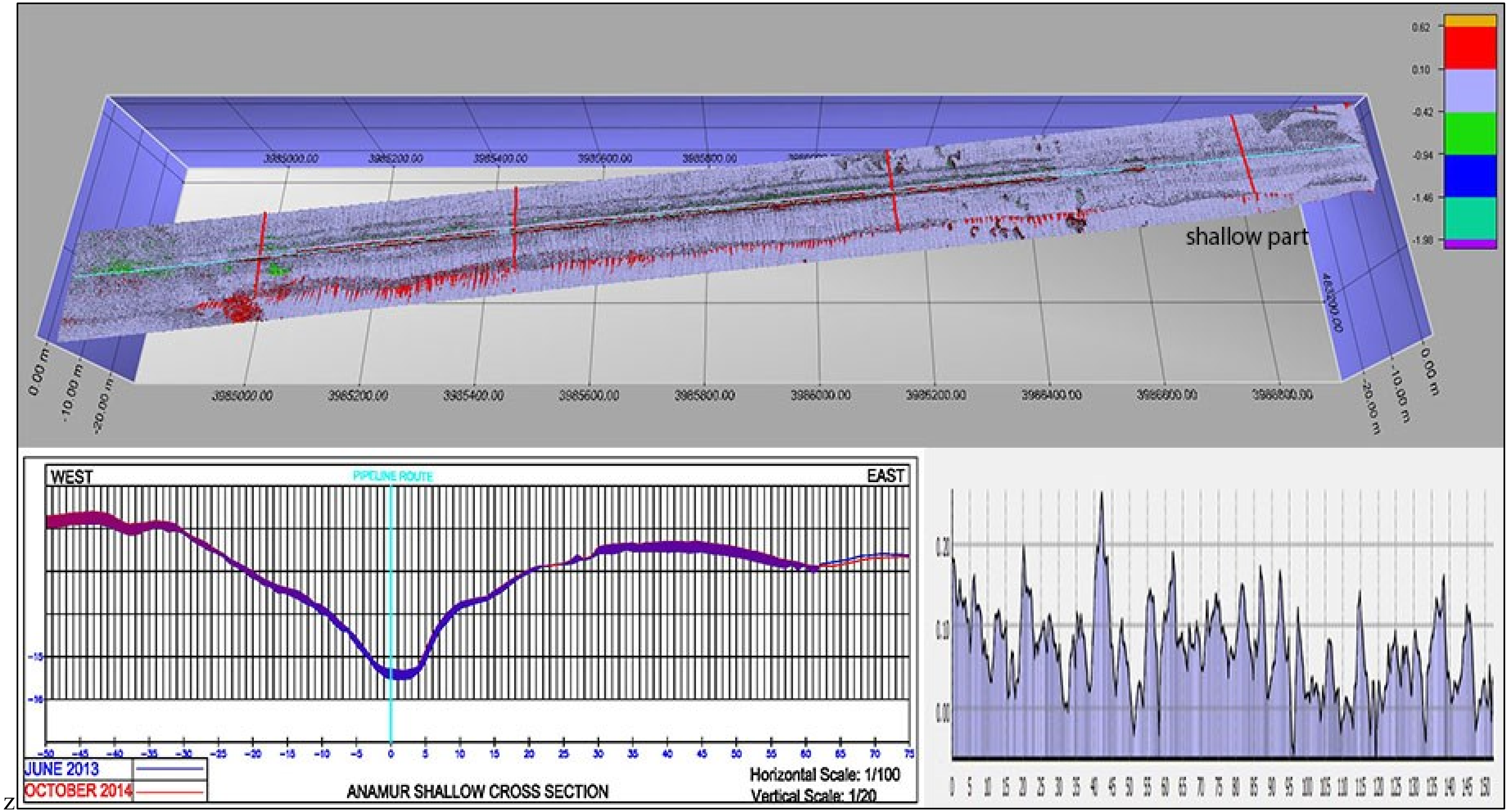

Figure 3.28 Shallow part cross section of the Anamur side.

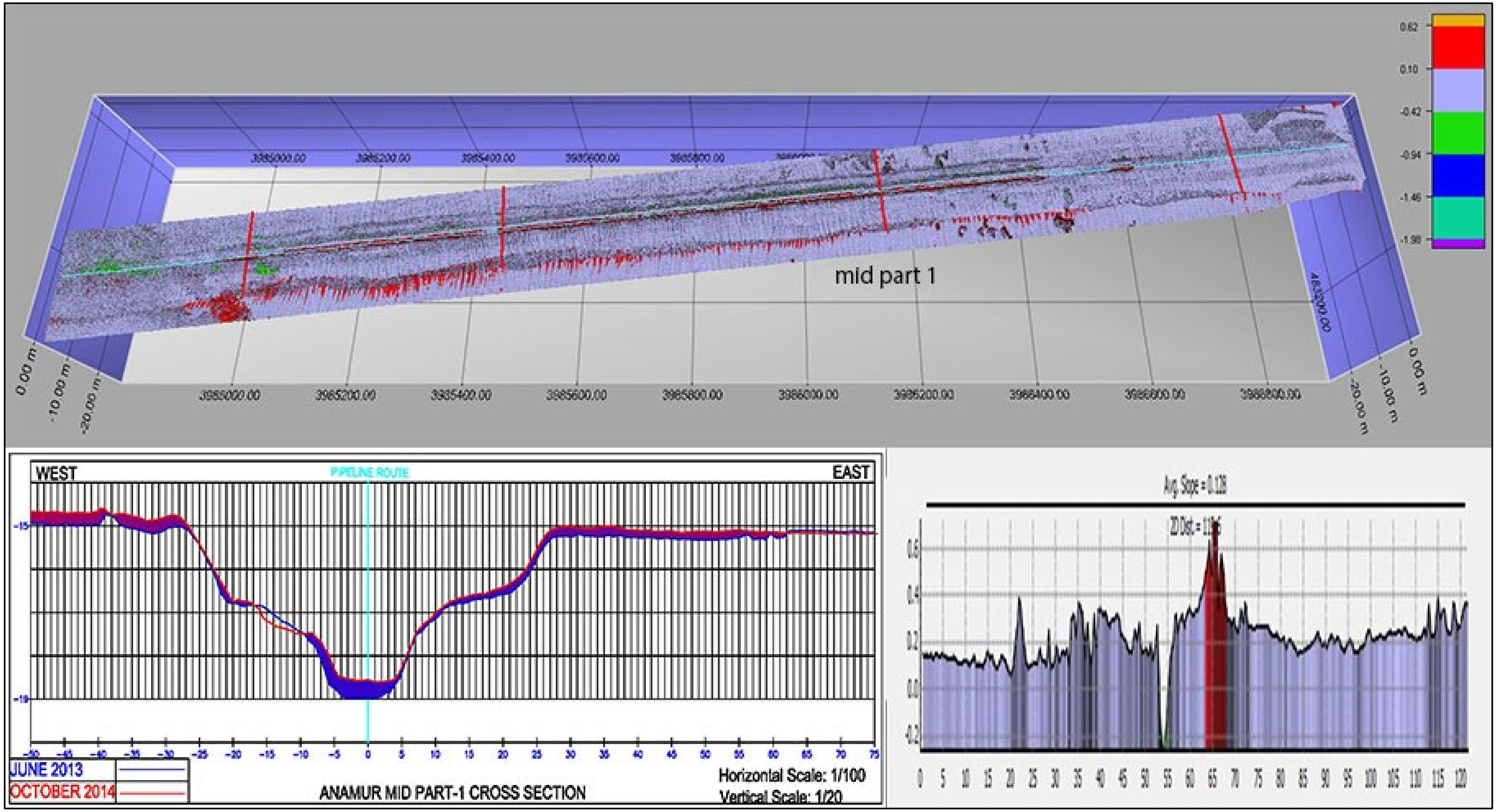

Figure 3.29 Mid part-1 cross section of the Anamur side.

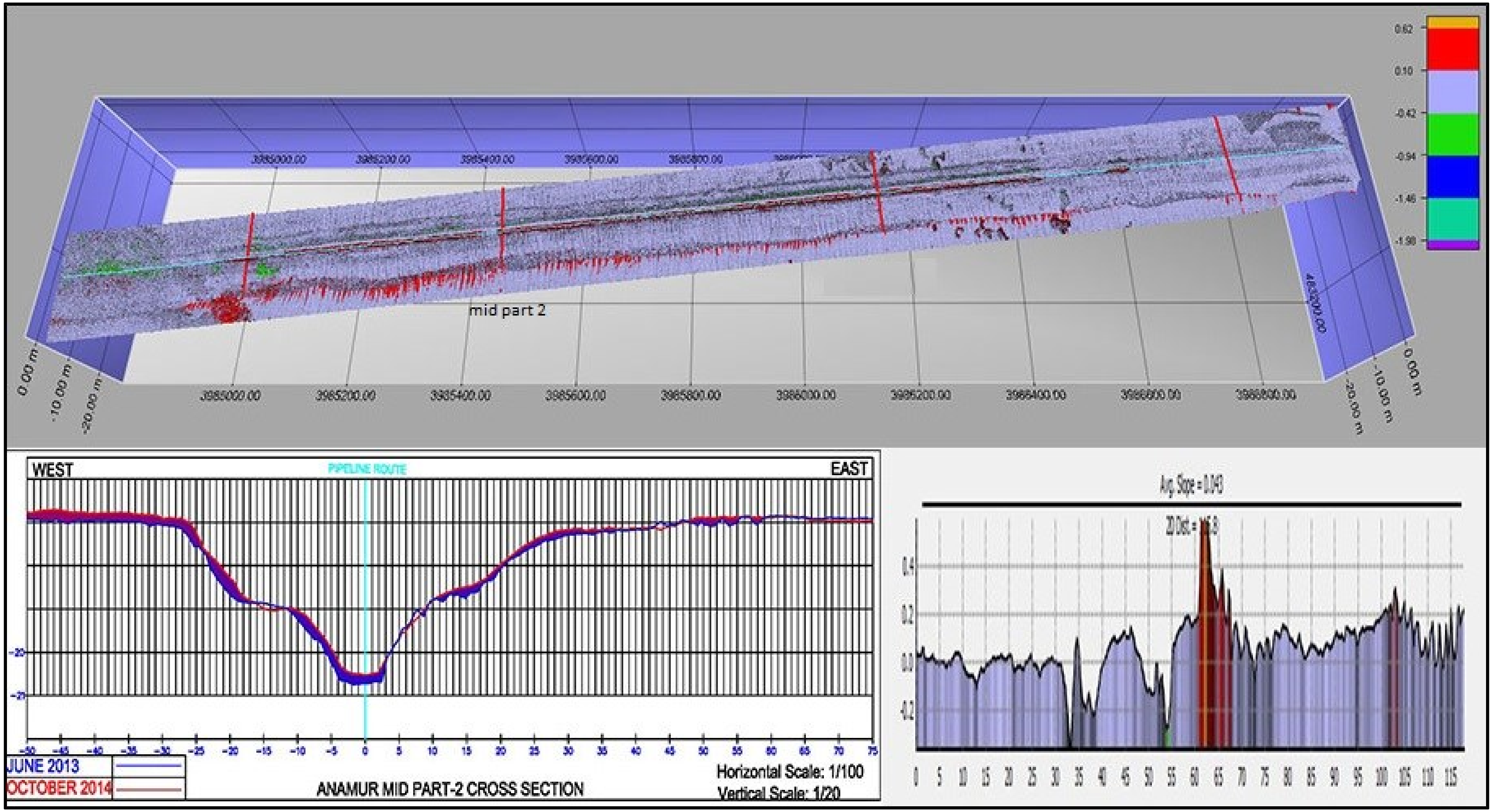

Figure 3.30 Mid part-2 cross section of the Anamur side.

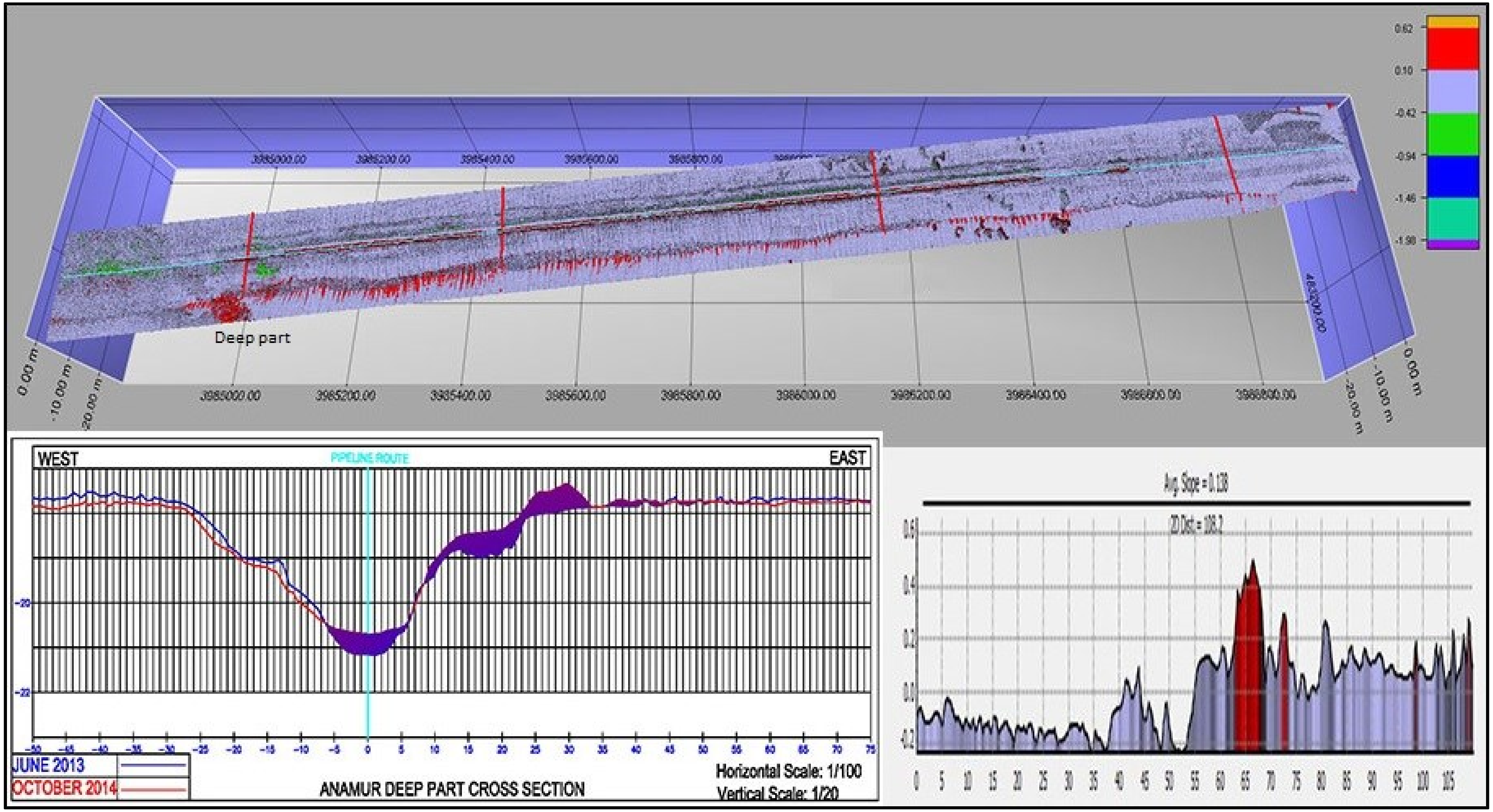

Figure 3.31 Deep part cross section of the Anamur side

For the other side of the project area, nine-month interval multi-temporal seafloor models are used. Change detection analysis is carried out in the TRNC side over 161.102 m² area. The results show that 26.746 cubic meters material is filled from in or around the survey area. Besides 14.044 cubic meters material is moved out or spread inside of the area. This shows that the area has changed 12.702 cubic meters according to the volume calculation done for nine months after dredging. This means 0.08 m change per m² in survey area and the standard deviation of surface difference is calculated as 0.12 m.

Same as the Anamur side, seafloor slides from channel slopes and materials left during the dredging operation caused a change. Also sea dynamics transported sediment materials into the channel. In this section, it is observed that especially the channel area has changed along the route.

The beginning of the channel dredge starts from -8 meters water depth. As the sea surface waves come to shores, they break and form a foamy, bubbly surface. This surface is defined as the surf zone which usually is between 5m and 10 m water depth. This area meets with the inflow of the channel of the TRNC side. Due to being a surf zone, major changes are detected in this area. For this reason, two cross sections are selected and named as 'shallow part 1 and 2' to display the effect of surf zone. Figure 3.32 and Figure 3.33 show approximate 2m depth change observed in the beginning of the channel.

The third profile is selected in the middle part of the channel and named as 'mid part'. It shows that the same transport regime occurs as in the Anamur side but nine months interval of data collection caused to detect more deposition on the channel which is approximately 50cm as shown in the Figure 3.34. In addition, because the TRNC is an island country in the middle of Mediterranean Sea, the shores are facing with more metocean factors like ocean currents, meteorological conditions, and so on.

The deeper part of the channel indicates consistency as regard to the surface differences with the profile in the middle part of the channel. The approximate depth change is observed as 50cm in this area (Figure 3.35).

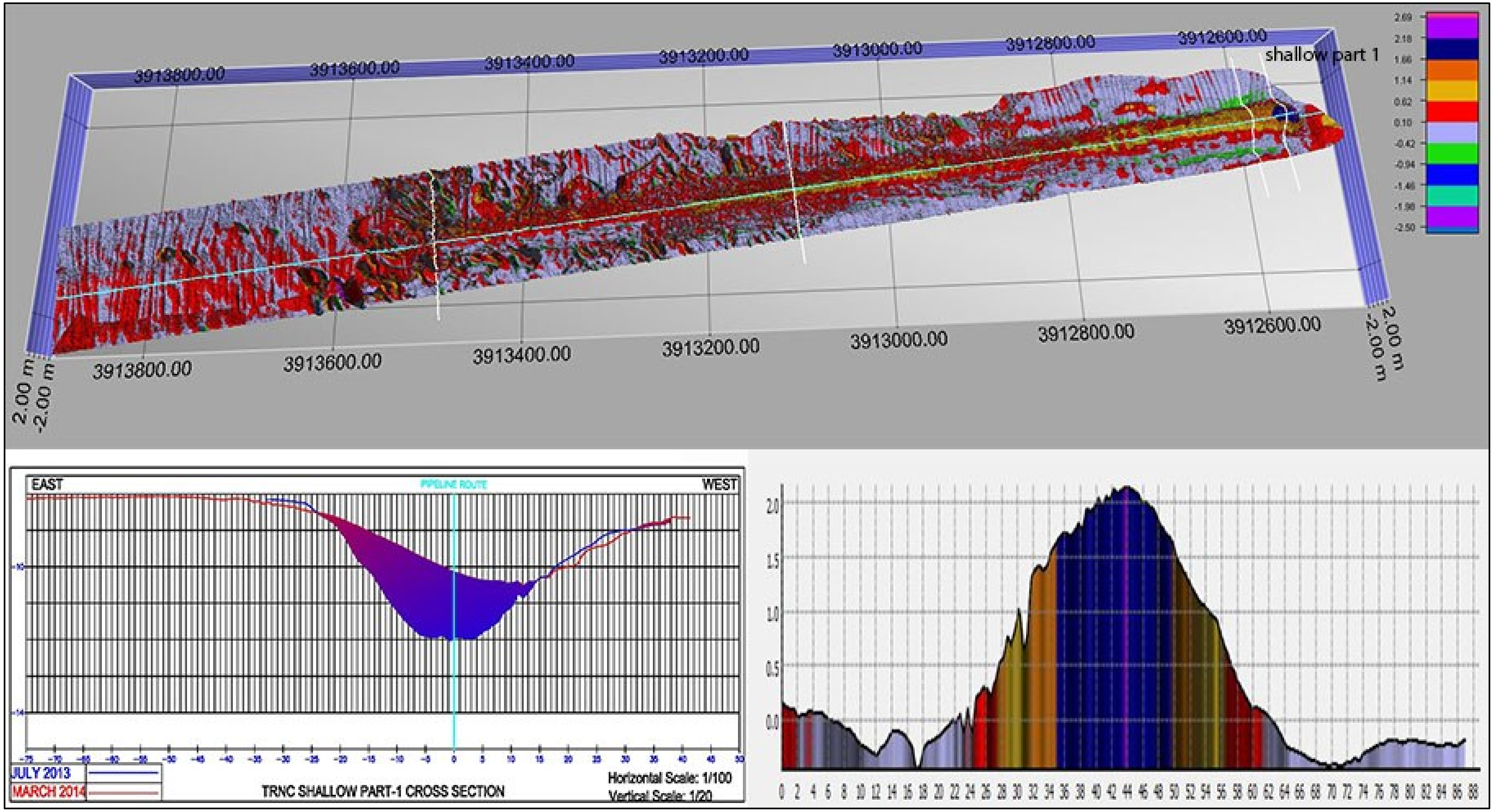

Figure 3.32 Shallow part-1 cross section of the TRNC side.

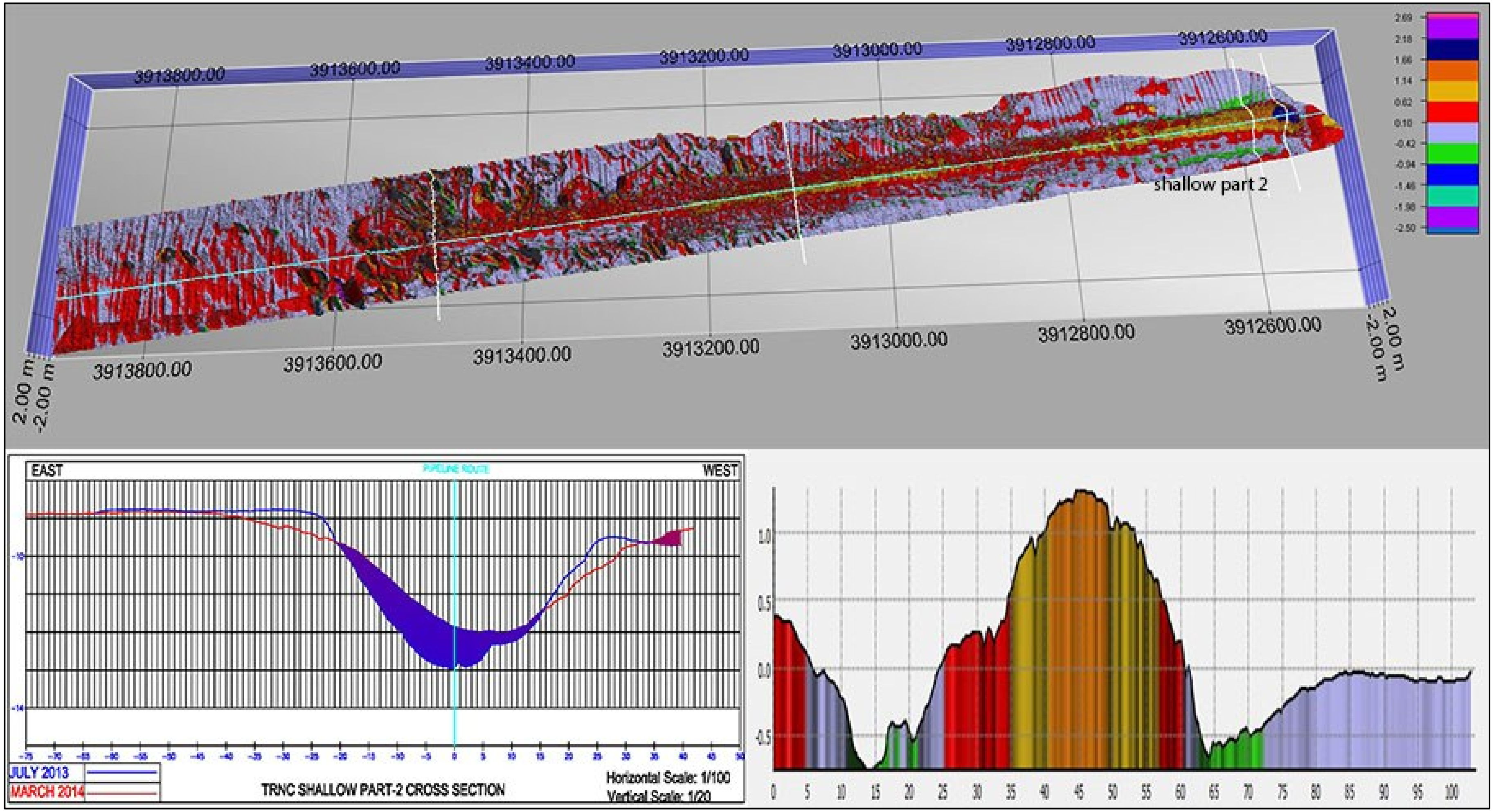

Figure 3.33 Shallow part-2 cross section of the TRNC side.

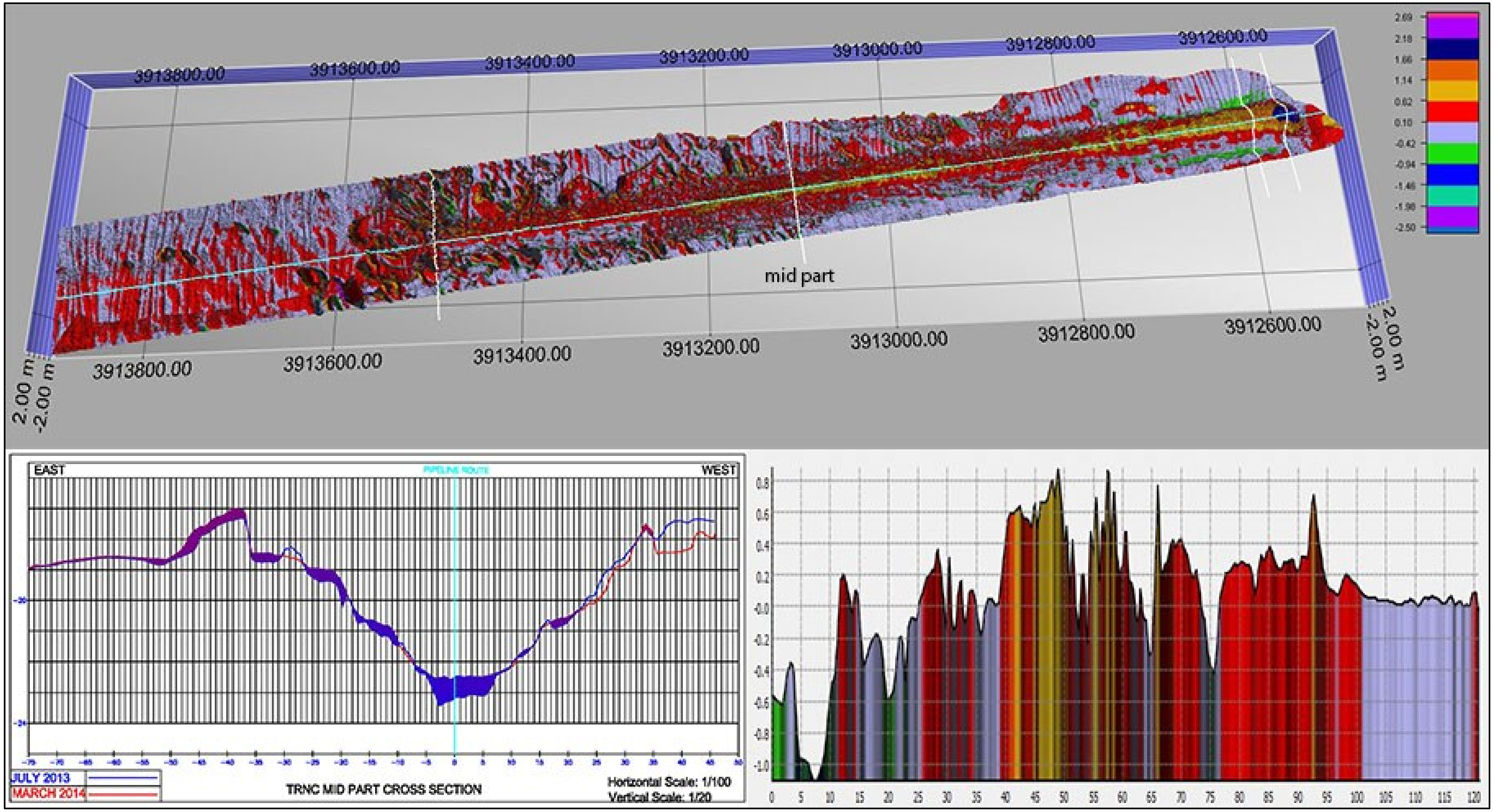

Figure 3.34 Middle part cross section of the TRNC side.

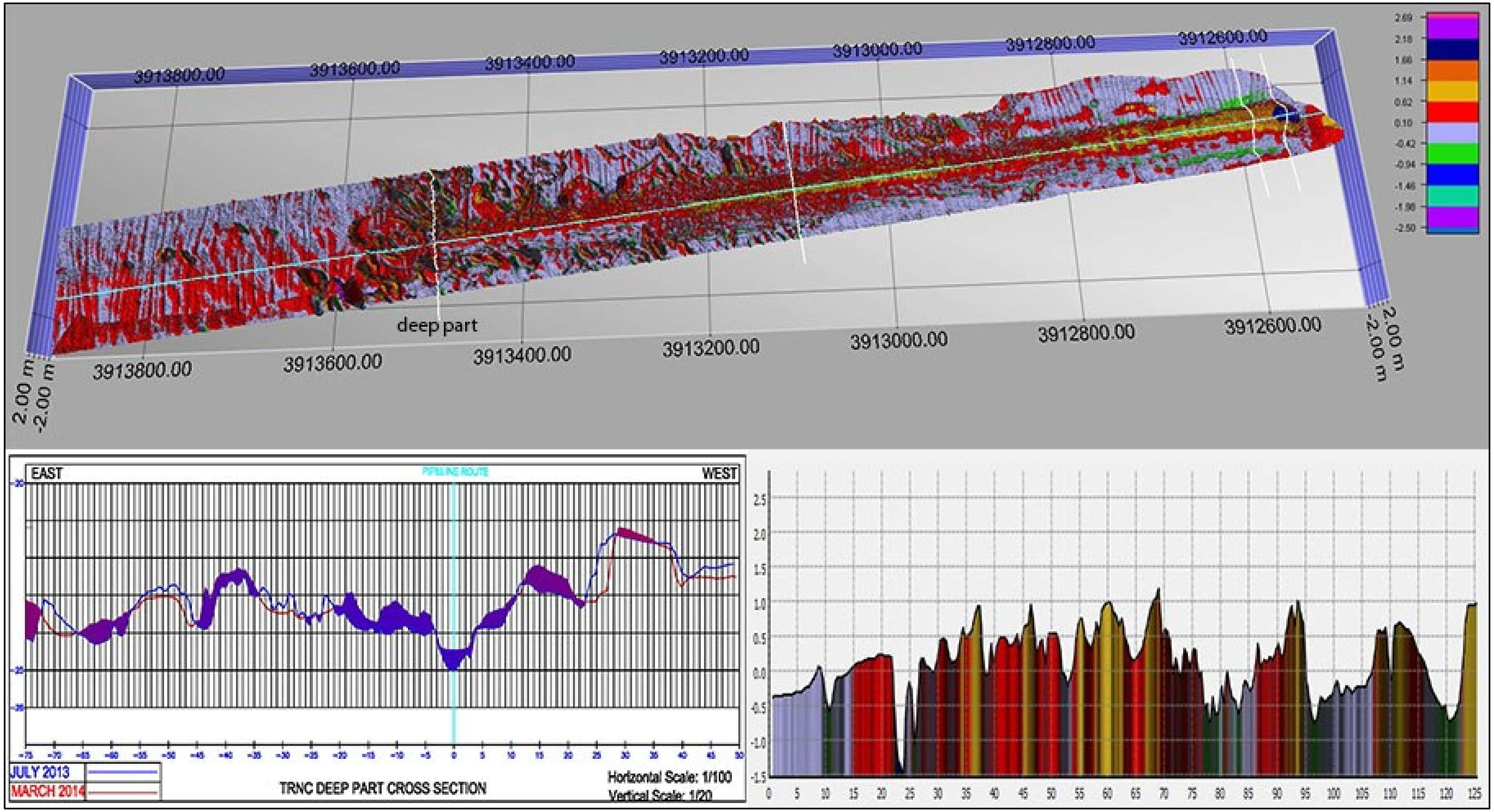

Figure 3.35 Deep part cross section of the TRNC side.

4. CONCLUSIONS

In this thesis, the analysis of the seafloor changes by using multi-temporal multibeam echo sounder data is aimed. The change of seafloor and the deformation of manmade structure on study area are calculated with 3D seafloor models created by using high-resolution multibeam data and data gridding method.

The high-resolution multi beam echo sounder together with accurate motion sensor is used and ensured 100% coverage of the survey area to produce the 3D seafloor model. First of all, the advantages and limitations of using MBES system for hydrographic measurement are outlined in this thesis. Since the system used consists of multiple equipment, the system installation and offset measurements have a critical importance. For this reason, easy installation on the same vessels for each survey phases is conducted. However, it is also seen that it is necessary to make similar installations for each survey couples to minimize equipment offset errors.

Another critical issue observed is the importance of the patch test for MBES surveys. This needs to be done to determine the main sources of errors due to multiple equipment installation and possible offset errors during the installation. In this context, the patch test used for the synchronization of the equipment in the multibeam system is crucial. Besides, the appropriate collection of the sound velocity and tidal data directly affects the reliability of the model. Collection of the sound velocity data in different time periods of the day enables to prevent the error caused by sound velocity change during the survey. For both the Anamur and the TRNC sides, ±5cm error is encountered between multi-temporal survey couples.

For the all surveys, the DGPS correction provided by Fugro is used. The accuracy is monitored and checked during the acquisition and also the post processing of the survey data. The accuracy is observed as 0.20m. For better positioning results, the RTK (Real Time Kinematic) positioning systems, which generally provides 0.07m accuracy, should be used. However, RTK solution could not be used in the Anamur side, since the radar station situated in the Anamur forehead causes to ruin the correction signal. Another solution is the PPP (Precise Point Positioning) which is becoming popular nowadays but was not available in survey dates. The PPP correction reaches 0.07m accuracy without using a base station on land. Although RTK or PPP would improve the accuracy but DGPS still provide the positioning requirements of IHO standards.

The change detection analysis is used to create a model for maintenance of the channel before the laying of the water pipes. This kind of investigations can be used for analysis and calculation of dredging works. With this detection, dredging performance can also be monitored by using the time variable. For areas where the under-keel clearance is critical, it is necessary to ensure 100% coverage as requested in IHO standards S-44. Especially the areas such as ports where the marine traffic density is high and the depths are shallower require maintenance. To adjust maintenance and predict the depth change regarding to time, change detection surveys need to be conducted periodically. Moreover, the areas where the seafloor changes are important regarding to time and therefore, need to be determined The lakes fed by rivers that are carrying materials, channels, water dams and straits can be a good example for this case. This detection method can be used to determine and predict seafloor changes and physical features of the study area.

Change detection analysis done in this thesis showed that shallow part is protected by a natural breakwater in the Anamur side; but along the channel, it is homogeneously filled by sea material. However, the TRNC side has different features as sea dynamics: the effects of surf zone in shallow parts of channel are clearly seen. Besides the changes in and around the channel, the dredged area is distinctly constituted in the area. Furthermore, it is also observed that the material, which filled up the channel area, can be identified as a coarse material because of its transport rate by sea dynamics. In addition, the different length of time interval between data sets also effected to detect the change. The longer time period reveals better change detection.

Like shown in this study, there are a number of studies which show the MBES system is more effective than the other hydrographic measurement systems. Nowadays, the most challenging system against the MBES is Lidar system, but it still has limitations. According to the Lidar system principles, the light travels along the water column, however, visibility is the biggest problem. Besides, the dredged areas like in the study area are up to for the challenge with the siltation; however this does not affect the MBES system easily, because the system uses the highest frequency as a depth data. Also MBES is a cost efficient system for such a large area, since operating a vessel is accepted cheaper than the air-borne systems.

For the future work, it is aimed to integrate all the existing data that have been collected, processed, and archived (multibeam echo sounder, side scan sonar, core data, fisheries data, etc.) into GIS environment and then to develop and implement different database architectures that facilitate large scale analysis for automatic seafloor mapping.

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APPENDICES

APPENDIX A: Datasheets of the Equipment Used

APPENDIX A1: Multi beam echo sounder datasheet.

APPENDIX A2: Motion sensor datasheet.

APPENDIX A3: Positioning system datasheet.

APPENDIX A4: Sound velocity profiler datasheet.

APPENDIX A5: Sound velocity sensor datasheet.

APPENDIX A6: Survey, data process and modeling software datasheet.

APPENDIX A1: Multi beam echo sounder datasheet.

R2SONIC

High Resolution Multibeam Systems for:

Hydrography

Offshore

Dredging

Defense

Research

SONIC 2024

Multibeam Echo Sounder

Features:

- 60kHz Wideband Signal Processing
- Focused 0.5° Beam Width
- Selectable Frequencies 200-400kHz
- Selectable Swath Sector 10° to 160°
- System Range to 500m
- Embedded Processor/Controller
- Equiangular or Equidistant Beams
- Roll Stabilization
- Rotate Swath Sector

Applications:

- Hydrographic Survey
- Offshore Site Survey
- Pre & Post Dredge Survey
- Defense & Security
- Marine Research

System Description:

The Sonic 2024 is the world's first proven wideband high resolution shallow water multibeam echo sounder. With proven results and unmatched performance, the Sonic 2024 produces reliable and remarkably clean data with maximum user flexibility through all range settings to 500m.

The unprecedented 60 kHz signal bandwidth offers twice the resolution of any other commercial sonar in both data accuracy and image. With over 20 selectable operating frequencies to chose from 200 to 400 kHz, the user has unparalleled flexibility in trading off resolution and range and controlling interference from other active acoustic systems.

In addition to selectable operating frequencies, the Sonic 2024 provides variable swath coverage selections from 10° to 160° as well as ability to rotate the swath sector. Both the frequency and swath coverage may be selected 'on-the-fly', in real-time during survey operations.

The Sonar consists of the three major components: a compact and lightweight projector, a receiver and a small dry-side Sonar Interface Module (SIM). Third party auxiliary sensors are connected to the SIM. Sonar data is tagged with GPS time.

The sonar operation is controlled from a graphical user interface on a PC or laptop which is typically equipped with navigation, data collection and storage applications software.

The operator sets the sonar parameters in the sonar control window, while depth, imagery and other sensor data are captured and displayed by the applications software.

Commands are transmitted through an Ethernet interface to the Sonar Interface Module. The Sonar Interface Module supplies power to the sonar heads, synchronizes multiple heads, time tags sensor data, and relays data to the applications workstation and commands to the sonar head. The receiver head decodes the sonar commands, triggers the transmit pulse, receives, amplifies, beamforms, bottom detects, packages and transmits the data through the Sonar Interface Module via Ethernet to the control PC.

The compact size, low weight, low power consumption of 50W and elimination of separate topside processors make Sonic 2024 *very well suited* for small survey vessel or ROV/AUV operations.

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Spec Sheet version 3.2 February 2010. Subject to change without notice

Sonic 2024 Multi Beam Echo Sounder

Systems Specification:	
Frequency	200kHz-400kHz
Beamwidth, across track	0.5°
Beamwidth, along track	1.0°
Number of beams	256
Swath sector	Up to 160°
Max Range	500m
Pulse Length	10µs-500µs
Pulse Type	Shaped CW
Ping Rate	Up to 60 Hz
Depth rating	100m
Operating Temperature	0°C to 50°C
Storage Temperature	-30°C to 55°C

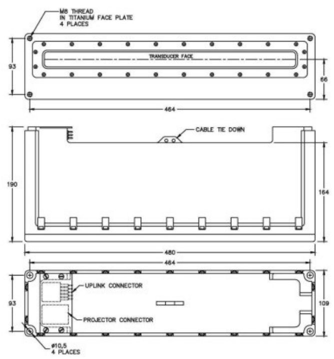
Electrical Interface	
Mains	90-260 VAC, 45-65Hz
Power consumption	<50W
Uplink/Downlink:	10/100/1000Base-T Ethernet
Data interface	10/100/1000Base-T Ethernet
Sync In, Sync out	TTL
GPS	1PPS, RS-232
Auxiliary Sensors	RS-232
Deck cable length	15m

Mechanical:	
Receiver Dim (LWD)	480 x 109 x 190 mm
Receiver Mass	12 kg
Projector Dim (LWD)	273 x 108 x 86 mm
Projector Mass	6 kg
Sonar Interface Module Dim (LWH)	280 x 170 x 60 mm
Sonar Interface Module Mass	2.4 kg

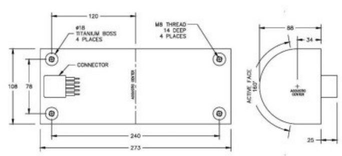
Sonar Options:

Snippets Imagery Output
Switchable Forward Looking Sonar Output
Mounting Frame & Hardware
Over-the-side Pole Mount
Sound Velocity Probe & Profiler
Extended Sonar Deck Cable, 25m or 50m
3000m Depth Immersion Depth

Sonar Interface Module



Sonic 2024 Receiver



Sonic 2022 Projector

High Resolution Multibeam Systems for:

Hydrography

Offshore

Dredging

Defense

Research

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APPENDIX A2: Motion sensor datasheet.

MAXIMIZE YOUR ROI WITH POS MV WAVEMASTER

POS MV WaveMaster is a user-friendly, turnkey system designed and built to provide accurate attitude, heading, heave, position, and velocity data of your marine vessel and onboard sensors. POS MV is proven in all conditions, and is the georeferencing and motion compensation solution of choice for the hydrographic professional.

POS MV blends GNSS data with angular rate and acceleration data from an IMU and heading from the GPS Azimuth Measurement System (GAMS) to produce a robust and accurate full six degrees-of-freedom position and orientation solution.

PERFORMANCE SUMMARY - POS MV WAVEMASTER ACCURACY[1]

	DGPS	Fugro Marinestar®	IARTK	POSPac MMS PPP	POSPac MMS IAPPK	During GNSS Outage
Positioning	0.5 - 2 m[2]	Horizontal: 10 cm 95% Vertical 15 cm 95%	Horizontal: +/- (8 mm + 1 ppm x baseline length)[3] Vertical: +/- (15 mm + 1 ppm x baseline length)[3]	Horizontal: < 0.1 m Vertical: < 0.2 m	Horizontal: +/- (8 mm + 1 ppm x baseline length)[3] Vertical: +/- (15 mm + 1 ppm x baseline length)[3]	~ 9 m for 60 s outage(RTK) ~ 3 m for 30 s outage(RTK) ~ 2 m for 60 s outage(IAPPK)
Roll & Pitch[4]	0.03°	0.02°	0.02°	< 0.02°	0.015°	0.04°
Heading[4]	0.015° with 4 m baseline 0.03° with 2 m baseline	-	-	-	-	< 2° per hour degradation (negligible for outages <60 s)
Heave TrueHeave™	5 cm or 5%[5] 2 cm or 2%[6]	-	-	-	-	5 cm or 5%[5] 2 cm or 2%[6]

PCS OPTIONS

COMPONENT	DIMENSIONS	WEIGHT	TEMPERATURE	HUMIDITY	POWER
Rack Mount PCS	L = 442 mm, W = 356 mm, H = 46 mm	3.9 kg	-20 ºC to +70 ºC	10 - 80% RH	AC 120/230 V, 50/60 Hz, auto-switching 40 W
Small Form Factor PCS	L = 167 mm, W = 185 mm, H = 68 mm	2.5 kg	-20 ºC to +60 ºC	0- 100% RH	DC 10-34 V, 35 W (peak)

INERTIAL MEASUREMENT UNIT (IMU)

ENCLOSURE	DIMENSIONS	WEIGHT	TEMPERATURE	IP RATING
Between Decks	L = 158 mm, W = 158 mm, H = 124 mm	2.5 kg	-40 ºC to +60 ºC	IP65
Submersible	Ø100 mm (base plate Ø132 mm) X 104 mm[7]	2.7 kg	-40 ºC to +60 ºC	IP68

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

COMPONENT	DIMENSIONS	WEIGHT	TEMPERATURE	HUMIDITY
GNSS Antenna	Ø178 mm, W = 73 mm	0.45 kg	-50 ºC to +70 ºC	0-100% RH

[1] 1 sigma unless otherwise stated
[2] Depending on quality of differential corrections
[3] Assumes 1 m IMU-GNSS antenna offset
[4] No range limit
[5] Whichever is greater, for periods of 20 seconds or less
[6] Whichever is greater, for periods of 35 seconds or less
[7] Height excludes connector

1. ETHERNET INPUT OUTPUT

Ethernet	(10/100 base-T)
Parameters	Time tag, status, position, attitude, heave, velocity, track and speed, dynamics, performance metrics, raw IMU data, raw GNSS data
Display Port	Low rate (1 Hz) UDP protocol output
Control Port	TCP/IP input for system commands
Primary Port	Real-time (up to 200 Hz) UDP protocol output
Secondary Port	Buffered TCP/IP protocol output for data logging to external device

2. SERIAL RS232 INPUT OUTPUT

5 COM Ports	User assignable to: NMEA output (0-5), Binary output (0-5), Auxiliary GNSS input (0-2), Base GNSS correction input (0-2)

3. NMEA ASCII OUTPUT

Parameters	NMEA Standard ASCII messages: Position ($INGGA), Heading ($INHDT), Track and Speed ($INVTG), Statistics ($INGST), Attitude ($PASHR, $PRDID), Time and Date
($INZDA,	$UTC)
Rate	Up to 50 Hz (user selectable)
Configuration	Output selections and rate individually configurable on each assigned com port

4. HIGH RATE ATTITUDE OUTPUT

Parameters	User selectable binary messages: attitude, heading, speed
Rate	Up to 200 Hz (user selectable)
Configuration	Output selections and rate individually configurable on each assigned com port

5. AUXILIARY GNSS INPUTS

Parameters NMEA Standard ASCII messages: $GPGGA, $GPGST, $GPGSA, $GPGSV
Uses Aux input with best quality
Rate 1 Hz

6. BASE GNSS CORRECTION INPUTS

Parameters RTCM V2.x, RTCM V3.x, CMR and CMR+, CMRx input formats accepted. Combined with raw GNSS observables in navigation solution
Rate 1 Hz

7. DIGITAL I/O

1PPS	1 pulse-per-second Time Sync output, normally high, active low pulse
Event Input (2)	Time mark of external events. TTL pulses > 1 msec width, rising or falling edge, max rate 200 Hz

8. USER SUPPLIED EQUIPMENT

- PC for POSView Software (Required for configuration): Pentium 90 processor (minimum), 16 MB RAM, 1 MB free disk space, Ethernet adapter (RJ45 100 base T), Windows 7 or Windows 8
- PC for POSPac MMS Post-processing Software: Pentium III 800Mhz or equivalent (minimum), 512 MB RAM, 400 MB free disk space, USB Port (for Security Key if specified, not required for network license), Windows 7 or Windows 8

Scan the QR Code on your mobile device to access information on POS MV

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applanix™
A TRIMBLE COMPANY

capture everything. precisely.

APPENDIX A3: Positioning system datasheet.

Fugro Satellite Positioning

Marinestar® 9205 GNSS Receiver

The Marinestar® 9205 GNSS receiver provides users with access to the latest developments in high performance Differential Global Satellite Navigation System (DGNSS) positioning.

All in View Receiver

The Marinestar® 9205 GNSS receiver is a multi frequency (L1/ L2/L5/E1/E5) receiver that incorporates GPS, GLONASS and Galileo reception capability. In addition it tracks the Fugro L-Band satellite broadcast of DGNSS corrections. As a backup it can receive the DGNSS corrections via Internet.

As well as providing increased accuracy, multi frequency operation means that the Marinestar® 9205 GNSS receiver is well equipped to cope with the effect of the forecast increase in solar activity and interference.

Used in conjunction with the Marinestar® GNSS service, it increases the number of satellites available by accessing the GLONASS satellite constellation (and future Galileo) in addition to the GPS constellation. More satellites means less likelihood of shadowing when operating close to rigs, platforms and other obstructions.

High Performance Service Compatibility

The Marinestar® 9205 GNSS receiver can be subscribed to the various DGNSS services offered by Fugro such as Marinestar® GPS and the integrated Marinestar GNSS service.

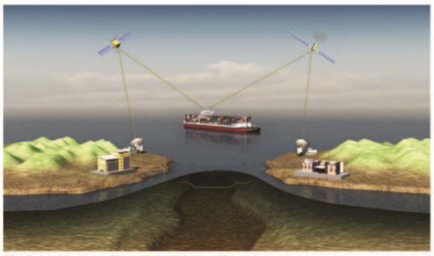
- Marinestar® GPS: GPS orbit and clock solution
- Marinestar® GNSS: Composite GPS/GLONASS orbit and clock solution

The above solutions are dual frequency carrier phase based to achieve decimetre level accuracy.

The receiver can be monitored and configured via the front panel display and keypad, or via a web interface.

The Marinestar® GNSS Operations Centre in Oslo

A mix of navigation satellites can be used



Dual satellite broadcast data links in all ocean regions

MARINESTAR®

Marinestar® 9205 GNSS Receiver

Marinestar® 9205 GNSS Receiver

Web interface

Marinestar® 9205 GNSS back panel

MAIN FEATURES

- L1/L2 GPS receiver
- L1/L2 GLONASS receiver
- E1/E5 Galileo receiver
- L-BAND DGNSS receiver
- Corrections via internet
- Display and keypad
- Web interface

ANTENNA OPTIONS

GA 810 – GNSS antenna

AD 492 – narrow band filter, interference resistant antenna

AD 493 – high performance L-band antenna

Zephyr Model 2 rugged antenna

TECHNICAL SPECIFICATIONS

Keypad and Display

Invertable VFD display 16 characters by 2 rows

Escape and enter key for menu navigation

4 arrow keys for option scroll and data entry

Channels

220-channels

GPS - L1 C/A, L2C code

GPS - L1/L2/L2C full cycle carrier

Galileo E1/E5

GLONASS - L1/L2 full cycle carrier

SBAS (WAAS/EGNOS/MSAS)

Fugro L-Band service

Position Accuracy Marinestar GPS/GNSS

Horizontal:	10 cm (95%)
Vertical:	15 cm (95%)

Communications

Lemo (serial):	3 wire RS232
Modem 1 serial:	full 9-wire RS232
Modem 2 serial:	full 3-wire RS232

1 PPS

Ethernet multiport adapter

Data outputs

NMEA messages: GGA; GST, GSA, VTG, ZDA, GNS, GBS, RMC

Power Requirements

9.5 V DC to 28 V DC, 30W at 24 V DC

AC input via external AC/DC PSU or Isolating Data and Power Unit (IPDU)

Temperature

Operating:	-40 to +65 ºC (-40 to +149 ºF)
Storage:	-40 to +80 ºC (-40 to +176 ºF)

Dimensions (L x W x D)

24 cm (9.4 in) x 12 cm (4.7 in) x 5 cm (1.9 in)

Weight

1.55 Kg (3.42 lb)

Approval

IEC 61108 GNSS performance

IEC 60945 environmental (IPDU required)

IEC 61162 interface output

Specifications subject to change without further notice

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E-mail: marinestar@fugro.com
Web: www.fugromarinestar.com

More info at WWW.FUGROMARINESTAR.COM

APPENDIX A4: Sound velocity profiler datasheet.

Your Path Through the Sea

MARINE | FRESHWATER | CRYOSPHERIC

Submersible CT and CTD Recorders

For Conductivity, Temperature and Depth

Loggers for CT and CTD

These recorders will provide derived measurements of Salinity, Speed of Sound and Density

The XR series CT/CTD offer three conductivity sensors; two case styles; and a maximum sampling rate of 1Hz or 6Hz. Temperature may be measured internally, or with an external probe of time constant 3s or ~0.1s.

Conductivity Measurement

The RBR XR series offer three sensors for conductivity, each with different applications.

Inductive cell

This is the simplest and most rugged sensor. It has one range, from 0 to 70mS/cm and is sufficiently robust that it may be frozen into the water. Noise level is ~3µS/cm rms

This option is specified with a suffix "m".

Electrode contact cell

This provides high resolution measurements in fresh water. The range is 0 to 2mS/cm. The noise level of this sensor is about 0.2µS/cm rms.

Specify with a "f" suffix.

Zero External Field Inductive cell

(ZEFICC). This innovation permits the use of an inductive cell without external field. The principle is to dynamically cancel the external field of the cell. This is valuable in the presence of mooring structures.

This option may be selected by using a suffix "z" in the model number.

Software

Integrated RBR Windows® software is available at no additional charge for all of our instruments. See reverse for further details or check our website for details, downloads and upgrades.

Outline Specifications

Conductivity:	±0.003 mS/cm
Temperature:	±0.002°C ITS-90
Depth:	±0.05% full scale (standard)

See overleaf for full specifications

Other Sensors

Sensors are available for a wide range of standard parameters. See the multichannel data sheet for more details.

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05/08

Your Path Through the Sea

MARINE | FRESHWATER | CRYOSPHERIC

Submersible CT and CTD Recorders — For Conductivity, Temperature and Depth

Conductivity, Temperature and Depth

General Specifications

Case Size:	310 or 420mm x 65mm diameter
Material:	Acetal copolymer: to 740m Titanium: to 6,600m
Memory:	8Mbyte Flash (2,400,000 samples) (May be extended to 2 Gbyte)
Power:	Four CR123A Lithium (3V) standard camera batteries or external power (6 to 15 V). Battery power sufficient for 2,400,000 readings or three years of operation
Weight:	1260g in air, 389g in water (Delrin®) 2400g in air, 1530g in water (titanium)
Calibration:	NIST traceable standards
Clock Accuracy:	±32 seconds/year
Sample Rates:	Up to 1Hz (XR-420) Up to 6Hz (XR-620)
Communications:	RS-232/485 RF Modem control or GSM/CDMA modem
Download Speed:	~115,000 samples/minute RS232 Or USB for large memory option

Ordering Information

Inductive:	XR-420CT(D)m	XR-620CT(D)m
Electrode:	XR-420CT(D)f	XR-620CT(D)f
ZEFICC:	XR-420CT(D)z	XR-620CT(D)z
Select depth range:	10/20/50/100/200/500/740m 1000/2000/4000/6000m	

Select fast temperature probe (~0.1s) if required

Other Options

External serial connector
External power connector
Interface for modem

Measurement Specifications

Conductivity

Range:	0 to 2mS/cm or 0 to 85mS/cm. Extended ranges available
Accuracy:	± 0.003 mS/cm at 35psu 15°C
Drift:	±0.005 mS/cm over 5° to 25°C
Resolution:	<0.0005 mS/cm
Time Constant:	Set by flow through cell
Measurement:	Inductive or Electrode cell Zero external field inductive option.

Temperature

Range:	-5 °C to 35 °C Standard -40°C to +50° optional
Accuracy:	± 0.002 °C (ITS-90 and NIST traceable standards)
Resolution:	<0.00005 °C
Time Constant:	~3 sec (standard) ~0.1 sec (option) < 20 sec (internal)

Depth (Optional)

Range:	10/20/50/100/200/500/740/1000/ 2000/4000/6000m (dBar)
Accuracy:	±0.05% full scale
Resolution:	<0.001% full scale
Time Constant:	< 10 msec
Sensor Type:	Keller strain gauge Option: Quartz resonant gauge ±0.015%

For further information on sensor performance please contact RBR.

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05/08

APPENDIX A5: Sound velocity sensor datasheet.

miniSVS Sound Velocity Sensor

Our unique digital time of flight technology gives unmatched performance figures, with signal noise an order of magnitude better than any other sensor. The miniSVS is available in a selection of configurations and with optional pressure or temperature sensors. There are a variety of sizes to suit many applications.

miniSVS - still the most accurate sound velocity sensor in the world. Nothing else comes close.

Sound Velocity Measurement

Each sound velocity measurement is made using a single pulse of sound travelling over a known distance, so is independent of the inherent calculation errors present in all CTDs. Our unique digital signal processing technique virtually eliminates signal noise, and gives almost instantaneous response; the digital measurement is also entirely linear, giving predictable performance under all conditions.

Range:	1375 - 1900m/s	
Resolution:	0.001m/s	
Accuracy:	Dependent on sensor size	
100mm	Random noise (point to point)	±0.002m/s
	Max systematic calibration error	±0.013m/s
	Max systematic clock error	±0.002m/s
	Total max theoretical error	**±0.017m/s**
50mm	Total max theoretical error	±0.019m/s
25mm	Total max theoretical error	±0.020m/s

Acoustic Frequency: 2.5MHz

Sample Rate: Selectable, dependent on configuration

Rate	SV	SV+P	SV+T
Single Sample	•	•	•
1Hz	•	•	•
2Hz	•	•	•
4Hz	•	•	•
8Hz	•	•	•
16Hz	•	•	•
32Hz	•	•	
60Hz	•		

Optional Sensors

The miniSVS may be optionally supplied with either a pressure or temperature sensor (but not both). Data is sampled at the rates shown above

Sensor	**Pressure**	**Temperature**
Type	Strain Gauge	PRT
Range	5, 10, 50, 100 or 600 Bar	-5°C to +35°C
Resolution	0.001% range	0.001°C
Accuracy	±0.05% range	±0.01°C

Data Output

Unit has RS232 & RS485 output, selected by command code. RS232 data may be taken directly into a PC over cables up to 200m long, whereas RS485 is suitable for longer cables (up to 1000m) and allows for multiple addressed units on a single cable.

Baud Rate: 2400 - 115200 (NB. Low baud rates may limit data rate)
Protocol: 8 data bits, 1 stop bit, No parity, No flow control

Electrical

Voltage: 8 - 30vDC
Power: 0.25W (SV only), 0.35W (SV + Pressure)
Connector: Subconn MCBH6F (alternatives on request)

Data Format

Examples of data formats are:
<space>{sound_velocity}<cr><lf>
<space>{pressure}<space>{sound_velocity}<cr><lf>
<space>{temperature}<space>{sound_velocity}<cr><lf>

SV: Choose from mm/s (1510123), m/s to 3 decimal places (1510.123), or m/s to 2 decimal places (1510.12)

Pressure: If fitted, pressure is always output in dBar with 5 digits, with a decimal point, including leading zeroes if necessary. Position of the point is dependent on sensor range, e.g.
50dBar 47.123
100dBar 047.12
1000dBar 0047.1

Temperature: If fitted, temperature is output as a 5 digit number with 3 decimal places and leading zeroes, signed if negative, e.g. 21.456
02.298
-03.174

Physical

Please refer to factory for detailed dimensions if required.

Depth Rating: 6000m (Titanium), 500m (acetal)
Weight: 1kg (housed type)
Housing & Bulkhead: Titanium or acetal, as selected
Transducer Window: Polycarbonate
Sensor Legs: Carbon Composite
Reflector Plate: Titanium.

Ordering

All systems supplied with operating manual and carry case. OEM units come with a test lead, housed units with a 0.5m pigtail.

Configuration	100mm	50mm	25mm
Titanium Housed	0652004	0652005	0652006
Acetal Housed	0652045	0652046	0652047
Bulkhead OEM	0652001	0652002	0652003
Remote OEM	0652007	0652008	0652009
Titanium + Pressure	0652004-P	0652005-P	0652006-P
Titanium +Temperature	0652004-T	0652005-T	0652006-T

Datasheet Reference: miniSVS version 2b, June 2013

Valeport Limited, St. Peter's Quay Totnes, Devon, TQ9 5EW UK
t. +44 (0)1803 869292 f. +44 (0)1803 869293 e. sales@valeport.co.uk w. www.valeport.co.uk

APPENDIX A.6.: Survey, data process and modeling software datasheet

A.6.1. Hypack Hysweep Navigation and Survey Software

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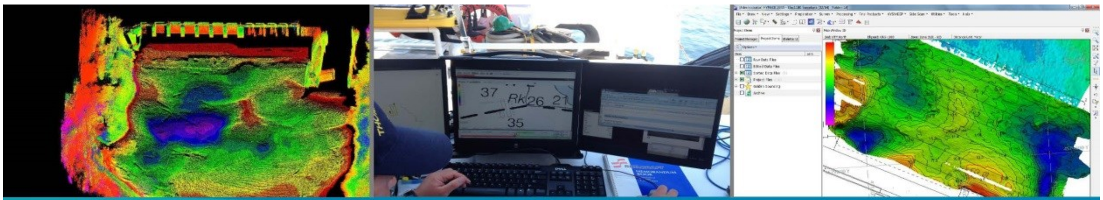
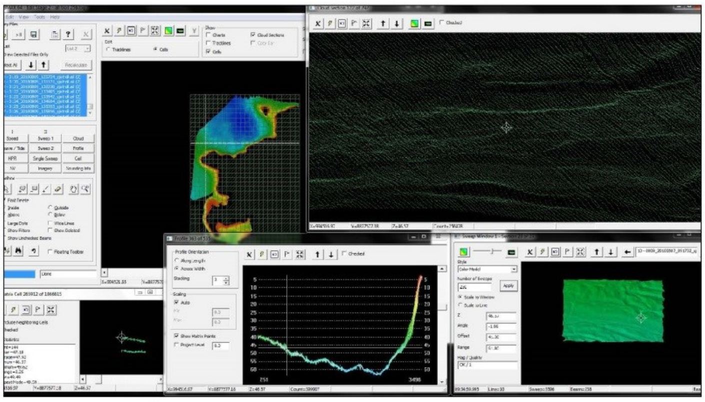
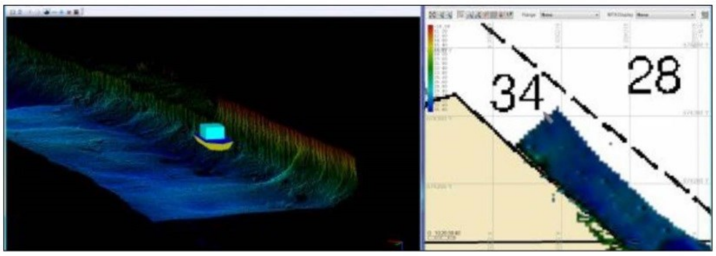


HYSWEEP®

Software for Calibrating, Collecting and Processing Multibeam, Topographic Laser Backscatter and Water Column Data.



64-bit HYSWEEP® EDITOR (MBMAX)



New REAL TIME POINT CLOUD: It displays both multibeam and topographic laser data in a corrected and geo-referenced, color-coded point cloud.

HYPACK
a xylem brand

HYSWEEP® is an optional module that allows you to calibrate, collect and process multibeam, multiple transducer and topographic laser data. A HYPACK® license is required.

With over 3,000 users around the world, HYSWEEP® includes interfaces for the following systems:

- Atlas Bomasweep, Fansweep and Hydrosweep
- Benthos C3D
- Bathy Swathplus
- Blueview multibeam
- Edgetech 4600 and 6205
- GeoAcoustics GeoSwath
- IBeam
- Imagenex Delta T
- Kongsberg MS1000
- Kongsberg EM1002/2000/2040/710
- Kongsberg EM 3000/3002/3002D/302
- Kongsberg Mesotech M3
- Klein HydroChart
- Leica PS20
- Norbit
- Odom ES3
- Odom MB1 - MB2
- Odom Echoscan
- Optech ILRIS
- PingDSP
- R2Sonic Sonic 20XX (Single and Dual Head)
- Reson 71xx, 81xx, 91xx
- Riegl LMS and V Series
- Reinshaw
- Ross Smart Sweep
- SEA
- Seabeam 2100/3000/SB1000
- Tritech Gemini
- Tritech SeaKing
- Velodyne
- WASSP Multibeam

The HYSWEEP®' Patch Test allows you to determine the exact mounting angles for your system in hours, not days.

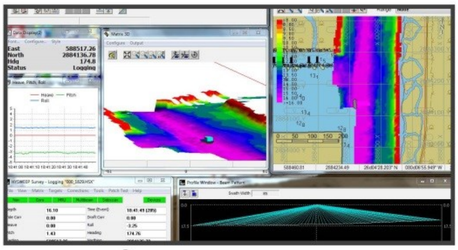
HYSWEEP® SURVEY provides you with coverage diagrams, real-time TPU displays, and QC tools needed to efficiently complete your multibeam survey.

REAL TIME POINT CLOUD: The new program runs in conjunction with HYSWEEP® SURVEY and displays both multibeam and topographic laser data in a corrected and geo-referenced, color-coded point cloud. The REAL TIME POINT CLOUD program is useful for easier feature detection and categorization, system calibration and verification, and data quality control.

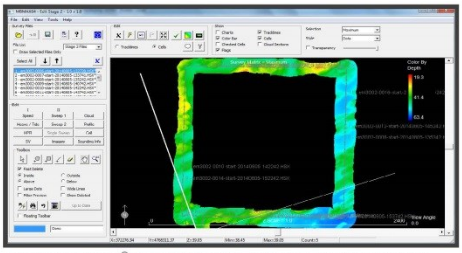
The HYSWEEP® Water Column Logger allows users to ensure that hard targets, such as wrecks, are fully detected, and to confirm the least depth in the water when fine features such as cables or masts may otherwise be missed.

The HYSWEEP® multibeam editor allows you to review your raw data components, incorporate sound velocity and water level corrections (including RTK TIDES and VDATUM), and apply geometric and statistical filters to quickly clean your data and output a variety of data subsets.

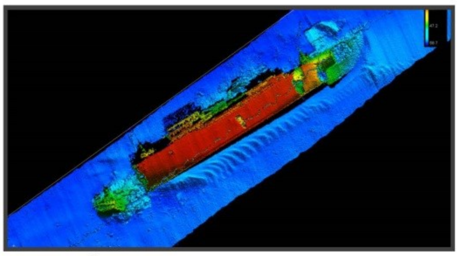
GEOCODER™, licensed from UNH-CCOM, allows you to generate mosaics and perform bottom classification from average backscatter and snippet data.



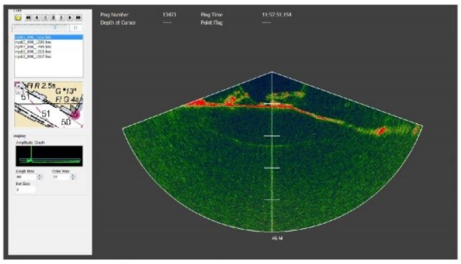
The HYSWEEP® SURVEY program showing 3D Seafloor, Beam Pattern, Coverage Map, and Motion Correction. Just some of 20 available real-time windows.



Our HYSWEEP® editor, MBMAX, allows you to graphically review your multibeam survey data, and remove outliers with geometric and statistical filters.



HYSWEEP® includes 3D visualization and processing tools using our CLOUD program.



The HYSWEEP® WATER COLUMN PLAYBACK allows you to replay the water column data provided by modern multibeam sonars, highlighting the powerful multibeam and backscatter collection capabilities of HYSWEEP®.

HYSWEEP®

Designed and supported by: HYPACK, A Xylem Brand

56 Bradley St. Middletown, CT 06457 USA ◈ Tel: +1-860-635-1500 ◈ www.hypack.com

A.6.2. IVS 4D Fledermaus

FLEDERMAUS

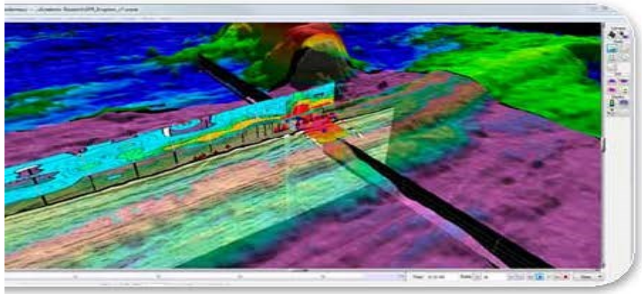
More than just a picture

Fledermaus is the industry leading interactive true 4D geospatial processing and analysis tool.

Commercial, academic and government organizations use Fledermaus to interact with massive geographical datasets of numerous data types for ocean mapping and land-based projects.

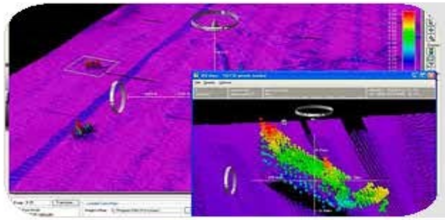
The intuitive 4D environment allows users to rapidly gain insight and extract more information from their underlying data. This provides added value in data processing efficiency, quality control accuracy, data analysis completeness, and project integration, that promotes clear communication. 4D Fledermaus scenes can be distributed and viewed using the freely available viewer, iView4D.

Instead of sharing the Fledermaus scene, impressive fly-throughs can be created and distributed as WMV or MPEG movie files. Or, data can be exported to KMZ for viewing in Google Earth. Fledermaus also provides image creation tools, allowing you to generate high-resolution perspective images, profile images, and sun-illuminated georeferenced images for posters, presentations, and publication.



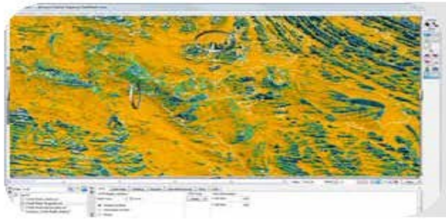
True space and time 4d environment

A wide variety of industry standard formats are supported for direct import of data to the 3D scene. The extensive functionality of Fledermaus allows its use across many phases of a project from the planning, processing and QC, through to analysis and production of images, plots and animations.



True 64-bit software, use of multiple processors, CUBE® and Area Based processing methods are utilized to shorten processing time and quickly take your data from unrefined survey data to the best possible seabed surface model, with higher confidence that your model is based on real data, not collection artefacts.

Additional grids, draped imagery, nautical charts, contours, Electronic Nautical Charts, and other information can be added to support your processing. Once data is refined to a clean sounding or point set, Fledermaus has the tools you need to produce your survey report and products.



Sounding-selection for charting or shoal-biased thinning can quickly be performed on the data using approved filters and algorithms; as you compile your feature reports, you can consult the multibeam water column data over wrecks and hazards to be sure the least-depths were detected. Bathymetric Attributed Grids (BAG) with proper metadata, survey area polygons, and Sounding Density Surfaces can be generated to show coverage and for quality assurance.

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PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Zirek E., Sunar, F.,** 2016. The Effects of Calibration on the Multi-Beam Echo Sounder Measurements. 8th National Engineering Measurements Symposium, October, 2016, Istanbul, Turkey.

- **Zirek E., Sunar, F.,** 2014. Change Detection of Seafloor Topography by Modeling Multitemporal Multibeam Echosounder Measurements. ISPRS Technical Commission VII Symposium, 29 September – 2 October 2014, ITU, Istanbul, Turkey.