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THE GEODESY IN THE HYDOGRAPHY

A Geodésia na Hidrografia

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ABSTRACT

The mathematics, the computer science and the physics are the foundations for many sciences, including geodesy. The Geodesy applies those disciplines to determine both size and shape of the Earth using its gravity field. The Hydrography uses geodesy as its main tool to determine, most of the time, the geographical coordinates of nautical features. This paper aims to demonstrate the strong connection between Geodesy and Hydrography, especially from the point of view of the construction of nautical chart.

Keywords: Geodesy, Hydrography, Horizontal Network, Coastline, GNSS, Nautical Chart.

RESUMO

A matemática, a ciência da computação e a física são os pilares para muitas ciências, incluindo a Geodésia. Essa, por sua vez, utiliza aquelas disciplinas para determinar a tamanho e a forma da Terra através do estudo do seu campo da gravidade. A Hidrografia, por sua vez, tem na Geodésia sua principal ferramenta para a determinação das coordenadas geográficas de feições náuticas, na maioria das vezes. Esse *paper* tem como propósito demonstrar a forte conexão entre a Geodésia e a Hidrografia, principalmente do ponto de vista da construção da carta náutica.

Palavras chaves: Geodésia, Hidrografia, Redes Horizontais, Linhas de Costa, GNSS, Cartas Náuticas.

1. INTRODUCTION

The well understanding among Geodesy and the others Sciences is a challenge for teachers. Sometimes the link AMONG them is a narrow and imperceptible line

The Geodesy has wide application in the field of earth sciences. According to Torge (1991), it is defined as the science of determining the size and the figure (shape) of the Earth, and its external gravity field. The definition includes the temporal variations of the Earth's orientation, its gravity field and its surface, and the orientation of the Earth in space.

Originally, all geodesic work was based on land. Now, satellites are used in conjunction with the land-based system. The Geodesy is strongly dependent on mathematics, because it provides the entire theory needed to solve complex equations that rule either the shape and the size of the Earth and punctually describes its gravitational field.

The Geodesy also has a strong relation to mapping operations, sea and space navigation, engineering, astronomy, hydrography, and etc. In many countries, the curriculum of Hydrography and Geodesy disciplines is overlapped. According to Mira (1999), at least 60% of these curriculums are mostly the same. Due to that, in some countries the hydrographic is attached to the geodesy classes.

Sometimes, the hydrography is said to be part of oceanography or even as a special type of marine survey. But, in both cases, the Geodesy fundamentals are always present.

According to Manual on Hydrography (IHO, 2011) the Hydrography is a branch of applied sciences which deals with the measurement and description of the features of the seas 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 environment, and prediction services.

The Geodesy and the Hydrography are completely connected linked. A single depth, by itself, has no meaning without Geodesy. Because that, since the beginning, surveyors always were concerned about determining coordinates on Earth surface. As a three dimension problem, latitude, longitude and depth were precisely determinated by astronomical techniques in the past. Nowadays, satellite positioning is used by positioning the hydrographic vessel, using different techniques

The Geodesy is also employed in Hydrographic Surveys in order to verify the dynamics of the coastline, to provide relative determination of altitude, to determine positions of marine objects, and etc.

The goal of this paper is to present how Geodesy can be applied in hydrography and how their techniques can be used for determining some of the elements that are represented at nautical charts.

2. RELATION BETWEEN GEODESY AND HYDROGRAPHY

Most of the techniques that are going to be shown in this paper are normally employed during the Hydrographic Surveys in order to gather important elements to produce nautical charts. These techniques, such as the establishment of horizontal network, determination of coastline and conspicuous features for nautical chart representation, positioning of the hydrographic vessel, geometric leveling among tidal ruler and benchmarks, etc., are covered by Geodesy lectures and show its relationship with hydrography.

2.1 Establishment of Horizontal Primary and Secondary Control Network

As mentioned, the hydrographic activities are performed based on geodetic procedures. The establishment of the horizontal primary and secondary control network is an example. Those networks are traditionally used to help surveyors to determine the position of the hydrographic vessel during the hydrographic survey; the shoreline; the navigation aids; beacons; buoys; and other features that are judged to be relevant regarding safety navigation.

Normally, the establishment of the horizontal primary network happens before than the secondary one. It is because the points that belong to the horizontal primary network must have high accuracy whose may be achieved using geodetic methods.

Nowadays, the geodetic positioning methods are based on satellite positioning techniques, but for a long term surveyors had used astronomical observation as the main method to determining latitude and longitude coordinates.

Generally, the hydrographic surveys are divided in the following phases: planning, reconnaissance, survey and data processing. It is recommended that coordinates of the landmarks that belong to the horizontal primary network should be determinated during the reconnaissance phase. In this phase, the GNSS positioning techniques have been largely used.

The secondary control network is stablished during the survey phase based on horizontal primary network. It will be done measuring distances and angles using traditional topographic techniques. Theodolites, electronic digital theodolites (total station), electronic distance measurement system (EDM), and so on, are normally employed for doing those mentioned measurements.

Basically, the main task of the horizontal primary control network is to allow the determination of the position of the hydrographic vessel and the landmarks of the secondary control network. The last one is traditionally used to determine the position of fixed and floating navigation aids, coastline and topographic features less significant to navigation.

2.2 Coastline Delineation

The coastline is defined by different ways. According to Suguio (1992) the coastline is defined as the boundary between the continent and the portion adjacent to the sea where there is no effective marine action beyond the maximum reach of the waves, which are identified by the cliffs, either in the boundary between the vegetation and the seashore or in the rocks, or by any other feature that determines the beginning of the continental area.

The shoreline is not stable. In some areas, it is possible to observe the effect of landward (retreat) or seaward (advance). Those phenomenons could be addressed by natural or artificial causes. The shoreline instability can be seen in Figure 1.

Generally, the coastline is defined with respect to a high water (HW) datum, Manual on Hydrography (IHO, 2011). According to the International Hydrographic Organization (IHO) Standards for Hydrographic Surveys (Special Publication, S-44), the accuracy of a certain shoreline may vary from 10 to 20 meters, depending on the order of the hydrographic survey.

The establishment of the coastline is critical task during the hydrographic surveys. Remote sensing, such as photogrammetry, LIDAR (Light detection and Raging) or satellite images; traditional topographic techniques; and geodetic survey using satellite positioning systems are the most common methodologies employed to establish the position of the coastline.

The determination of the shoreline using satellite images is strongly dependent on visual interpretation and on the characteristics of the objects that define the shoreline. The line derived from the satellite image is less accurate than the line derived from topographic or GNSS techniques. Although geodetic surveys using GNSS was cheaper than topographic surveys, the last one is more accurate.

Nowadays, Brazilian Navy Hydrographic Center is employing a new technology to perform aero photogrammetry using helicopters.

Employing GNSS techniques, it is possible to determine the shoreline using absolute, relative or differential positioning principle. An example of relative positioning is the kinematic relative positioning processed by Precise Point Positioning (PPP) methodology, as shown in Figure 2.

Sometimes, the shoreline monitoring is desired. So, Coastal Geographical Information System (CGIS) is essential for analyzing the evolution of the natural phenomena in time using spatiotemporal models. Figure 3 shows an example from Matinhos beach. The photogrammetry temporal mapping (1954, 1963, 1980, 1991 and 1997) is in the left side. The GPS temporal mapping for the years 2001, 2002, 2005 and 2007, with an accuracy of about 2cm, in the right side. Based on this information it is possible

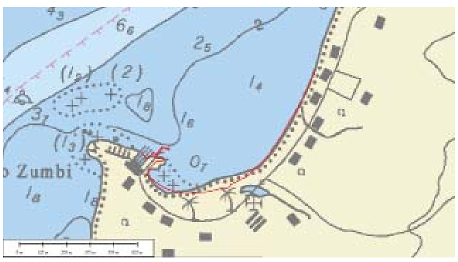

Fig. 1 - Centro de Adestramento e Avaliação da Ilha da Marambaia – RJ. The change of the shoreline in the Brazilian Nautical Chart 1622.

Fig. 2 - Centro de Adestramento e Avaliação da Ilha da Marambaia Berth. The shoreline obtained from GPS kinematic relative positioning.

to make a model for future prediction (Gonçalvez 2009, Gonçalvez et al., 2012a and 2012b).

2.3 Conspicuous Features for Nautical Chart Representation

The nautical charts are composed by many conspicuous and prominent features, such as churches, radio masts, mountain tops, lighthouses, towers, etc. Those features are used to help the orientation and positioning of the mariners.

For hydrographic proposes traditional land-based techniques, for instance, sextant resection, triangulation, tag lines, microwave electronic distance measurement system (EDM) and electronic total station can be used. Since 1990's, land-based techniques were replaced by satellite-based positioning methods, such as GNSS positioning, Differential GNSS (DGNSS), Real Time Kinematic (RTK).

2.4 Hydrographic Vessel Positioning

Since the ancient Greeks ages, the humanity has been attempting to determine the earth´s dimensions and the locations of features on its surface. In the beginning, astronomical techniques were widely employed. But, with passing times, new technologies were been discovered, such as GNSS positioning based on artificial satellites.

However, independently of the technique used to compute the location of points on earth's surface, some problems still remain in time, for example the intervisibility between geodetics stations.

To overcome problems regarding control points intervisibility, astronomic positioning was widely used in order to compute the latitude and longitude of separated points.

So, the geodetic points determinated by astronomic technique, considered as the first order, as used as reference. From them, others points, were calculated employing topographic techniques.

Some years ago, the usage of electromagnetic waves allowed the measurements of distances and directions of intervisible points located on the coast. Since them, the fix position of the vessel increased rapidly.

Other techniques, such as triangulation or intersection were also largely used for positioning vessels offshore. Those measurements were done using geodetic theodolites, electronic distance measurements systems (EDM), and recently

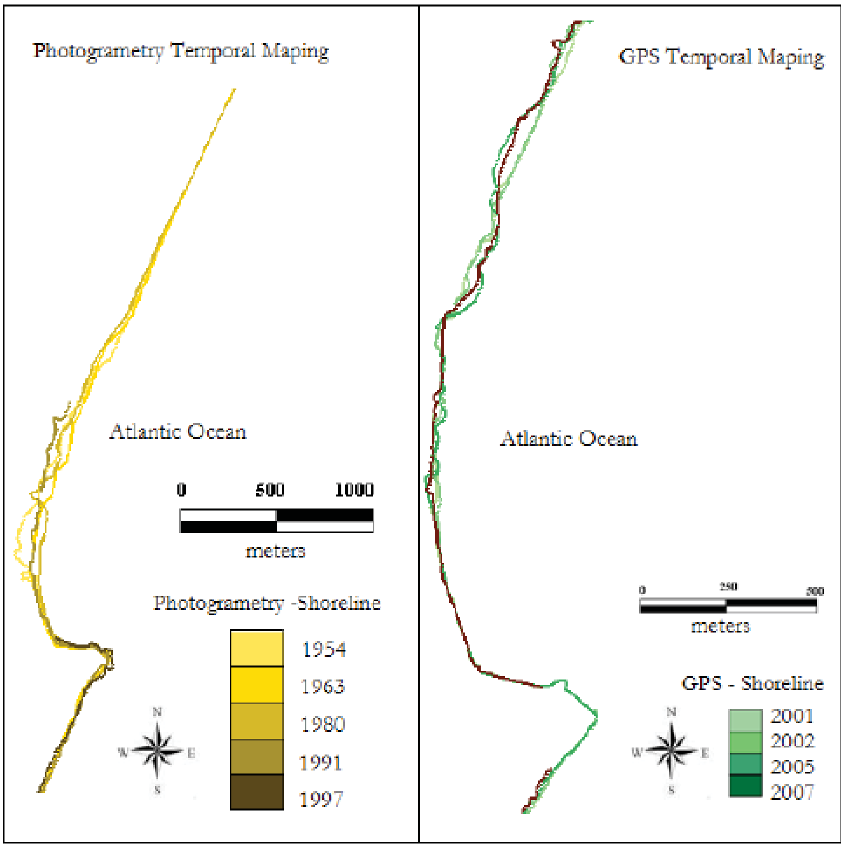

Fig. 3 - Temporal resolution of the data.

using total station.

To accomplish the hydrographic vessel positioning, depths, distances and directions must be measured synchronized by time.

The measuring instruments were set over control and aligned regarding monuments or landmarks, whose coordinates were precisely determinated.

After that, geodesists have adopted land-based electronic positioning system. According to Seeber (2003) this system played an important role in the hydrographic surveys until about 1995. The usages of EDM (Electronic Distance Measurement) techniques were developed during World War II. This technique started using hyperbolic and range-range electronic positioning during the mid 1950's. Examples from this method are systems such as DECCA (Decca Navigator System) and LORAN-C (LOng Range Navigation). The first is a Medium-frequency (300-3000 KHz) positioning systems were used up to the early 1970's. Systems in this frequency range operated by time/phase differencing methods—resulting in either circular or hyperbolic lattices (time differences). The LORAN-C is a Low-frequency (30-300 KHz) positioning system. It has been the primary marine and airborne navigation system for over 40 years. It is a low-frequency time-differencing hyperbolic system. These systems could only fulfill many accuracy requirements when used near the coast.

With the launching of artificial satellites in 1957, geodesy entered a new era. The satellite radio navigation technique is used since the TRANSIT system, that used the Doppler effect for radio signals. There were some limitations with the Dopller method, like: position information can only be derived from a single satellite pass. This positioning data can only be obtained for a limited period of 15 to 18 minutes during a particular satellite pass. The Doppler technique was substituted by GPS (Global Positioning System) after 1990.

GPS is a very good system for hydrographic surveys due to the constellation satellites visible from any position in the world, at any time, offering 24-hour of worldwide navigation capability.

The position of the vessel is available in real-time. After having been off the SA-technical security, the accuracy for a stand-alone user is sufficient for general navigation, in many cases. However, for precise positioning and navigation in areas of risk to navigation it is possible to use Differential GPS (DGPS).

DGPS comprises the positioning of a mobile station (vessel) through the corrections generated in the reference station. Those corrections are sent in real-time via data link (transmission radio, phone line, or communication satellites) and in accordance to an appropriate format, set forth by the Radio Technical Commitee for Marine Services (RTCM) (RTCM, 2006; KRUEGER, 1996).

The coordinates of the reference station are well known and have high accuracy. The corrections consist of the difference between the true pseudoranges and those computed for each one of the satellites in the reference station (KRUEGER, 1996). The data link is a critical component of differential GPS, special to RTK-Real Time Kinematic.

There are some possibilities to DGPS, like: the ordinary DGPS, the carrier smoothed DGPS and the Precise DGPS (PDGPS or RTK). In the first case, the code range corrections are used (relative accuracy 1 to 3 m); in the second case the carrier observations are used to smooth the coarse code observation with a suitable filter without solving ambiguities (relative accuracy < 0.5m) and the RTK uses the carrier phase observations, or carrier phase corrections are used to resolve ambiguities (relative accuracy of better than 0.1 m down to several centimeters).

The application of DGPS mitigates the errors regarding: satellite clock, ephemerides and atmospheric signal propagation. If those errors are the same at the reference and mobile stations, they will be eliminated. The observables in that system are the phase of the code or the carrier phase smoothed code. Also, the quality of DGPS position is influenced by the distance between the reference and mobile stations, as well as, the quality of the communication system (KRUEGER, 1996).

The main obstacle of RTK is data communication, because transmission and range depend on the distance between stations. The effect of the ionosphere must be considered, as well (WANNIGER, 1995).

According to the Special Publication S-44 from International Hydrographic Organization (IHO, 2008), the maximum horizontal uncertainty of the soundings or a feature, with respect to a geodetic reference frame, is 2 meters, considering a Special Order Survey. For such reason, the usage of RTK is recommended. For other hydrographic surveys orders (1a, 1b or 2) DGPS can be employed.

Nowadays, hydrographic vessels use Real Time GPS Reference Network. In this network, the spatial and temporal correlations of distance dependent errors are determined using observations from several GPS reference stations with precisely known coordinates. The residuals at these stations are used to derive an interpolation model that is used in turn to derive corrections toward the location of any rover within the network.

That enables a fast and correct ambiguity resolution, so the coordinates of the rover can be precisely determined almost independently from the distance of the distance to the next reference station.

According Willgalis et al (2002) the deployed RTK network in Brazil provided results for the resultant of the horizontal components, see Figure 4. In this figure it is possible to see that the majority of the residuals are smaller than 1 cm and 90% is below of the threshold of 2 cm. These results prove that even under the unfavorable ionosphere conditions in Brazil multi station RTK is a powerful GPS positioning method for different hydrographic surveys.

Brazilian Navy Hydrographic Vessels uses RTG (Real Time GIPSY) technique. It is referred to as Globally corrected GPS (GcGPS) and produces globally uniform precise GPS orbit and clock corrections. Using StarFire's satellite-based RTG signal with corrections for solid Earth tide, NAVOCEANO tests indicate that IHO horizontal and vertical accuracy standards can be achieved without establishing shore stations. These tests indicated horizontal accuracies of 20 cm (2 sigma) and vertical accuracies of 24 cm (2 sigma) wherever the INMARSAT-C signals can be reached (VAN NORDEN et al, 2005).

Today has been different satellite-based navigation system, like GLONASS (Russian system) and Compass (Chinese system), that may be used together, in order to compute the positioning of the vessels.

2.5 Benchmark Leveling and Positioning

One of the concerns in a hydrographic survey is the elevation of the sea surface, which is significantly affected by gravitational interactions between the Sun, Moon and Earth. Although with little effect, the elevation could happen in lakes and rivers surfaces.

The term tide is traditionally accepted and widely used by surveyors in connection with the instrumentation used to measure the elevation of the water level.

The water level datum is a local plane of elevation only applied in a specific area where water level measurements have been made. Whether tidal or non-tidal, it is permanently referred to the benchmark by geometric levelling.

According to NORMAM-25 (2014), the tide station must be connected to at least three benchmarks and it is necessary to determine the geographic coordinates (latitude, longitude and geometric height) of the primary benchmark.

Nowadays, the geodetic coordinates have been determined through Global Navigation Satellite Systems (GNSS) using relative static positioning. The time of the positioning depends on the distance between this benchmark and the base stations. To estimate the amount of time necessary Figure 5 brings a table, provided by the National Geographical Institute (IGN-Spain), which can be used as reference.

It is important that geometric leveling among benchmarks and tide station happens before the beginning of the hydrographic survey, even though a permanent tidal gauge already exits.

In the Figure 6, it is possible to see a schema among three benchmarks and a tidal gauge (right side), and a diagram (left side) with the cotes among the benchmarks, the ruler, the local mean sea level plan, datum plan, and etc.

2.6 Real Time Kinematic GNSS Positioning for Hydrographic Surveys

The possibility of using GNSS (Global Navigation Satellite Systems) technology for vertical control of hydrographic surveys has been improved.

The tide determination using GNSS-RTK will provide a local tide oscillation. However, the tidal computation requires a model hat is capable

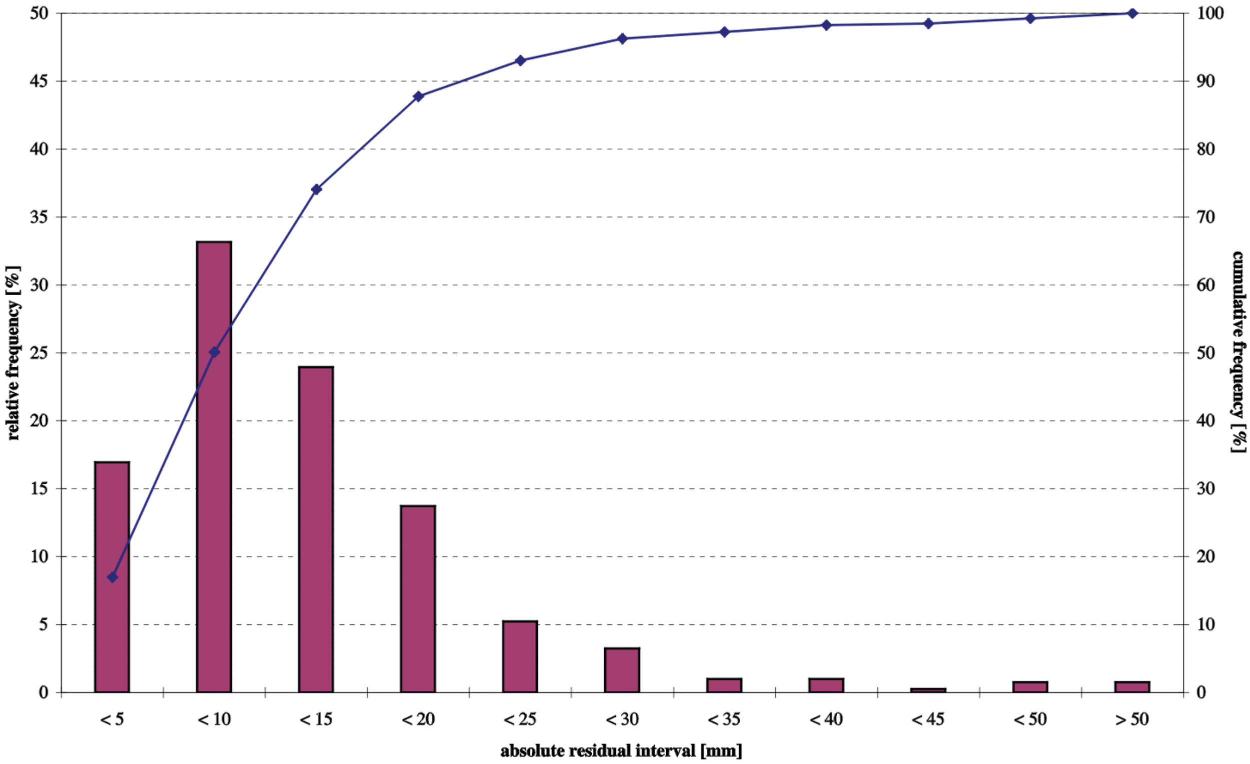

Fig. 4 – Horizontal (2D) positioning accuracy.

Baseline	Observation time	Observable	Accuracy
00-05 km	05-10min	L1 or L1/L2	5-10mm + 1ppm
05-10km	10-15min	L1 or L1/L2	5-10mm + 1ppm
10-20km	15-30min	L1 or L1/L2	5-10mm + 1ppm
20-50km	2-3h	L1/L2	5mm + 1ppm
50-100km	minimum of 3h	L1/L2	5mm + 1ppm
>100km	minimum of 4h	L1/L2	5mm + 1ppm

Fig. 5 – Time of the occupation and accuracy in relative positioning.

to return the separation between the reference ellipsoid and the local vertical datum.

According to the Manual on Hydrography (IHO, 2011) the following requirements need to be performed in order to use GNSS-RTK:

a) Perform wide area GPS static surveys in the selected area;

b) Install sufficient tide gauges in the area to obtain details of tidal datum at these gauge sites computed form long observation periods of data;

c) Perform GPS tidal measurements in the survey area at the same time to obtain a comparable data set of GPS water measurements against conventional tide gauge measurements;

d) Anchor a survey vessel fitted (or GNSS buoys) with a RTK Rover Receiver for 25 hour periods in sufficient locations to generate intermediate datum points within the area, to allow correlation between the conventional tide gauge methods and the GPS tidal datum method, and to check any changes in ellipsoid heights between the RTK stations and the gauge sites over a full tide cycle of 28 days; and

e) Use a suitable software configuration in the hydrographic survey package which allows for the ellipsoid separation values to MLLW to be used to compute tidal height measurements from the waterline of the survey vessel.

The ellipsoid height values and the GNSS reference station are used to measure the separation between ellipsoid and the mean lower low water reference plane. The separation enables Kinematic GNSS hydrographic surveys to be conducted without using tide gauges data.

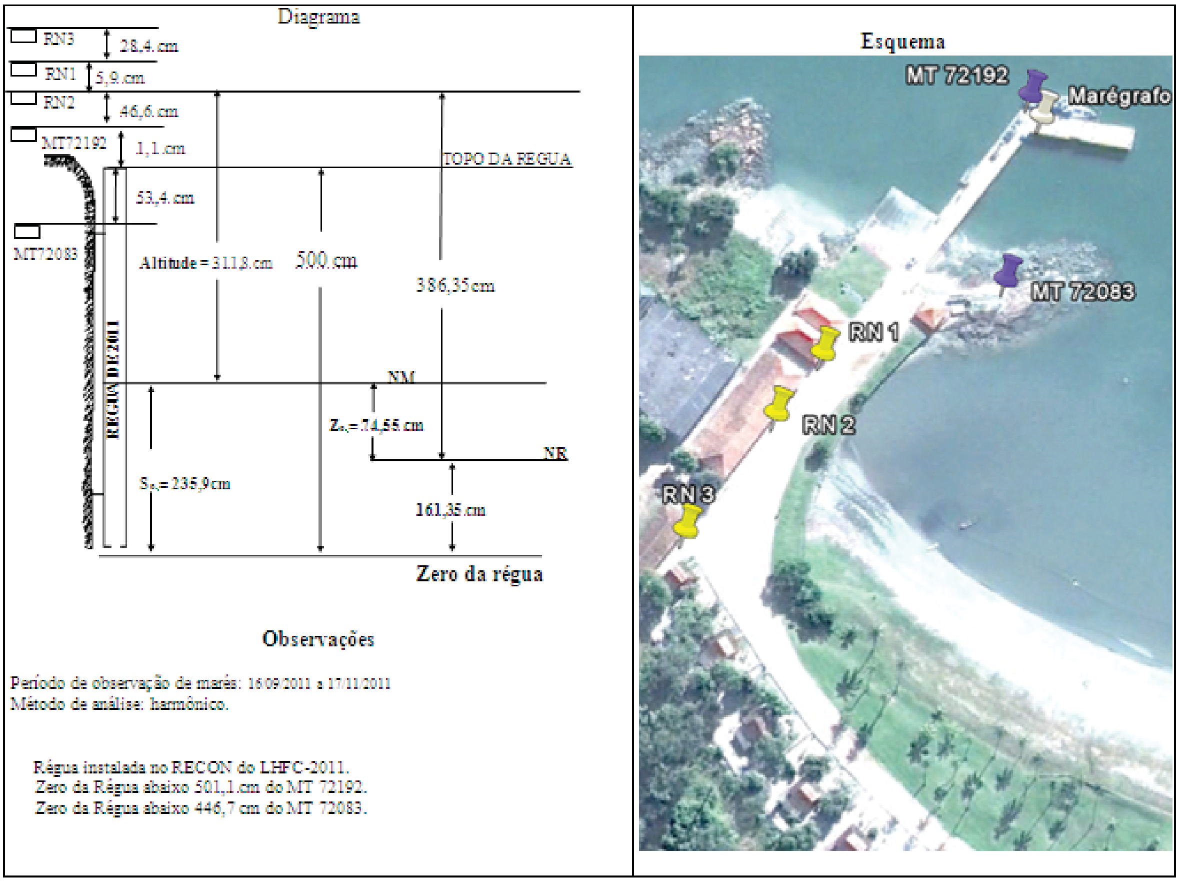

Fig. 6 – Tide Gauge located in Centro de Adestramento e Avaliação da Ilha da Marambaia Berth.

3. CONCLUSION

New Geodetic technologies may be used to support Brazilian Hydrographic Surveys in the future.

The integration between sea topographic models with land surveys, employing LIDAR (LIght Detection And Ranging) technology or a multi sensor system by integrating the terrestrial laser scanning system with high precise acoustic systems can be cited as an example.

The LIDAR can be used in hydrographic surveys for creating three dimension digital elevation models from which navigation and shore protection projects can be monitored and managed.

Also, the application of the satellites positioning system has not been used in Brazil in order to determine tide over the hydrographic surveys. Some tests have been developed with the use of GPS buoys. According to Krueger et al (2013), comparative analysis of tidal measurements made between the GPS buoy data and the tide gauge data showed that GPS buoys can be used to create zones of tidal reduction.

Improve the understanding about the shape of the geoid is needed to enable the usage of altimetry satellites in several studies such as the oceanic mesoscale currents. Nowadays, this lack of understanding represents a considerable limitation because the ocean geoid is at least an order of magnitude larger than the signal from mesoscale ocean currents.

After exposing all subjects here it is possible to conclude that there are many issues to be done and a lot of researches to be developed in order to integrate, even more, geodesy with hydrography.

REFERENCES

BOEDER,V.; KERSTEN,T.P.; HESSE,C.; THIES,T.; SAUER.A. **Initial experience with the integration of a terrestrial laser scanner into the mobile hydrographic multi sensor system on a ship**. Istanbul, 2010.

CAHO. **Report of the end hydro oceanographic course**. 85p. Niteroi, 2011

CROWELL, M.; LETHERMAN, S. P. BUCKLEY, M. K. Historical shoreline change:

error analysis and mapping accuracy. **Journal of coastal research** 7, 839-852, 1991.

GONÇALVES, R.M.; KRUEGER, C.P.; HECK, B. and AWANGE. A comparison between three short-term shoreline prediction models. **Ocean & Coastal Management**, v. 69, p. 102-110, 2012a.

GONÇALVES, R.M.; AWANGE, and KRUEGER, C.P. GNSS-based monitoring and mapping of shoreline position in support of planning and management of Matinhos/ PR (Brazil). **Journal of Global Positioning Systems (Print),** v. 11, p. 156-168, 2012b.

GONÇALVES, R.M. **Predição de Mudanças a Curto-Prazo da Movimentação de Linha de Costa Utilizando Dados Geodésicos Temporais.** Universidade Federal do Paraná. Tese de Doutorado em Ciências Geodésicas. Curitiba, 2009.

HEIMBERG, F.; SEEBER, G. Kinematische Anwendungen von GPS – GPS-eine universelle geodätische Methode. **Schriftehreihe, 11/1993**, DVW e.V., Wittwer.

KRUEGER, C.P. **Investigações sobre aplicações de alta precisão do GPS no âmbito marinho**. Universidade Federal do Paraná. Tese de Doutorado em Ciências Geodésicas. Curitiba, 1996.

KRUEGER, C. P.; SOARES C. R.; PRADO, A. Monitoramento do Recuo e da Progradação da Linha de Costa Utilizando o Sistema de Posicionamento Global (GPS) In: **COBRAC 98 – Congresso Brasileiro de Cadastro Técnico Multifinalitário –** UFSC, Florianópolis 18 a 22 de Outubro, 1998.

KRUEGER, C. P.; CENTENO, J. A.; MITSHITA, E. A.; VEIGA, L. A. K; ZOCOLOTTI FILHO, C. A; JUBANSKI, J. J.; URAKAWA, M. J. Determinação da Linha de Costa na região de Matinhos (PR) através de Diferentes Métodos. **In: GEODÉSICAS**, Coordenador do Curso de Pós-graduação Em Ciências. (Org.). **Séries em Ciências Geodésicas.** Curitiba, 2003, v. 2.

KRUEGER, C. P.; SOARES, C. R.; LEANDRO, D.; HUINCA, S. M.; and GONÇALVES, R. M. Satellite Positioning on the Coast of the Parana, Brazil. **Journal of Coastal Research**, v. 27, p. 1352-1356, 2011.

LAURILA, S.H. **Electronic Surveyng & Navigation**. Wiley-Interscience. 1976.

MANUAL ON HYDROGRAPHY. Published by International Hydrographic Bureau, Monaco, 2005.

MIRA, S. Hydrography and its Education. **Schriftenreihe der Institute des Studiengangs Geodäsie und Geoinformatik**. Technical Reports Department of Geodesy and Geoinformatics. Univesität Stuttgart. SSN 0933-2839, Report Nr. 6, 1999.

RTCM STANDARD 10403.1 FOR DIFFERENTIAL GNSS (GLOBAL NAVIGATION SATELLITE SYSTEMS) SERVICES – VERSION 3, 2006.

SEEBER, G. **Satellite Geodesy: Foundations, Methods and Applications**. Berlin,New York: Walter de Gruyter, 612 páginas, 2003.

SUGUIO, K. **Dicionário de geologia marinha**. T.A. Queiroz, São Paulo p.171, 1992.

TANAJURA, E.; KRUEGER, C. P.; and GONÇALVES, R. M. Análise da Acurácia dos Métodos Cinemáticos de Posicionamento GPS em Aplicações Costeiras. **Boletim de Ciências Geodésicas**, v. 17, p. 23-36, 2011.

TORGE, W. **Geodesy.** 2nd. Ed. W. de Gruyner, Berlin-New York, 1991.

TORGE, W. The International Association of Geodesy (IAG)- more than 130 years of international cooperation**. Journal of Geodesy**, Volume 70, Issue 12, pp 840-845, 1996.

VAN NORDEN, M.F.; ARROYO-SUAREZ, E.N.; NAJJAR, A.S. Concept for military surveys to IHO standards without shore stations using the Real-Time GIPSY (RTG) Global Positioning System (GPS). In **Proceedings of MTS/IEEE W**v.1, p.615-621, 2005.

WILLGALIS, S., SEEBER, G., KRUEGER, C.P., ROMÃO, V.M.C. A Real Time GPS Reference Network for Recife, Brazil, Enabeling Precise and Reliable Cadastral Surveys. In **FIG XXII International Congress,** Washington, D.C. USA, April 19-26 2002