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Satellite Positioning on the Coast of the Parana, Brazil

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ABSTRACT

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This paper describes different surveys developed by the Spatial Geodetic Laboratory (LAGE) of the Federal University of Parana (UFPR), Brazil, in cooperation with different institutions. The main focus of the studies was the coastal zone, where High Precision GPS techniques (absolute, relative or differential) were applied to give support for the implementation of a geodetic network, and from these points precisely established, special applications (or case studies) were performed, as the variation of the coastline (erosion, accretion) monitoring, high precision bathymetric surveys, cadaster of the piers of the ports and positioning of artificial reefs, In each case, always was emphasized the methods employed, accuracy obtained and probable sources of errors.

ADDITIONAL INDEX WORDS: *Coastal Mapping, GPS, Marine Positioning.*

INTRODUCTION

The determination of global positioning (land and sea) using artificial satellite systems started to be planed in 60´s and the development and improvement are present until today. The distances between satellites and ground stations are determined or fixed, allowing the positioning of those referential frame stations.

The first generation of satellite-based on navigation systems was developed by Transit and Tsikada. At around 80´s, it has been established the NAVigation System with Time And Ranging - Global Positioning System (NAVSTAR-GPS) and GLONASS (Russian Global Navigation Satellite System). Around the turn of the century, the ideas of the European and Chinese development navigation satellite systems Galileo and Compass, respectively. The NAVigation System with Time And Ranging - Global Positioning System (NAVSTAR-GPS) has been successfully used in the marine environment since 1985. The interest grew up in the face of predominant properties as continuous signal availability, easy applications and independence in relation to the meteorological conditions.

Nowadays there are new applications in environment fields for Global Navigation Satellite System (GNSS) that has being discovered, such the cases of: precise navigation in coastal areas, mapping of sea bottom, precise hydrographic surveys, access to ports, monitoring of dredging activities, support to coastal engineering, attitude control in vessels, buoys and flotation platforms, continuous and accurate control of heights and positioning of sensors underwater. Today, there is a growing interest in real-time applications and integration with other fields, which rely on accurate coordinates like GIS applications and ecobathymetric surveys. For such applications, it is necessary accurate precision better than a meter.

There are several methods of satellite positioning that can be applied by the users, in this work it is important to cite: Absolute (or Point Positioning), Relative Positioning and Differential GPS.

In general, *Absolute Positioning* uses a single receiver and is defined as one in which the coordinates of the point occupied on the land surface are directly related to the geocentric. When *GPS* is used the coordinates has been referred to the WGS-84 (G1150) (World Geodetic System, 1984 - refined for the week of 1150). The fundamental principle of this placement is based on measurements of the pseudoranges derived from the code C/A in the L1 carrier phase. Four observations are necessary to account for the three coordinate components and the receiver clock error. There are two levels of service: the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). The first enables the access for civilian users and the second for authorized users. The error in absolute positioning for users SPS and PPS is shown in Table 01.

Table 1: Absolute Positioning Error for Users (Seeber,2003).

SPS Users	Horizontal	Vertical
Global Media	≤ 13 m (95%)	≤ 22 m (95%)
Worst situation	≤ 36 m (05%)	≤ 77 m (05%)

The *Relative Positioning* is characterized by the simultaneous observation of satellite signals at least two distinct stations. It is associated with baselines, i.e., the three-dimensional vector between a known base station and the location to be determined. It is possible to use different types of observations as the code phase, the phase of the carrier smoothed code and carrier phase (Krueger, 1996). The highest accuracies are achieved with carrier phases. This method of positioning contributes to significant minimization of errors, especially the satellite clock error, ephemeris and signal propagation in the atmosphere. It can be classified as: static, fast static, cinematic and Stop and Go. In the first two ones, station antenna incognita remain static and the other will be moved. In the cinematic technique the interest is the trajectory to be covered and in the Stop and Go only in the points of interest are occupied.

The principle of the *Differential GPS* (DGPS) is the positioning of a mobile station using differential corrections generated relative to the reference station. These corrections are sent in real time through a system of communication (broadcast radio, mobile telephone and satellite of communications) and within an appropriate format, defined by the Radio Technical Committee for Maritime Service (RTCM) (Krueger, 1996). It is divided into: DGPS (GPS Differential); RTK (Real Time Kinematic); PDGPS (Precise DGPS); and WADGPS (Wide Area DGPS). The main differences consist in the kind of used observable and in the number of reference stations.

In Figure 1 it is possible to see the obtainable accuracy and reliability depending on observation time and positioning method.

In Brazil, since 1996 surveys with Global Positioning System (GPS) have been developed in coastal areas of Paraná State. The introduction of satellite positioning on this coast was and has been extremely valuable to the community by the generation of reliable data, providing a holistic and systematic approach to environmental issues and options for the effective monitoring of the coastal environment through geo-referenced information, that serve for management of the coastal ecosystem basis.

The objective of this paper is to show surveys realized at Parana coastal area with satellites positioning systems. It emphasizes the methods employed and the observable, as well as the investigations and to conclude the results.

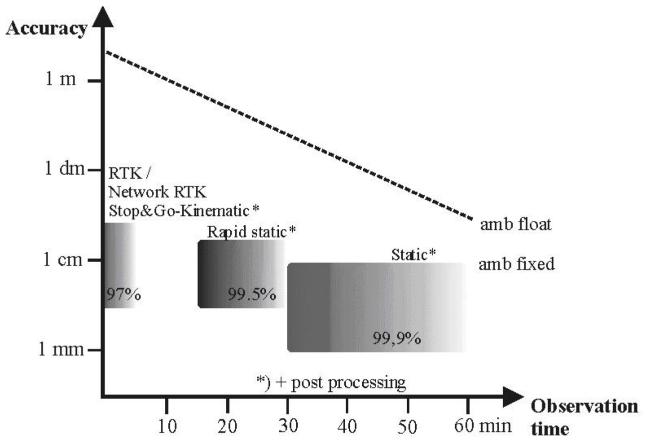

Figure 1: Obtainable accuracy and reliability depending on observation time and positioning method (Willigalis *et. al.*, 2003).

STUDIED AREA

The coastal region of the State of Parana, Brazil, is located between 25º and 26º S parallels and 48º and 49º W meridians It is formed by the Serra do Mar mountain range with extensive coastal plains (marine terraces), which includes actual estuarine systems. The Serra do Mar comprises two general types of mountains: a) mountains of plateau edge, originated by the dissection of the Curitiba plateau border, on the west side and with altitudes around 900 m; and b) mountains formed by differential erosion, sustained by rocks that are more resistant then weathering, such as with elevations ranging from 1,300 m to 1,800 m (Angulo, 1996). The geomorphologic characteristics of the Serra do Mar originate hydrographic basins, which drain to the estuarine complexes. The main cities of Parana coastal zone are: Paranagua, Morretes, Antonina, Guaraqueçaba, Pontal do Parana and Guaratuba.

SURVEYS AT COAST OF PARANA STATE

Since 1996 many surveys with Global Positioning System (GPS) have been developed in the coastal zone of Parana. It started with the sandwich Ph.D. thesis entitled "Investigations on the Application of High Precision GPS in Marine Scope" (Krueger, 1996). Other surveys has been developed, like: the implementation and materialization of 11 points in the region, that compose a geodetic network frame to support surveys; monitoring of those points that; positioning and monitoring of the shoreline positioning; high precision bathymetric surveys; register of Paranagua pier contained in the port; positioning of artificial reefs; integrated study of consequences of human inadequate occupation of the coastline, taking Matinhos district as a case study. Different methods of positioning by satellite (absolute, relative or differential) has been used in such sites aiming to a desired accuracy and for the purpose of such survey. The GPS data have been processed with commercial and scientific GPS software packages. Also, as in some cases as hydrographic surveys, software package was used.

Investigations on the Application of High Precision GPS in Marine Environment

This study was carried out at the Pontal do Sul resort. It was analyzed data collected from bathimetryc surveys using different reference stations and collection rate. There is the viability or otherwise of the introduction of the scale factor and tropospheric current parameters (eg. dry temperature, wet temperature and pressure) in the post-processing of data, using the scientific program GEONAP-K.

The profiles were carried out by sailing the GEO vessel (Rove station) and using Ashtech Z-XII receivers to collect data each one second and in the accurate DGPS solution. The ability to PDGPS solution was found for some planned lines of survey using different reference stations, one of which was located in Paranguá (Pgua) and another in Curitiba (Ecc3). These data were also processed in the GEONAP software. The baselines formed between base and rove stations are approximately equal to 16 and 90km, respectively. Relatively satisfactory accuracy for the reference station located close to the vessel (16km) was observed. On the other hand, the station (90km), which was farther than the first one, showed a height difference next to 920 m, the results obtained were not satisfactory.

After processing the data collected, it was found that explanation, the short baseline (Pgua/Rove), less than the recommended for PDGPS, better than 10cm. This accuracy is within the precision indicated for kinematic surveys.

The long baseline (Ecc3/Rove) does not present a satisfactory solution PDGPS, i.e., lies outside the limits.

Probably this stems from the fact that a the reference station was located an altitude about 18m, and the other one approximately 924 m, and also they are far from the rove station about 16km and 90km, respectively. In these cases, the precise ephemeris and a science program play an important role.

The comparison of the positioning of the boat trajectory for the different reference stations applied was not satisfactory. The differences obtained for the trajectories with different processing from the baseline were at the order of centimeters to meters, and there they were stronger than for the longitudes for latitude.

With investigations into the solutions, with respect to tropospheric scale factor, it appears that acts in a representative at the long baseline, which is not true for the short baseline. The differences between the latitudes, longitudes and altitudes showed significant changes during the introduction of this factor. The major influence was in the altitude. For the short baseline the tropospheric scale factor is not necessary and it is preferable to avoid it. It happens because the troposphere conditions for nearby stations were almost equal and when they are used, standard deviations increase and there is a weakness in the system. It is necessary to calculate the influence of tropospheric errors rigorously; it means the need to use a scientific program with an appropriate model for tropospheric environmental conditions.

Further investigations were made regarding the removal of satellites during the data processing and found that the consequences may be the most diverse possible. It was obtained variations in the solutions from centimeters to meters.

It was also noted that the resolution of ambiguities became satisfactory with the presence of two-carrier phase. They contributed to the tropospheric modeling, minimizing errors inherent in the system, and for the ambiguity resolution.

It was found that the ionospheric disturbances during these surveys were limited, which contributes to affirm, in a safer way, that the main cause of differences between the solutions generated for the long base line follows from the actions of troposphere effects and of the difference altitude of these stations.

The possibility of achieving high precision in marine environment is attractive, for example, to obtain control points in the relief marine in geodynamics, tides in the observation, monitoring platforms, buoys and monitoring of sedimentation and erosion.

Establishment of a local geodetic network

Brazil relies today on the so-called Brazilian Network for Continuous Monitoring of GPS (RBMC). It is made up of 80 permanent GPS stations, located in 76 cities, like: Manaus, Imperatriz, Fortaleza, Bom Jesus da Lapa, Brasilia, Cuiaba, Presidente Prudente, Viçosa, Rio de Janeiro, São Paulo, Curitiba. They are part of the Network of the South American Geocentric Reference System (SIRGAS). The accuracy of the RBMC stations coordinates is of the order of ± 5 mm, being configured as one of the most precise networks of the world.

Along the Brazilian coast the establishment of a network can be verified with 11 DGPS stations and with a reach of 200 to 300 nautical miles. According to the National Hydrographic Directory (DHN), organization of the Brazilian Navy, responsible for this network, the reached accuracy is better than 9 m ((3σ) + 2 ppm). This network was installed in 1993 and allows DGPS differential corrections freely to users, which are sent by radio beacon station. It supplies some supports like: marine navigation, hydrographic surveying, nautical signs and dredging. According to Briones (1999) comparing the tracks, it was possible to define the medium quality positioning degradation in function of the distance between stations, that was shown be 11,5 ppm. Since 2009 the accuracy in DGPS achieved is less than 4 m (95%) with old equipment and less than 2 m (95%) with new equipment (Ramos, 2009).

Having in mind the development of a geodetic system which will allow high accuracy, a local geodetic network is due to be implemented connected to RBMC stations. The stations that will be part of this local network will be located in key places of interest for entire technical scientific community that works in the area.

Figure 2 shows 11 stations of this geodetic network frame at Parana coast.

The network is made of 11 stations and has been tracked in one surveying campaign so far. The CEM1 station (belongings this network), is located at headquarters of the Center of Studies of the Sea (CEM). This site was connected with PARA station (RBMC) through relative positioning. Its coordinates were determined with the data collected for 8 days of measurements, being post-processed and adjusted by the BERNESE software. In the future, this connection will be made to another station of RBMC that will be located in the city of Porto Alegre. For the other stations of this network the relative positioning with static technique was used. The base station was CEM1, the measurements were obtained every 15s and the time of occupation in these stations was equal to

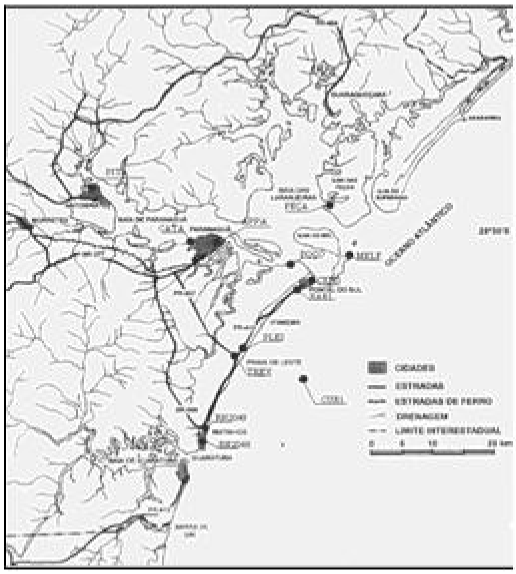

Figure 2. Map of Location of the Geodetic Network of the Coast of Paraná and of the main cities.

5 hours. In this campaign Ashtech Z-XII receivers were used with dual frequency antennas receiving.

The next step to be followed by this group is the reoccupation of these statios to determine new geodetic coordinates and detect possible displacement of these landmarks.

Positioning and Monitoring of the coastline

Maps using shoreline information extracted by GPS were very useful for environmental analysis. In Matinhos was used historical shoreline between 2001 and 2008 to show the local dynamical in a short-term of time. The idea is to measurement the velocity of local retreat and advance for shoreline according to the time with those maps (Krueger *et. al*, 2009).

In this paper 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, vegetation and cliffs, or by any other feature that determines the beginning of the continental area (Soares, C.R., 1995). The determination of these lines can be made through several methods. GPS has been used since 1996 (Krueger *et al*., 1996) in the detection of the variation of the coastline in different sectors of Parana. In the surveys and monitoring of coastlines has been used the cinematic continuous relative positioning method. Different kinds of GPS receivers and recording rate were used. An elevation angel of 10 degrees was used too.

Several surveys were conducted following the coastal lines in the municipality of Matinhos, Pontal do Sul and Ilha do Mel. The reference station (base station) are established around each area of study in a landmark and the mobile station, in these cases, are determined by an individual traveling along the coast by foot with an average speed of 4km/h, with receiver and antenna installed in a backpack. First of all it was necessary to carry out an initialization, staying for 5 to 15 minutes in the initial point of the trajectory that was followed. These surveys have been done using redundant satellites (≥ 4 satellites), dual frequency data and code/carrier combinations. Those factors are extremely important in Cycles Slips recovery, in the cinematic method (Seeber, 1993).

In the municipality of Matinhos, the monitoring of the shoreline has been done along 5km. The Ashtech Solutions software was used to post-processing the data. Figure 3 shows a shoreline with 2.6km and it was divided into five segments (from I to V) and a comparison between the shorelines extracted for the years 2001 to 2008.

It was observed the instability of the shoreline or in some parts there was a retreat and anthers advance. The results showed two critical situations: retreat of 13.5 m and advance of 11.09m.

The next goal of this team was the study of prediction models for shoreline movement using temporal data. The idea was to use photogrammetric data and GPS (Global Position System) data for 2001, 2002, 2005 and 2008 (as control), this study aims to demonstrated a comparison and assessment between 3 different models of shoreline prediction: *Robust Parameter Estimation*, *Neural Network* and *Linear Regression*. The best statistics results shows the MAPE (Mean Absolute Percentage Error) when compared with the residuals between the prediction and the shoreline of control are respectively 0,33% for Linear Regression, 0,14% for Robust Estimation and 0,33% for the case of Neural Network with the feedforward backpropagation network using the Levenberg-Marquardt training function and 4 neurons in the hidden layer (Gonçalves, 2009).

The cinematic relative positioning when done properly and under normal conditions for work with a GPS, presents itself as the most suitable for applications in this category because of that provide a coordinated quality assurance of post-processing. The RTK survey is an important tool. The level of precision achieved allows their use in various GPS applications requiring precise coordinates in real time.

With those measures more information may be obtained on the studied area consequently keeping updated records of the coastlines.

The GPS is accurate and practical for mapping the shoreline, but sometimes it is not possible to walk along it, due to the obstacles (like cliffs and fallen trees) as well can be affected by the loss of signal.

Cadastral surveying of the Paranagua port

GPS is an effective component to support a marine *Geographic Information Systems* (GIS). It contributes to the formation of a uniform geometric base and for the geometric location of objects that enter into GIS (cradles, buoys, ports, canalizations of water and electricity, pipelines). So far cadastral surveys have been carried out on port wharfs of Paranagua's port and on Capitania's port.

Paranagua's port is the largest exporter of grains of Latin America and the second in the Brazilian economic ranking. Its profile began to change with the Law of Modernization of Brazilian ports (Law n^{o}. 8,630/93) and the consolidation of MERCOSUR. The modernization program of the Administration of Paranagua and Antonina's ports-APPA – has been carried out by works of the Marine Studies Center (CEM) for the port operation. Such works will include several types of surveys such as the design of a number of remarkable sites along the port wharfs.

In the Figure 4 it is possible to see a detail of some surveyed points along the port wharfs, in the Bay of Paranagua, 24 remarkable sites were surveyed along this port. In these surveys, the relative fast static positioning was used, with a sampling rate of 2s and with a time of occupation in each point equal to 5 minutes. The base station was installed in the mark APPA, located in the administrative headquarters of Paranagua and Antonina's ports. Ashtech Reliance receivers were used with antennas that receive L1 signal. The geodetic coordinates (WGS-84) were obtained with a post-processing of data through the software Reliance.

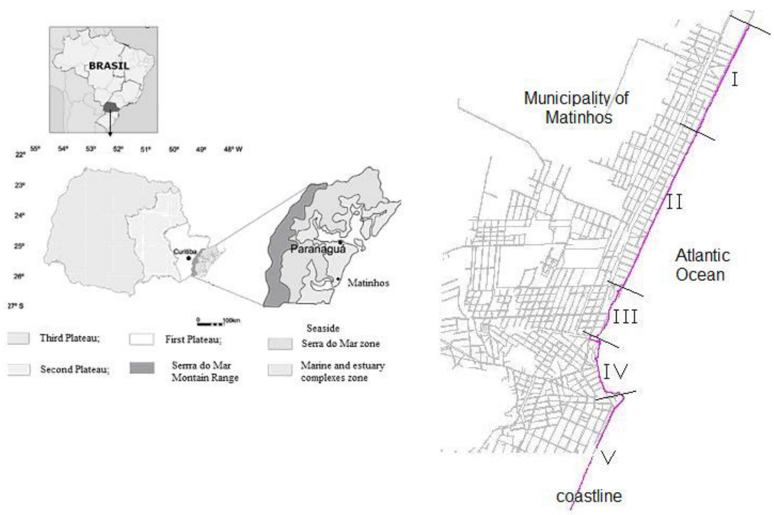

Figure 3. The layout of the shoreline in the municipality of Matinhos – year 2008 (adapted from da Maia and Mazur, 2008).

Precise positioning of artificial reefs

The launching of artificial reefs in the oceans should be performed accurately because of the need of frequent visits. The implantation of such reefs in short and medium term aim at the conservation of the marine biodiversity; the creation of fishing runners and exclusion areas; the development of the local fishing and of the sustainable tourism; a better understanding of the ecological and hydrological processes in the continental platform of the Parana. Additionally, it suggests strategies for the implementation of programs of artificial reefs in Brazil. They are being relatively positioned with GPS and their coordinates have been obtained by data post-processing.

Regular locations of the artificial reefs have been carried out through DGPS having as reference station the mark located on CEM. This positioning has been done with Ashtech Reliance receivers and the corrections are sent to the mobile station (vessels) through a communication system (radios of 35 W in the reference station and 2 W in the mobile station). The format of the differential corrections has been the RTCM 2.0.

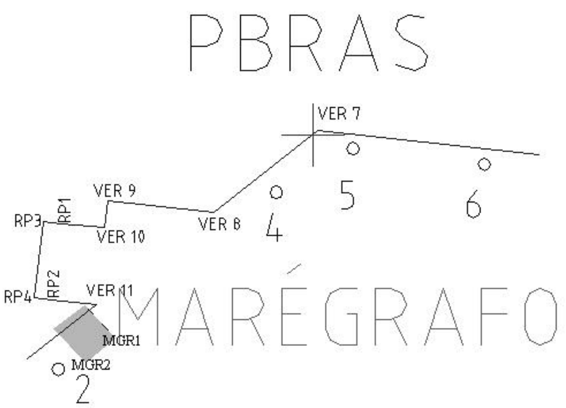

Figure 4. Detail of some surveyed points along the port wharfs, in the Bay of Paranagua .

CONCLUSION

It was noted that the economy of this region is highly dependent on the marine environment. The introduction of satellite positioning on the coast of Paraná was and has been extremely valuable to the community by generating reliable data and current, providing a holistic and systematic about environmental issues and options for the effective monitoring of the coastal environment through geo-referenced information that serve as a base line for coastal ecosystems management.

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