Improving the Cuban National Geodetic Network by means of the Global Positioning System (GPS)

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SUMMARY

The National Geodetic Network (RGN) of the Republic of Cuba was created in the late 40’s and early 50’s of the past century, a first order triangulation network was built and the North American Datum 1927 (NAD27) was adopted in the framework of the Interamerican Geodetic Survey (IAGS).

At the beginning of the 70’s, the RGN modernization and densification were carried out, in closed collaboration with the Soviet geodetic service.

In order to develop mapping in the key areas, between 1989 and 1990 a Doppler campaign, which led to the creation of a reference network with by 14 stations was carried out. Station relative errors were in the order of 0,30 m - 0,40 m.

In 1998, as part of the national efforts to meet the agreements with the International Civil Aeronautical Organization (ICAO) of adopting the WGS84 normalized surface in the aeronautical cartography, a National GPS Campaign by specialists belonging to the Cuban Geodetic Service, conformed by the National Hydrographic and Geodetic Office (ONHG) and the Managerial Group GEOCUBA- the Cuban National Mapping Agency was projected and developed. The network was composed of 20 stations, most of them were the same as with first order triangulation network stations. Relative errors of adjusted coordinates of the stations were obtained in the order of 0,01 m - 0,02 m. Also transformation parameters between WGS84 datum and the national geodetic system were calculated. New geodetic station positions allowed improving the RGN main quality parameters, while being adopted as initial positions in a first order triangulation network combined adjustment.

At present the Cuban Geodetic Service has intended an ambitious plan to improve and modernize NGN through the creation of a high precision GPS reference geodetic network and its gradual densification, the creation of an Active GNSS Network, as well as the adoption of a new geodetic reference system that will satisfy the current demands of the national Economy and Defense.
RESUMEN

La Red Geodésica Nacional (RGN) de la República de Cuba se conforma a finales de la década del 40 e inicios del 50 del siglo pasado, cuando en el marco del Servicio Geodésico Interamericano (IAGS) se crea una red de triangulación de 1er. orden y se importa el Datum Norteamericano del año 1927 (NAD27).

A inicios de los años 70, se desarrolla la modernización y densificación de la RGN, en estrecha colaboración con los servicios geodésicos soviéticos.

Con vistas a desarrollar la mapificación en las zonas de las cayerías, entre los años 1989 y 1990 se realizó una campaña Doppler, que conllevó a la creación de una red de referencia compuesta por 14 estaciones, las que contaron con un error relativo del orden de los 0,30 m – 0,40 m.

En el año 1998, y como parte de los esfuerzos por cumplir los compromisos ante la Organización Internacional de Aeronáutica Civil (OACI) de adoptar la superficie normalizada WGS84 en la cartografía aeronáutica, se proyecta y desarrolla una Campaña de determinaciones GPS por especialistas pertenecientes al Servicio Geodésico de la República de Cuba, conformado por la Oficina Nacional de Hidrografía y Geodesia (ONHG) y el Grupo Empresarial GEOCUBA, la agencia nacional cartográfica del país. La red quedó conformada por 20 estaciones, la mayoría de ellas coincidentes con estaciones de la red de triangulación de 1er. orden. El error relativo de las coordenadas ajustadas de las estaciones se obtuvo en el orden de 0,01 m – 0,02 m. Se obtuvieron también los parámetros de transformación entre el datum WGS84 y el datum del sistema geodésico nacional. Los nuevos valores de las coordenadas de las estaciones geodésicas permitieron mejorar los parámetros de calidad de la RGN, al ser adoptados como iniciales en un ajuste conjunto de la red de triangulación de 1er. orden.

En la actualidad el Servicio Geodésico de la República de Cuba se ha propuesto un plan ambicioso con vistas a perfeccionar y modernizar la RGN, mediante la creación de una red geodésica GPS de referencia de mayor precisión, la paulatina densificación de la misma, así como la creación de una Red GNSS Activa y la adopción de un nuevo sistema geodésico de referencia, que satisfaga las exigencias actuales de diversas aplicaciones científicas y la Economía nacional.
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1 INTRODUCTION

The North American Datum of 1927 (NAD27), imported from the United States of America by the Inter American Geodetic Survey (IAGS) in the middle of the last century, by means of electronic connections between Florida and our island is still effectively employed in the Cuban Geodetic System

Apart from the errors and problems inherent to the NAD27 in the North American territory, in time and with the introduction of new techniques of geodetic measurements, some data inconsistencies were detected.

At present fast population growth and economic development, together with the newly scientific and technical advances that require a dynamic analysis of the earth crust movements, demand the adoption of reference geodetic systems sustained on the International Terrestrial Reference Frames (ITRF) as well as on the Geodetic Reference System of 1980 (GRS80) ellipsoid.

In 1998 in Cuba a high precision GPS network was created for future reference of those works carried out in aeronautical facilities aimed to adopt the World Geodetic System of 1984 (WGS84) normalized geodetic surface in the Cuban Civil Aeronautics. The GPS network was referred to the ITRF96 system and later the coordinates were transformed to the WGS84 and Clarke 1866 systems, since the occupied geodetic stations belonged to the first order triangulation horizontal network. Although the errors of the transformation lineal parameters did not reach one decimeter, they overcome in more than an order the precision of GPS determinations, contaminating the high level of precision that can offer available GPS receivers. On the other hand, the significant differences among the transformation parameters obtained for each airport of the country, reaffirm the idea of random component of local distortions in geodetic networks.

In this paper the origins, further process of development of the State Horizontal Geodetic Network (HGN) of the Republic of Cuba, as well as the most recent works where satellite positioning techniques were involved, are presented. At the end some directives proposed by the Cuban National Geodetic Service for continuously performing the HGN are discussed.
2 CREATION OF THE STATE HORIZONTAL GEODETIC NETWORK (SHGN) OF THE REPUBLIC OF CUBA

2.1 Origins of the Cuban SHGN

The first works of precision triangulation in Cuba are reported on the half of the XIX century. Among them it is necessary to highlight determinations required for the construction of the Albear Aqueduct, which allowed publishing the topographical plane from the capital on 1:5000 scale (De Albear J.F., 1951).

The precision triangulation carried out to control the Havana municipal limits has been considered the first outstanding geodetic work before 1959. These works were developed to solve some tasks of limited reach, for that reason they did not respond to a general geodetic planning idea.

In 1912 Washington Hydrographic Office executed astrogeodetic determinations on 23 stations located in the whole contour of the Cuban costs. Two decades later, in the frame of the program for navigation aids, the US Navy Hydrographic Office carried out oceanographic works as well as third and fourth order triangulation of the Cuban costs and keys, in order to obtain the astrogeodetic coordinates of great number of sites (De Albear J.F., 1951).

In the late 40’s and early 50’s of the last century, our country is integrated to the hemispherical works developed by the IAGS, aimed to unify the national geodetic systems.

Some geodetic determinations by means of electronic connection from the Florida, which lead to the insertion of the Cuban geodetic system to the North American Datum 1927 - NAD27 (De Albear J.F., 1954) were projected in 1950

Between 1951 and 1953 aerial-electronic missions were repeated, applying the High Precision Range (Hiran) trilateration method. The selected stations were linked to the fundamental triangulation network. After the campaign was over and a common adjustment by the parametric method performed, all the stations were referred to the NAD 27. It was considered that a relative precision of 1:113000 was achieved (De Albear J.F., 1954).

Up to 1958, the basic network was constituted by 87 stations, while another 181 stations belonged to other types of networks.

In order of create the geodetic base for high precision mapping on different scales, the astrogeodetic network modernization was carried out on 1970-1973.

2.2 Modernization of the astrogeodetic network

Detailed analysis of fundamental and complementary circuits of first order triangulation network, lead to conclude that the network accuracy did not correspond to the new demands
for first order triangulation. Outliers errors on the triangles closures, the conditional equation free terms, as well as the loss of geodetic stations were also detected (ICGC, 1974).

Once the modernization was over; the new network covered the whole Cuban territory, except for the extreme peninsulas, the Peninsula of Zapata and the current Island of Youth, being conformed by 237 first order triangulation stations, 15 lineal bases and 28 Laplace stations. The second and third order networks were developed in the whole national territory by the triangulation and traverse methods among 1974 and 1983. Triangulation was developed, fundamentally in the mountainous areas, in form of compact meshes, while traverse networks were carried out by means of single polygonal systems, as well as by node systems. After the densification task was finished, 490 and 1903 of second and third stations respectively were established.

Between 1981 and 1985 the basic horizontal fourth order network was developed in prioritized rural areas, settling down 3500 station by means of the triangulation or traverse methods, depending on the terrain topography (Martínez, A.H., 1995).

From 1985 to 1990 fourth order and first category densification in urban areas was carried out, with about 28806 points. In 1989, the Special Havana City Horizontal Network was created to support further geodetic works in the construction of the capital subway (being formed by of 26 stations). This is the most precise geodetic network ever built by conventional methods in the country (Cabrera P., 1991).

2.3 The Doppler campaign

Between December 1989 and March 1990, a national Doppler campaign was carried out. (Prada G. R. - Martínez H., 1990). Works were developed in closed collaboration with the Soviet Geodetic Services, in order to achieve the following objectives:

- The improvement in the precision of the astrogeodetic initial data, through the inclusion of the campaign results in an overall combined network adjustment.
- The determination of the most probable transformation parameters between the Cuban geodetic system (CGS) utilized in Cuba (referred to the Clarke 1866 ellipsoid) and the World Geodetic System of 1972 (WGS72).
- The more accurate determination of the network datum coordinates.
- Geodetic link of the geodetic points or geodetic network at Cuban basin area, as a support to different works for topographical mapping.

Doppler network consisted of fourteen stations; six of them are located on key territories (figure 2-1).
The Doppler network adjustment took place in the WGS 72 by the short arc approach. The overall network was adjusted adopting as initial station Limones, which allowed referring the adjusted coordinates of Doppler stations to the SHGN. As a result of the adjustment, transformation parameters between the CGS and WGS72 were obtained using positions from eight common stations. Finally the three-dimensional root mean square (3D) for relative positions, in the order of ± 0.30 m and ± 0.40 m, were calculated (Prada G. R. - Martínez H., 1990).

2.4 Havana city GPS reference network

In 2001, Havana city GPS reference network was built in order to provide an accurate geodetic control for 1:500 scale mapping in the Cuban capital. Network stations (figure 2-2) were coincident with most of the Special Havana City Horizontal Network. A total of 18 stations were selected as part of the Cuban capital GPS reference network (dark triangles in figure 2-2). After the vector processing and adjustment, a three-dimensional root mean square better than ± 0.015 m was achieved.
2.5 The 1998’s National GPS Campaign

In 1998, due to the emerging needs of having stations with precise coordinates referred to the World Geodetic System of 1984 (WGS84), to support several tasks for adopting the WGS84 normalized geodetic surface in the aeronautical mapping, as well as to improve the SHGN, a high precision GPS Campaign was projected and carried out on several stations of the first order triangulation network. The network consisted of 20 stations: 3 stations belonged to the first order triangulation network, 5 Laplace stations, 4 stations belonged to the Doppler network, 7 stations where converged astrogeodetic as well as Doppler measurements and 1 station belonging to the Siboney tide-gage circuit, which is intended to become soon as the national vertical datum. Figure 2-3 shows the 1998’s National GPS Network (Rodríguez R.E. - Martinez H., 1998).
The campaign was carried out in two stages. First five stations were occupied during a whole week and later the rest ones, forming nine quadrilaterals with common sides. First stage stations positions were calculated setting as reference for the relative processing, positions of a GPS station belonging to the former International GPS Service for Geodynamics (IGS), at present the International Global Navigation Satellite Service located in Florida and its spatial coordinates were obtained with a relative precision in the order of ± 0,010 m to ± 0,013 m. These coordinates were adopted as initials to calculate the rest of the station positions, being reached a precision of the order of ± 0,010 m to ± 0,015 m. All measurements were referred to the ITRF96 (epoch 1998.46). Finally transformation parameters between the reference surfaces WGS84 and the NGS were determined (Rodríguez R.E, 1999).

The inclusion of the 1998’s GPS campaign in the joined first order triangulation network readjustment, allowed improving most of the quality parameters of quality of the SHGN initial data (Rodríguez R.E., 1999).

3. PROBLEMS WITH THE CURRENT DATUM

Discrepancies between measurements obtained with the most recent technology and those topocentric datum adopted all around the world, depend on two groups of factors:

- Those associated with the creation of the adopted datum. In the case of the NAD27, the approximate character of calculations which lead to the datum creation can be highlighted, as well as the high data dispersion.
- Those associated to the changes which took place from the date of the datum adoption up to the present, among them it can be pointed out the growth of the geodetic network without a new readjustment, the effect of the crustal movement in California and Alaska at the time the datum was imported to Cuba (Schwarz Ch.R., 1989), crustal activity in Cuban eastern zone (from the 50th of last century so far), as well as the introduction of...
geodetic instruments able to provide higher relative precisions levels that those defined by the own adopted datum: electronic distance meters (EDM), total stations, Doppler and GPS receivers.

These reasons lead to the conclusion that the old NAD27 datum was no longer appropriate as a reference geodetic frame.

New needs imposed by the scientific, technical and economic development, as well as military reasons, lead out to the adoption of new reference systems, initially in the developed countries and more recently in undeveloped ones. In fact in the international civil aerial navigation it has been already adopted, with the new century arriving, the WGS84 normalized reference surface for cartographic purposes.

When GPS determinations are carried out, it is necessary to transform the coordinates positions from the WGS84 to the NGS. Due to the local geodetic network distortions, and in order to maintain homogeneous results it is recommended to calculate local transformation parameters, which from a practical point of view leads to minimize geodetic work productivity and precision. That is another of the disadvantages of continuously operating with a topocentric and obsolete datum (Rodríguez R.E., 2005).

Although at the beginnings change of the geodetic datum generates certain opposition in diverse society sectors, several social, economic and technological requirements have propitiated more and more the orderly adoption of new geocentric geodetic datum in all around the world. In general this process has been impelled by the following causes:

- The increasing automation level for the geodetic and cadastral activities.
- The need for simplifying digital space data management.
- The necessity to facilitate the employment of international reference frame.
- The requirements to count with dynamic or quasi-dynamic systems, able to consider the crustal deformations, the mean sea level variations, etc.

These reasons have lead to the International Union of Geodesy and Geophysics (IUGG) to propose the ITRF systems, as well as the GRS80 ellipsoid as reference surface, respectively, for national geodetic networks.

In 1986, joint efforts of USA, Canada and Denmark, lead with the North American Datum of 1983 (NAD83), which was adopted as a new geodetic datum for north-american countries. Inclusion of new observations as well as the periodic datum revision has allowed obtaining further versions, more and more compatible with WGS84 and ITRF annual solutions. In a similar way had proceeded in Europe, where most of the states of the Union have adopted different versions of the European Reference Frame (EUREF) (Schwarz Ch.R., 1989).

In 1994 Mexico adopted the ITRF92 datum for its geodetic system, supported like in the rest of the cases, by a network of active (continuously operating) GPS stations (INEGI, 1994).
4. MODERNIZATION OF THE NSGN OF THE REPUBLIC DE CUBA

4.1 Needs for adopting a new reference geodetic system for the country

Considering that at the present time GPS method as the most used procedure to build, modernize and develop horizontal geodetic networks, it can be pointed out that to the Cuban state horizontal geodetic system suffers of the following problems (Rodríguez R.E., 2005):

- Fast destruction of geodetic networks.
- Inconsistency of the old NAD27 datum for current economical and geomatic demands, as well as the need to adopt a geocentric datum, which totally fits the modern GPS geodetic positioning techniques.
- Insufficient distribution of geodetic stations with precise coordinates determined through direct GPS connections.
- Impossibility of being able to validate the GPS technology performance involved in different surveying and geodetic.
- Absence of continuously operating GPS stations in a national basis, which leads to decrease the relative GPS positioning productivity.

Needs for changing the geodetic reference surface are supported by economic, scientific, technical and practical reasons.

Economic reason. Widespread employment of GPS positioning techniques in different geomatic applications, together with its high automation level, allow to increase the productivity of different processes, since execution time is drastically decreased while obtaining substantial benefits in terms of precision, confidence and saving of human resources. Introduction of a geocentric geodetic surface would allow eliminating needs for routinely transformations to the CGS.

Scientific and technical needs. Adopting a geocentric datum would allow to count with an appropriate geodetic frame for those precisions actually provided by modern geodetic equipments. At the present time the vertical ellipsoidal component resulting from GPS determinations, which practically coincides with the ITRF datum, acquires more and more interest. Also it can to be account the fact that international geocentric datum allow to analyze the crustal dynamics, due to its associated velocity models for tectonic plates. These international reference frames are annually recalculated with a high level of precision, through simultaneous measurements in a worldwide network consisted of more than 300 stations.

Practical needs. Using a geocentric datum, which is practically consistent with the WGS84, would eliminate the annoyances of knowing the transformation parameters between CGS and WGS84 during GPS determinations. As has been stated previously SHGN local distortions demand of knowing of the local parameters for each project, mainly for middle and high precision applications, which at can lead to confusions and decreasing of productivity.
The adoption of a new geocentric geodetic surface, would allow to the country to open up to the international reference systems, achieving a better fitting and uniformity of our geodetic system with the international one. Cuba could easily being incorporated to international scientific and technical projects which require for GPS positioning, related to regional and global climatic change studies, such as the variation of mean sea level and geodynamics, besides the benefits that such insertion could bring us in terms of technological and equipment transfer.

The need to count with these patterns of practical, technical and economic nature demands for the Cuban Geodetic Service to carry out a critical analysis of the state of the SHGN, as well as to plans some strategies and policies which allow its improvement in several stages.

4.2 Strategies for improving the SHGN

In summarized form the outlined strategies to improve and modernize the SHGN, consist of the following patterns (Rodríguez R.E., 2005):

- To improve and to rationalize the rescue and protection processes of geodetic stations belonging to the SHGN, introducing the GPS approach to locate sites. The GPS stake out procedure would significantly allow increasing the productivity in the searching and reconstruction station process. A further analysis would point out those network areas which require a biggest initial effort, as well as the current deterioration network level.

- To complete the normalization referred to the creation of state geodetic networks through the employment of the GPS technology. At the present time in Cuba the GPS precision positioning is developed according to empiric approaches, without unified strategies that would facilitate to homogenize results. In such way it has been planned to make and to approve some methodologies aim to an orderly and efficient employment of the GPS system while building geodetic networks, according to the international and national experience.

- To build up special validation networks for GPS technology in support to different precision applications. At present, for GPS stations involved in precision positioning tasks usually work without knowing the real technical condition of the equipment. In Cuban eastern zone GPS receiver calibration has been investigated in the traditional EDM calibration polygons. However, international practice points out to the GPS technology validation in a more complex way, through the building of special geodetic networks, the so call validation polygons. For that reason it has also been planned to create both validation polygons in the western and eastern zones of the country.

- To build up a high accuracy and sparsely geodetic network, which overall density could satisfy the referencing demands on GPS relative positioning. The 1998’s GPS network does not guarantee the productivity and accuracy level required by many high precision GPS applications. In such a way taking into account previous results of different order SHGN combined adjustments, as well as the pointed above analysis, it has been projected a new GPS network, which would allow to achieve relative precision levels of about 0,01 p.p.m. (part per million), being sparsely distributed by the whole national territory and
that at least would duplicates the number of currently high precision GPS stations. In this project is expected to use more sophisticated strategies and procedures that include the employment of geodetic (choke ring) antennas, as well as a professional software like Bernese for rigorous observation processing. Adopting this network as reference, it will be planned its further densification, in such a way so in a near future a overall SHGN combined adjustment could be carry out, including only those stations with positions realized by GNSS methods.

- Starting from the creation of a prototype, to investigate the feasibility of building up a nationwide GNSS active network, able to provide differential corrections to any user.
- To adopt a new geocentric geodetic reference system to allow taking advantages of the campaign results, as well as the high precision level provided by the GNSS relative positioning. It also would able to account with the geometric station positions which meet the international geodetic systems. Using an active GNSS network will minimize the project costs, as well as maximize the observation confidence levels. Considering the fact that Cuba does not have a national GNSS differential service, several users has to set up one or more reference stations for relative positioning. In such a way, starting from a reduced initial budget, it could be able to recommend and to project a wide nation DGNSS service DGNSS to satisfy the user’s needs, not only for surveying but also for navigation purposes.

5. CONCLUSIONS

The SHGN of the Republic of Cuba began to be built in the late 40’s and early of 50’s of the last century, when the NAD27 was adopted. In 70s the SHGN modernization took place up to the 4th order densification in the 80s. Among the main GNSS applications to meet geodetic goals it can be point out the 1990’s Doppler campaign, the 1998’s National GPS Campaign which allowed the improvement of the SHGN initial data, as well as the creation of the Havana city GPS reference network.

In order to up date and improve the Cuban SHGNR the following tasks must be carried out:

- Under new strategies permanently to develop, the rescue and reconstruction of the geodetic stations.
- To complete the normalization referred to the creation of state geodetic networks through the employment of the GPS technology.
- To build up special GNSS validation polygons to define the overall equipment performance for future high precision geodetic applications.
- To build up a wide nation spread GNSS reference network, to satisfy several scientific and technical applications.
- To investigate the feasibility of establishing a national DGNSS service, starting from the creation of a prototype of an active GNSS station.
- To investigate and carry out the adoption of a reference geocentric geodetic surface.
REFERENCES


BIOGRAPHICAL NOTES

Dr. Ernesto Rodríguez Roche was graduated as Engineer in Aerophotosurveying from the Novosibirsk Institute of Engineers on Geodesy, Aerophotosurveying and Cartography (NIIGAIK) in 1984. He holds a PhD degree from José Martí Technical Institute in Havana, Cuba in 2000. Between 1986 and 1995 he worked at Cuban Institute of Geodesy and Cartography (ICGC), the former Cuban National Geodetic and Mapping Agency. During those years his positions included satellite geodesy and geodetic astronomy. Since 1995 he works as researcher at GEOCUBA’s Research and Consultancy Center (GEOCUBA IC). Since 2001 he is the head of the Geodetic Department at GEOCUBA IC, responsible for different GPS applications, especially for those addressed to improve the Cuban National Geodetic Network.

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