Day vs. Night GPS Observations Performance in Puerto Rico's RTK Network

Carlos J. RODRÍGUEZ ROSARIO and Carlos R. VEGA SANTOS, Puerto Rico

Keywords: Day GPS Observations, Night GPS Observations, Precise RTK Network Performance, IMAX-Technology benefits

SUMMARY

Many countries around the world similar to Puerto Rico already have Global Positioning System Networks (GPSN) providing real time corrections over the internet or by radio link systems. The multi-user network helps to create or maintain a countries precise geodetic framework. The geodetic framework is extremely necessary to create different geo-databases used by thousands of industries and government agencies. Communication between user and Real Time Network data centers are managed using different national mobile networks, like GSM (Global System for Mobile) or CDMA (Code Division of Multiple Access), responsible for transporting to the user the real time differential corrections over the internet necessary to built-up the countries geo-database infrastructure.

Many positioning professional around the world today rely and use on a daily basis this modern marvel. Even with this modern marvel sometimes Mother Nature's behavior generates performance differences in Real Time Kinematics (RTK) or through differential correction data streams. The troposphere and ionosphere are examples of factors that cause variances in the performance of geodetic networks.

Our study is a comparative analysis of RTK GPS observation performance during day and night hours using the Puerto Rico Real Time GPS Network operated by Vernix Engineering Corp. The main reference used was the island's existing geodetic network of the National Geodetic Survey (NGS). A short term observation will be realized at the pre-selected GPS bench marks of NGS and compare the performance of different real time data streams with single base solution and automatic cell selection. The island wide system already consists of different GPS receivers. The GPS Reference Stations installed in the Real Time Network are brands such as: Leica 1200 systems, Trimble 4000 SSI and Ashetch all property of Vernix Engineering and a data stream from the National Geodetic Survey which uses a Trimble NetRS. The data center is controlled by a Leica Geosystem using Leica Spider Network Software.

The performance study in the future will provide an important tool for positioning professionals. Data provided by this study is a lethal weapon for GPS observation planning in special projects that need a short time frame to complete a task. Important decisions and budget costs will be supported by data obtained in this analysis.

RESUMEN

Muchos países alrededor del mundo como por ejemplo Puerto Rico poseen y usan Sistemas de Posicionamiento Global en Red (GPSN) la cual provee correcciones a tiempo real a través de la “Internet” o sistemas de radiofrecuencia. El sistema multi-usuario incentiva a la creación y el mantenimiento de la infraestructura geodésica precisa de un país. La infraestructura geodésica es extremadamente necesaria para crear las diferentes capas de geo-datos utilizados por miles de industrias y agencias gubernamentales. Las comunicaciones entre el centro de cómputos de la Red a Tiempo Real y los usuarios es realizada por redes de telefonía celular móvil como, GSM (Global System for Mobile) ó CDMA (Code Division of Multiple Access), responsables de trasportar los mensajes de corrección diferencial a tiempo real a través de la “Internet” necesarios para construir los geo-datos de un país.

Un sin número de profesionales del posicionamiento alrededor del mundo hoy día dependen y usan diariamente estas maravillas modernas. Pero lo cierto es que estas maravillas modernas algunas veces son afectadas por nuestra madre tierra la cual puede generar diferencias en el desempeño de las correcciones a tiempo real de la Red de Posicionamiento Global. La troposfera y la ionosfera son algunos ejemplos de los factores que causan diferencias en el desempeño de las redes geodésicas anteriormente mencionadas.

Nuestro estudio es un análisis comparativo del desempeño de las observaciones GPS a tiempo real durante el día y la noche usando la Red a Tiempo Real de Puerto Rico operada por la compañía Vernix Engineering Corp. Utilizando esta red geodésica instalada estratégicamente por toda la isla se realizaron unas observaciones de GPS, de corta duración sobre estaciones de control pre-seleccionadas y establecidas por el “National Geodetic Survey” (NGS) para comparar el desempeño de diferentes fuentes de corrección a tiempo real como diferenciación de base de referencia simple y diferenciación por red de celda automática.

El sistema de Posicionamiento en Red de la Isla utiliza diferentes receptores de GPS. Las estaciones de referencias instaladas, utilizadas y operadas por Vernix Engineering en la Red a Tiempo Real son diferentes modelos de varias compañías como lo son: Leica 1200, Trimble 4000ssi y Ashtech, también recibimos una fuente de datos a tiempo real del National Geodetic Survey usando un sistema Trimble NetRS. El centro de control computadorizado es controlado por un Leica Geosystem utilizando el programa de computadoras Leica Spider Network.

El estudio de desempeño proveerá en un futuro una importante herramienta para los profesionales del posicionamiento. Los datos provistos por este estudio pueden ser un arma letal para la planificación de observaciones de GPS en especial cuando la tarea a realizarse esta restringida por un corto periodo de tiempo. Decisiones importantes y presupuestos pueden ser sustentados con los datos presentados en este análisis.

Day vs. Night GPS Observations Performance in Puerto Rico's RTK Network

Carlos J. RODRÍGUEZ ROSARIO and Carlos R. VEGA SANTOS, Puerto Rico

1. INTRODUCTION

Real Time Global Positioning System Network (RTGPSN) around the world provides the benefits of positioning any object within submeter or centimeter accuracy coordinates inside the coverage area. A Caribbean island, Puerto Rico remains ahead to the development of this world's cutting edge technology. In a near future the dependence of this modern marvel will impact the 100% of the population in different ways. Real time monitoring and positioning systems using satellites actually are being used in professional disciplines and workgroups. Technology such as computers, spread through our world very quickly and provide some times priceless data or benefits that in the early 20th century could not be obtained. Fast engineering results; economic surveying; dam, structure and mine monitoring and home land security are only few examples of the benefits that a country will obtain with the implementation of a RTGPSN.

The development of a country is based on land, economy and political planning. One of the benefits of a RTGPSN is that it can impact in all three ways the development of a country. In terms of land planning it provides the necessary infrastructure to create and update the geo-databases for engineering design, land surveying and country road, parcel, forest mapping among others. The economy is directly affected because more professionals, industries and government agencies can help to create and update the geo-databases. An example of this is government income received by property tax, which will be seriously impacted as more accurate and realistic income taxes can be applied by the government agencies. Figure 1 shows the actual Puerto Rico Real Time GPS Network which is streaming data to the main data center located in San Juan.

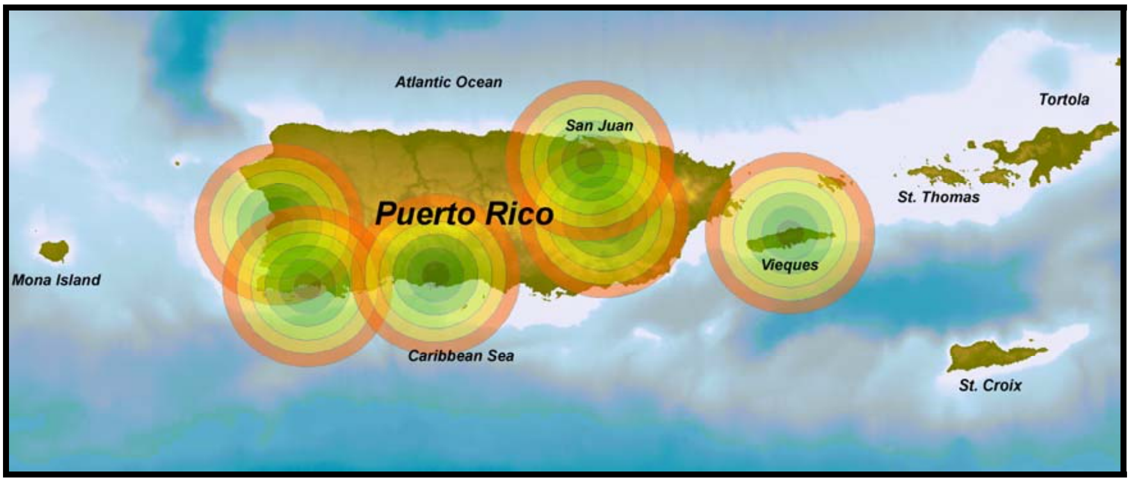


Figure 1: Puerto Rico's Real Time Network

2. GPS INFRASTRUCTURE

Puerto Rico's RTGPSN has been operating since the year 2005 with an initial GPS reference station and has been updated recently in the first quarter of 2008. A variety of high quality and precise antennas of different brands such as Leica, Trimble and Ashtech compose six (6) permanent GPS reference stations which feed in real time data to the main data center, with raw satellite data and powered with network processing software called Leica Spider, version 2.3. Originally the system was operated using only a Microsoft (MS) Windows Operating Systems (OS) but due to the instability of this system it gave way to the use of a computer running with a Linux Core OS. Full communication from reference stations to the main data center are controlled by a specialized custom made software for RTGPSN. And by running within Linux OP assures the stability of the real time reference stations raw data streams. The Linux OS operates using special procedures and an algorithm which creates an isolated virtual machine running on Windows OS and controls the Leica Spider software. By isolating a machine this provides a reliable and high stability needed to broadcast corrections over the internet to field users. Simultaneously the real time data stream from the reference stations are archived into RINEX file format at a thirty (30) second sampling rate and are archived in a public FTP server; at http://12.174.245.111/CORS_DATA/rinex.

Reference stations established by Vernix Engineering Corp. were strategically and geographically distributed throughout the island considering Puerto Rico's most important cities such as our capital, San Juan located at the northern coast; Caguas at the center of the Island which provides a backup data stream for the metropolitan area; Ponce at the southern coast where the construction of an important port for the Caribbean named Puerto de Las Americas Rafael Cordero Santiago is under construction; Mayagüez at the west coast which recently has new urban planning programs and will have a modern infrastructure development because it will be host city in 2010 of the Central American and Caribbean Games; Vieques an island at the east coast with a good geographic position to establish in the future a real time link between St. Thomas and St. Croix. An additional data stream established by National Geodetic Survey in Lajas at the southwest coast of the island provides redundancy and backup to our network with its main objective to collaborate with the Caribbean Tsunami Warning and Mitigation program which integrates satellites and real time tidal monitoring systems for seismic activities. Figure 2 shows the web interface used by Leica reference stations which provide information such as position, satellites, connections logs, power and memory status.

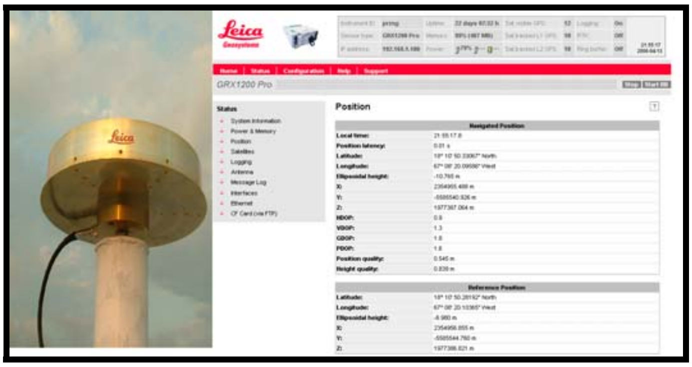
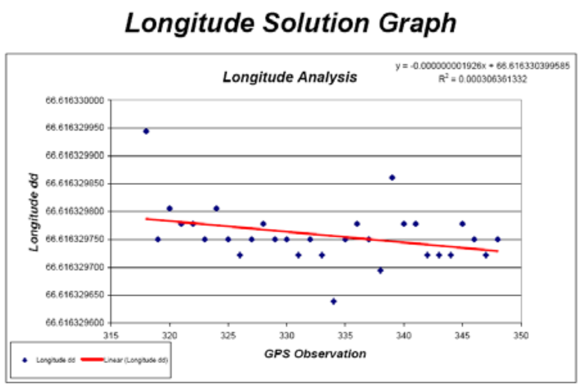
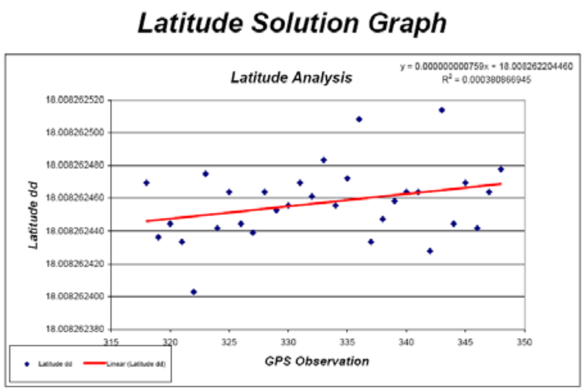


Figure 2: Caguas GPS Reference Station Web Control Systems

A RTGPSN needs highly accurate reference station coordinates to assure the best performance of the system. Every GPS reference station installed and operated by Vernix Engineering has its coordinates precisely computed using a 28 consecutive day observation, obtaining 24 hours of 30 second sampling rate in one hour archives. Data archived in the File Transfer Protocol (FTP) was merged using a NGS tool creating 24, one hour files and submitted to the NGS Online Positioning User Service (OPUS) with an automatic station selection. All data was submitted when the precise ephemerides at the OPUS web page were available. Coordinates derived by the NGS network were listed in a programmed spreadsheet which performs statistical computations for each station. Once the NGS OPUS reports are provided network accuracy for each station monitored on a 28 consecutive day GPS observation can be determined and then a weight factor is applied to the most accurate solution. Latitude, longitude, ellipsoidal and orthometric elevation solution were plotted in a graphic by solution vs. day, see Figure 3. A linear regression was applied to the graph and using the linear equation of the linear regression the spreadsheet computes the most accurate coordinate of the 28 day observations. A weight factor is applied to this analysis to improve the performance of this computation analysis. At the end of the procedure we compute the average of the most accurate coordinate computed day by day with the weight factor applied.





Orthometric Elevation Graph

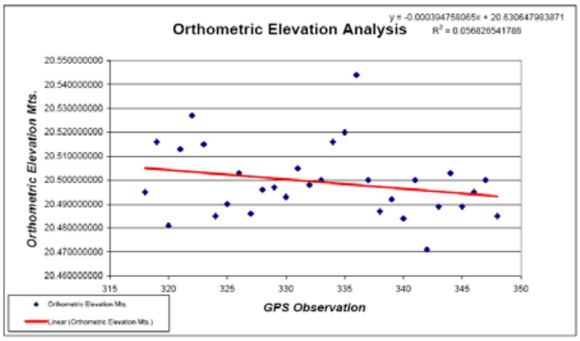
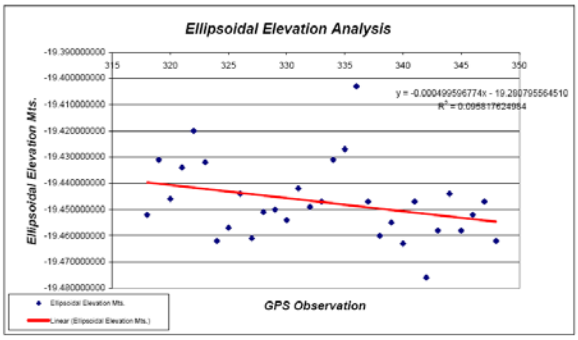


Figure 3: Computing Precise Geodetic Coordinates

Ellipsoidal Elevation Graph



The result of this kind of analysis is a high accurate GPSN coordinate system with real time network adjustment capabilities. All solutions are used in World Geodetic System 1984 and orthometric elevations were derived using the NGS official geoid developed in 2003. Table 1 shows the final coordinates of the reference stations used in this published study.

Station	*Municipality*	*Latitude*	*Longitude*	*Elev.*	*Ellipisoidal Elevation*	*Geoid Separations*
PRMG	Mayagüez	18° 10' 50.28196"	67° 08' 20.10342"	33.816	-6.987	-40.803
PRVE	Ponce	18° 00' 29.74488"	66° 36' 58.78713"	20.499	-19.447	-39.946
PRCG	Caguas	18° 13' 36.53800"	66° 02' 27.52688"	86.678	86.678	46.724
PRMI	Lajas	17° 58' 13.41814"	67° 02' 43.34300"	16.652	-23.588	-40.240

Table 1: Reference Stations, Coordinates and Elevations used for this study**.**

Puerto Rico's Real Time GPS Network is a promising solution anywhere on the island and has a compromise with society to keep going forward and developing this methodology to its most cutting edge technology. In partnership with Puerto Rico's Seismic Network and the US Coast Guard the network in 2008 will expand the real time data services with three new reference stations that will be established at the municipalities of Arecibo, Fajardo and Salinas. The benefit of a dense network is very clear; we can expect more accurate data in less time, faster survey quality fix solution inside the network, redundancy of data and faster computation can make the field surveying process easy.

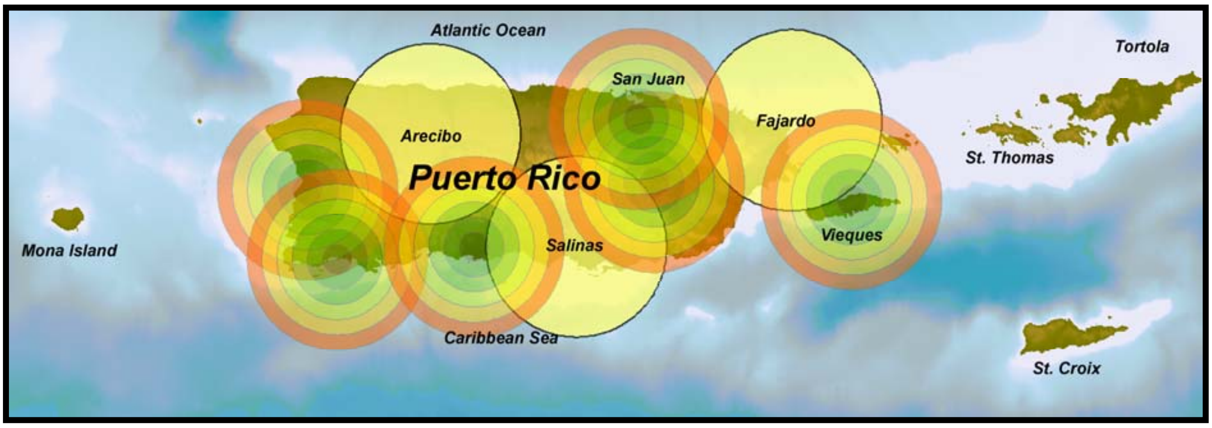


Figure 3: Upcoming New Reference Stations for 2008 (yellow coverage)

3. STUDY APPROACH

This study consists in a set of one minute GPS Observations on selected GPS Benchmarks throughout the Island. The selected benchmarks were established by the NGS and University of Puerto Rico at Mayagüez. GPS Benchmarks on the northern coastline will be used to compare the vertical difference between the Puerto Rico Vertical Datum 2002 and the derived elevations using the NGS Geoid 2003. The short term observations will be used to compare the performance of a single base solution versus a network solution using the Imax correction technology developed by Leica Geosystems. Reference stations selected by us to provide real time correction were PRCG (Caguas), PRVE (Ponce), PRMI (Lajas) and PRMG (Mayagüez).

Official NGS Benchmarks selected throughout the island were selected by stability and classification. Benchmarks used for short term observations were SANABRIA, BERRIOS, F 1004, QUEBRAS 2, VÉLEZ, UPRM GPS-27, LAS MARIAS 2, ARENAS 2, LAJAS 2, MAGAS, COCO and EL OJO. Every control point was observed using a Leica 1200 System with a very stable bipod system and data correction was received from the data center in Leica format.

Figure 4: Selected Benchmarks used in the Project

3.1 Single Base Correction Approach

One of the conditions put to the test was utilizing a single base correction at each benchmark (Figure 5). The limitation is that data collected at a specific point will only use corrections from one reference station. This case represents a large number of surveyors who don't have the resources to establish a GPS network and have to limit their observations to a single base. The results obtained are coordinates which are calculated from a base that is in a single direction and distance. Any problems with communications, weather or software with this particular base will most likely produce errors in final positioning of point being observed. In the worst case the final coordinate will not be possible due to the lack of redundancy with other stations. As a solution to these problems the use of a GPS network is a solution to many of the problems confronted with single base solution.

3.2 Network Adjustment using the Master-Auxiliary Concept

Using RTGPSN in Puerto Rico to realize GPS surveying provides numerous advantages over single base RT corrections. The benefits using network corrections results in a greater distance operation from the nearest reference station maintaining excellent reliability and accuracy. Network operators obtain maximum benefits, providing the same service with fewer reference stations. The optimization of the systems is achieved using various reference stations strategically distributed over a large region to compute and analyze the special distribution of the domain error sources (Figure 6). Ionosphere delays, troposphere delays and orbit errors are the most significant sources of errors for a position solution. Corrections for these types of errors can be transmitted from the network using different models. This reduces the distance-dependency resulting in a stable rover performance throughout the network.

Figure 5: Single Base Solution Diagram

Figure 6: Network Adjustment Diagram used to calculate F 1004 position.

3.3 Single Base vs. Network Adjustment

This study represents data obtained in a 60 seconds time span using a single base solution and a network solution. Table 2 illustrates the NGS published coordinates for benchmarks identified as F1004 and VÉLEZ. On the other hand Tables 3 and 4 show results obtained from observations realized at the same two stations during day and night times. The distance between the reference station and the rover are more than 30 kilometers although precision beyond this region is not suggested by manufacturer. Surprisingly the results in position obtained beyond this region are quite acceptable for many disciples. As part of this study it is very important to discuss final coordinate's obtained using single base solution vs. network solution.

NGS Published Coordinates					
Station	Northing	Easting	Elev.	Ellip. Elev.	GH
F-1004	268,639.866	169,895.721	6.074	-37.583	-43.980
VELEZ	267,825.241	124,618.851	134.30	90.388	-44.200

Table 2: NGS Published Coordinates for F-1004 and VÉLEZ stations

	RT Data		Day Measurements					Analysis			
Base	GIS	Survey	Baseline	Northing	Easting	Elev.	Ellip. Elev.	Δ N	Δ E	Δ E	Δ Ellip.
PRMG	2	14	29,369.863	267,825.258	124,618.872	134.625	90.422	-0.017	0.021	0.325	-0.034
PRMI	5	10	53,596.002	267,825.249	124,618.889	134.642	90.439	-0.008	0.038	0.342	-0.051
PRVE	2	133	74,054.156	267,825.258	124,618.893	134.630	90.427	-0.017	0.042	0.330	-0.039
PRCG	2	NA	119,364.609	267,825.043	124,618.881	134.586	90.383	0.198	0.030	0.286	0.005
NET	4	19	Net Adjust	267,825.263	124,618.849	134.620	90.416	-0.022	-0.003	0.319	-0.028

	RT Data		Night Measurements					Analysis			
Base	GIS	Survey	Baseline	Northing	Easting	Elev.	Ellip. Elev.	Δ N	Δ E	Δ E	Δ Ellip.
PRMG	2	7	29,369.864	267,825.259	124,618.879	134.565	90.361	-0.018	-0.028	0.264	0.027
PRMI	2	10	53,596.009	267,825.245	124,618.835	134.584	90.381	-0.004	0.016	0.284	0.007
PRVE	4	16	74,054.177	267,825.250	124,618.858	134.584	90.381	-0.009	-0.007	0.284	0.007
PRCG	5	35	119,364.665	267,825.250	124,618.866	134.638	90.435	-0.009	-0.015	0.338	-0.047
NET	5	9	Net Adjust	267,825.258	124,618.870	134.579	90.376	-0.017	-0.019	0.279	0.013

Table 4: Coordinate Results of GPS Observation at VÉLEZ

	RT Data (sec)		Day Observations					Analysis			
Base	GIS	Survey	Baseline	Northing	Easting	Elev.	Ellip. Elev.	Δ N	Δ E	Δ E	Δ Ellip.
PRMG	6	NA	53,802.254	268,639.728	169,895.865	6.363	-37.613	0.138	-0.144	-0.289	0.030
PRMI	4	NA	63,665.462	268,639.939	169,895.938	6.210	-37.766	-0.073	-0.217	-0.136	0.183
PRVE	5	18	50,422.836	268,639.969	169,895.723	6.470	-37.506	-0.103	-0.002	-0.396	-0.077
PRCG	4	NA	75,856.603	268,639.876	169,895.374	6.835	-37.140	-0.010	0.347	-0.761	-0.443
NET	3	47	Net Adj.	268,639.893	169,895.729	6.379	-37.597	-0.027	-0.008	-0.305	0.014

	RT Data (sec)		Night Observations					Analysis			
Base	GIS	Survey	Baseline	Northing	Easting	Elev.	Ellip. Elev.	Δ N	Δ E	Δ E	Δ Ellip.
PRMG	4	12	53,802.244	268,639.884	169,895.748	6.369	-37.606	-0.018	-0.027	0.023	0.023
PRMI	2	113	63,665.270	268,639.864	169,895.701	6.302	-37.674	0.002	0.020	0.091	0.091
PRVE	2	13	50,422.746	268,639.880	169,895.737	6.359	-37.616	-0.014	-0.016	0.033	0.033
PRCG	2	NA	75,856.338	268,639.908	169,895.665	6.489	-37.487	-0.041	0.056	-0.096	-0.096
NET	2	7	Net Adj.	268,639.883	169,895.735	6.357	-37.619	-0.017	-0.014	0.036	0.036

Table 3: Coordinate Results of GPS Observation at F-1004

STUDY RESULTS ANALYSIS

The study results presented in Table 5 include a total of 48 day and 48 night GPS observations using single base solutions which demonstrate the differences in time to fix and the distances at which each observation was taken. The time to obtain a fix for a GIS quality coordinate is similar during day and night hours but on the other hand the time to obtain survey quality coordinates frequently is better by more or less fifty percent less in time during night hours than during the day. In a similar manner the distance plays an important role in time to fix, we can see that the father the distance more time is needed. When distances are more than 90 kilometers, the time to obtain a fix value with a survey quality is a bit less than two minutes. A surprising result if you notice these observations were made at a distance three times more distant to what the specifications suggest (30 km)

		Day		Night		
Distance	**Analysis**	**GIS Quality**	**Survey Quality**	**GIS Quality**	**Survey Quality**	
Less that 30 KM	**Count**	11.00	11.00	9.00	7.00	**Fix Solution**
	Average	5.82	42.00	5.22	19.14	**Delay (Sec)**
30 to 60 KM	**Count**	15.00	9.00	15.00	14.00	**Fix Solution**
	Average	5.00	61.22	5.80	37.07	**Delay (Sec)**
60 to 90 KM	**Count**	9.00	3.00	11.00	9.00	**Fix Solution**
	Average	4.00	142.00	4.18	92.67	**Delay (Sec)**
90 to 150 KM	**Count**	9.00	4.00	8.00	8.00	**Fix Solution**
	Average	4.44	106.25	5.13	108.50	**Delay (Sec)**

Table 5: Day vs. Night Observation analyzing distance and time to fix solution.

4. CONCLUSIONS

As part of the study realized by Vernix Engineering we conclude that night observations are an excellent source of obtaining precise data with fewer reference stations and at greater distances for larger regions although time to fix increases a bit. Also during night hours the dominant error sources such as ionospheric and tropospheric delays don't affect positions as strongly as compared to day hours. We recommend for short period projects with high demanding positioning services the planning of GPS observations during night hours when ever possible. This will reduce expenses made in the purchase of new equipment and the ability to reach larger distances from existing reference stations without costly inversions.

REFERENCES

Brown N., Geisher I. and Triyer L. (2006). *RTK Rover Performance using the Master-Auxiliary Concept*, Journal of Global Positioning Systems, Vol 5, No. 1-2:135-144

Dai L., S. Han, Wang J. & Rizos C. (2003). *Comparison of interpolation algorithms in network-based GPS techniques*, submitted to *Journal of Navigation*.

Han S. (1997). *Carrier Phase-Based Long-Range GPS Kinematic Positioning*, UNISURV S-49, School of Geomatic Engineering, The University of New South Wales, Sydney, Australia, 185pp, ISBN 0 85839 074 4.

Keihm, S.J., (1995). *Water Vapor Radiometer Measurements of the Tropospheric Delay Fluctuations at Goldstone Over a Full Year*, TDA Project Report 42-122, Pag. 8, NASA

Rizos C. & S. Han (2002). *Reference station network based RTK sys*tems: Concepts and progress, 4th Int. Symp. On GPS/GNSS, Wuhan, P.R. China, 6-8 November

Van Cranenbroeck J., (2005). *A New Total Station Tracking GPS Satellites in a Network RTK Infrastructure Perspective*, FIG Working Week 2005 and GSDI-8, Cairo, Egypt

BIOGRAPHICAL NOTES

Carlos R. Vega Santos
Academic experience: Bachelor's degree in Land Surveying (2001) and Civil Engineering bachelor's degree (2006) at the University of Puerto Rico at Mayagüez

Professional Standing: Land Surveyor in Training

Current position: Land Surveyor, Vernix Engineering

Practical experience: Topography, geodetic leveling, bathymetric maps, route location, boundary definition, coastal surveys among others.

March 2006: COINAR Congress, San Juan, Puerto Rico
April 2006: ASCM & NSPS Annual Conference, Orlando, FL
October 2006: FIG Conference, Munich, Germany
April 2007: ASCM & NSPS Annual Conference, St. Louis, MI
April 2007: ASCE Annual Conference, Knoxville, TN
April 2008: ASCM & NSPS Annual Conference, Spokane, WA

Carlos J. Rodríguez Rosario
Academic experience: Bachelor's degree in Land Surveying (2002) and Civil Engineering bachelor's degree (2003) at the University of Puerto Rico at Mayagüez

Professional Standing: Professional Land Surveyor and Civil Engineer
Member of Puerto Rico College of Engineers and Land Surveyors

Current position: Associate of Vernix Engineering at Mayagüez, Puerto Rico since 2005.

Practical experience: Topography, geodetic leveling, route location, project stakeout, as-built plans, legal boundary survey, GPS static and RTK Surveys, GIS, CAD specialist, coastal surveys, hydrographic surveys, land use mapping, land development, project management, tsunami evacuation map specialist among others.
Participation in Activities:

July 2000: Italy Study travel (3 credits in history and art of Italy)

March 2001: Regional and Southeast ASCE Civil Engineering Competition, Alabama, US

April 2002: Regional and Southeast ASCE Civil Engineering Competition, Florida, US

October 2002: FIG Conference Mayagüez, Puerto Rico

November 2004: NGS Convocation Washington, US

March 2005: COINAR Congress San Juan, Puerto Rico

October 2005: COPIMERA Congress La Habana, Cuba

March 2006: COINAR Congress San Juan, Puerto Rico

April 2006: ACSM Annual Conference, Florida, US

October 2006: FIG Conference, Munich, Germany

October 2007: COPIMERA Congress, Lima, Peru

November 2007: FIG working week, San José, Costa Rica

CONTACTS

Carlos R. Vega Santos
Land Surveyor in Training
Vernix Engineering-Puerto Rico
PO Box 5399
Mayagüez,
PUERTO RICO 00681-5399
Tel. 787-543-6704
Fax.787-833-8260
Email. carlos_vega@vernixeng.com

Carlos J. Rodríguez Rosario
Professional Land Surveyor/ Professional Civil Engineer
Vernix Engineering-Puerto Rico
No. 617 Frank Souffront Street
Urb. Río Cristal, Mayagüez,
PUERTO RICO 00680
Tel. + 787 833 9918
Fax.+ 787 833 9918
Email. carlos_rodriguez@vernixeng.com
Web site: www.vernixeng.com