Local Area Augmentation System
Performance Analysis/Activities Report

Report #11

Reporting Period: July 1 to September 30, 2006

Federal Aviation Administration
William J. Hughes Technical Center
Engineering Development Services
Navigation / LAAS T&E Team
Atlantic City International Airport, NJ 0840

Executive Summary

The Local Area Augmentation System (LAAS) Test and Evaluation (T&E) team, under the direction of the Systems Engineering – Engineering Development Services Division of the Federal Aviation Administration (FAA) located at the William J. Hughes Technical Center provides this LAAS Performance Analysis/Activities Report (LPAR). This quarterly report is the eleventh such document, and for this reporting period utilizes the FAA's LAAS Test Prototype (LTP) #1[1] as the subject LAAS Ground Facility (LGF) for performance characteristics. Major LAAS related research and testing activities for the reporting period are included in summary form for a brief snapshot of LAAS Technical Center program directives, and related technical progress.

LTP #1 is a government-owned suite of equipment located on the Air Operations Area (AOA) of the FAA William J Hughes Technical Center at the Atlantic City International Airport (ACY). The LTP is completely operational and is utilized for flight-testing, in addition to data collection utilized in this report.

The LTP is the FAA's primary LAAS Research and Development (R&D) tool and is used to characterize and test performance of a typical LAAS installation in an operational airport environment. The LTP was designed with testing in mind, and its testing legacy continues to this day. As an FAA test system, the LTP is utilized in limited modified configurations for various test and evaluation activities. This system is capable of excluding any single non-standard reference station configuration from the position solution. The performance reporting of the system is represented only from LAAS standard operating configurations. Special configurations and maintenance details are included in a separate section within this report.

Table 1 summarizes observations of the major performance parameters used as a representation of accuracy and integrity for this reporting period. All units are in meters.

Parameter	Maximum Observation	Minimum Observation
Vertical Protection Level (VPL)	4.072	1.367
Horizontal Protection Level (HPL)	2.437	1.183
Clock Error	16.132	0.976
Dilution of Precision (DOP)		
(VDOP)	2.736	0.862
(HDOP)	1.651	0.742

Table 1: Key Performance Summary

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[1] LTP # 2 is deployed in Rio De Janeiro, Brazil where Government LAAS flight-testing is being conducted, while critical ionospheric ground data is being collected.
LTP # 3 is located on the FAA controlled area of the Atlantic City International Airport. This system is configured for multiple purpose testing.

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1. Introduction

The FAA is actively involved in the development of LAAS performance requirements and architecture, and maintains a LAAS Test Prototype (LTP) to evaluate new concepts and resulting performance benefits. The LAAS T&E team utilizes a number of tools and methods to analyze system performance. These tools include a raw data analysis technique known as Code Minus Carrier (CMC), to closely observe errors down to a single Satellite Vehicle (SV) on a single Reference Receiver (RR). Additional system level techniques are mature enough to display key system performance parameters in real time. The LAAS T&E team has adapted the LAAS software to actively gather these key parameters for the data plots to be presented in this report.

Objectives of this report are:

a) To briefly introduce LAAS concepts and benefits.
b) To provide a LTP (LAAS Test Prototype) system level overview to aid in comprehension for persons unfamiliar with the material.
c) To present Global Positioning System (GPS) constellation, and SV availability at ACY, and any unfavorable bearing on overall system performance.
d) To briefly document LAAS related R&D, testing, and maintenance activities.
e) To present the LAAS system's ability to augment GPS by characterizing key performance parameters.
f) To provide a key performance summary and complete performance plots.

2. Aerial Photograph of LTP at ACY with Overlay

Figure 1 is an aerial shot of the FAA's LTP taken during a LAAS flight test. This valuable FAA R&D tool provides a valid representation an actual LAAS installation in an operational airport environment. The major system sites are identified.

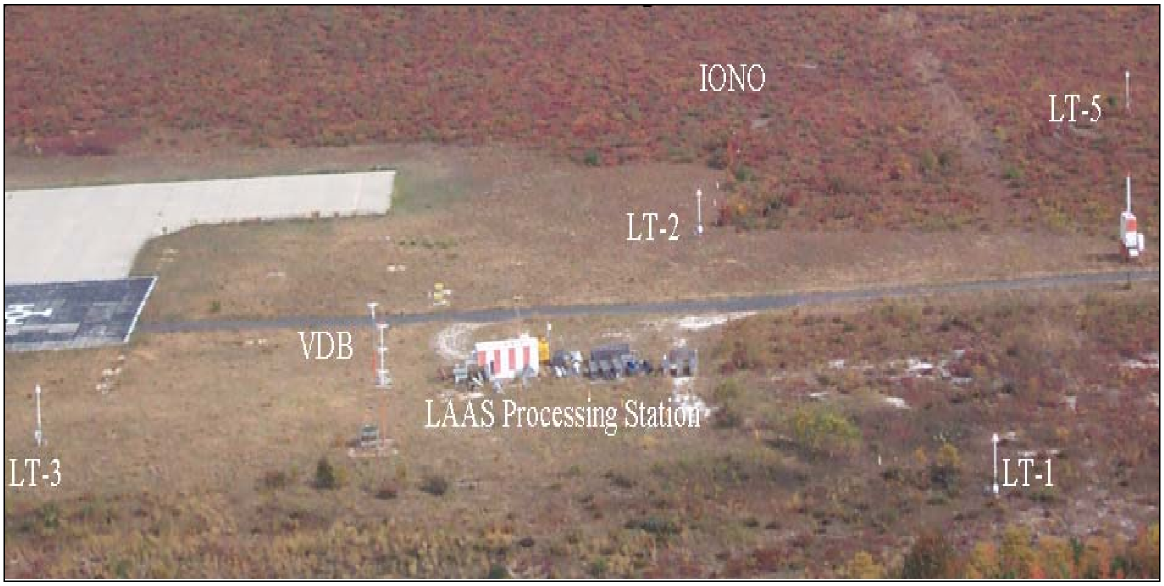

Figure 1: Aerial of LTP at ACY

3. LAAS Overview

This section is provided for persons unfamiliar with LAAS concepts and components. This brief overview is intended solely as an introduction.

A LAAS is essentially an area navigation system with its primary function being a precision landing system. The LAAS provides this capability by augmenting the Global Positioning System (GPS) with real-time broadcasted differential corrections.

3.1 LAAS Operational Overview

A Local Area Augmentation System (LAAS) ground facility (LGF) includes four GPS Reference Receivers (RR), four RR antenna (RRA) pairs, a Very High Frequency (VHF) Data Broadcast (VDB) Transmitter Unit (VTU) feeding an Elliptically Polarized VDB antenna. These sets of equipment are generally installed on the airport property where LAAS is intended to provide service. The LGF receives, decodes, and monitors GPS satellite pseudorange information and produces pseudorange correction (PRC) messages. To compute corrections, the ground facility compares each pseudorange measurement to the range measurement based on the survey location of the given RRA.

Once the corrections are computed, integrity checks are performed on the generated correction messages to ensure that the messages will not produce misleading information for the users. This correction message, along with required integrity parameters and approach path information, is then sent to the airborne LAAS user(s) using the VDB from the ground-based transmitter. The integrity checks and broadcast parameters are based on the LGF Specification, FAA-E-2937A, and RTCA DO-253A (Airborne LAAS Minimum Aviation Performance Standards or MOPS).

Airborne LAAS users receive this data broadcast from the LGF and use the information to assess the accuracy and integrity of the messages, and then compute accurate Position, Velocity, and Time (PVT) information using the same data. This PVT is utilized for the area navigation (RNAV) guidance and for generating instrument landing system (ILS)-look-alike indications to aid the aircraft on an approach. A developmental airborne system that is capable of this type of navigation is referred to as a Multi-Mode Receiver (MMR). The MMR coupled with a LAAS can generate mathematical paths in space to any number of waypoints and touchdown points in the local area.

One key benefit of the LAAS, in contrast to traditional terrestrial navigation and landing systems (i.e. ILS, MLS, TLS, etc.), is that a single LAAS system can provide precision guidance to multiple runway ends, and users, simultaneously. Only the local RF environment limits this multiple runway capability. Where RF blockages exist Auxiliary VDB Units (AVU) and antennas can be added to provide service to the additional runways. This capability can also be built upon to provide service to adjacent airports.

3.2 LAAS Simplified Architecture Diagram

Figure 2 is provided as an illustration of LAAS operation with major subsystems, ranging sources, and aircraft user(s) represented.

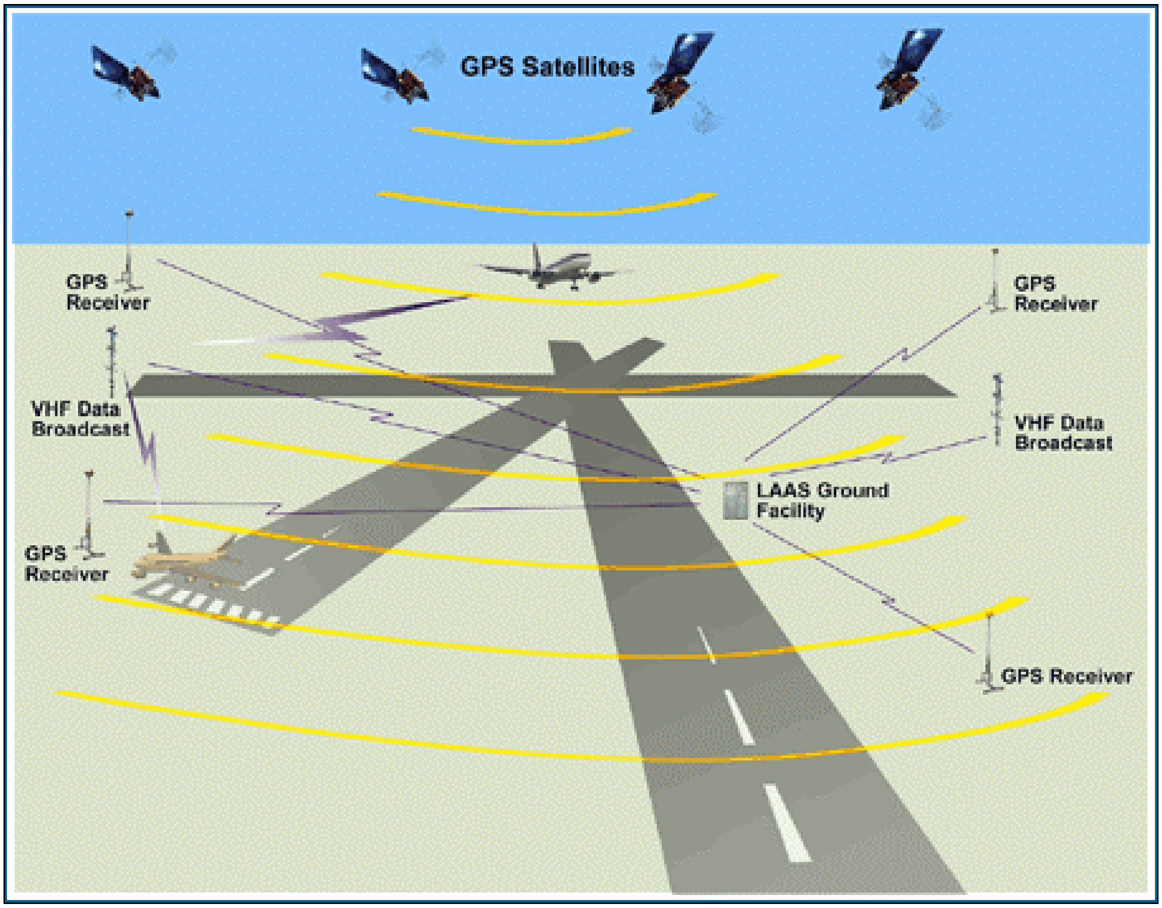

Figure 2: LAAS Simplified Architecture Diagram

4. GPS Constellation from ACY

Satellite Vehicle (SV) availability and constellation geometry has an impact on overall LAAS system performance. This section provides a snapshot of the expected constellation for the reporting period. GPS Notice Advisory to Navstar Users (NANUs) are known SV outages events that are excluded from these plots, but are included at the end of this section.

4.1 SV Availability Plot

ACY has a fairly robust available constellation expected throughout most of the sidereal day with limited periods where the observable SVs are forecasted to drop below nine.

Figure 3 is an SV availability prediction graph representative of the reporting period. The graph does not account for any NANUs following the generation of the plot. It also does not include the WAAS geo-stationary satellite.

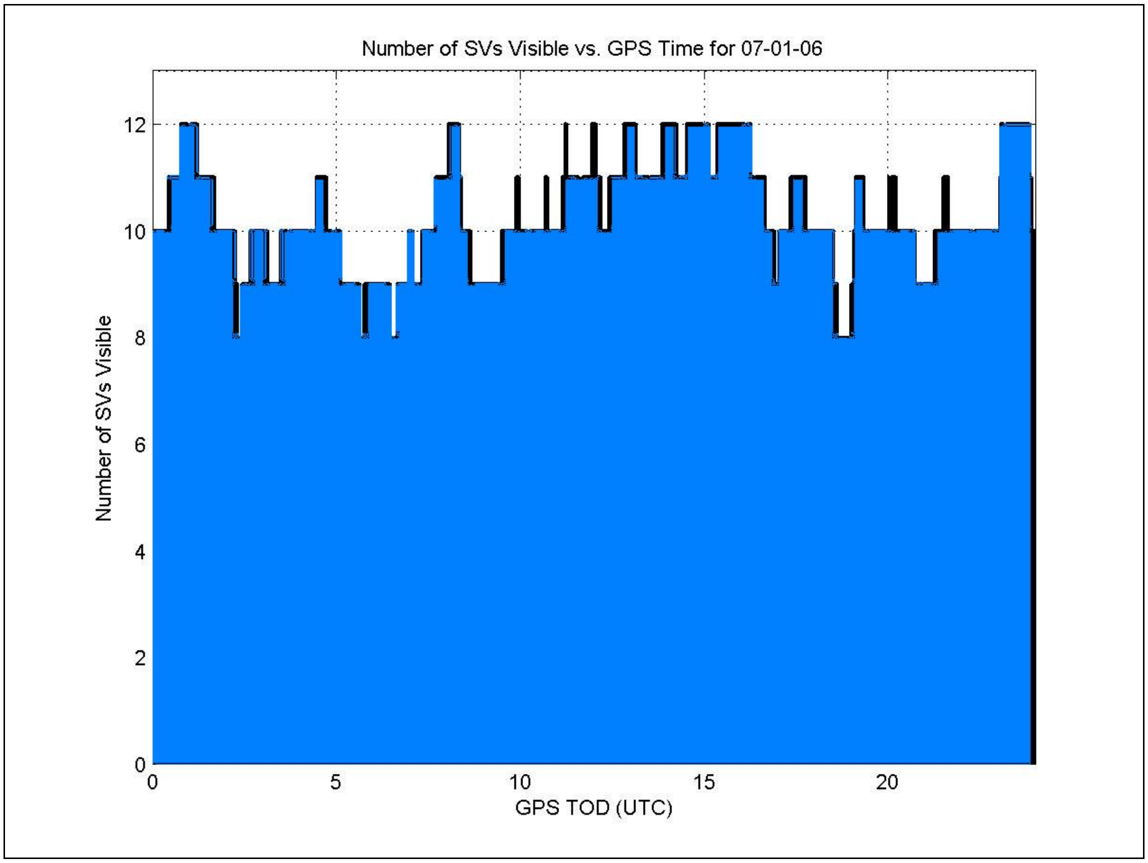

Figure 3: SV Availability at ACY

4.2 SV Elevation Plot

SV elevation and the resulting geometry have a bearing on the overall LAAS performance. The LAAS reference station antennas are of a dual segment design and are referred to as the Integrated Multi-Path Limiting Antenna (IMLA). The two segments (upper and lower) have patterns that overlap each other centered at approximately 29 degrees elevation with an overlap of about 13 degrees above and below this point. At least one common SV must be tracked by the two segments in order for the LAAS software to calculate the hardware bias inherent in such systems. The more common satellites tracked, the better the estimation of the hardware bias. The elevation of the Wide Area Augmentation System (WAAS) geo-stationary satellite from ACY is approximately 39 degrees, and can serve as a steady ranging source available for the bias calculation.

Figure 4 is an SV elevation prediction graph representative of the reporting period. The graph does not account for any NANUs following the generation of the plot. The graphic also does not include the WAAS SV(s).

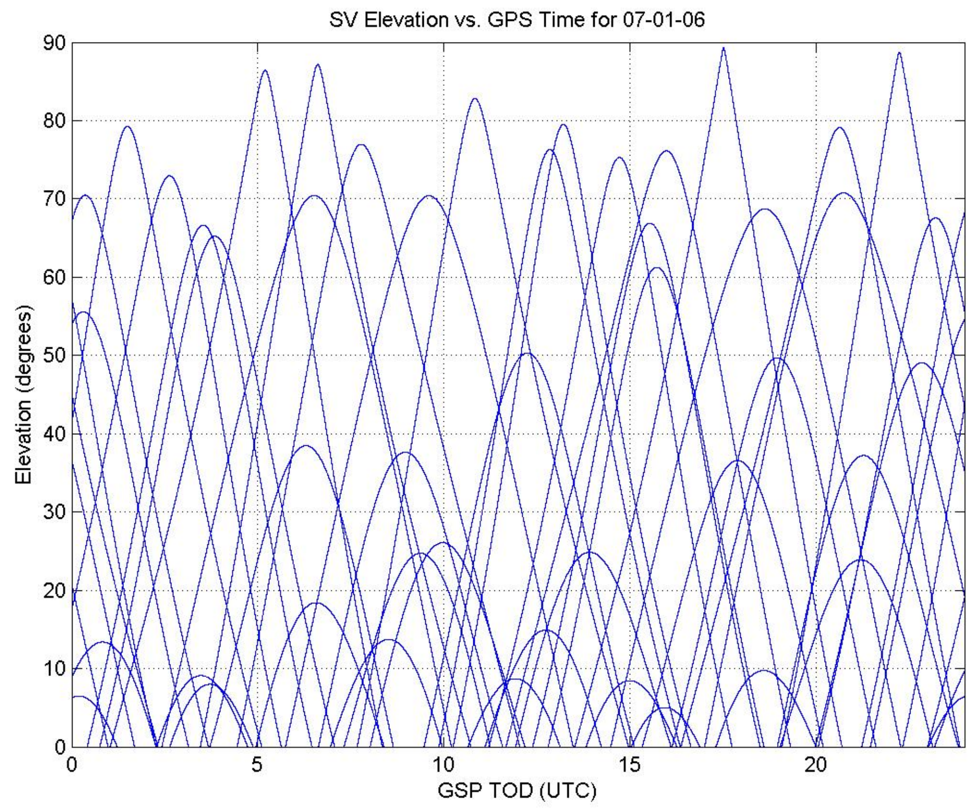

Figure 4: SV Elevations at ACY

4.3 Notice Advisory to Navstar Users (NANUs)

The GPS constellation is designed to provide adequate coverage for the continental United States for the majority of the sidereal day. A NANU is a forecasted or reported (un-forecasted) event of GPS SV outages, and could cause concern if the SV outage(s) affects minimum required SV availability or causes a period of no common satellites in the overlap region of the IMLA antenna.

NANUs that caused an interruption in service (where Alert Limits are exceeded) will be highlighted within NANU summary (see **Table 2**). Although such an interruption is unlikely, the LAAS T&E team closely tracks the NANUs in the event that post-data processing reveals a rise in key performance parameters. Any highlighted NANUs will include additional data plots, and accompanying narrative in the “Performance Summary” section.

The NANUs provided include only definitive SV outages and decommissions. An “Outage Summary” provides the actual period of the forecasted SV outage. An “Unusable” provides the same information for an un-forecasted SV outage, or a previous “Unusable UFN” (Until Further Notice). An occasional “Usable” will be seen for SVs that were previously “Unusable”, “Unusable UFN”, or newly commissioned SVs. An

"Unusable UFN" is an SV outage that remained unusable Until Further Notice (no forecast on return to "Usable" status). **Table 2** provides actual SV outages for the reporting period.

NANU #	NANU Type	PRN	Date Begin	UTC Begin	Date End	UTC End
2006062	Unusable	PRN-06	06/29/06	11:05	07/17/06	16:48
2006063	Outage Summary	PRN-03	07/17/06	16:15	07/17/06	19:57
2006067	Outage Summary	PRN-25	08/04/06	14:34	08/04/06	16:55
2006070	Outage Summary	PRN-08	08/05/06	19:08	08/05/06	19:57
2006071	Unusable	PRN-03	08/01/06	20:34	08/07/06	19:44
2006077	Outage Summary	PRN-05	08/15/06	03:12	08/15/06	08:36
2006078	Outage Summary	PRN-29	08/18/06	00:51	08/18/06	04:07
2006079	Unusable UFN	PRN-15	08/21/06	13:58	UFN	UFN
2006085	Unusable	PRN-18	09/05/06	00:52	09/05/06	05:35
2006086	Unusable	PRN-03	08/24/06	15:02	09/08/06	19:04
2006090	Outage Summary	PRN-17	09/12/06	16:33	09/12/06	17:59
2006091	Outage Summary	PRN-25	09/14/06	11:15	09/14/06	21:44

Table 2: NANU Summary

5. LTP Configuration, and Monitoring

This section provides a description of the LTP system, monitoring, and testing configurations in terms of hardware and software for the reporting period. Since the LTP is the FAA's primary R&D tool for LAAS these sections could vary somewhat between reporting periods. The majority of these changes will likely first emerge in the final sections of this report.

5.1 Master Station

The LTP Master Station or Processing Station is a complex collection of hardware and related interfaces driven by a custom software program. The master station hardware and software operations are described in this section.

5.1.1 Master Station Hardware

The Master Station (or processing station) consists of an industrialized Central Processing Unit (CPU) configured with a Unix type real time operating system. The CPU is configured with a SCSI I/O card for mounting an external hard drive. This hard drive collects all raw reference station GPS data messages in parallel to the processing of those messages. The drive is also used to collect debugging files and special ASCII files utilized to generate the plots found in this report. These collected files are used for component and system level performance and simulation post processing.

The CPU is also configured with a multi-port RS-232 serial card to communicate in real time with the four reference stations and to the VDB. The reference stations continuously output raw GPS messages to the CPU at a frequency of 2 Hz. Data to and from the reference station fiber lines is run through media converters (fiber to/from copper), which provides a RS-232 serial signal to the CPU's multi-port serial card. The CPU then generates the LAAS corrections and integrity information and outputs them to the VDB.

The VDB Transmitter Unit (VTU) is capable of output of 150 watts and employs a TDMA output structure that allows for the addition of auxiliary VDBs (up to three additional) on the same frequency for coverage to terrestrially or structure blocked areas. The LTP's VTU is tuned to 112.15 MHz and its output is run through a band pass, and then through two cascaded tuned can filters. The filtered output is then fed to an elliptically polarized three bay VHF antenna capable of reliably broadcasting correction data the required 23 nautical miles.

Surge and back-up power protection is present on all active master station components.

5.1.2 Master Station Software

Ohio University (OU) originally developed the LAAS code through a FAA research grant. Once the code reached a minimum of maturity, OU tested and then furnished the code to the FAA (circa 1996). It was developed using the C programming language under the QNX operating system. QNX was chosen because of its high reliability and real-time processing capability. This LTP code has been maintained by the LAAS T&E team since that time and has undergone numerous updates to incorporate evolving requirements and hardware. The current internal master station software version is 3.0.

The code stores the precise survey data of the four LAAS reference station antennas (all eight RRA segments). The data structures are initialized, input files are opened, and the output files are created. Messages are received via four serial RS-232 connections, which are connected to four GPS receivers. The program cycles through the serial buffers and checks for messages, if one is found it gets passed to a decoding function. From there it is parsed out to functions according to message type and the information from the messages will be extracted into local LTP variables. Once the system has received sufficient messages the satellite positions are calculated in relation to the individual reference receivers. Next the system corrects the phase center measurements for the stacked dipole antenna array and converts the measurements from the individual reference locations to one simple reference location. The High Zenith Antenna (HZA) and dipole measurements are then combined to form one virtual reference receiver at the reference location. Then the integrity and protection equations are processed which produces the alert levels for the LGF. Next the position solution and reference position is calculated. Messages are then encoded and sent to the VDB via a RS-232 connection. Each of the three message types are encoded separately and sent according to DO-246B standards. The final step in the LGF software is to update the graphics and respond to the user inputs. At this point the software checks for problems that could have occurred during the processing and will either stop the program, or restart the cycle by reading the serial data.

5.2 Reference Stations

There are four reference stations included in the FAA's LTP as required in the LAAS specification. The LTP's reference stations are identified as LAAS Test (LT) sites; there were originally five LT sites (LT1 through LT5) but LT4 was abandoned in favor of the four remaining LT sites (see **Figure 1**).

Each reference station consists of two major component systems. The first is a hybrid GPS antenna, known as an IMLA. The second is the reference receiver and transmit system.

5.2.1 The Integrated Multipath Limiting Antenna (IMLA)

The IMLA (see **Figure 5**) is a hybrid, two receiving segment, GPS antenna that is approximately 12 feet in height and 100 pounds in weight. The two segments (top and bottom) have specially designed overlapping patterns and high Multipath rejection.

Multipath is a phenomenon, which is common to all Radio Frequency (RF) signals, and is a particular concern in differential GPS navigation (i.e., LAAS). The two major types are Reflected and Diffracted Multipath. Diffracted Multipath is the bending of a signal around the edges and corners of structures and other obstructions. Reflected Multipath is the bouncing of the signal on any number of objects including the local water table. Signals that bounce off the water table is often referred to as Ground-Bounce Multipath. In all cases the path length is increased. This path length is critical in GPS since the ranging is based on signal's Time of Arrival (TOA). Multipath can cause a standard GPS system to track an indirect signal rather than the direct GPS signal. This causes a pseudorange error, for the SV being miss-tracked, in the amount of the indirect signal's additional path length. These Multipath induced pseudorange errors can translate directly into a differential GPS position solution, which would be detrimental to applications such as LAAS. Multipath limiting antennas, such as the IMLA, were therefore developed to address the Multipath threat to differential GPS.

Siting criteria developed around the IMLA antenna mitigates the diffracted and above ground level Reflected Multipath. The IMLA pattern design itself serves to mitigate the Ground-Bounce Multipath.

The top segment, referred to as a Multipath Limiting High Zenith Antenna (MLHZA, or HZA for short), is a two element cross-v dipole used to include SV measurements from 40 to 90 degrees in elevation. This HZA is mounted on top of the stacked dipole array with a feed that runs inside the null chamber (center) of the 8-foot tall bottom segment. The HZA provides at least 20 dB of direct to indirect pattern isolation.

Figure 5: The IMLA Antenna

The bottom segment, the most critical component of the IMLA, is a 14-element stacked dipole array, which is used to include SV measurements from 5 to 40 degrees in elevation. Signals from low elevation satellites are generally lower in power and more susceptible to ground bounce Multipath, which enter conventional GPS antennas from below 0 degrees. The measurement error caused by the Multipath reflection is proportional to the ratio of the signal strength of the desired direct signal path to the strength of the undesired reflected path. The stacked dipole array is designed with a high gain lobe in the direction extending from 5 to 30 degrees, and is reduced by 35 dB at –5 degrees, providing a strong desired to undesired ratio. The result is a limit on pseudorange measurement errors on the order of 0.3 meters.

5.2.2 Reference Station Receive and Transmit System

At the heart of the LTP's four reference stations is a dual deck, 12-channel (24 total), narrow correlator GPS receiver tied to a common clock. The dual deck design accommodates the IMLA's two feeds, while the common clock ensures that the pseudorange measurements on both decks are taken simultaneously. A final calibration in the Master Station software is performed using an SV that is common to both decks which removes any remaining hardware biases. The current version of the receiver firmware is 7.51s9.

Data to and from the reference stations are put on fiber lines, which run through media converters (fiber to copper), which provide a RS-232 serial signal to the receiver communications port and master station CPU.

Surge and back-up power protection is present on all active reference station components.

5.3 Field Monitoring Stations

The LTP's operation and performance is closely monitored with several dedicated systems. This section outlines the two major monitoring tools that provide an instantaneous performance indication as well as post data processing capability.

Raw monitoring station data collected is useful for observing variations in the differential position since the position can be compared to the survey position of the fixed GPS antenna. Also, it provides a continuous position calculation reference in the absence of actual flight-testing.

5.3.1 Multi-Mode Receiver (MMR) Station

The first LTP monitoring station is a static ground based MMR system. The LAAS T&E team maintains an MMR on a precise surveyed GPS antenna to monitor ground station performance and to evaluate MMR software updates. The MMR drives a dedicated Course Deviation Indicator (CDI). The CDI is a cockpit instrument that indicates fly left/right and up/down information with respect to the intended flight path. The CDI should always be centered when the MMR is tuned to the virtual runway that coincides with the antenna's survey position. The version of MMR firmware for this reporting period is Flight Change (FC) 21.

5.3.2 LTP User Monitoring Station

The second monitoring station is an LTP airborne subsystem (LTP Air), which is used as a static user platform. The LTP Air is a prototypical mock-up with navigational capabilities similar to that of the MMR. The LTP Air, however, provides more configuration flexibility than the MMR and serves well as an R&D tool. These systems are used for actual flight-testing, and for MMR update verification or troubleshooting. This dedicated LAAS field monitor, as the MMR, is placed on a precise surveyed GPS antenna. Data is collected in 24-hour intervals without interruption and is used to post evaluate system navigational performance. Live data is also fed via a wireless network and is available via the Internet. This data is displayed in graphic form and provides the user an hourly performance history glimpse. All major performance parameters, available to an airborne user, are displayed. The web address for this live service is: http://www.gps.tc.faa.gov/acylaas1.asp

The LTP Air system is the LTP's primary performance field monitoring tool. The operational configuration of this system is briefly described in the following text. The custom program initializes all the variables, sends the initialization commands to the VHF Data Link (VDL), and opens up the necessary files. The GPS receiver and VDL are connected to a multi-port RS-232 serial card, which multiplexes the inputs and connects to the computer. The messages are then parsed out according to the type, and processed accordingly. The GPS messages are then split into the different GPS message types (range, ephemeris, clock...etc) and the VDL messages are separated into each of the DO-246B LAAS message types and decoded. Next the satellite position is calculated using the range and ephemeris messages from the GPS measurements. The position of the aircraft is determined and a differential position is calculated based on the measurements from the LGF. Protection levels are calculated for the aircraft and compared to current threshold alarm levels while the satellite measurements are also checked for errors.

To drive the LTP Air's Course Deviation Indicator (CDI), an output message is constructed and is sent via the RS-232 card to an analog conversion unit. The display screen is updated to reflect the new data, and the user inputs are processed. If the program continues with no errors or user input to terminate the program, it retrieves another message from the serial buffer and begins the process again. The LTP airborne internal RCS version number for this reporting period is 1.8.

5.3.3 Position Domain Monitor (PDM) Station

Figure 6: PDM Station

The Position Domain Monitor (PDM) station (**Figure 6**) at ACY is located at the approach end of runway 13, and is just outside of the aircraft movement area (red sign on left of **Figure 6**). The location was carefully chosen to provide not only a long baseline (2330 meters) from the LTP, but also a best-case proximity to the final approach and runway touchdown point. This location therefore provides an excellent representation of what signals (GPS and VDB), constellation, and conditions a user would be experiencing on the landing portion of their approach.

The PDM is a GPS LAAS monitor of the LTP system. It incorporates the transmitted

LTP corrections through a VHF receiver, along with the position it generates from an L1 frequency GPS RX, a Novatel Millennium, which gathers GPS data through a choke-ring antenna. The present architecture also includes a dual frequency receiver, a Novatel OEM4, which is hooked up to a Trimble ground plane antenna. This allows for calculating of many errors and biases, including CMC in real-time. The main goals of the PDM monitor is to verify errors in the LTP are below the threshold set in the MOPS before this information is broadcast, and that the user's position errors are within a safe range before that information is used.

The PDM requires a minimum of 6 SVs for proper functionality. The PDM uses the satellite constellation and takes into account every possible combination of 6 SVs available to the user. The worst 6-SV constellation, according to the MOPS, would be thrown out of the calculations. With this geometry, surveyed locations at the PDM are assessed.

The PDM includes a Minimum Satellite Configuration Constraint. In a 4 satellite minimum configuration, an approach cannot be begun if in that 4-satellite configuration, one of the satellites is expected to set before the approach is finished. However, a 4-satellite configuration is allowed as a "degraded" mode. Also included is a Critical Satellite Limit, which are satellites whose loss from the present constellation would cause the VPL to exceed the VAL. In this constraint, for an airborne user to begin approach, there must be fewer critical SVs in the current geometry than the critical satellites limit. Satellites that set during approach do not count towards the minimum satellite configuration. The current software is pdm-20060517.tar.gz.

5.4 L1/L2 Ionospheric (IONO) Station

A separate, but equally important, station is maintained at the FAA's LTP to conduct, centimeter level post processing performance analysis down to a single SV observable on a single reference antenna segment.

This station is referred to as the IONO (short for ionospheric) station (see **Figure 7**). The name is largely due to the purpose of observing the ionospheric propagation delay, as well as other path delays. The L2 carrier observable (L2 code is unobservable for civilian use) is useful in determining propagation delays in the L1 carrier due to the frequency difference in L2. The L1 frequency is centered at 1575.42 MHz, while the L2 center is at 1227.60 MHz.

Since both signals (L1 and L2) originate from the same point and time the difference in the signal's arrival times can be used to extrapolate the actual path delay. The determined delay covers the ionosphere path as well as multi-path and other delays. This total delay, due to the signal path length, and short baselines, can be applied to all 8 RRA segments. See Code-Minus-Carrier (CMC) area for further detail on where the IONO data is applied.

The IONO station can also serve as a full time L1/L2 reference station for local survey work and precise aircraft tracking processing (aka Time Space Position Information or TSPI). Both activities require a static L1/L2 data collection setup on a known (surveyed) point. This static L1/L2 station data can then be merged, after the fact, with the dynamic (aircraft) data or the unknown static (survey) point data to determine precision aircraft path or survey position figures.

Figure 7: ACY LAAS IONO Station Antenna (with IMLA)

5 LTP Maintenance and Updates

The FAA's LTP requires little maintenance. The system's components do falter on infrequent occasions and require replacement. More common is the need to retrieve the raw archive data, which entails the swapping out an empty external hard-drive.

The LTP is an AOA-installed operational LAAS system and requires the same type of airport maintenance activities required for other AOA-installed systems.

6.1 Routine Maintenance

External hard-drives for raw data collection are switched on a weekly basis, but could go as long as 45 days without this operation. This operation requires an interruption of service due to the hardware limitations inherent to the real time operating system. An interruption of approximately seven minutes is required to perform this operation.

6.2 Upgrades and Updates

6.2.1 Software Updates

No long-term updates (testing related updates only) were done on the ground or air systems during this reporting period.

6.2.2 Hardware Updates

No long-term updates (testing related updates only) were done on the ground or air systems during this reporting period.

7. System Availability

This section is reserved to highlight events that could have effects on system availability. The LTP, as a prototype experimental LAAS station, is not expected to meet availability requirements as defined in the specification documents. This section is included in this report as a running record, and as a placeholder for future reports, which will utilize systems other than the LTP as the subject LAAS system.

7.1 Failures and Forced Events

This section highlights failure modes experienced during the reporting period. Being a prototype system, the LTP doesn't employ all the backups and protections that would be incorporated into a fully compliant Category I LAAS. The LTP also utilizes some consumer grade hardware, which can contribute to certain failure modes.

No significant failures or other imposed events for this reporting period.

7.2 Significant Weather and Other Environmental Events

This section is reserved to highlight any environmental events that drove system performance to inflated or unacceptable levels or caused a system outage. Events of this type are rare but could include: solar flares, ionosphere storms, geomagnetic disturbances, and limited catastrophic weather events.

No significant weather or other environmental events for this reporting period.

8. LAAS Performance and Performance Type (Category)

The GPS Standard Positioning Service (SPS), while accurate, is subject to error sources that degrade its positioning performance. These errors sources include ground bounce multi-path, ionospheric delay, and atmospheric (white) noise among others. The SPS is therefore insufficient to provide the required accuracy, integrity, continuity, and availability demands of precision approach and landing navigation. A differentially corrected positioning service, with short baselines to the user(s), is suitable to provide precision guidance.

The relatively short baselines between the user and the LAAS reference stations, and custom hardware and software, is what sets LAAS apart form WAAS. Special LAAS hardware such as the IMLA serves to mitigate the multi-path problems, while the LAAS software monitors and corrects for the majority of the remaining errors providing the local user a precision position solution.

The LAAS Ground Facility (LGF) is required to monitor and transmit data for the calculation of protection parameters to the user. The LAAS specification also requires monitoring to mitigate Misleading Information (MI) that can be utilized in the position solution. These requirements allow the LAAS to meet the accuracy, integrity, availability, and continuity required for precision approach and landing navigation.

There are three Performance Types (PT) defined within the LAAS Minimum Aviation System Performance Standards (MASPS). The three performance types, also known as Categories, (Cat I, and Cat II/III) all have the same parameters but with different quantity constraints. For the purposes of this report, the LTP assumes Cat I Alert Limits and hardware classification.

8.1 Parameters and Related Requirements Overview

This section highlights the key parameters and related requirements used to depict LAAS system performance in this report. In order to provide the reader a clearer understanding of the plots provided, a little background is useful.

Cat I precision approach requirements for LAAS are often expressed in terms of Accuracy, Integrity, Availability, and Continuity. For clarity the use of these four terms, in the context of basic navigation, are briefly described below:

- **Accuracy -** is used to describe the correctness of the user position estimate that is being utilized.
- **Integrity –** is the ability of the system to generate a timely warning when system usage should be terminated.
- **Availability** - is used to describe the user's ability to access the system with the defined Accuracy and Integrity.
- **Continuity** - is used to describe the probability that an approach procedure can be conducted, start to finish, without interruption.

Parameters used to depict LAAS performance in the remainder of this report are outlined below:

8.1.1 VPL and LPL

Accuracy for a Cat I LAAS is best quantified in terms of the vertical and lateral (horizontal) Navigation Sensor Error (NSE). LAAS position is translated into vertical and lateral components of error with respect to the pre-defined path in space. The 95% limits for lateral and vertical NSE defined in the LAAS MASPS are used as a performance measure. The 95% Vertical NSE limit tightens as the user descends toward the Runway Datum Point (RDP) on the final approach path. For heights above the RDP of 1290 ft or more, the Vertical NSE limit is 16.7 meters. For heights between 1290 and 200 feet the vertical NSE limit begins at 16.7 meters (at 1290 feet) and traces a straight line down to 4 meters (at 200 feet). This 4-meter Vertical NSE limit is maintained to 100 feet above RDP along the final approach path. The 95% Lateral NSE limit is similar in construct, but is related to horizontal distance from the RDP along the final approach path. For distances beyond 7212 meters the Lateral NSE limit is 27.2 meters. For distances between 7212 and 873 meters the Lateral NSE Limit begins at 27.2 meters (at 7212 meters) and traces a straight line to 16 meters (at 873 meters). This 16-meter Lateral NSE Limit is maintained to 291 meters from the RDP along the final approach path. Vertical/Lateral NSE and Vertical/Lateral Protection Levels (VPL and LPL) are closely related. The user's Vertical/Lateral NSE can only be determined through post processing with a precision truth tracking system. The FAA has processed hundreds of actual LAAS approaches, and monitoring station data sets, to verify the 95% Vertical/Lateral NSE of LAAS. The 95% NSEs obtained must be bounded by the user's computed VPL and LPL (a.k.a., HPL). These Protection Levels are in turn bounded by the corresponding Alert Limits. It has been shown that the NSE performance is easily within the MASPS requirements, and the need for splaying is a benefit only when it comes to the integrity bound that must be computed based on a real-time estimate of the user's position.

Integrity for LAAS is associated with known failure modes within the system and the monitors that are designed to detect the failures before it is manifested in the airborne receiver as Misleading Information (MI). Each failure mode has an associated monitor that is assigned a corresponding probability of the failure occurring, or a prior probability, and an associated probability that the failure is detected, or a missed detection probability. The Cat I LAAS Specification states "the probability that the LGF transmits Misleading Information (MI)…shall not exceed 1.5X10^(-7) during any 150-second approach interval". The LAAS MASPS defines MI as a Navigation System Error, which exceeds the Vertical or Lateral Alert Limits (VAL or LAL) without annunciation within the time to alert (3 seconds). The VAL and LAL are fixed at 10 and 40 meters (radius) respectively. These limits are not to be exceeded by the user's calculated Vertical and Lateral Protection Levels (VPL and LPL) bounds. The VPL and LPL are upper confidence bounds on the positioning error with specified probabilities. The NSE is bounded by the Protection Levels, which are in turn compared to the Alert Limits. If the user's Protection Levels exceed the Alert Limits the approach is flagged within the time to alert of 6 seconds. There are actually a number of parallel hypotheses (see LAAS MASPS) used in determining the user's Protection Levels. The VPLmax and LPLmax (worst case) calculation is the level that is applied for comparison to the alert limits. In basic terms, the relation is as follows:

Vertical NSE < VPLmax < VAL = 10 meters
Lateral NSE < LPLmax < LAL = 40 meters

Continuity and ***Availability*** are related, but are not interchangeable. A system must first be available before you can determine if it meets continuity. LAAS could be available at the initiation of the approach, but an unfavorable constellation change or other event could make the approach unavailable before it is completed. Therefore, this approach would suffer a loss of continuity. For the purposes of this report Availability and Continuity are analyzed in terms of LAAS Protection Levels that are within the alert limits for a given time period (24 hours). The LAAS MASPS states, for Cat I, that "the overall probability of a loss Continuity due to a Protection Level exceeding the Alert Limit shall not exceed 7.8X10^(-6) per 15 seconds". A properly configured and maintained LAAS, such as the FAA's LTP, can meet this constraint without any difficulty. The 24-hour VPL/HPL plots provided in this report are most stable and repeatable, and in fact appear identical from one day to the next. Long and short-term system Availability is difficult to quantify for a prototype system such as the LTP, and is accordingly out of the scope of this report.

8.1.2 VDOP and HDOP

Vertical and Horizontal Dilution of Precision (VDOP and HDOP) parameters of the SPS is actively monitored since the LAAS is required to perform with a worse case constellation and geometry. VDOP/HDOP parameters are directly tied to constellation geometry, and when combined with pseudorange errors affect the SPS position estimate and time bias. Diverse constellation geometry will provide less dilution, while confined constellation geometry will drive dilution higher. What is ultimately diluted is the user's uncorrected Vertical and Horizontal position estimate. Monitoring the VDOP and HDOP in the LAAS ground station gives a valid picture of what the user is experiencing and provides a quantity to the DOP components of error that is experienced prior to applying to a differential correction.

8.1.3 Clock Error

The average Clock Error is important to monitor since rapid changes in the ionosphere can drive the clock error to unusual levels. For the purposes of this report the clock error is presented solely to present a history of a typical clock error condition on a typical day. Clock error will invariably rise when the Total Electron Count (TEC) of the ionosphere is high (day), and fall when the TEC is lower (night). The derived average system clock error is correctable and in general amounts to between 5 and 15 meters (between 0.166 and 0.550 nano-seconds). Much larger clock biases are tolerable as well. The reference receiver clock biases are largely removed from the pseudorange correction (PRC) before these corrections are sent to the airborne equipment. Each PRC measurement could contain a residual clock error that is not removed. The residual clock error is relatively small and complicated to accurately measure. Therefore an estimate of the PRC error (referred to as a B-Value) is calculated elsewhere in the system and is software monitored to actively exclude any single measurement(s) that exceeds a given threshold. Deviations from the cyclical and roughly sinusoidal shape and magnitude of the graph will likely indicate a disturbance that will prompt further investigating to see if other parameters were adversely affected.

8.1.4 Code-Minus Carrier (CMC) and Reference Segment Status

(**CMC**)[2] values are computed for each SV on each antenna segment (eight total, two per reference). The initial CMC quantity is computed by converting the L1 Carrier phase into a range and subtracting it from the Code range (also known as the pseudorange). Additional processing is required to isolate the code Multipath and noise components,

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[2] CMC – For in-depth explanation on this method refer to ION Navigation Journal, Winter 94/95, volume 41, Number 4, page 415, "Isolation of GPS Multipath and Receiver Tracking Errors" (Braasch).

which include subtraction of the sample-mean to remove the carrier phase integer ambiguity. Further computation is required for the removal of the ionospheric delay. The ionospheric delay is computed from the L1/L2 carrier phase measurements obtained from the L1/L2 IONO station.

The CMC values have had the effect of ionospheric delay (as determined from the L1/L2 IONO antenna data) removed from it, and has been smoothed. The CMC value can therefore be considered error that is uncorrectable, and uncommon to the ground station and airborne user. This uncorrectable error consists primarily of Multipath, noise, and hardware biases. The error is minimized by custom LAAS hardware design and adherence to the LAAS siting requirements.

Due to the configuration and siting of the reference stations of the LTP the typical antenna segment error reported has a standard deviation trace residing in the 0.05-meter region. The CMC values and statistic plots are continually monitored to unsure minimum obtainable levels are maintained.

In order to observe overall system performance, the CMC, **number of samples (NOS)**, and **carrier-to-noise** (**C/No**) ratio values from all four reference stations' dipole segments and HZA segments are averaged together so as to create only two sets of data (dipole and HZA) for all SVs, from the original eight antenna segments. C/No is critical to optimum reference receiver (RR) performance, and is closely monitored. The C/No is a density ratio, with units in dB-Hz, and is driven by the amount of total signal power that is permitted to enter two RF inputs of the RR. The LAAS T&E team maintains proper total input power through external attenuation the value of which is obtained by performing an AGC calibration. The NOS also serves as a representation RR performance and health. System level NOS for a given elevation bin is reasonably repeatable for a given GPS constellation. Marked changes in the NOS, without a constellation change, would prompt the LAAS T&E team to investigate and address the potential cause.

Depicted in this section are four ensemble (all data averaged and overlaid) plots that are generated using the data from all SVs over a 24-hour period. Carrier-to-noise versus time and elevation and CMC versus time and elevation, are made up of individual traces for each satellite overlaid atop one another. Also depicted are two statistics plots—mean and standard deviation of the CMC versus elevation bin and number of samples versus elevation bin, combine the data from all available SVs based on their elevation at the time the sample was recorded. For the dipole segment, data is broken into 2-degree bins from 4 to 40 degrees, for the HZA, from 25 to 90 degrees.

The standard deviation of the CMC estimate of pseudorange error is compared to the Ground Accuracy Designator (**GAD**) **"C"- curve**. Any exceedance of the GAD C-curve at the specification required elevations (5 to 40 for dipole, 40 to 90 for HZA, as applied in the LTP) is considered a performance deficiency. These deficiencies are repeatable and will not improve/degrade without human/environmental intervention. This is when the LAAS team inspects RR/RRA environment and hardware to address the problem.

There are two CMC and antenna segment status sections presented in this report for each month of the reporting period. The first is the dipole antenna section, followed by the HZA antenna section. The CMC process that the LAAS T&E team has developed generates multiple system average plots, which include: CMC error, receiver status, and statistics plots, which are presented together in the CMC sections.

The plot of CMC error magnitude versus azimuth/elevation value shows the performance of each satellite individually, with points on the plot color-coded to the maximum CMC value observed at a given azimuth/elevation pair. Referred to as the "**Average Error Characterization Plot**" these figures reveal much about the Multipath environment, and error a SV signal experiences on its path to the receiving element. Any increase in the average reported error indicates a possible problem with the system or environment, which would prompt immediate investigation by the LAAS T&E team.

8.2 Performance Analysis Reporting Method

For a given configuration the LTP's 24-hour data sets repeat performance, with little variation, over finite periods. The LAAS T&E team can make that statement due to the continual processing of raw LTP data, and volume of legacy data that has been analyzed from the LTP by the FAA and academia. Constellation and environmental monitoring, in addition to active performance monitoring tools such as the web and lab resources provide the LAAS T&E team cues for closer investigation in the presence, or suspicion, of uncharacteristic performance.

Data sets from the LTP ground and monitoring stations are retrieved on a weekly basis and are processed immediately. A representative data-day can then be drawn from the week of data to be formally processed. The resultant performance plots could then serve as a snapshot of the LTP's performance for the given week. These weekly plots are afterward compared to adjacent weeks to select a monthly representative set of plots.

8.3 Performance Summary

This reporting period witnessed acceptable overall system performance, and well within Category I limits. The performance plots depicted typify historical performance for the current LTP configuration.

No NANUs are highlighted in the NANU section. Actual SV outages experienced for this reporting period caused no interruptions of service, or significant rise in key values.

9. Performance Plots and Plot Organization

This report provides the reader a LTP system level performance snapshot. For narratives on the utilized parameters refer to section 8. In the interest of space a representative set of plots is chosen on a monthly basis. These monthly plots are presented in the remainder of this section.

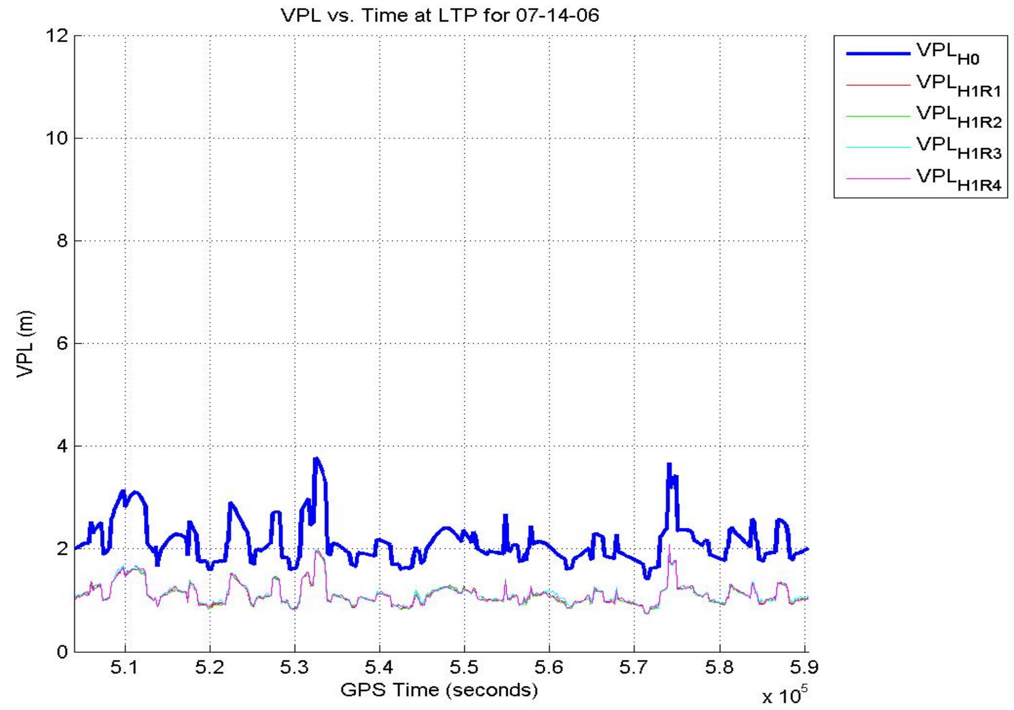
The content and organization of the LTP system performance plots, contained in the remainder of this report, are outlined below.

Reporting Period Month and Year

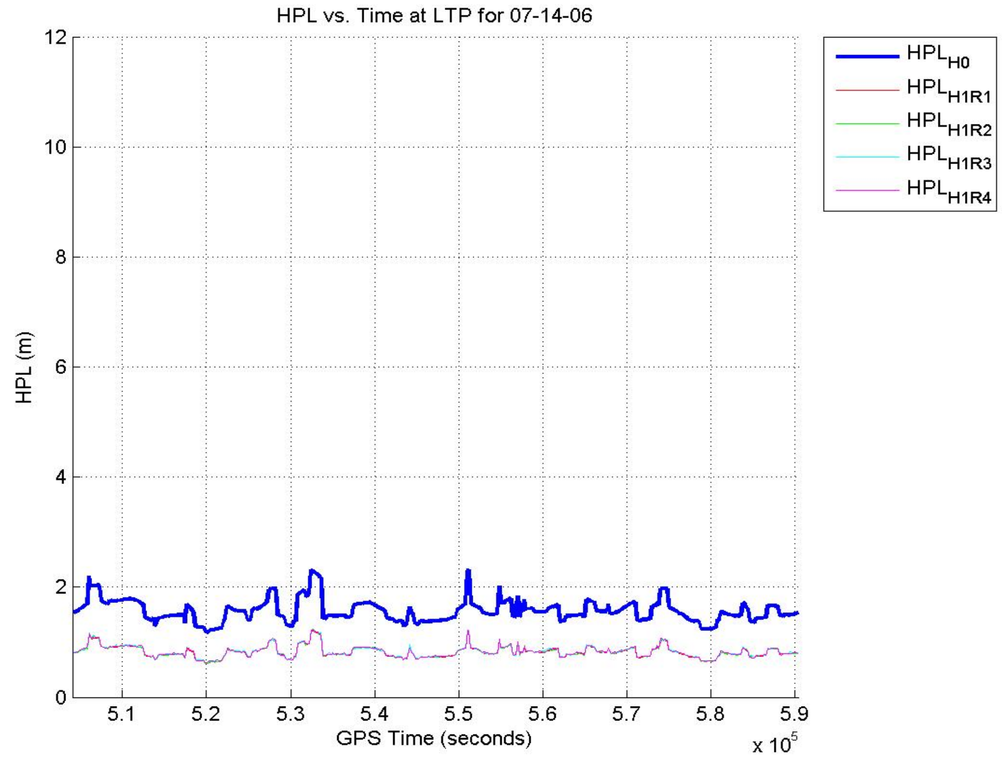
1) **VPL versus Time**
2) **HPL (LPL) versus Time**
3) **VDOP and Number of SV Observations versus Time**
4) **HDOP and Number of SV Observations versus Time**
5) **Clock Error versus Time**
6) **Dipole Status and CMC (System Average) (multiple)**
    System Dipole CMC Standard Deviation and Mean versus Elevation
    System Dipole Error Characterization versus Azimuth and Elevation
    System Dipole Number of Samples versus Elevation
    System Dipole CMC versus Elevation
    System Dipole CMC versus Time
    System Dipole Carrier to Noise versus Elevation
    System Dipole Carrier to Noise versus Time
7) **HZA Status and CMC (System Average) (multiple)**
    System HZA CMC Standard Deviation and Mean versus Elevation
    System HZA Error Characterization versus Azimuth and Elevation
    System HZA Number of Samples versus Elevation
    System HZA CMC versus Elevation
    System HZA CMC versus Time
    System HZA Carrier to Noise versus Elevation
    System HZA Carrier to Noise versus Time

9.1 July 2006 Performance Plots

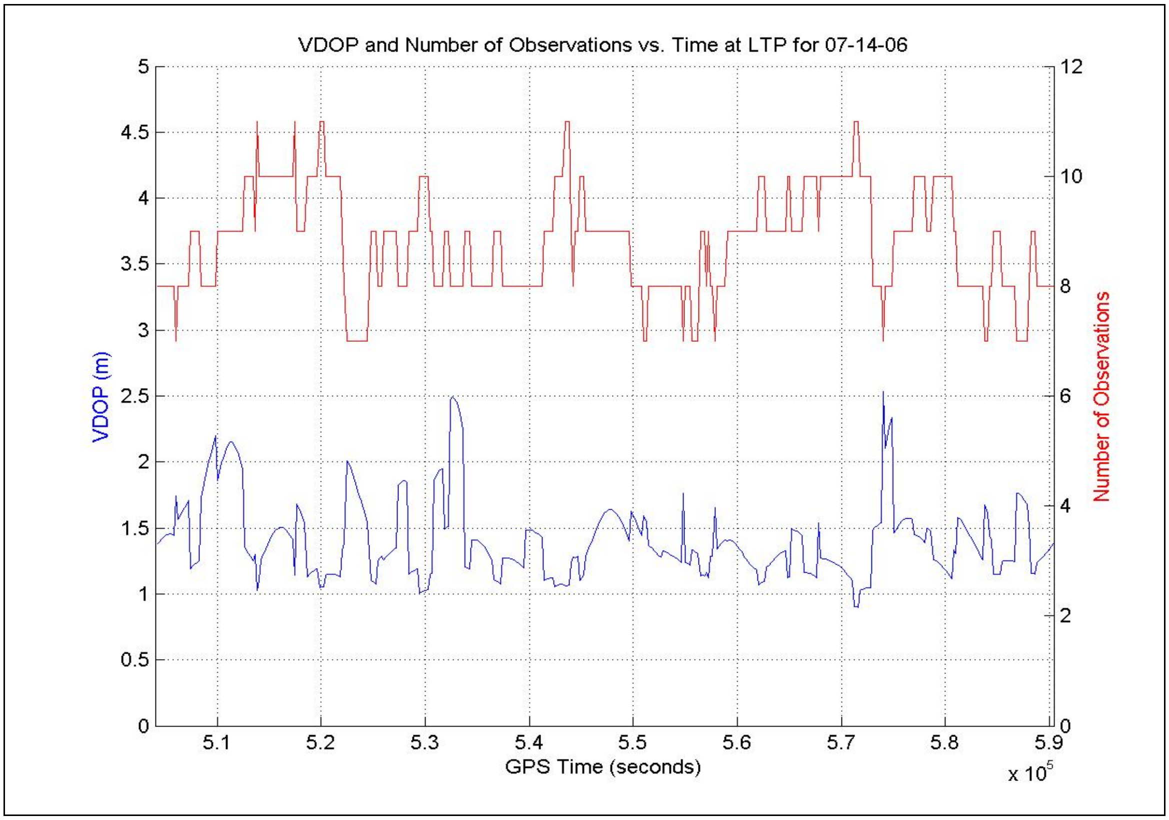
9.1.1 July VPL versus Time



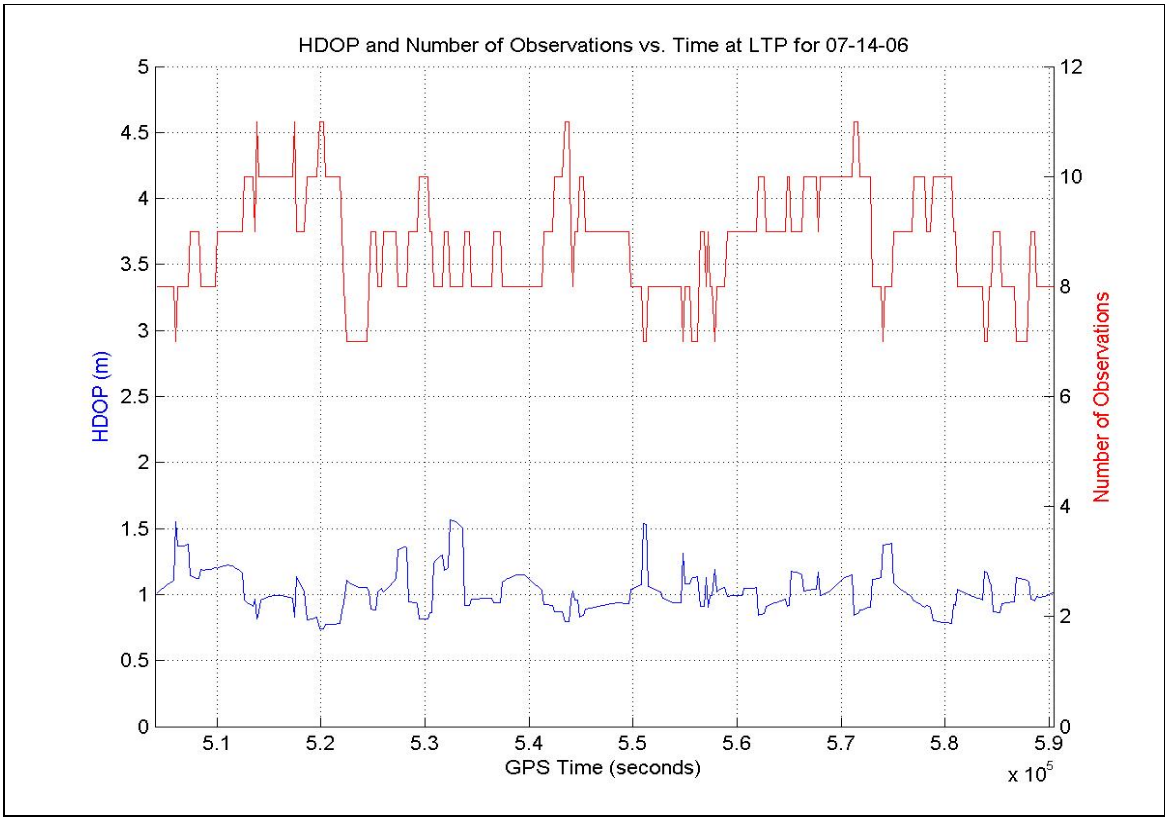
9.1.2 July HPL versus Time



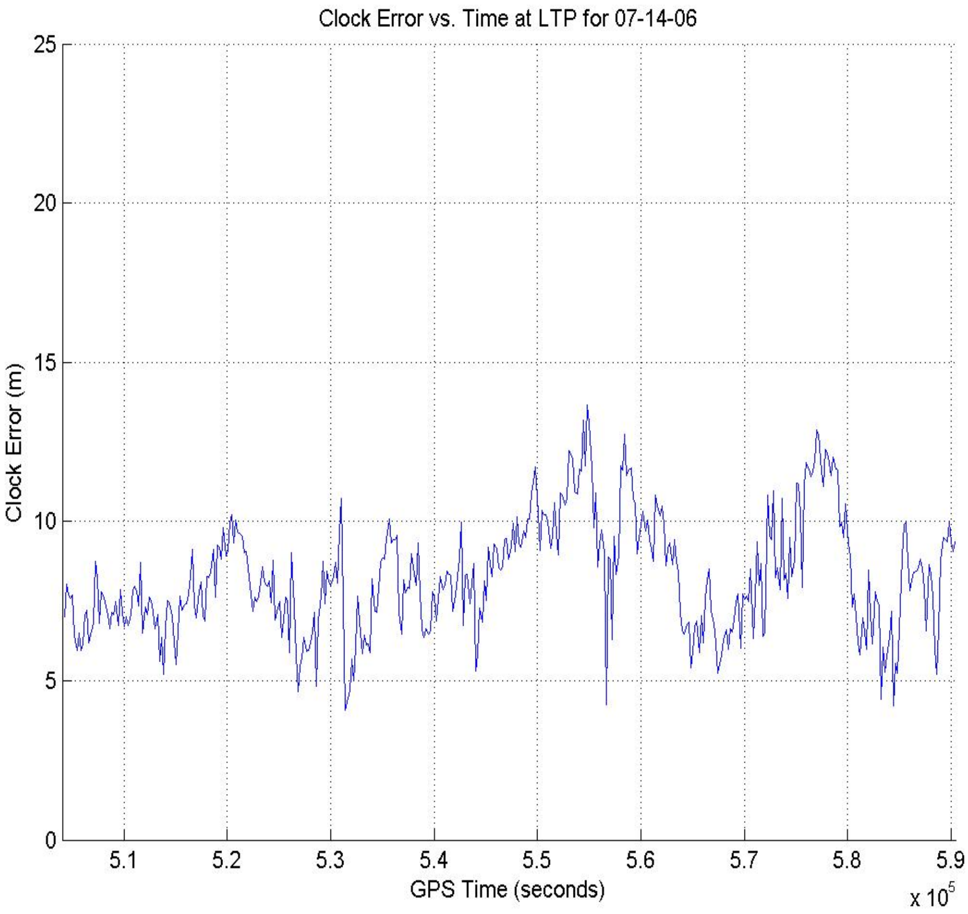
9.1.3 July VDOP and # of SV Observations versus Time



9.1.4 July HDOP and # of SV Observations versus Time

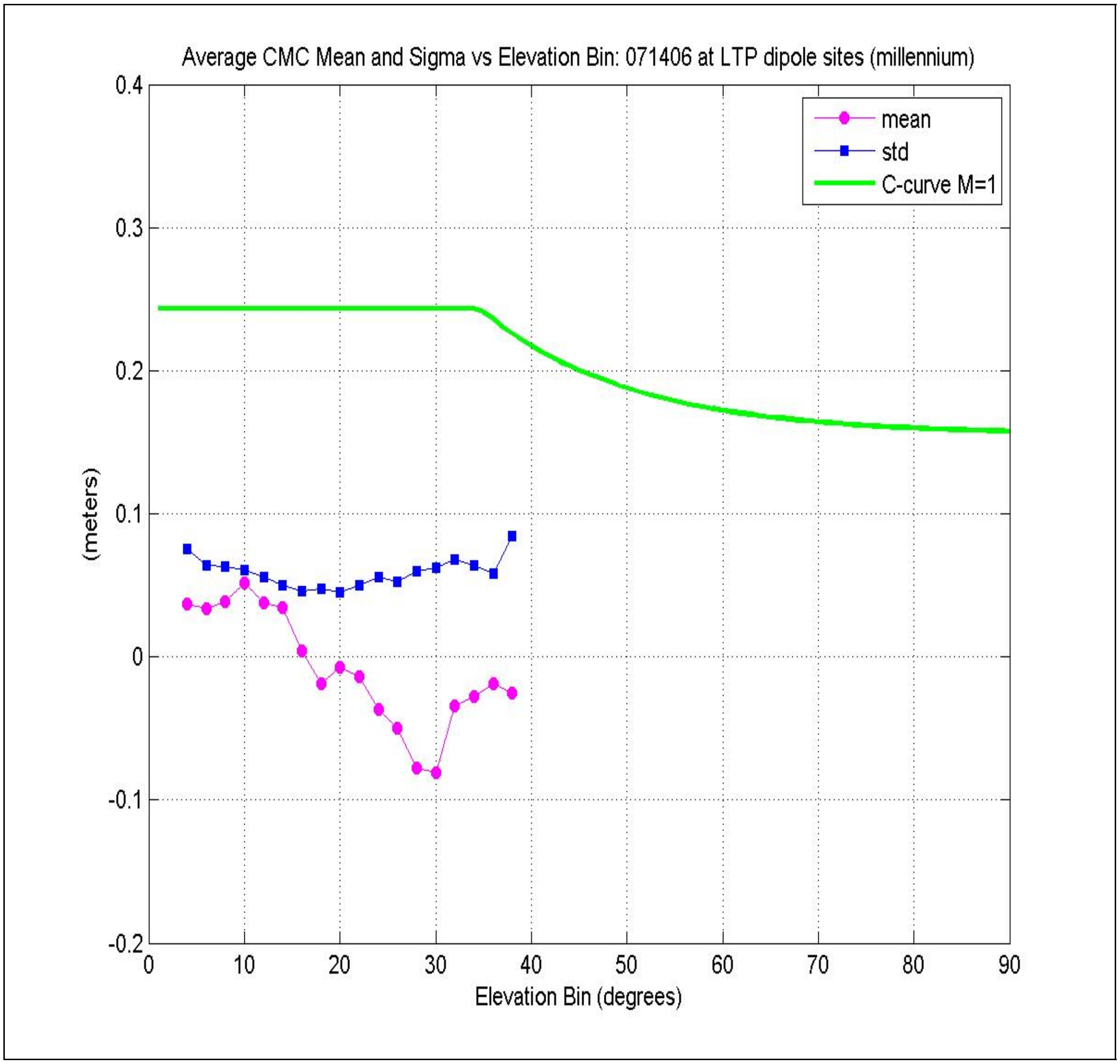


9.1.5 July Clock Error versus Time

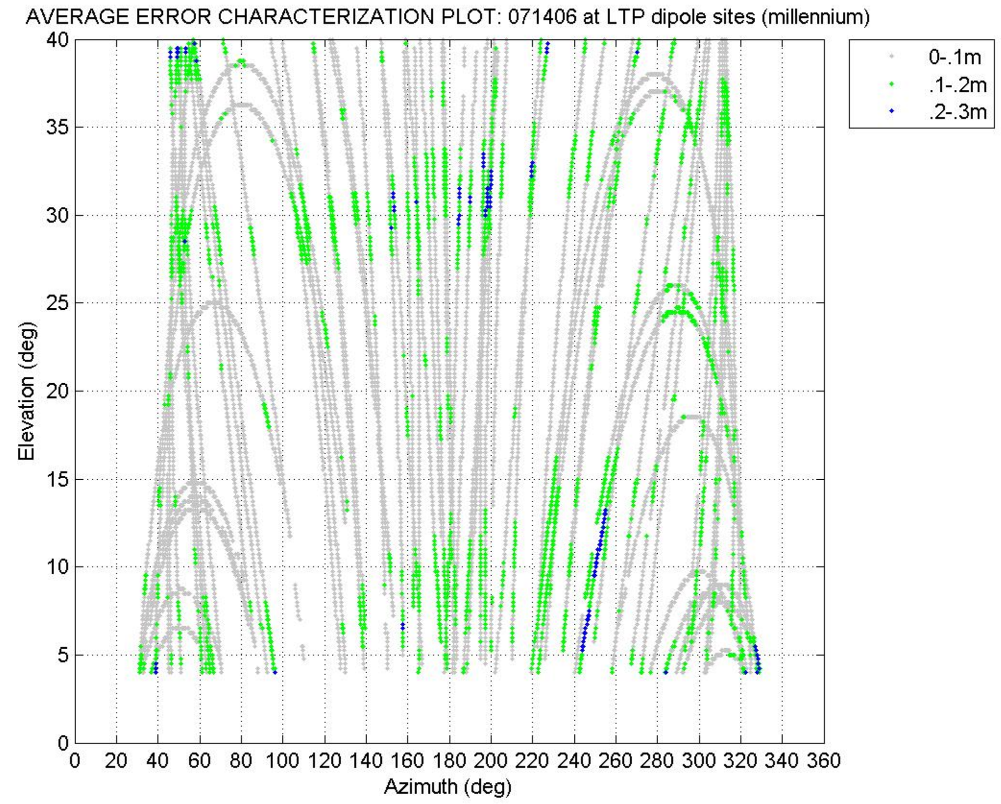


9.1.6 July Dipole Status and CMC (System Average) (multiple)

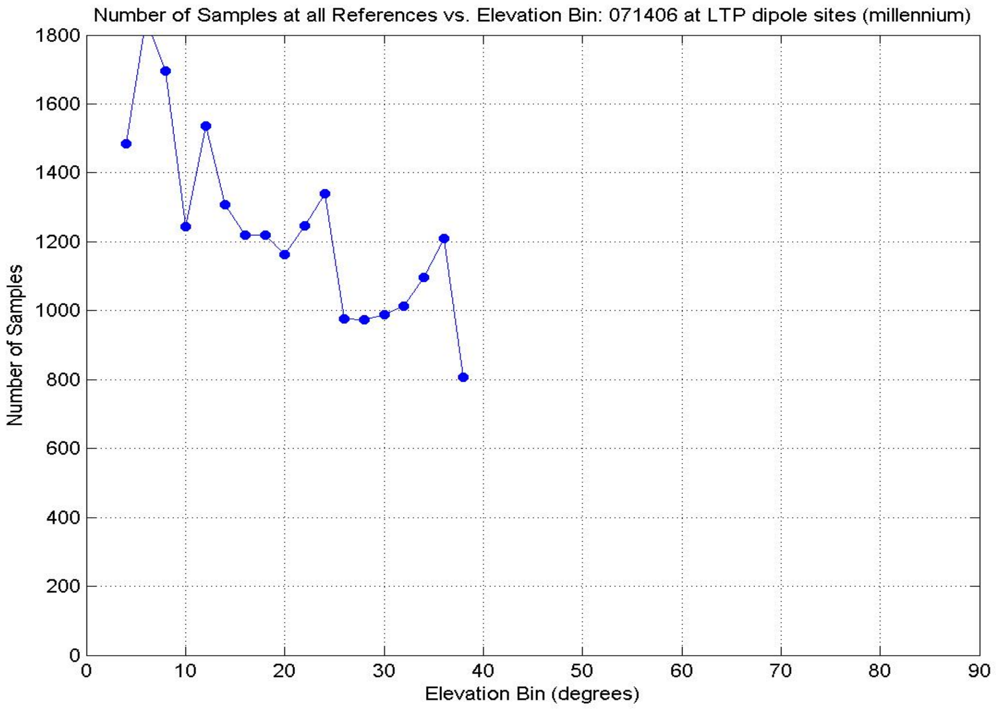
9.16.1 July System Dipole CMC Standard Deviation and Mean versus Elevation



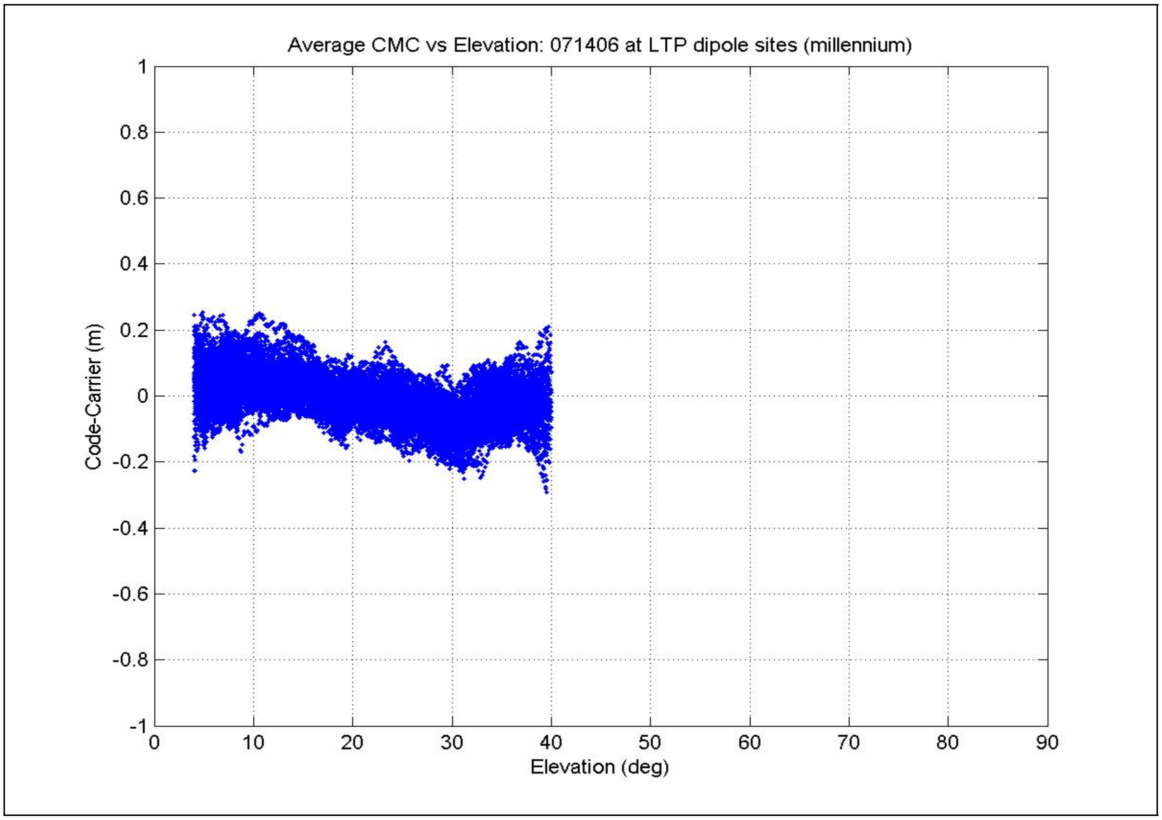
9.1.6.2 July System Dipole Error Characterization vs Azimuth and Elevation



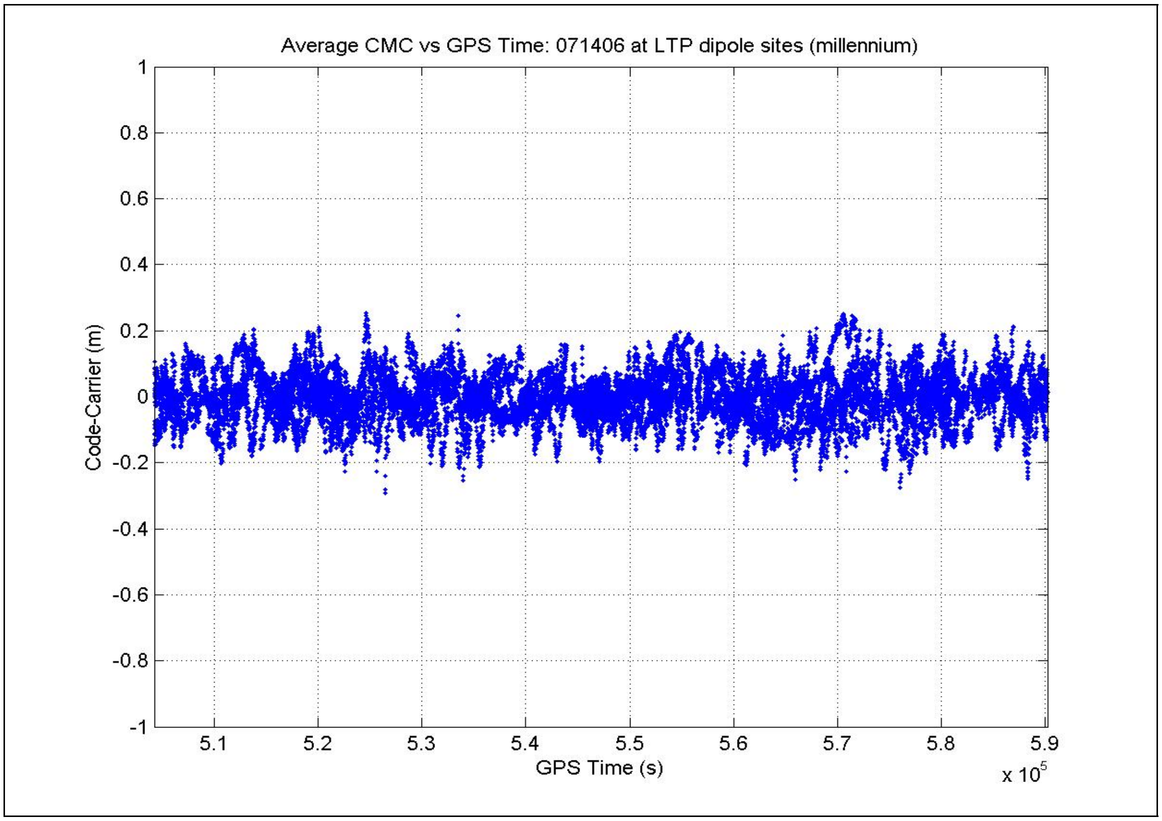
9.1.6.3 July System Dipole Number of Samples versus Elevation



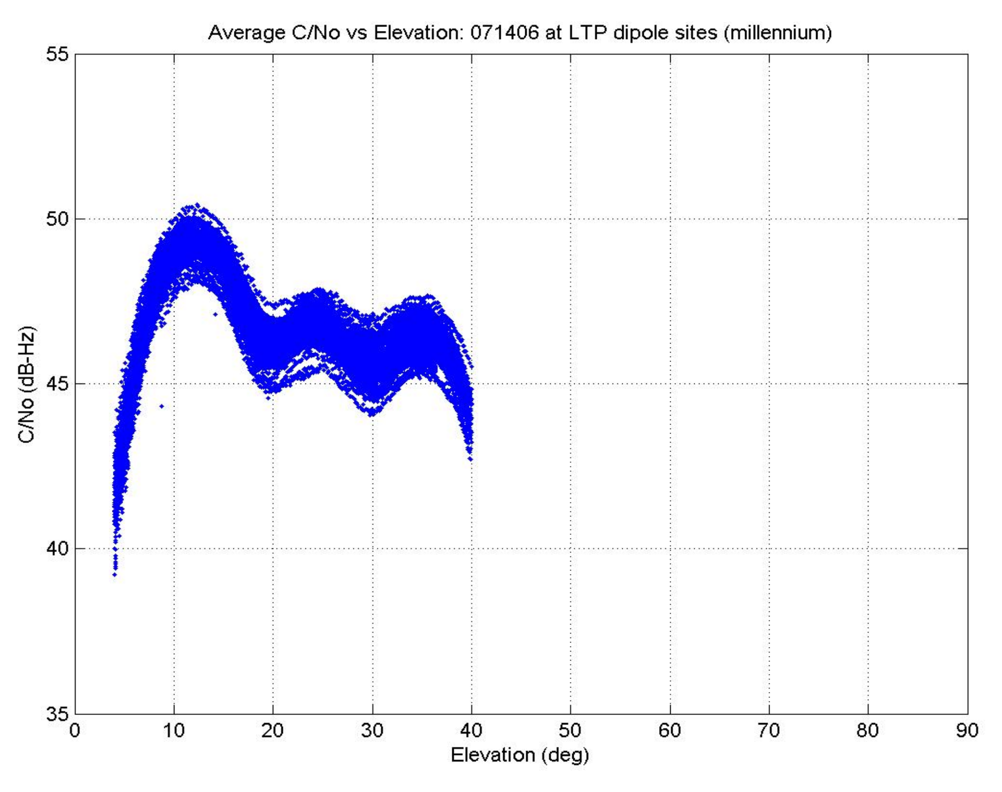
9.1.6.4 July System Dipole CMC versus Elevation



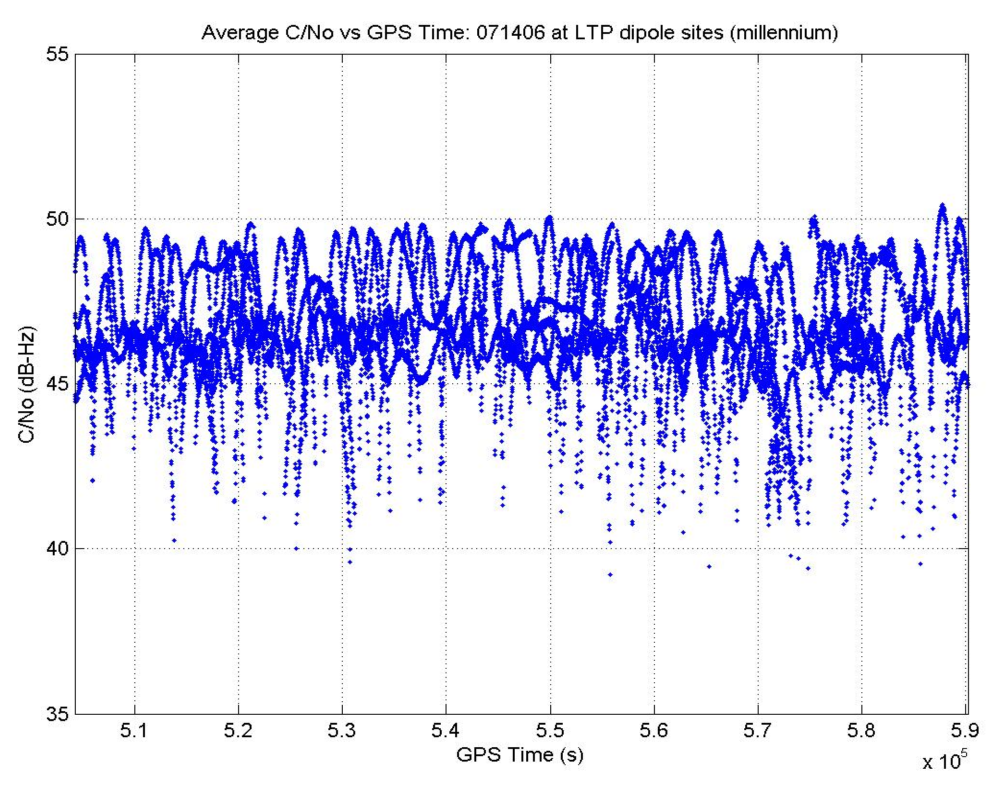
9.1.6.5 July System Dipole CMC versus Time



9.1.6.6 July System Dipole Carrier to Noise versus Elevation

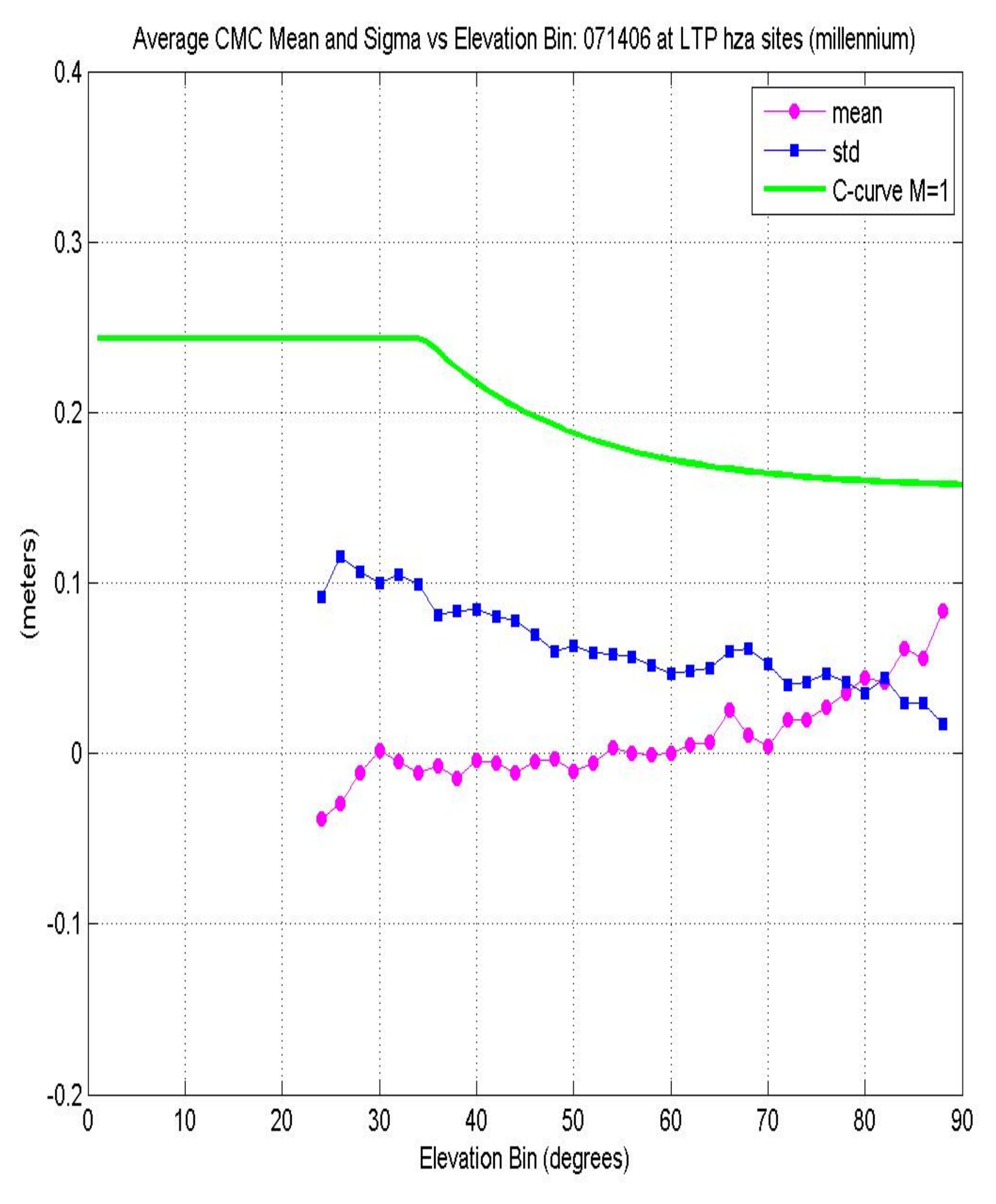


9.1.6.7 July System Dipole Carrier to Noise versus Time

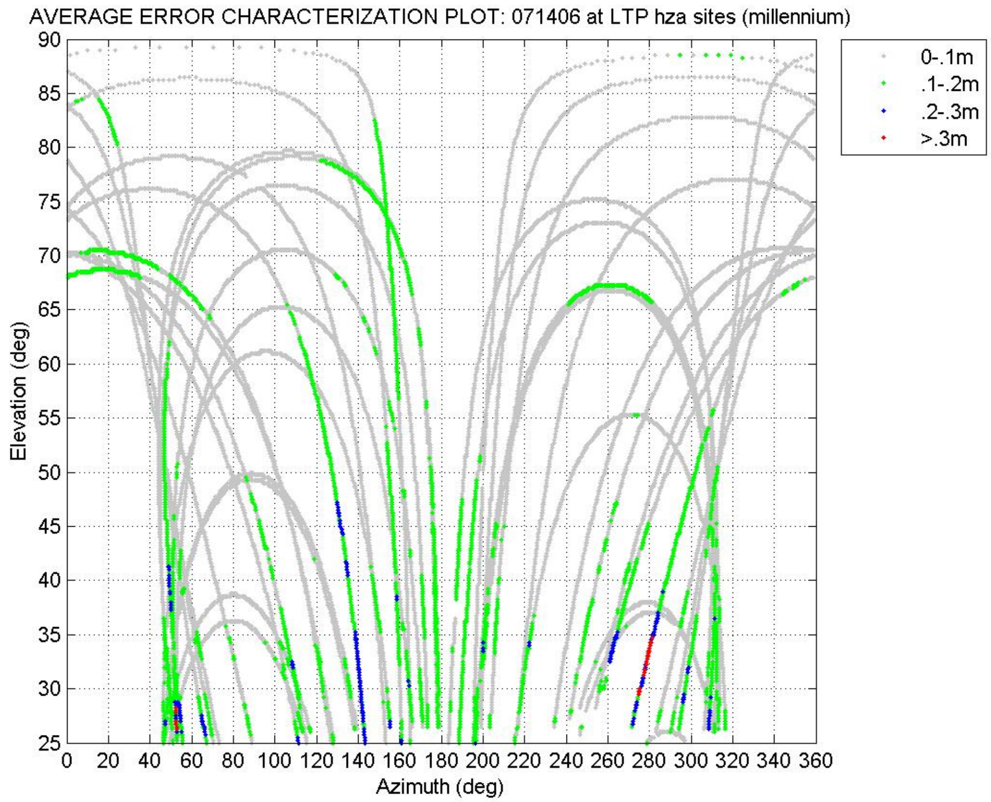


9.1.7 July HZA Status and CMC (System Average) (multiple)

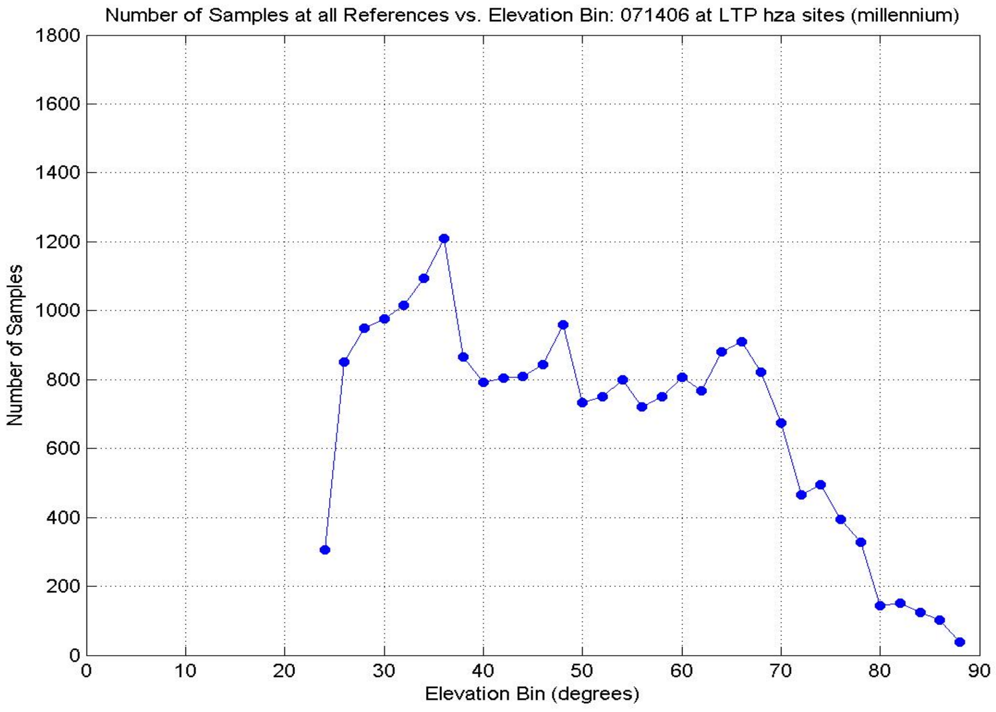
9.1.7.1 July System HZA CMC Standard Deviation and Mean versus Elevation



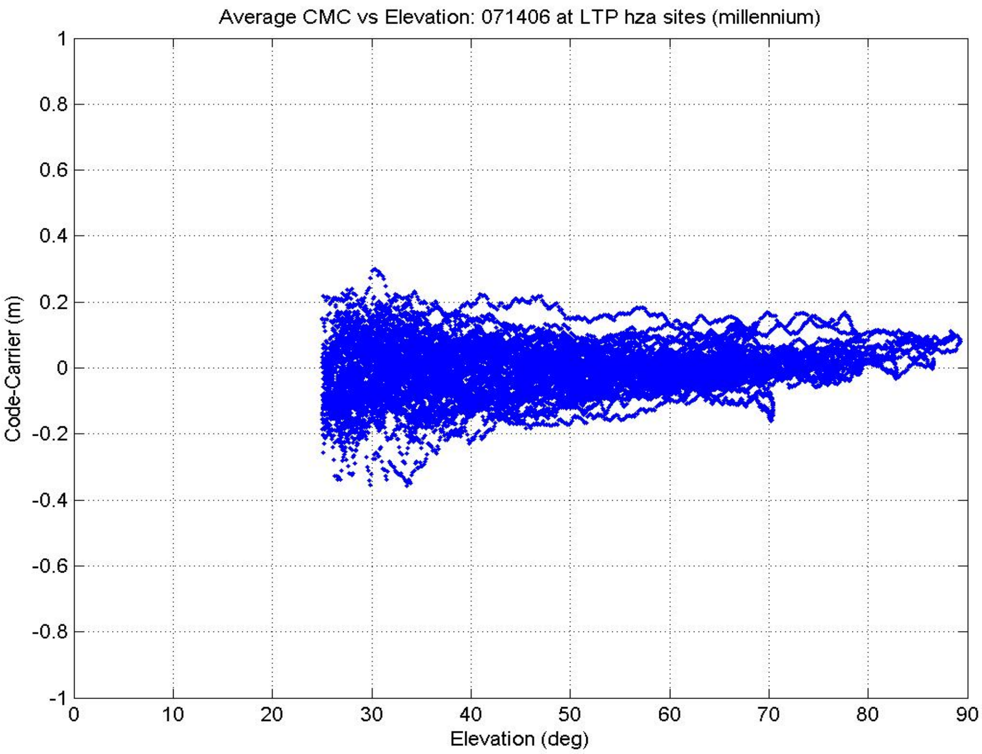
9.1.7.2 July System HZA Error Characterization versus Azimuth and Elevation



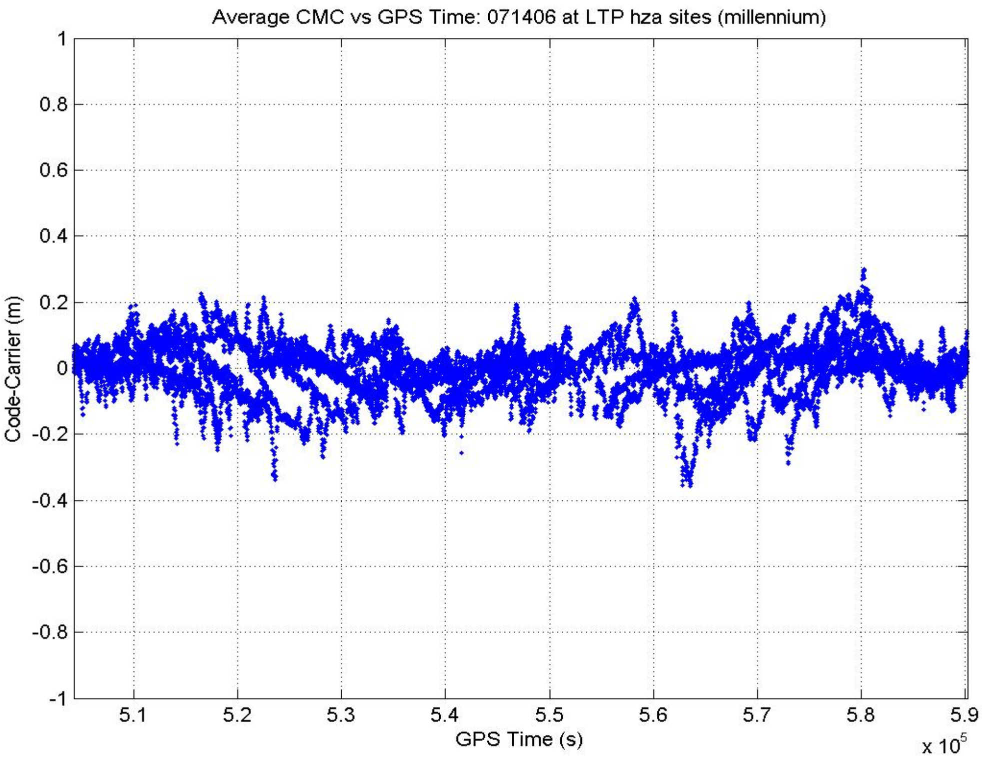
9.1.7.3 July System HZA Number of Samples versus Elevation



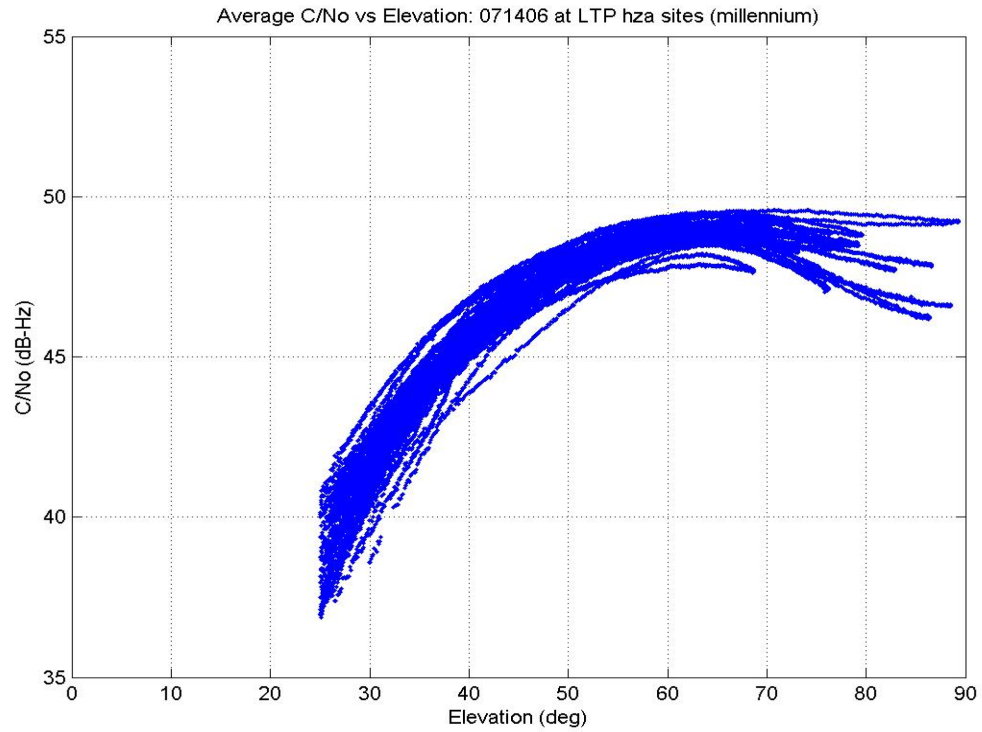
9.1.7.4 July System HZA CMC versus Elevation



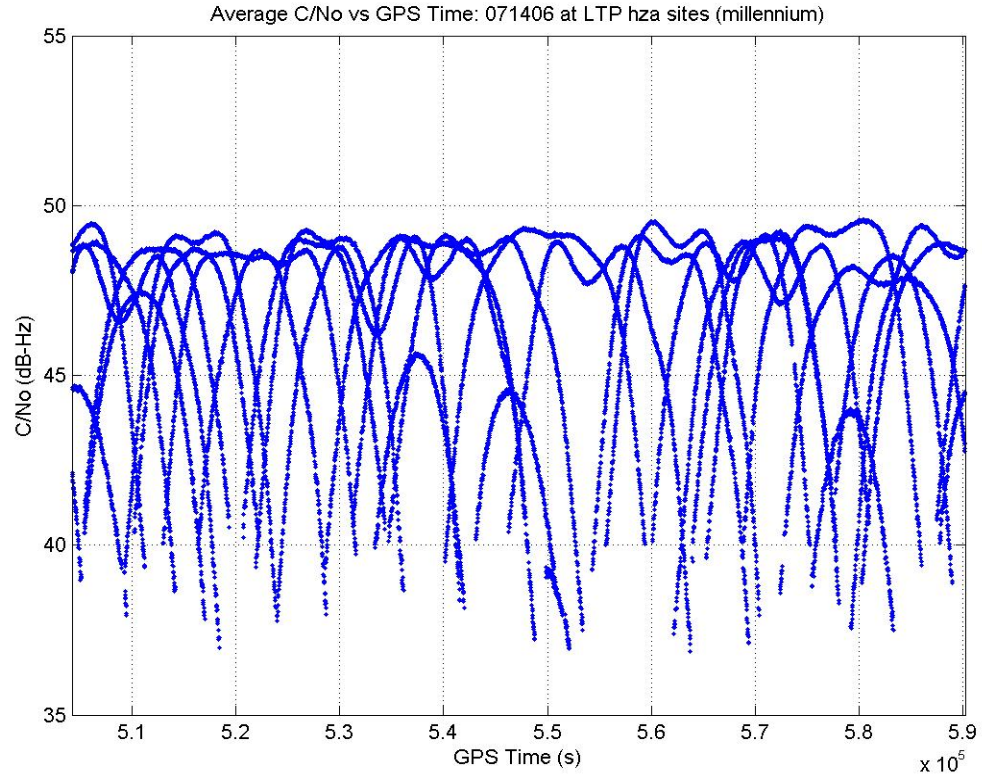
9.1.7.5 July System HZA CMC versus Time



9.1.7.6 July System HZA Carrier to Noise versus Elevation

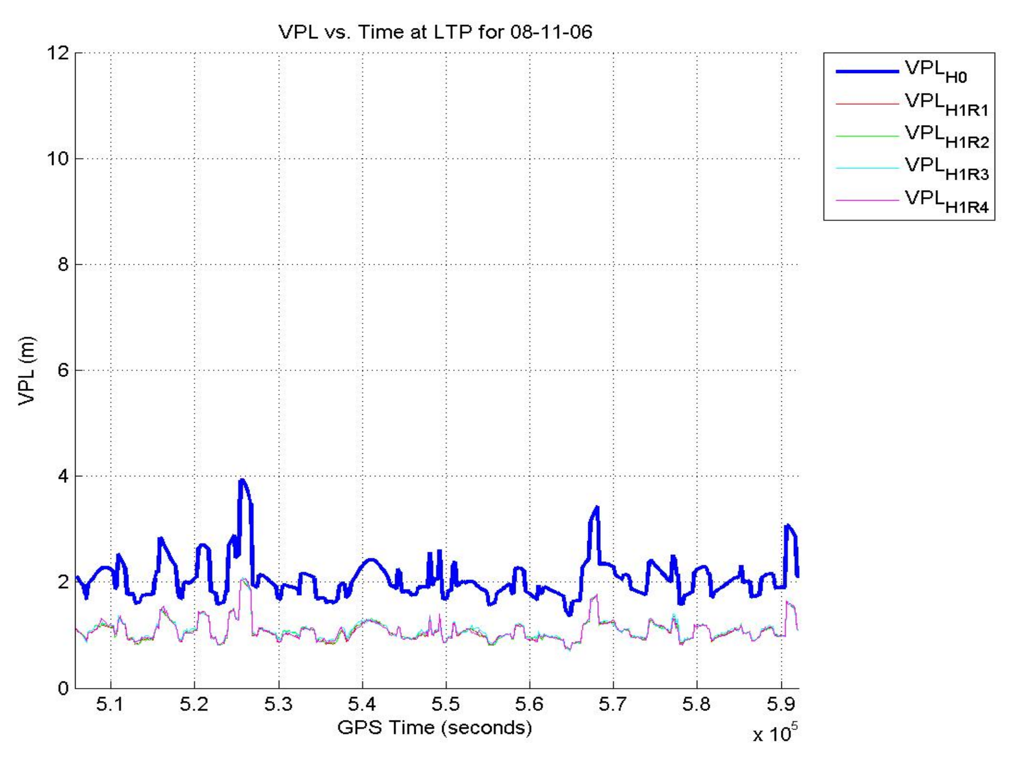


9.1.7.7 July System HZA Carrier to Noise versus Time

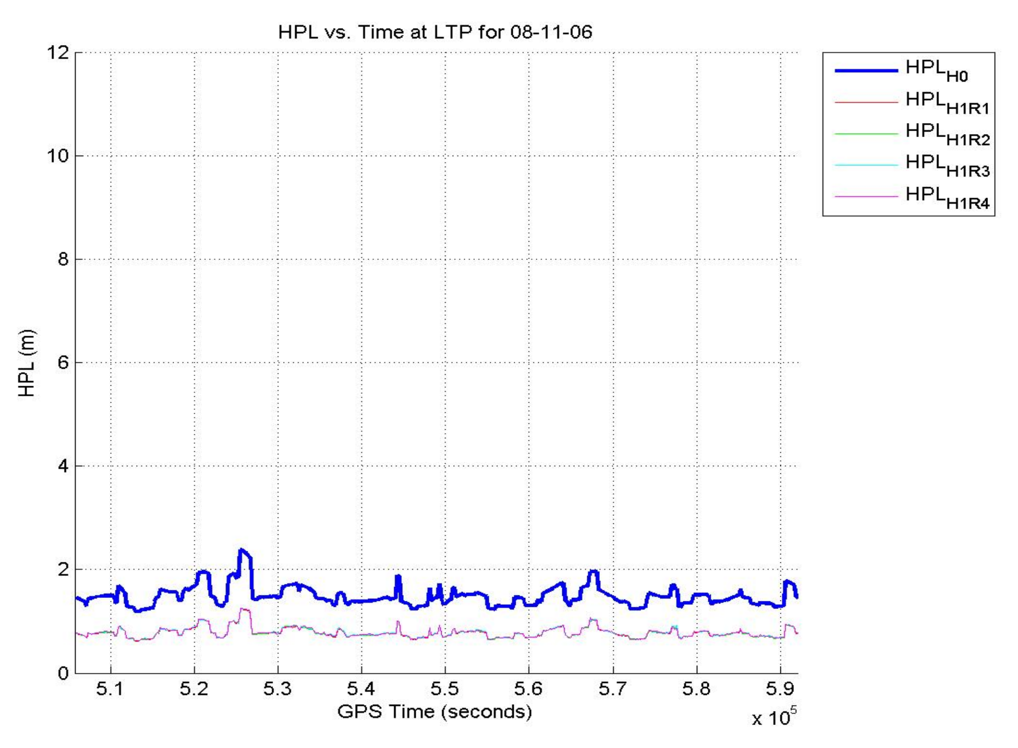


9.2 August 2006 Performance Plots

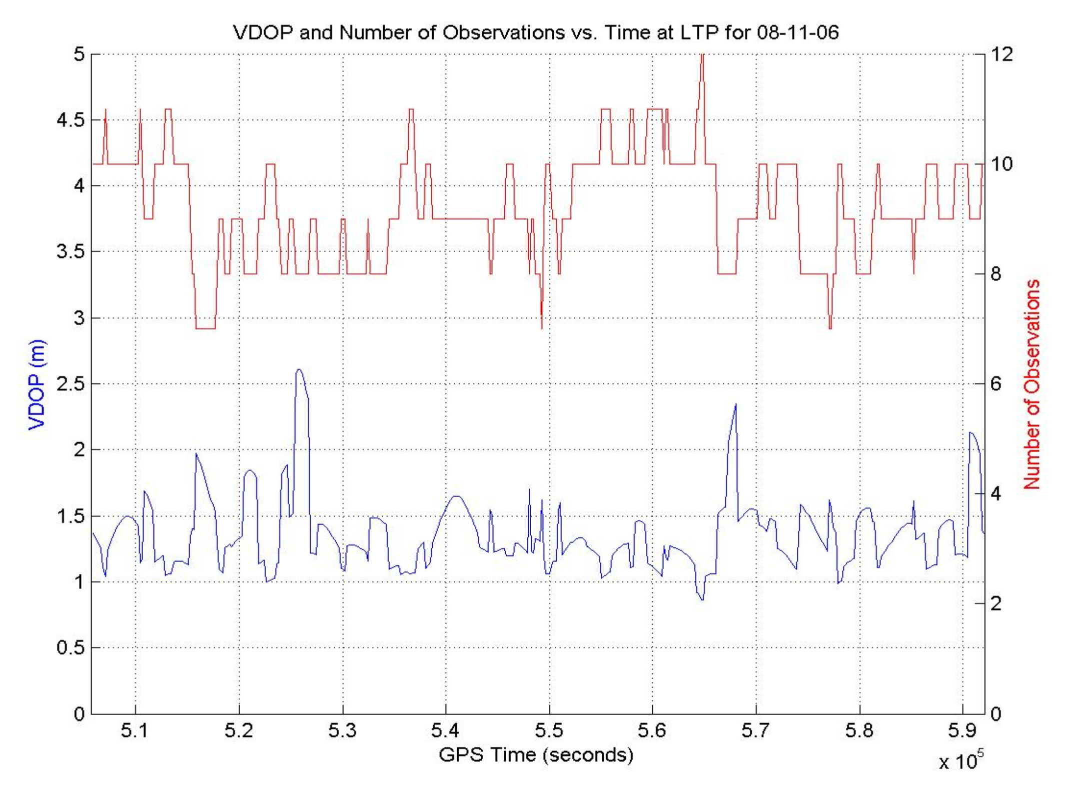
9.2.1 August VPL versus Time



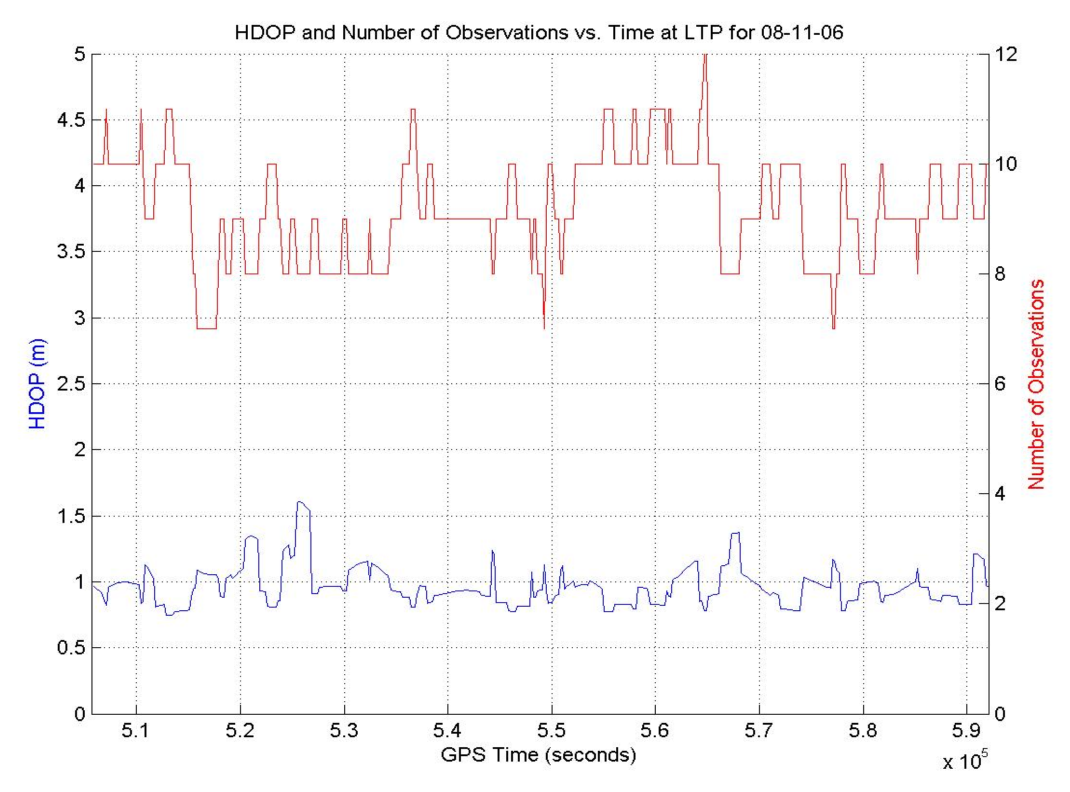
9.2.2 August HPL versus Time



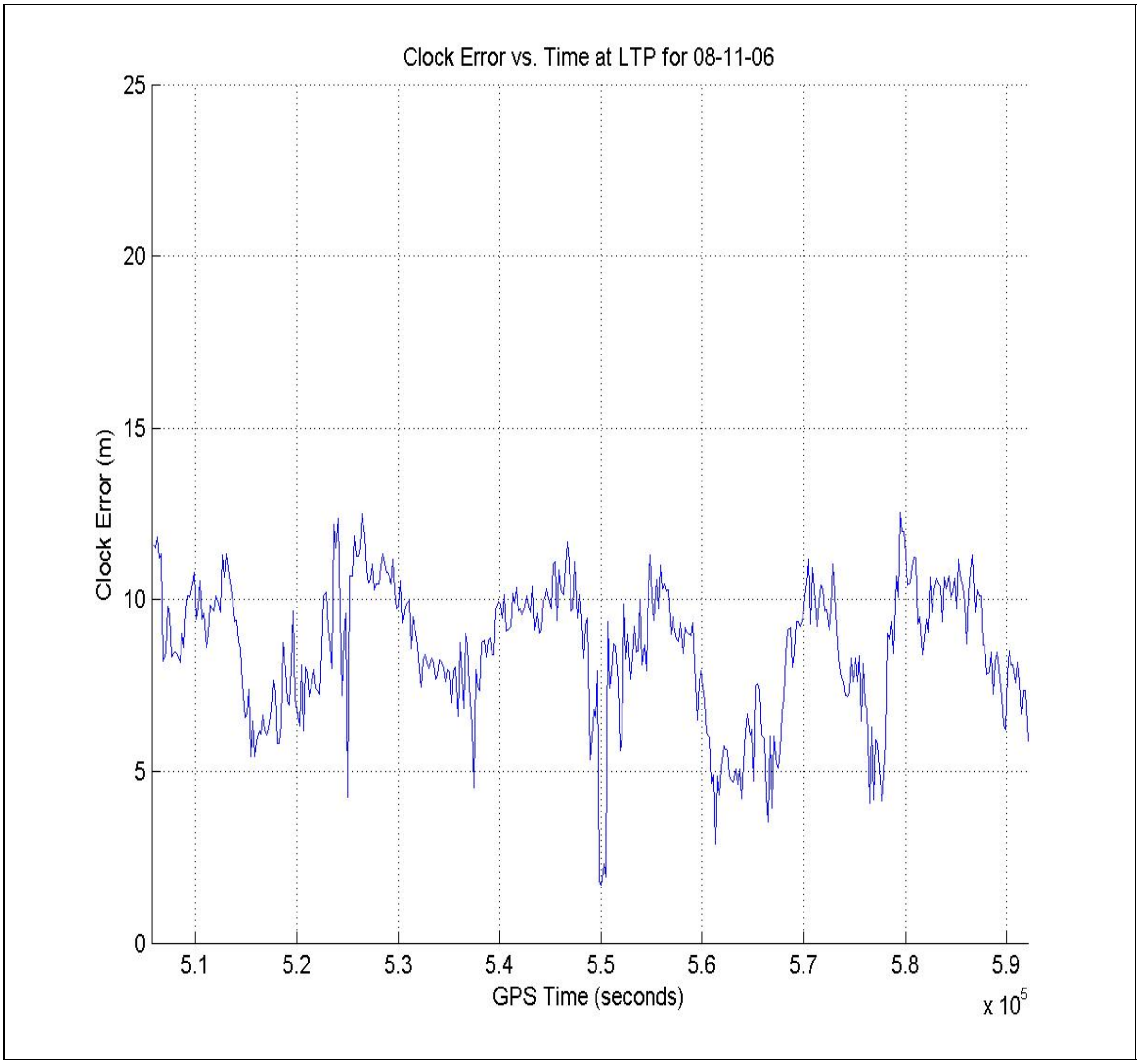
9.2.3 August VDOP and # of SV Observations versus Time



9.2.4 August HDOP and # of SV Observations versus Time

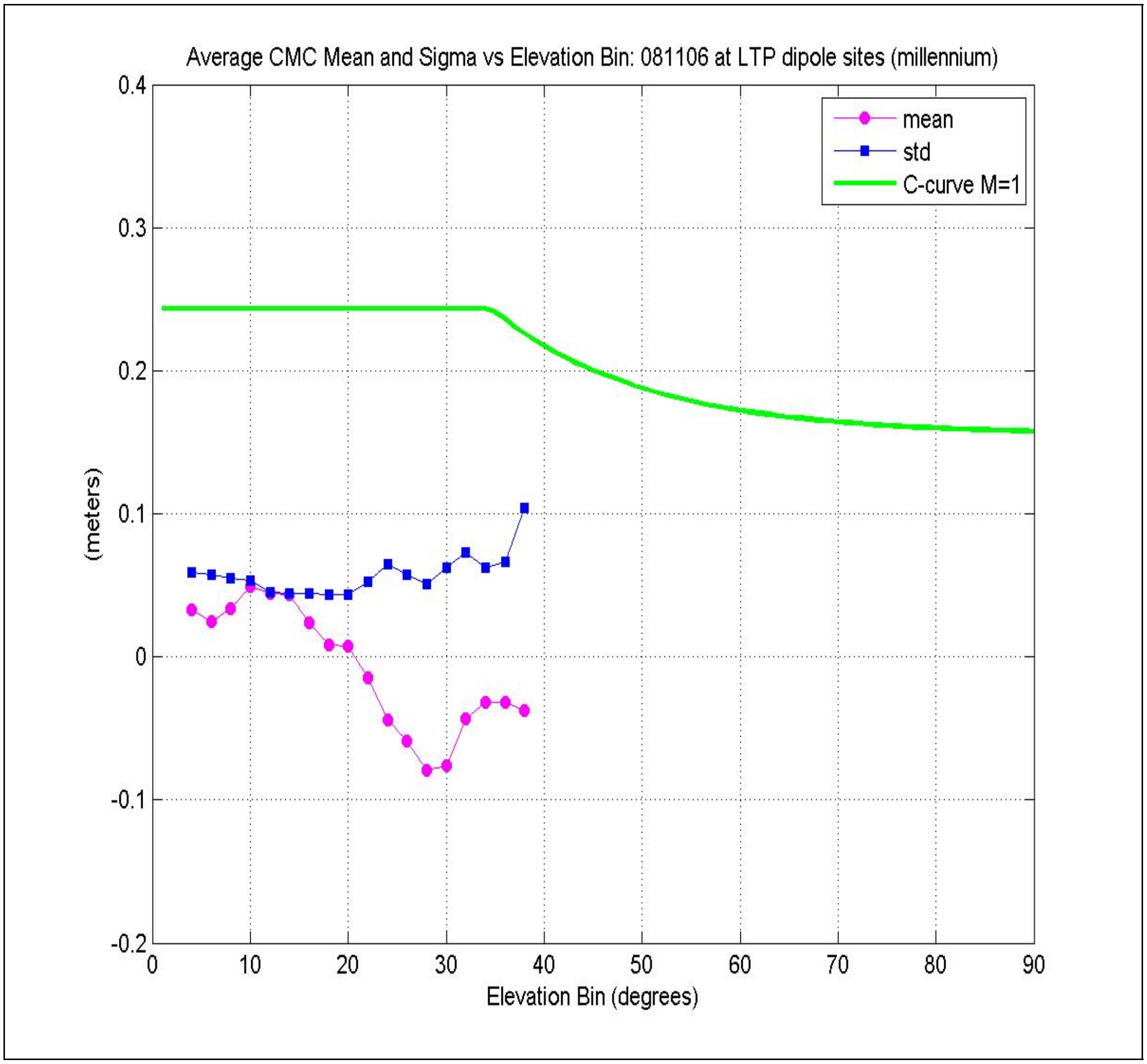


9.2.5 August Clock Error versus Time

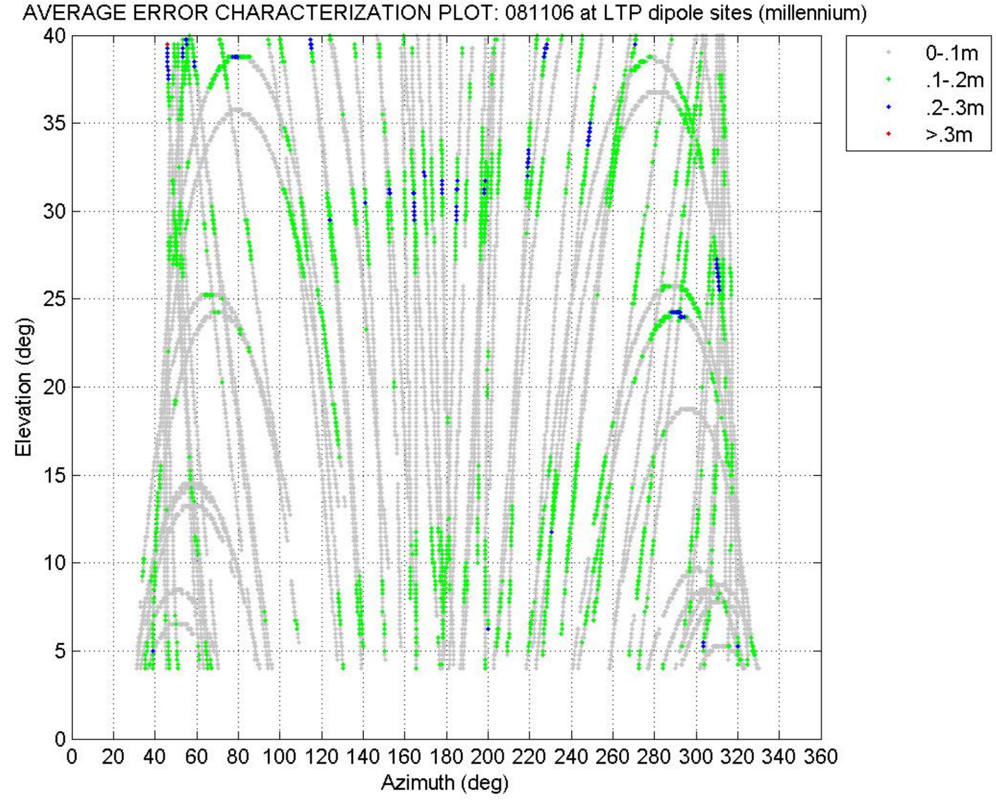


9.2.6 August Dipole Status and CMC (System Average) (multiple)

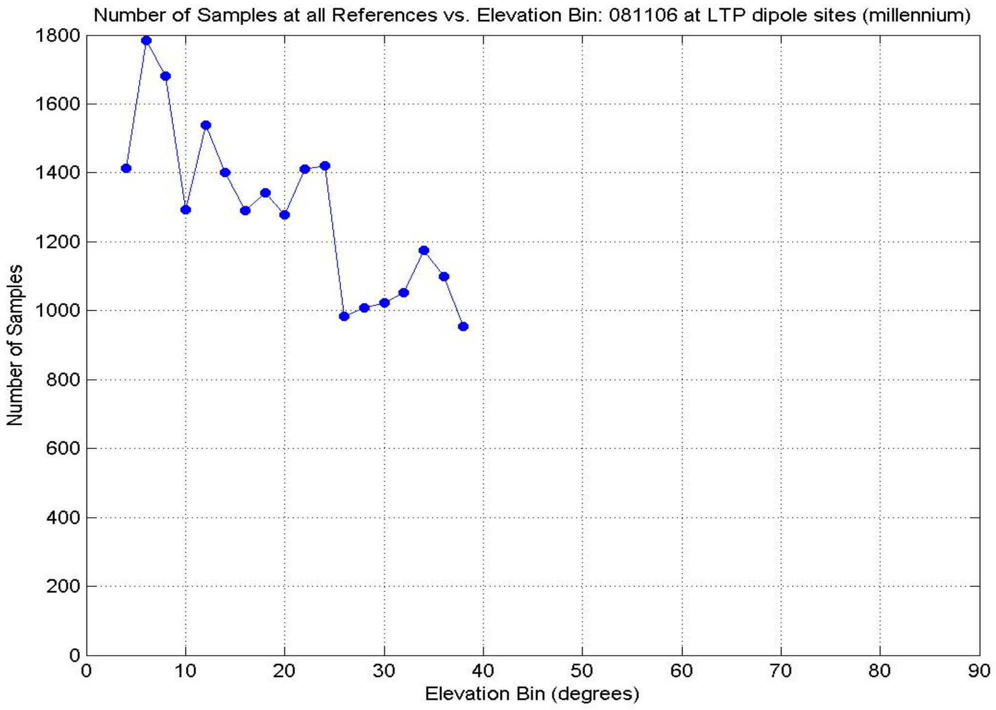
9.2.6.1 August System Dipole CMC Standard Deviation and Mean vs Elevation



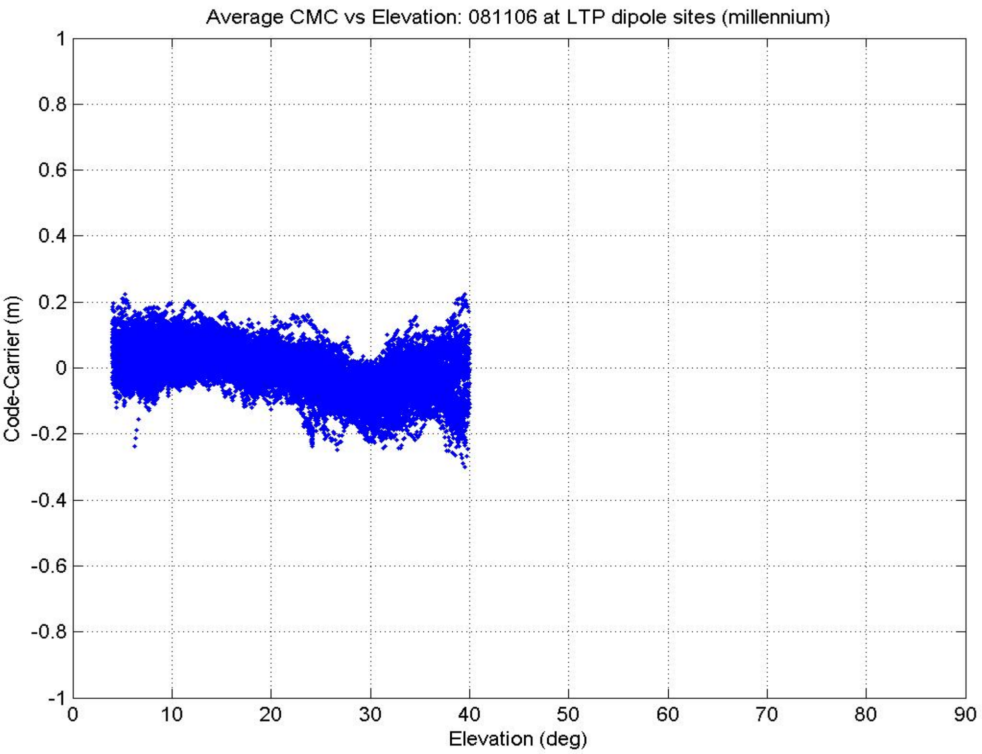
9.2.6.2 August System Dipole Error Characterization vs Azimuth and Elevation



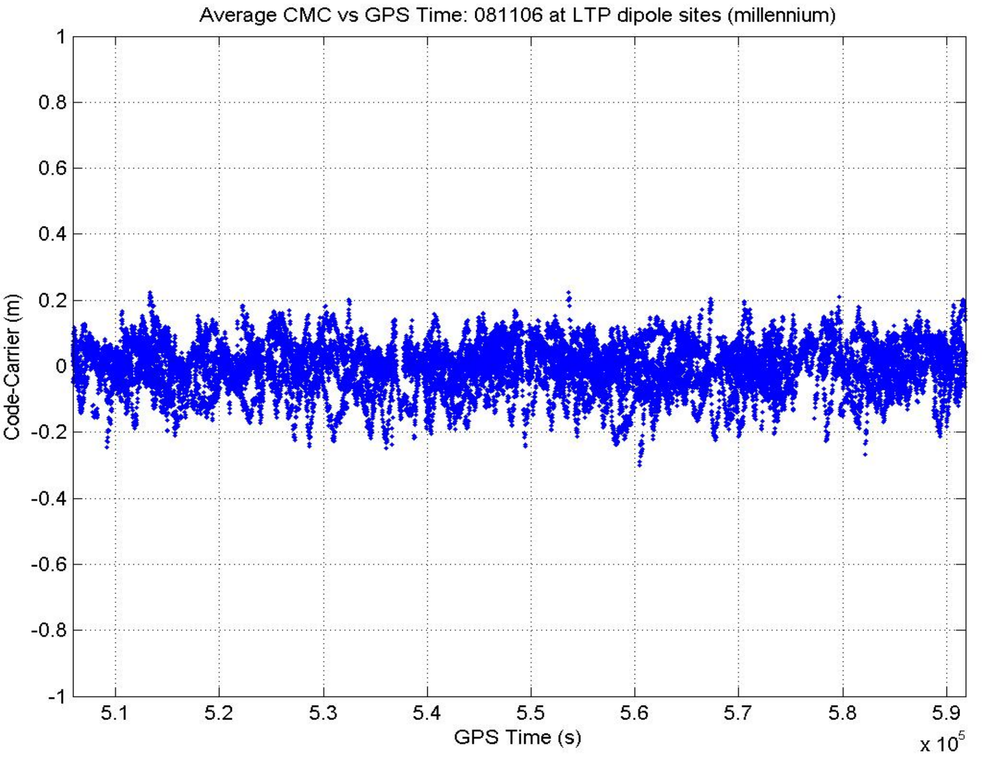
9.2.6.3 August System Dipole Number of Samples versus Elevation



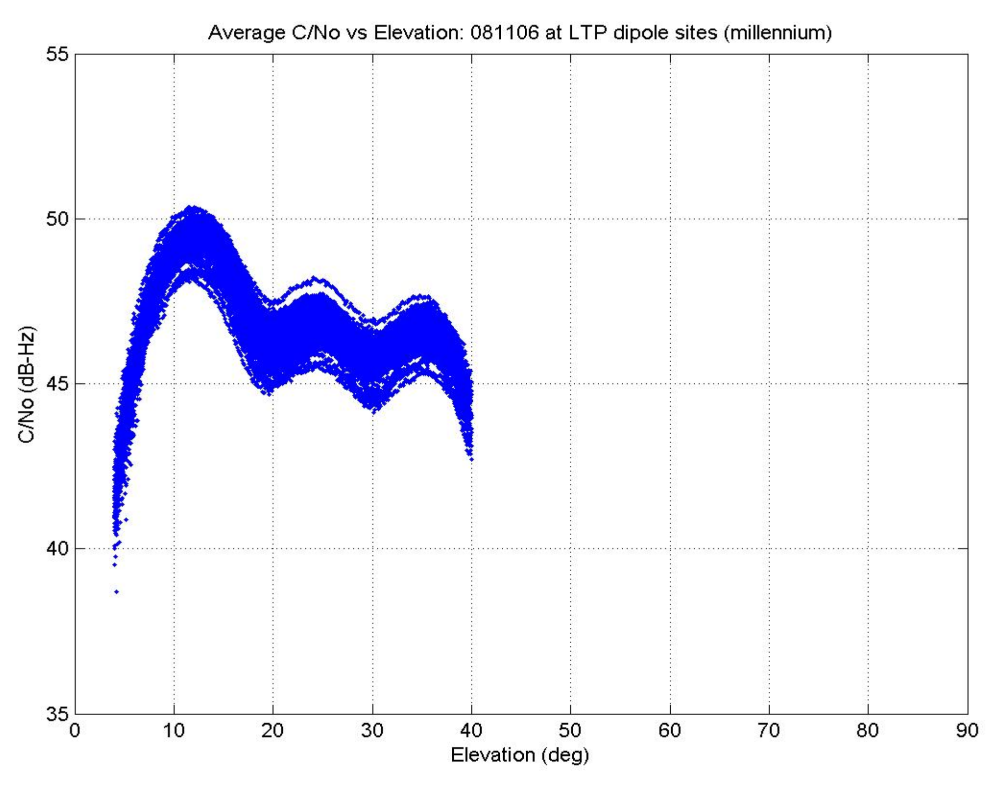
9.2.6.4 August System Dipole CMC versus Elevation



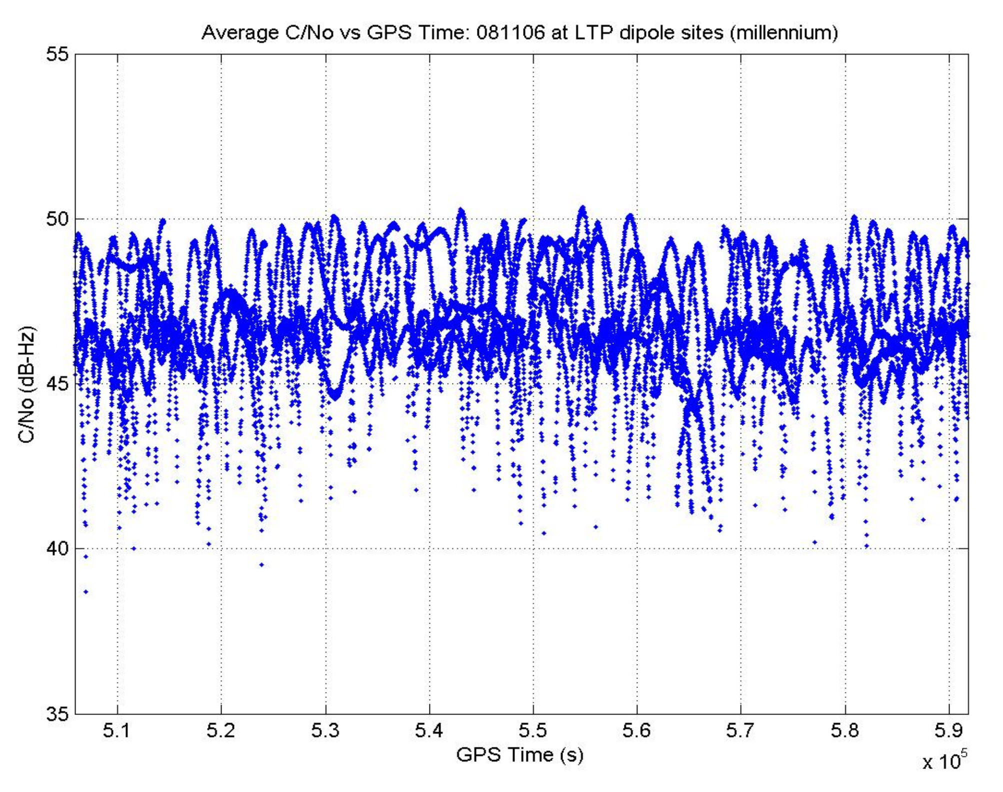
9.2.6.5 August System Dipole CMC versus Time



9.2.6.6 August System Dipole Carrier to Noise versus Elevation

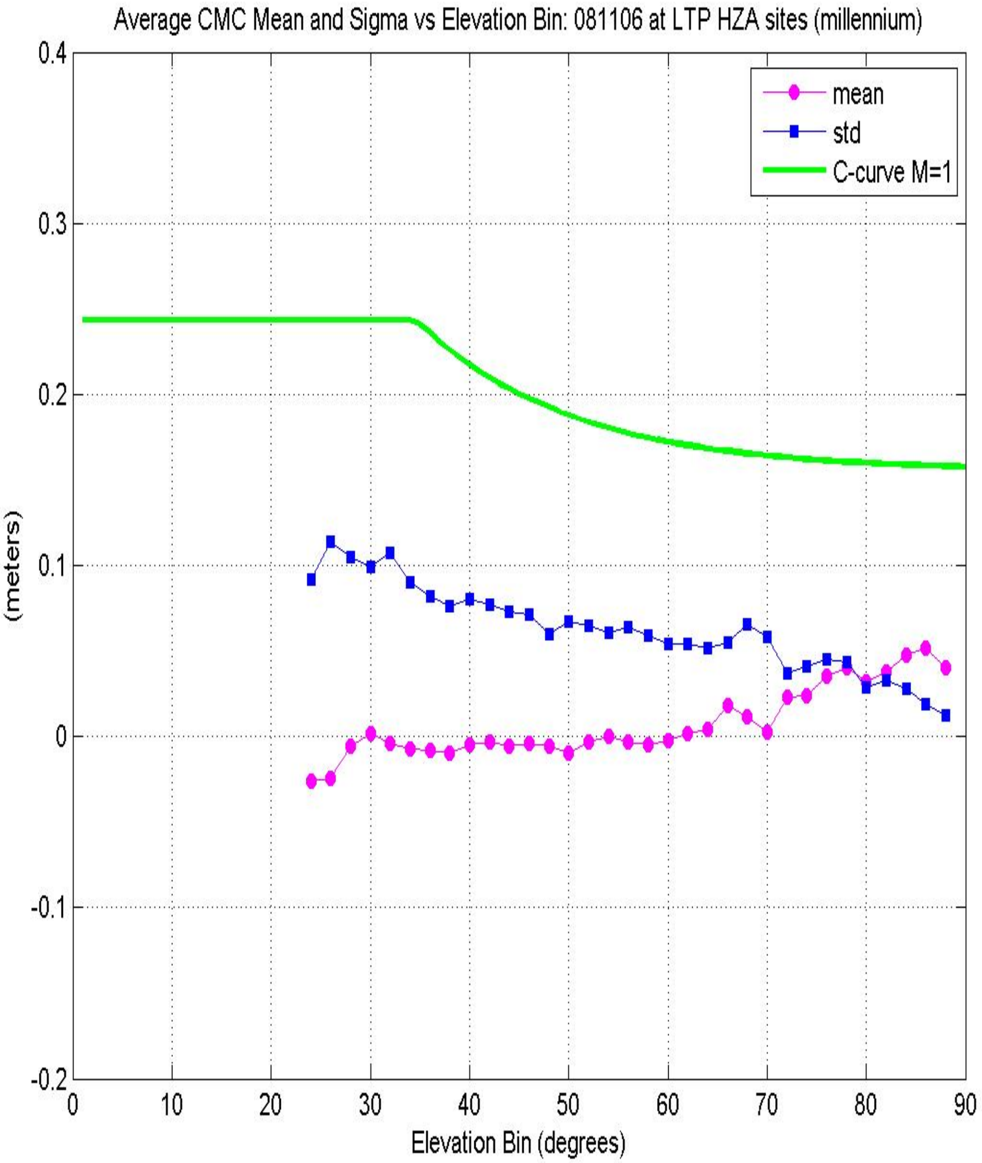


9.2.6.7 August System Dipole Carrier to Noise versus Time

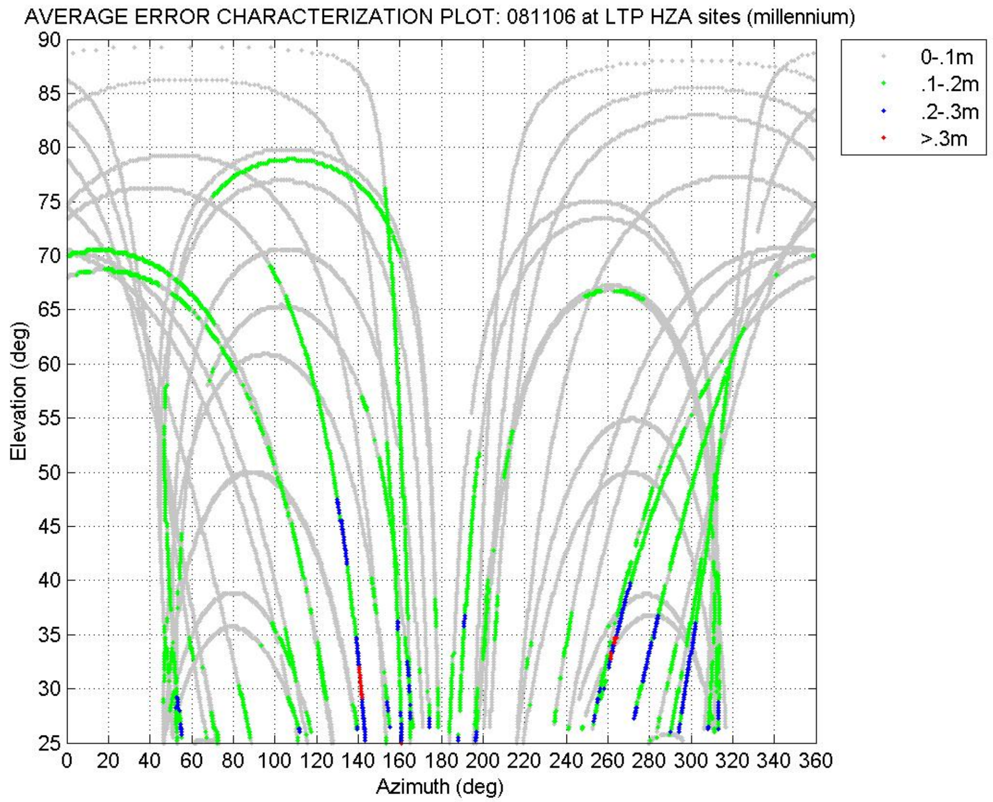


9.2.7 August HZA Status and CMC (System Average) (multiple)

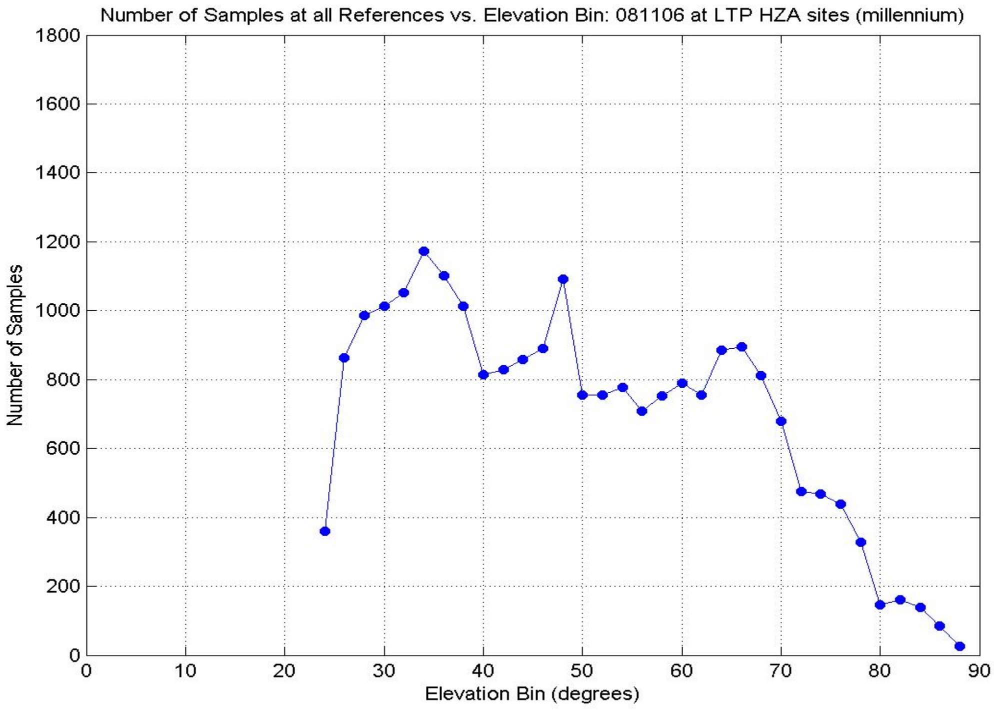
9.2.7.1 August System HZA CMC Standard Deviation and Mean vs Elevation



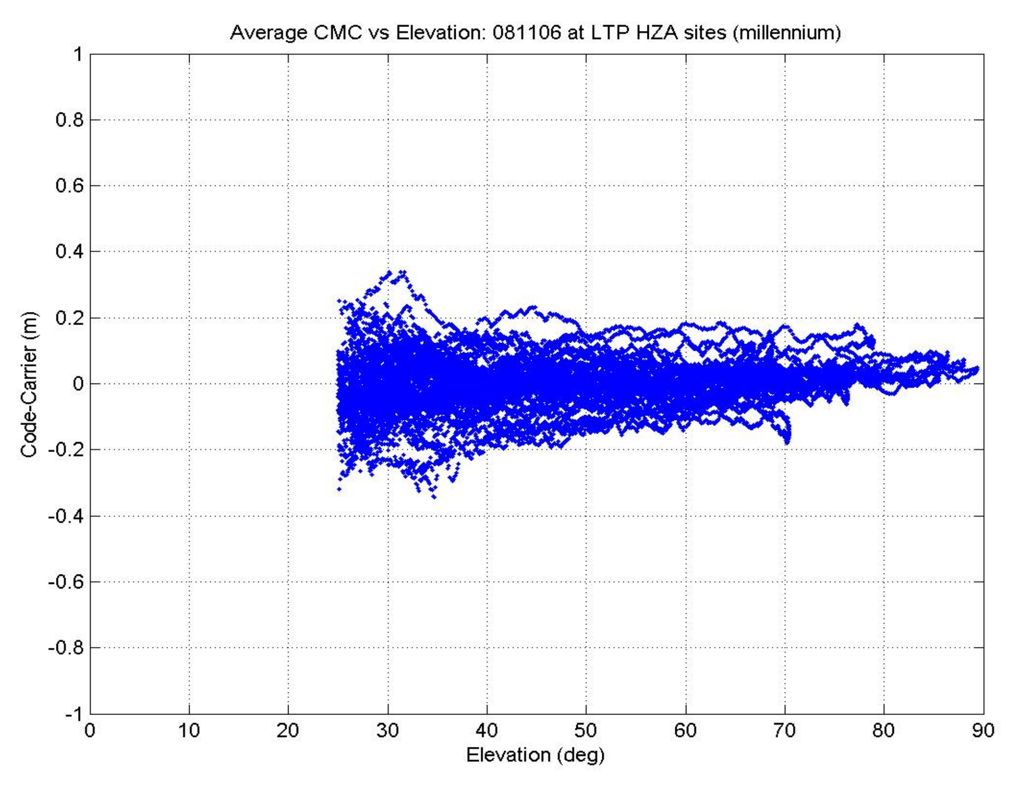
9.2.7.2 August System HZA Error Characterization vs Azimuth and Elevation



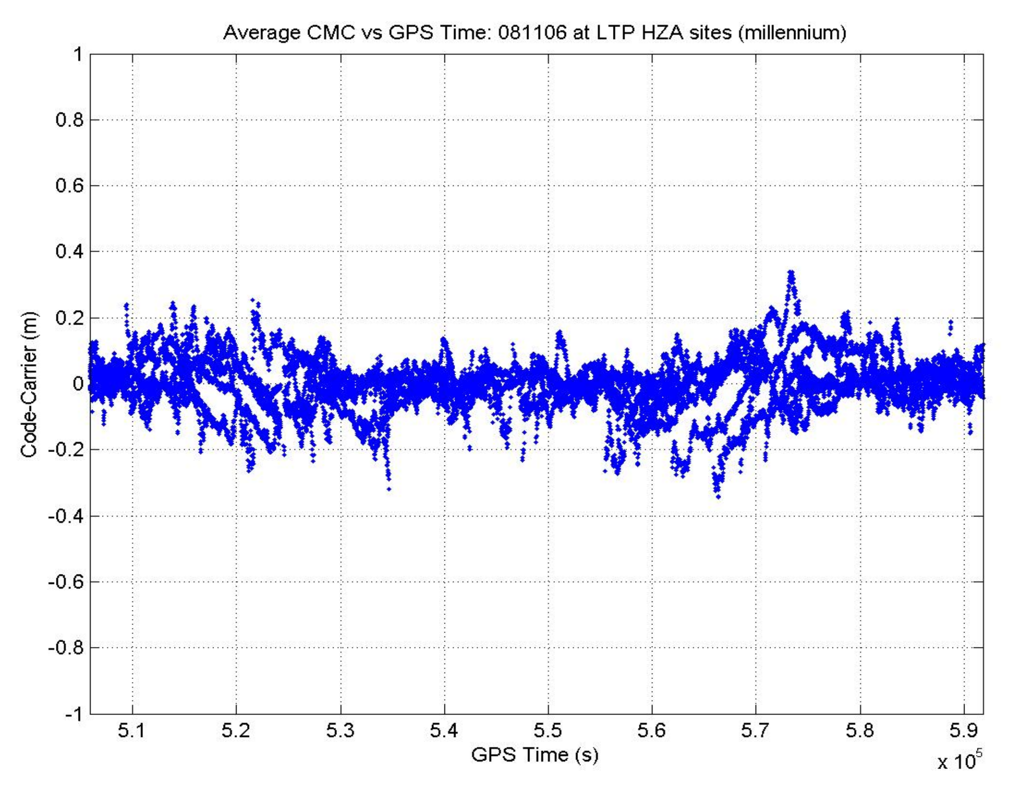
9.2.7.3 August System HZA Number of Samples versus Elevation



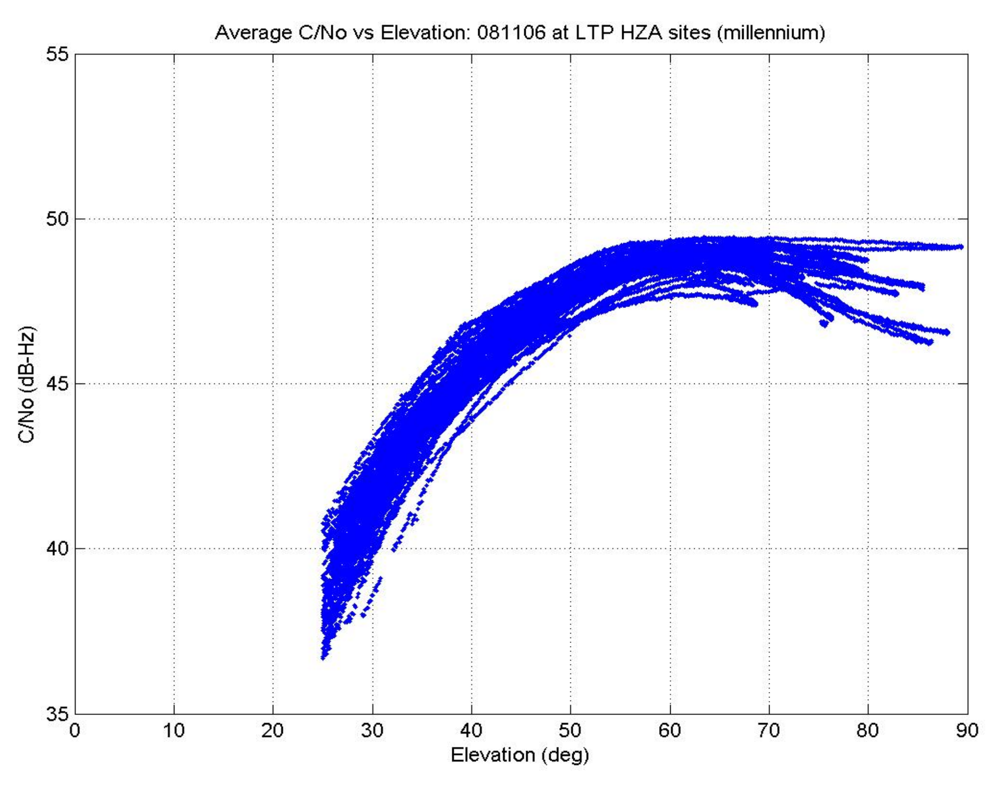
9.2.7.4 August System HZA CMC versus Elevation



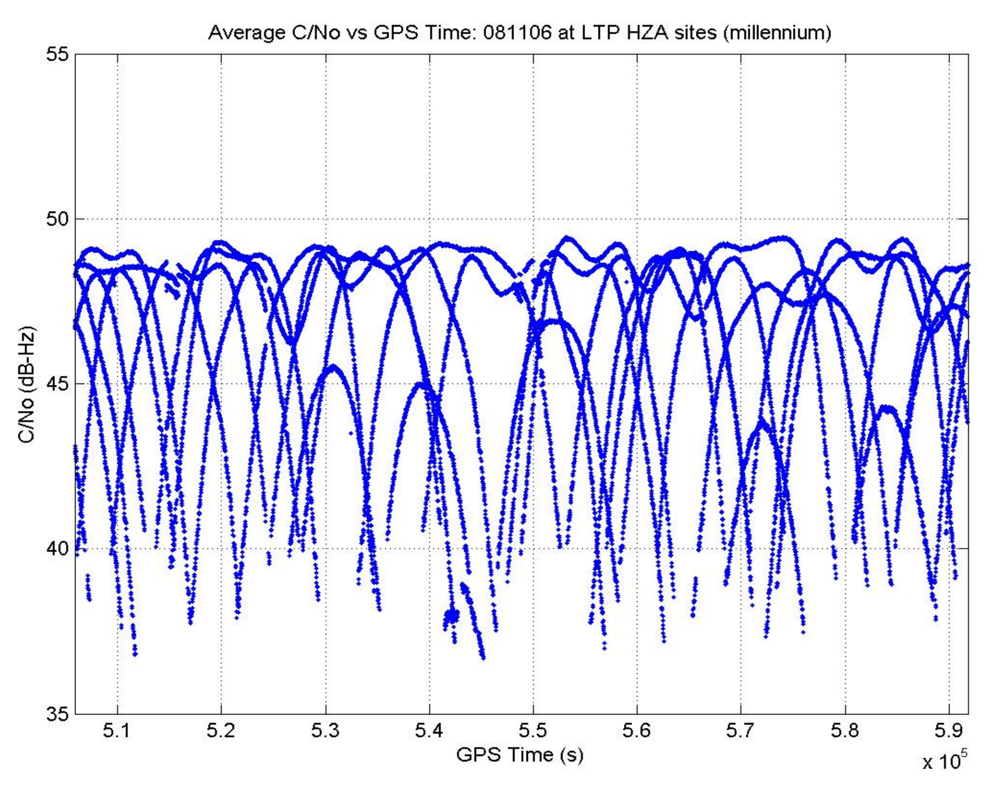
9.2.7.5 August System HZA CMC versus Time



9.2.7.6 August System HZA Carrier to Noise versus Elevation

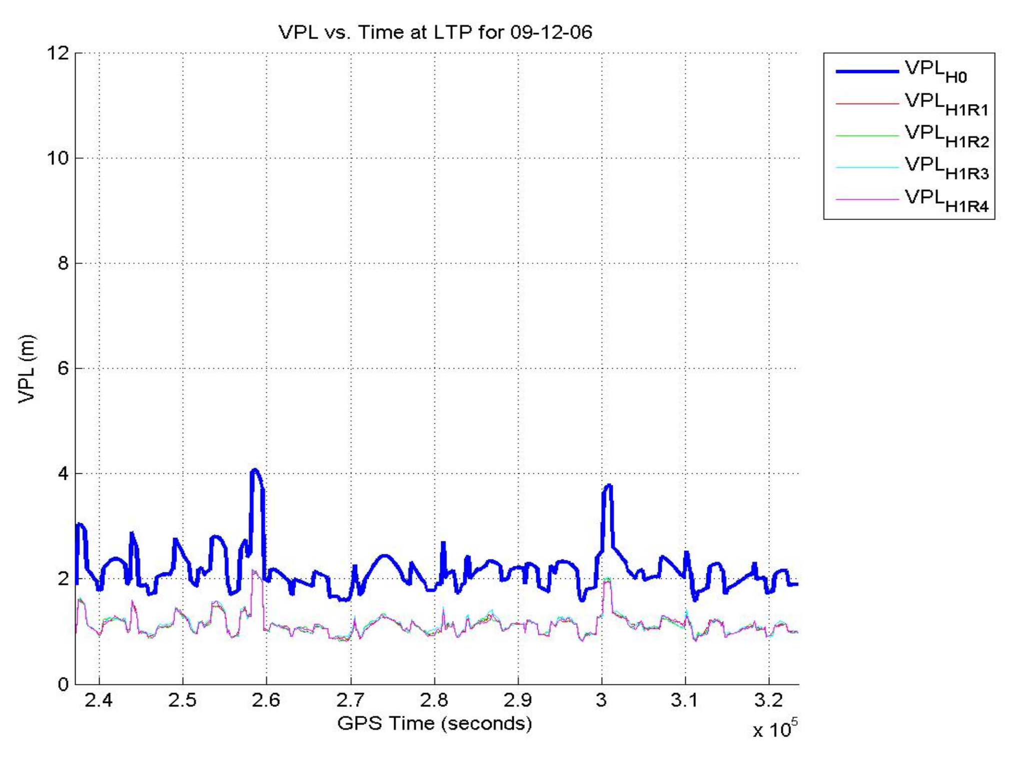


9.2.7.7 August System HZA Carrier to Noise versus Time

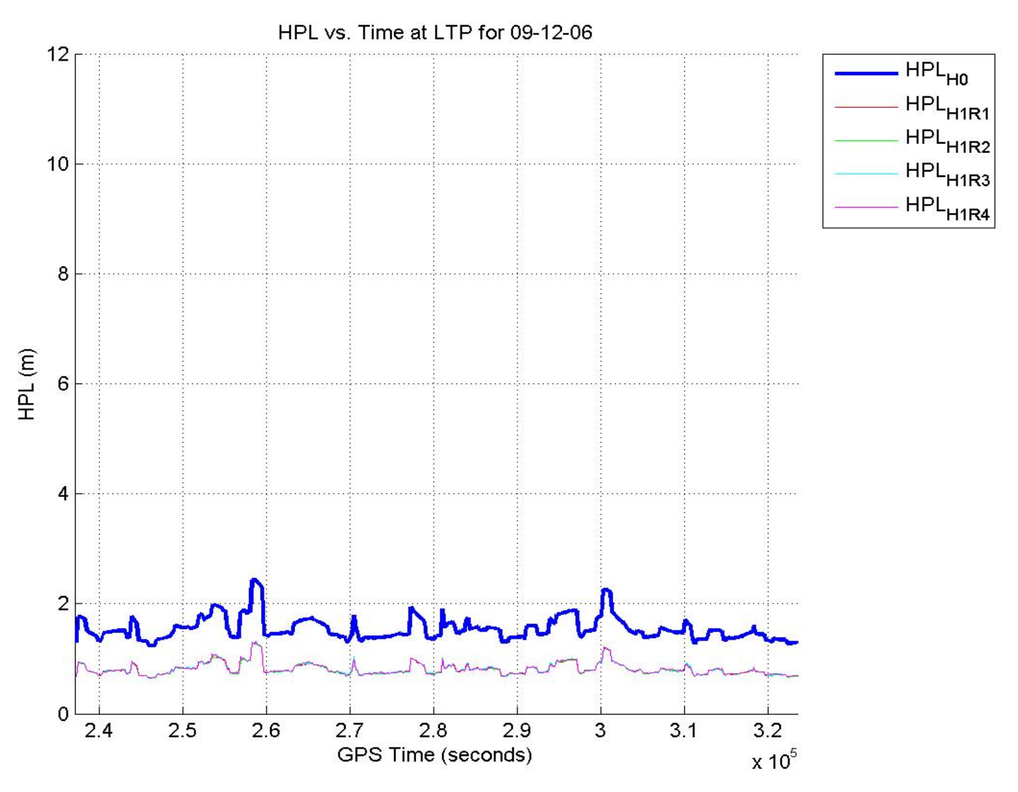


9.3 September 2006 Performance Plots

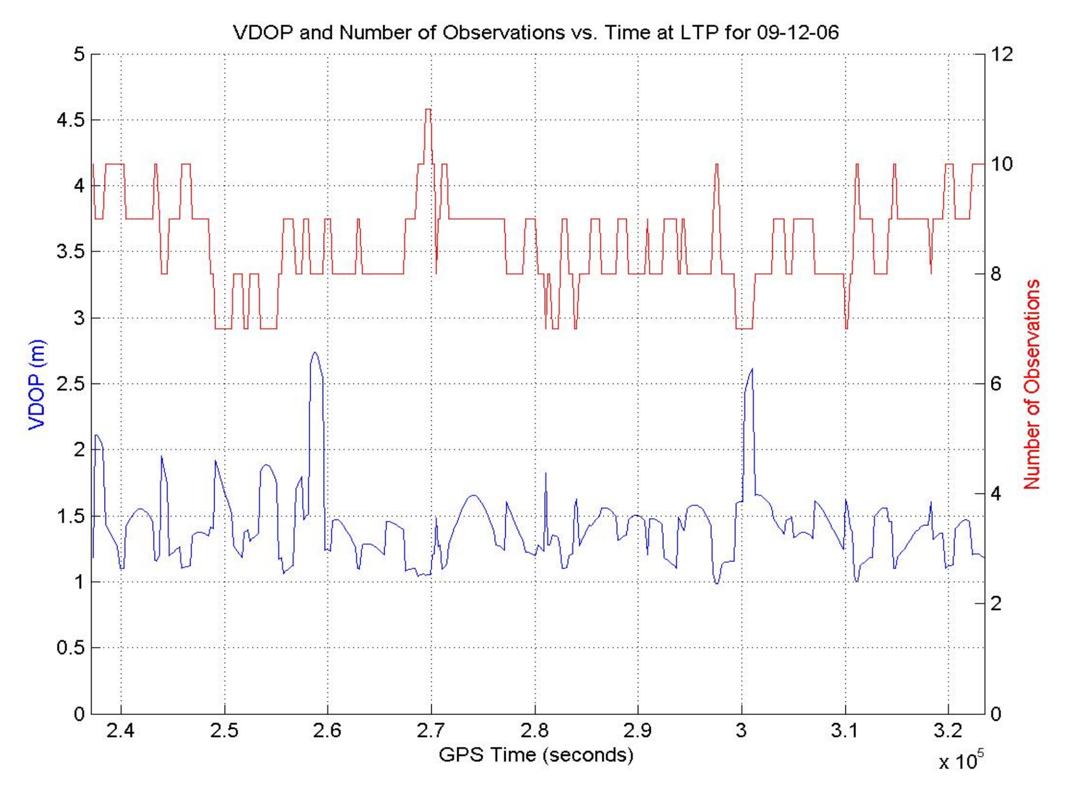
9.3.1 September VPL versus Time



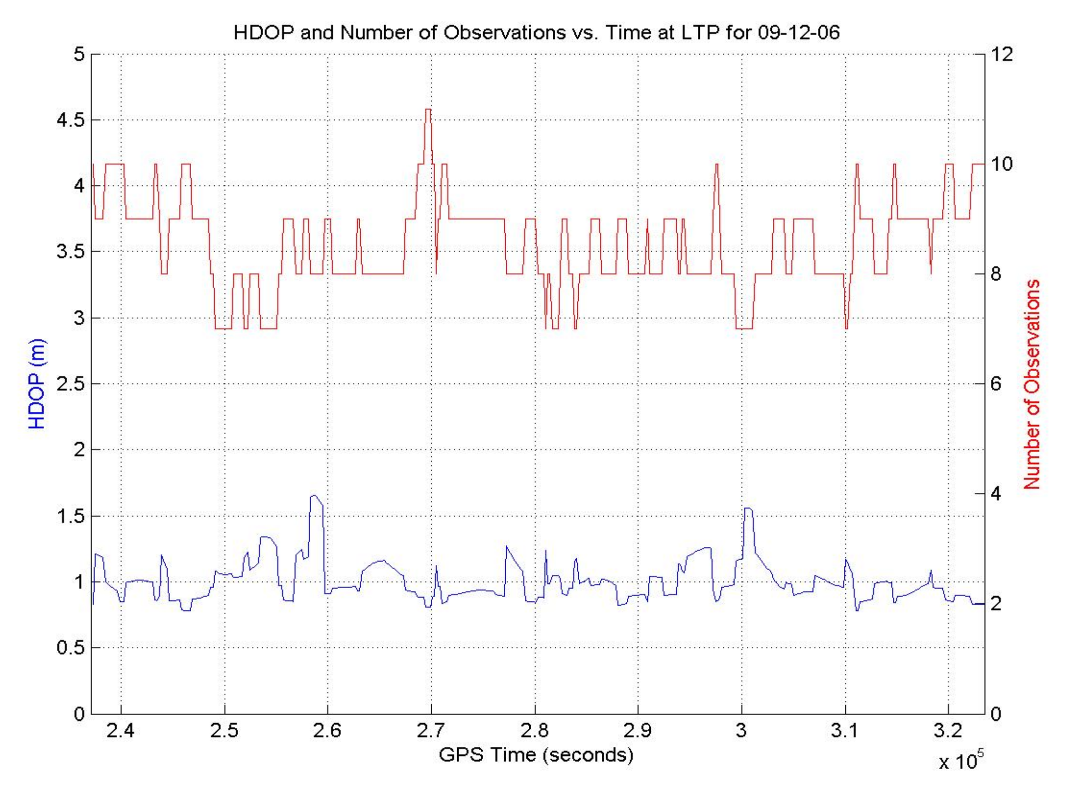
9.3.2 September HPL versus Time



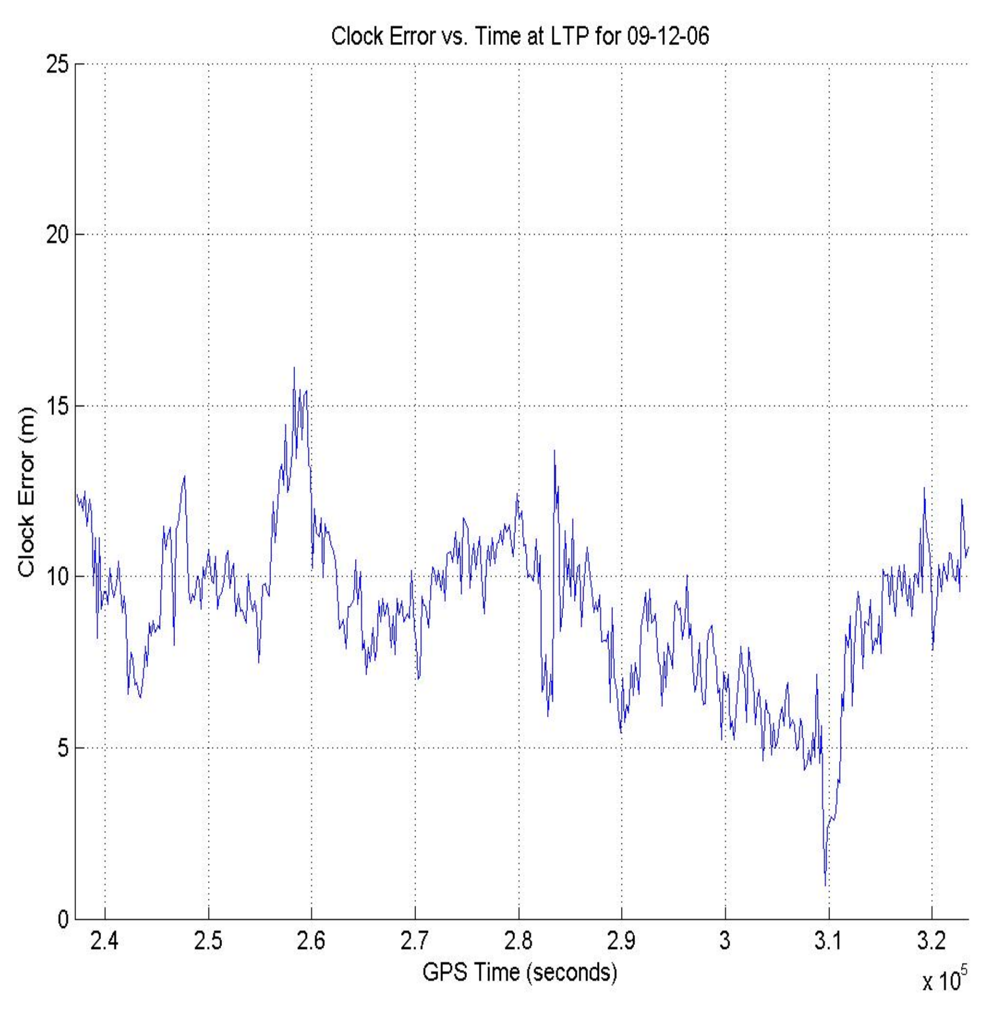
9.3.3 September VDOP and # of SV Observations versus Time



9.3.4 September HDOP and # of SV Observations versus Time

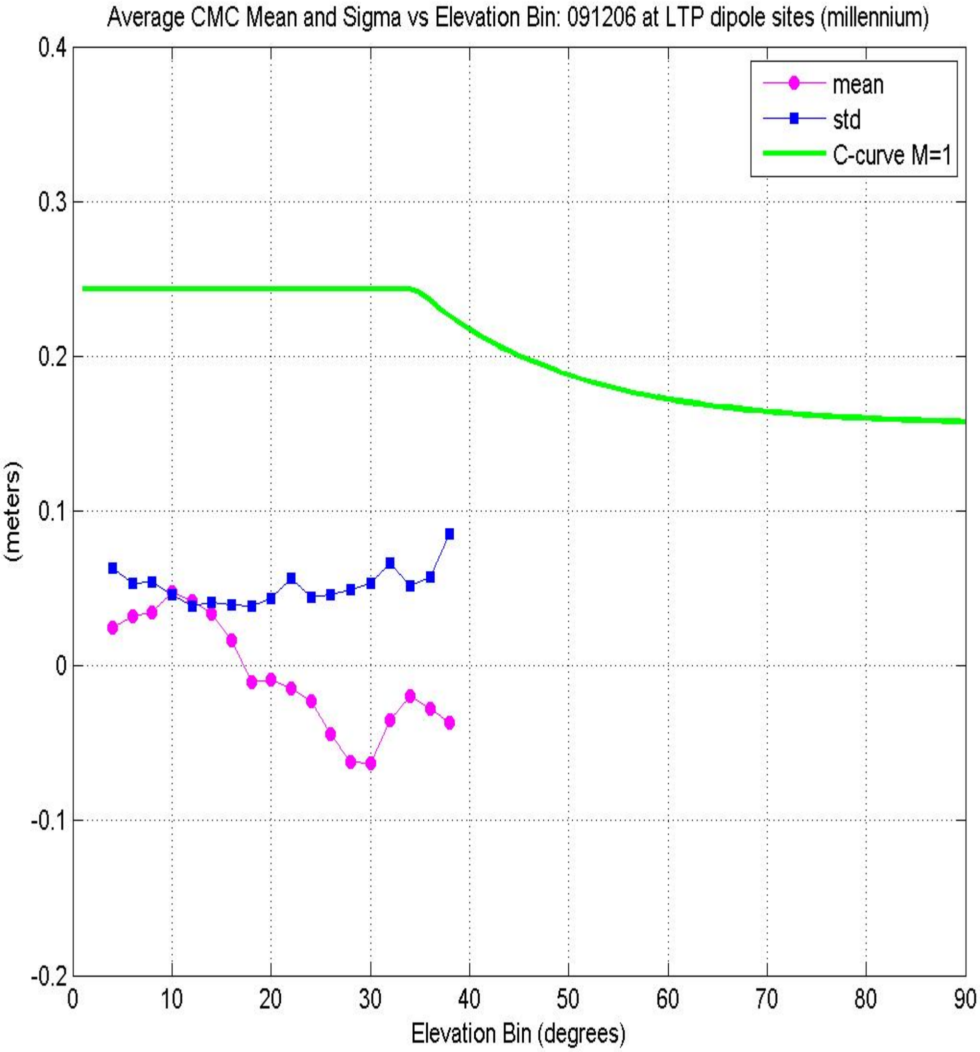


9.3.5 September Clock Error versus Time

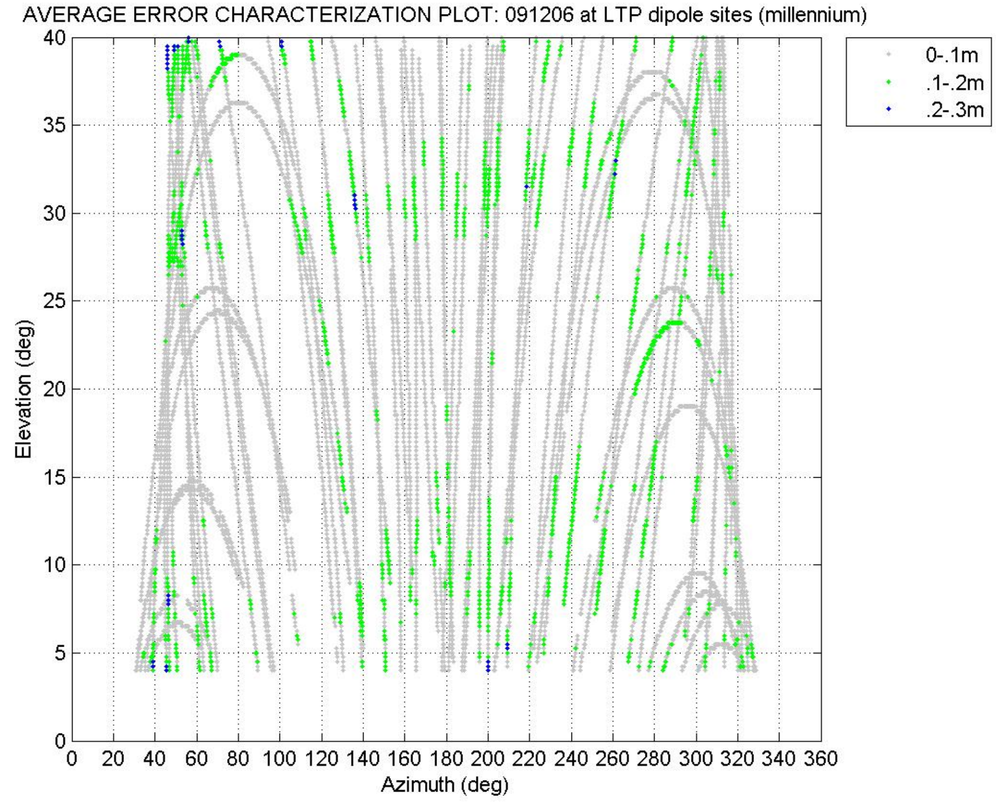


9.3.6 September Dipole Status and CMC (System Average) (multiple)

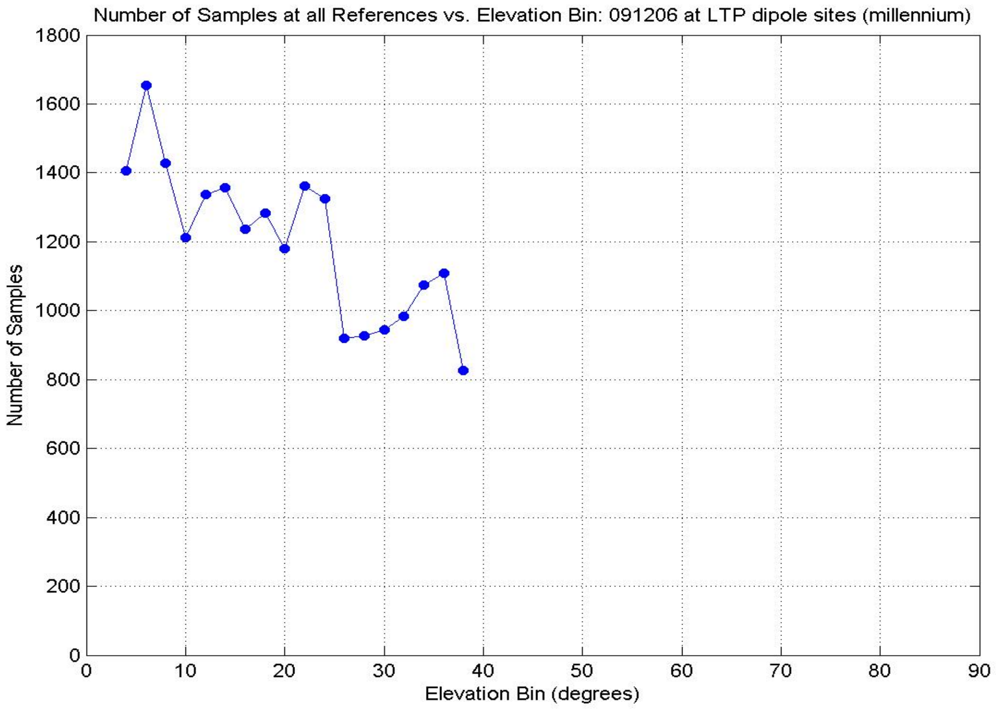
9.3.6.1 September System Dipole CMC Standard Deviation and Mean vs Elevation



9.3.6.2 Dipole Error Characterization versus Azimuth and Elevation



9.3.6.3 September System Dipole Number of Samples versus Elevation



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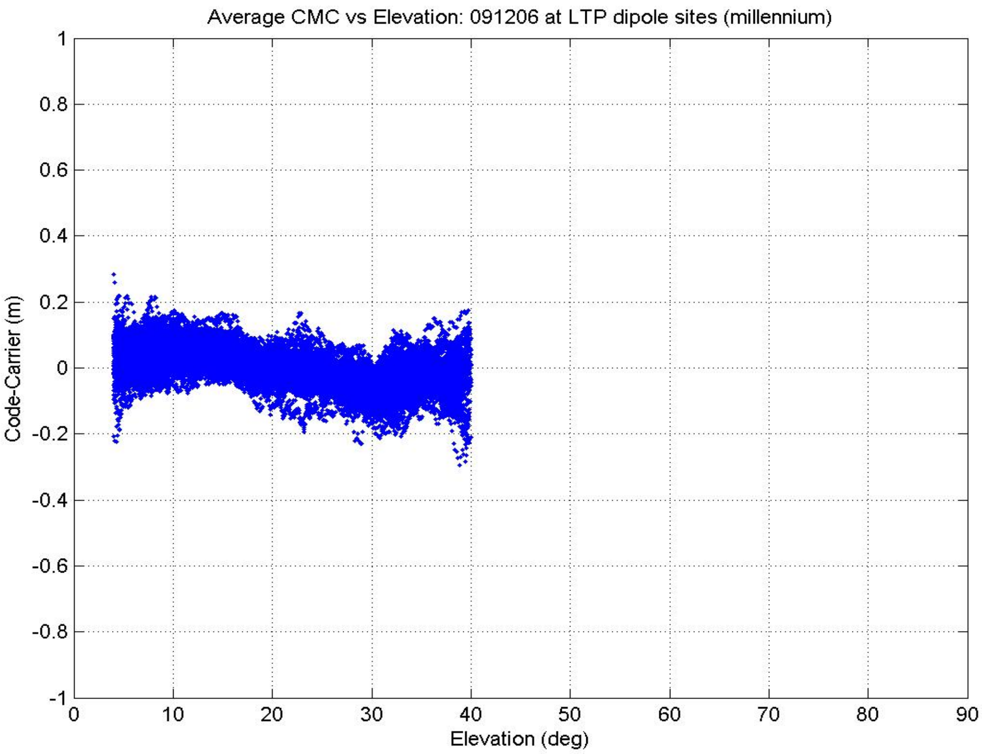

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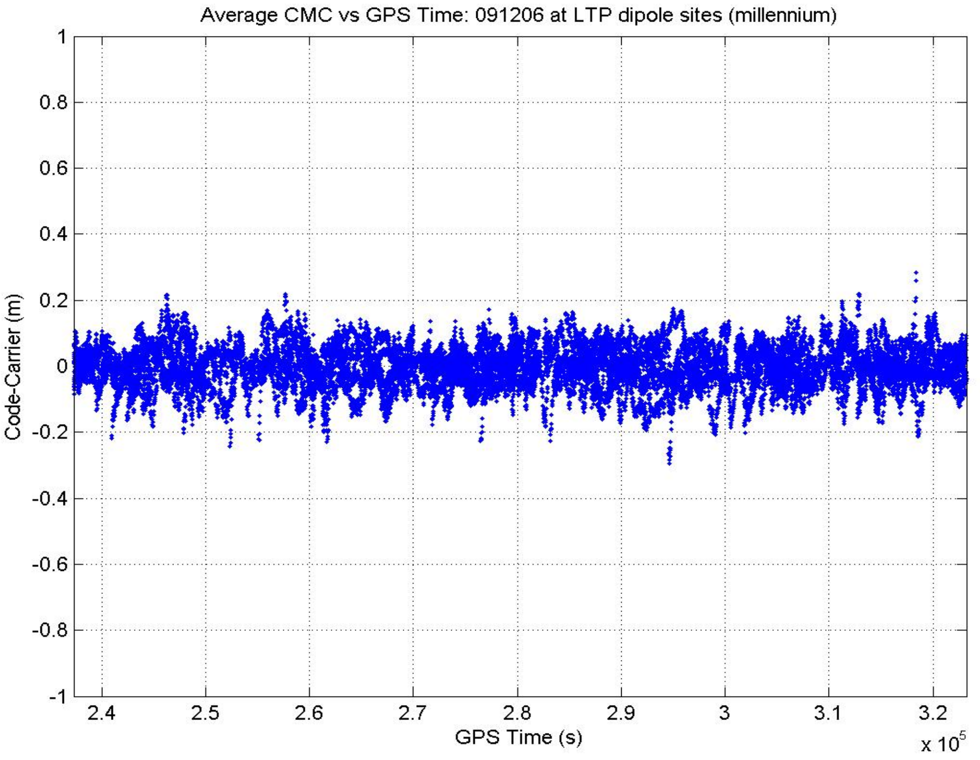
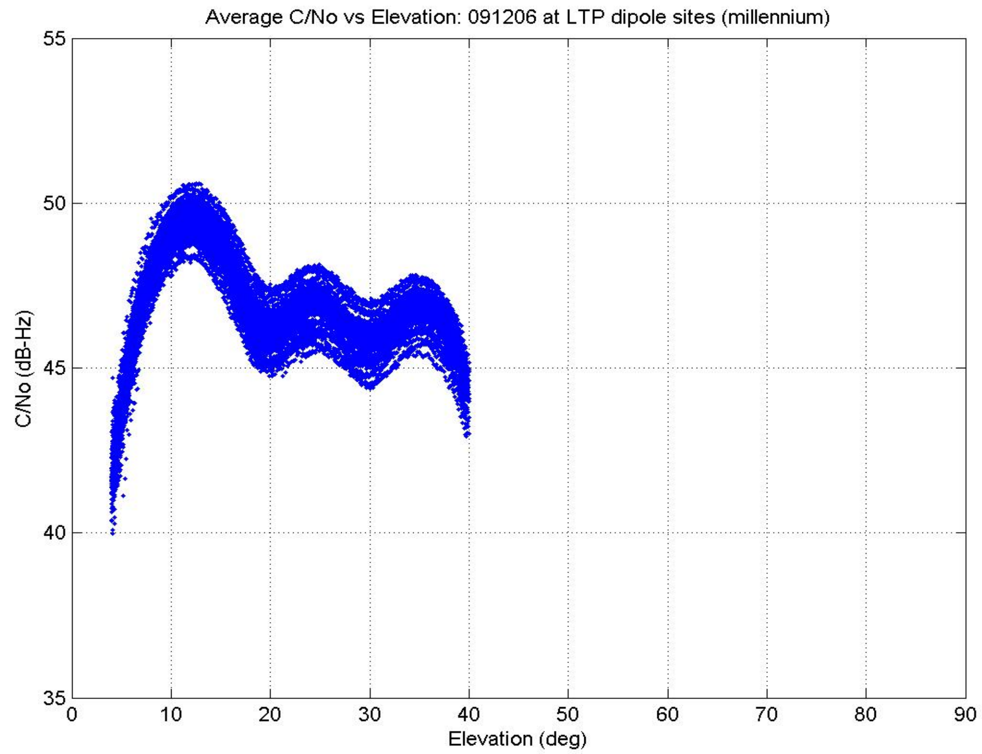
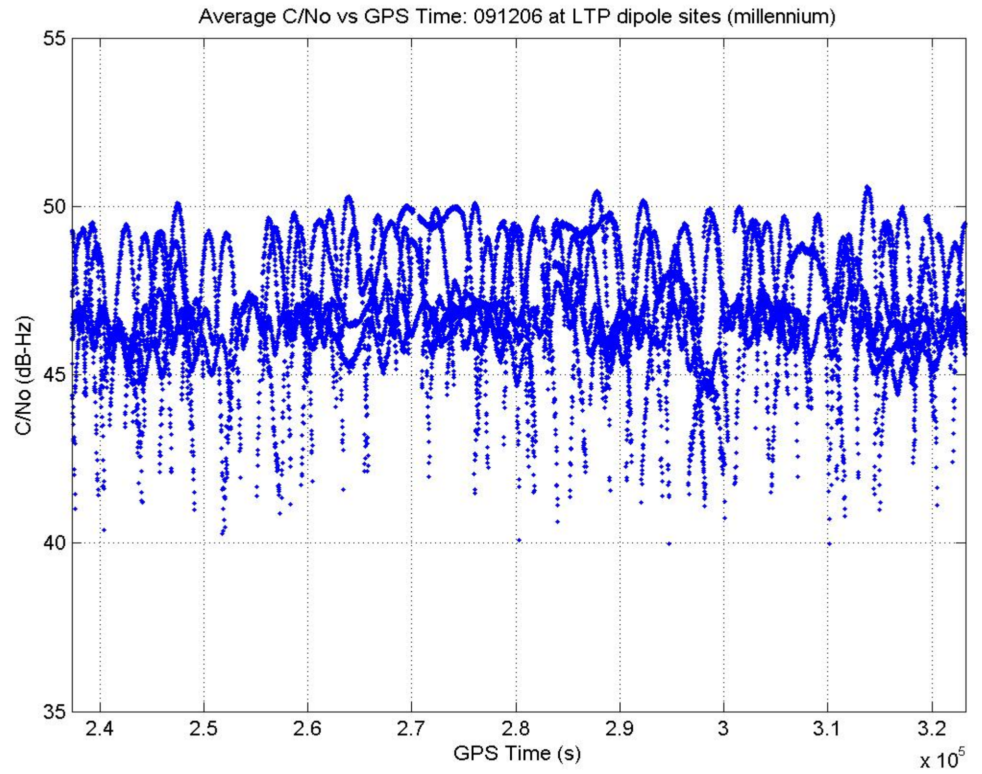


9.3.6.6 September System Dipole Carrier to Noise versus Elevation

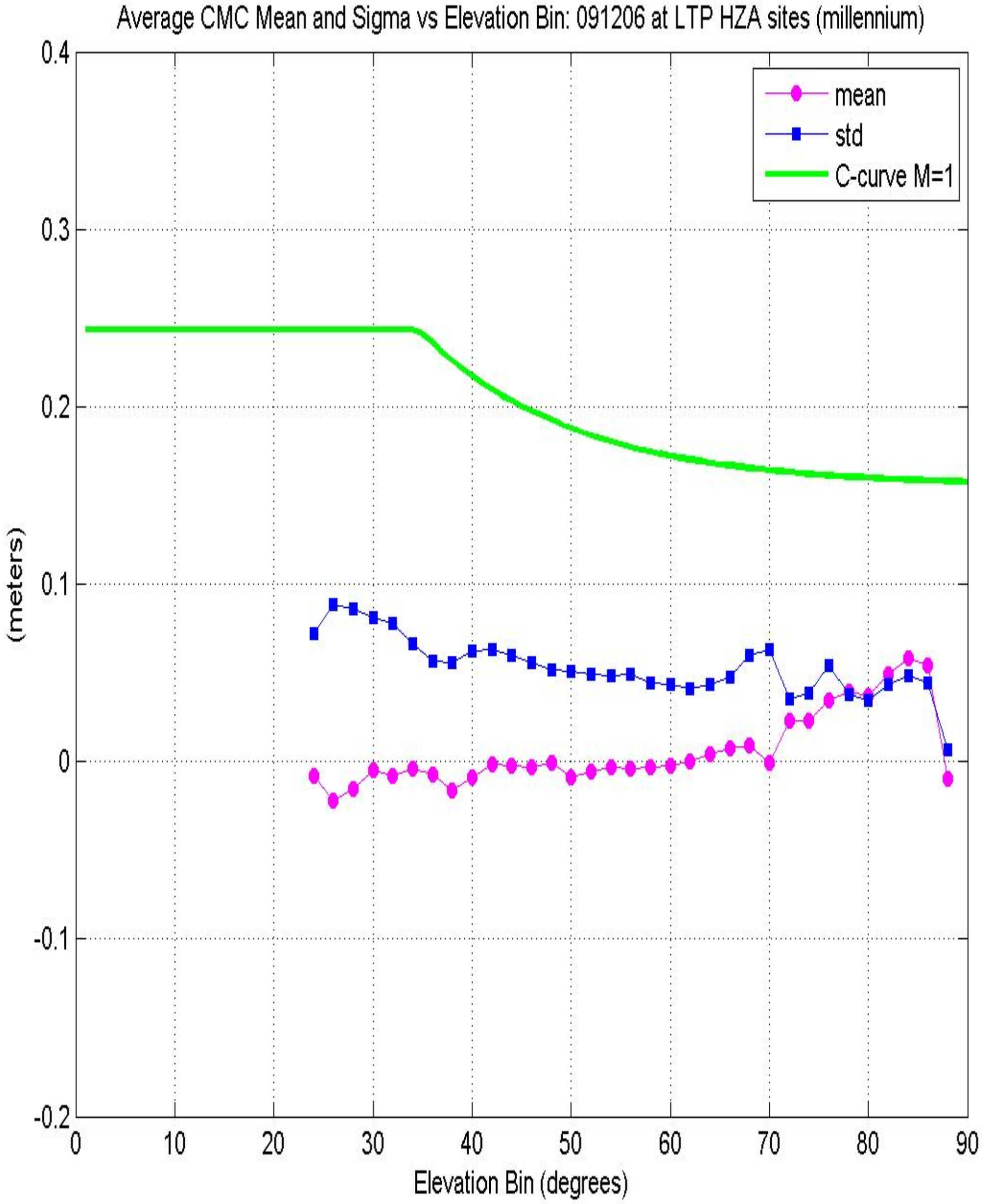


9.3.6.7 September System Dipole Carrier to Noise versus Time

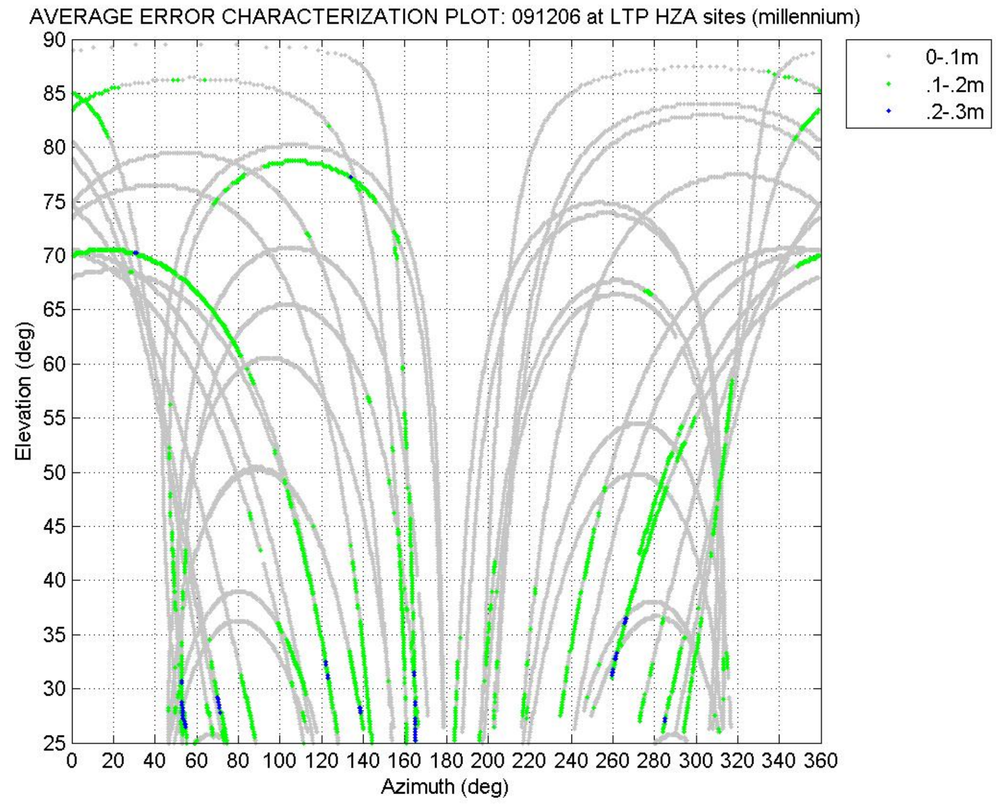


9.3.7 September HZA Status and CMC (System Average) (multiple)

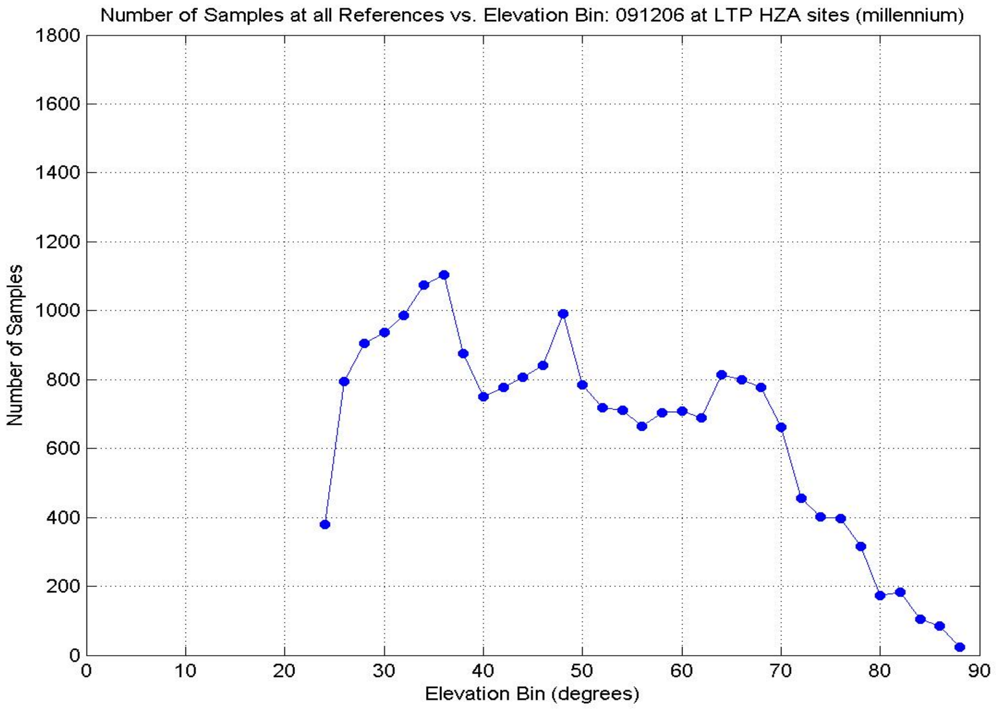
9.3.7.1 September System HZA CMC Standard Deviation and Mean vs Elevation



9.3.7.2 September System HZA Error Characterization vs Azimuth and Elevation



9.3.7.3 September System HZA Number of Samples versus Elevation



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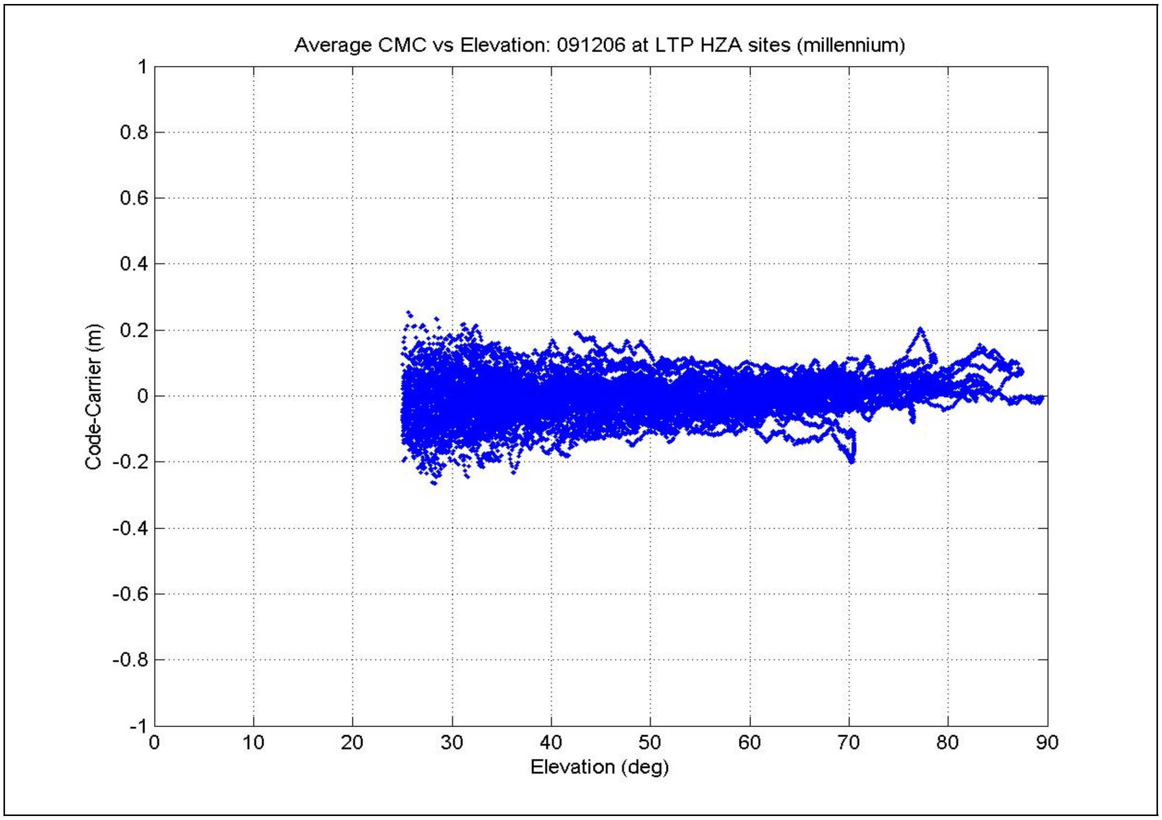

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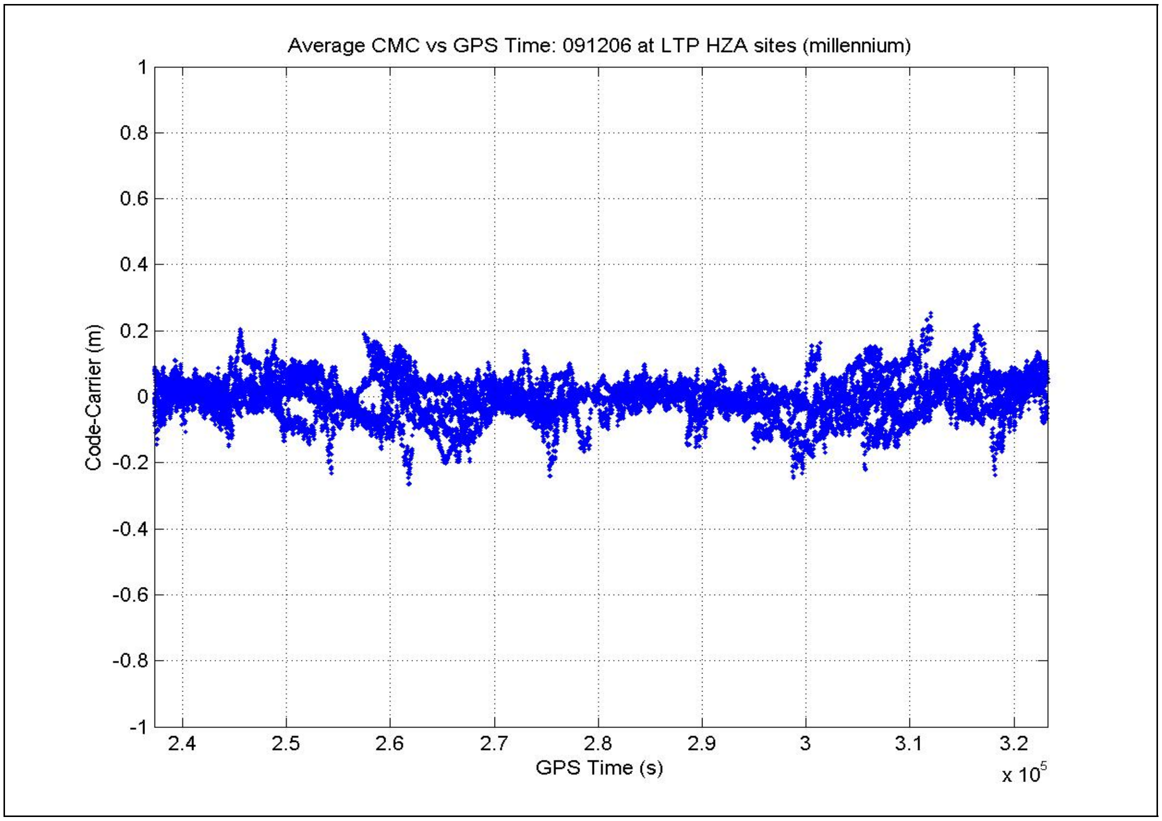
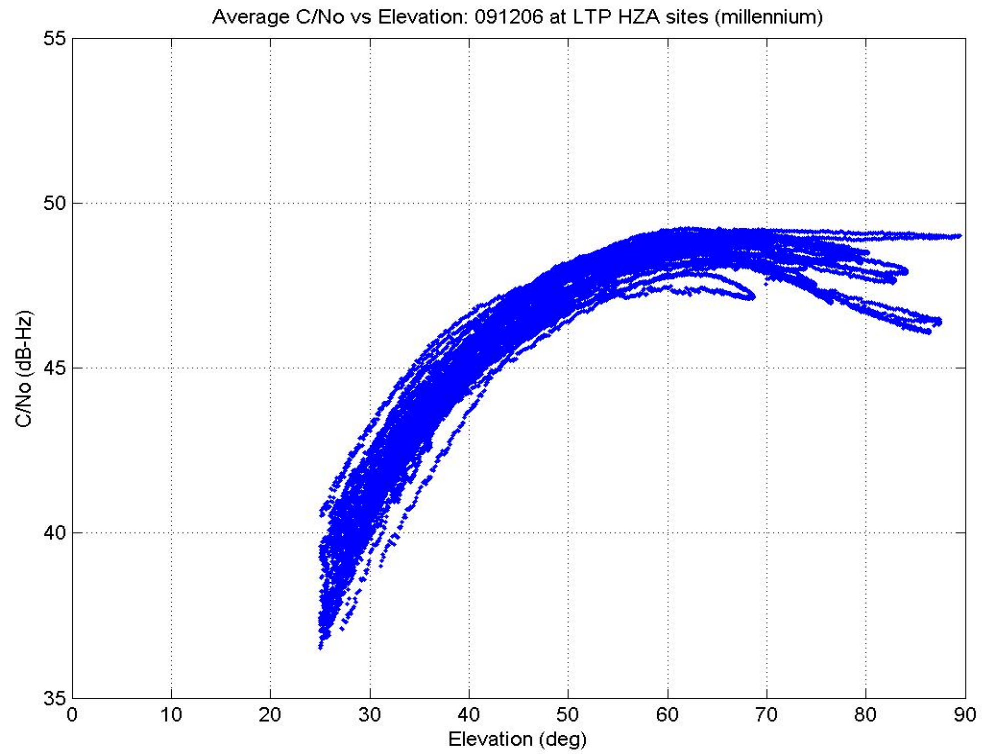
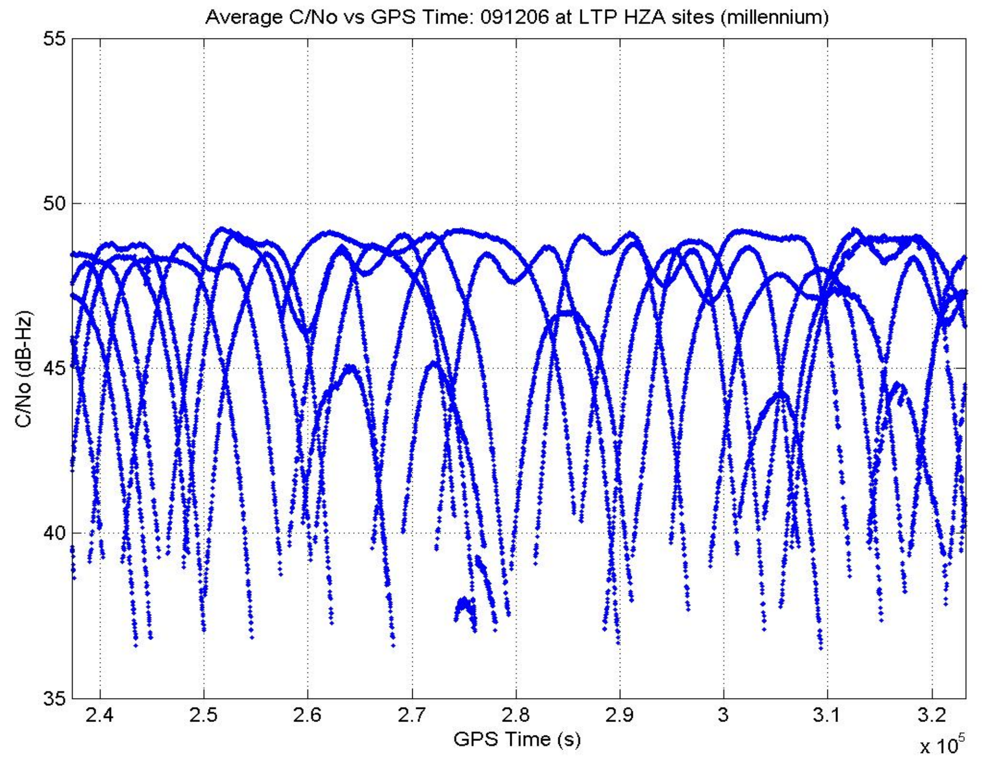


9.3.7.6 September System HZA Carrier to Noise versus Elevation



9.3.7.7 September System HZA Carrier to Noise versus Time



10 Research, Development, and Testing Activities

The LAAS T&E team is responsible for directing and supporting LAAS related R&D engineering activities. This team also is engaged in verifying the performance of experimental LAAS hardware and software configurations. Any changes in configuration, or degradations in performance, are captured and rigorously analyzed. This section outlines LAAS engineering and testing activities for the reporting period, and are presented in chronological order whenever possible.

10.1 The GPS Anomalous Event Monitor (GAEM) – Memphis Deployment

10.1.1 Background and GAEM Overview

Performance and integrity monitoring systems have been developed and deployed to verify the effectiveness of the Memphis Honeywell PSP LAAS system upgrades as the system approaches "provably safe integrity prototype" (PSP) system status. One of these systems is referred to as the GPS Anomalous Event Monitor (**GAEM**). Ohio University's Avionics Engineering Center (AEC) developed the GAEM concept, and the original prototype system. The AEC and FAA have been collaborating over the past year to develop the latest version of the GAEM for the FAA's use in Memphis. **Figure 8** is a rudimentary block diagram of the functional units in the GAEM system.

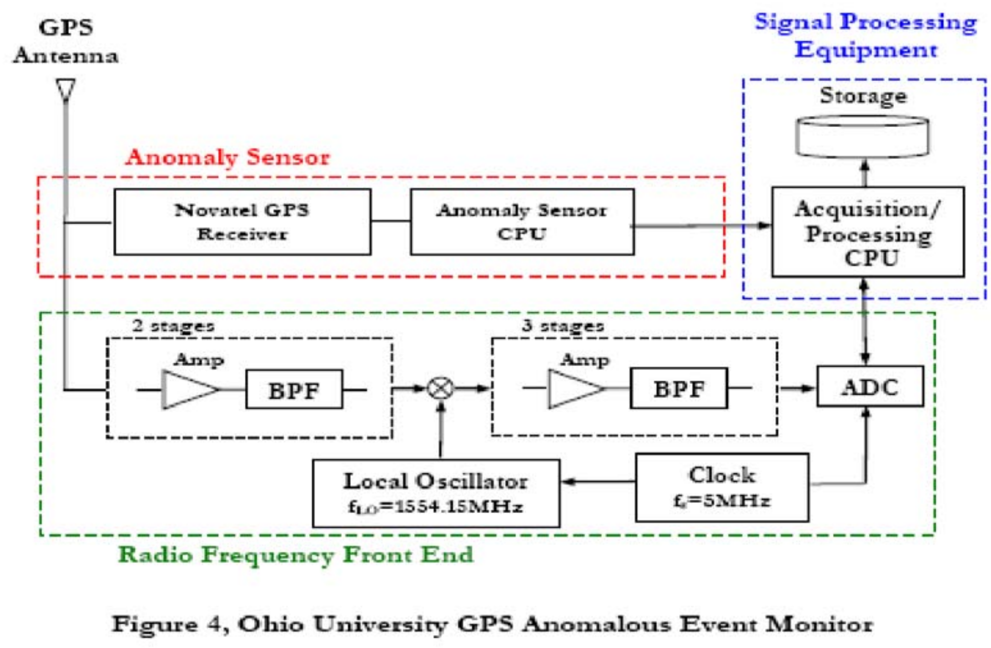


Figure 8: GAEM Block Diagram

The GAEM system, although complex, is basically a stand-alone GPS RF spectrum performance monitor with enhanced GPS Signal Quality Monitoring (SQM) capabilities.

When a signal anomaly is detected the entire GPS spectrum, which is continuously being digitized in RAM, is archive recorded for a ten second duration surrounding the event (5 seconds on each side). This digitized spectrum data can be used to further study the anomaly at a later time. The data can also be used verify the operation of, recently implemented, integrity monitors for the Honeywell LAAS system in Memphis. These integrity monitors (also referred to as Algorithm Description Document or ADD) that are active, require an independent method of verification. Verification will involve a comparison of Honeywell system integrity alerts versus GAEM events. This comparison will allow the FAA to judge if the Honeywell system is integrity alarming when it should, and/or should not.

10.1.2 Memphis GAEM Installation Details

A subset of the LAAS T&E team traveled to Memphis from 07/18/06 to 07/21/06 to install, and begin operation of the OU/FAA developed GAEM system. Shipment of the required system equipment and supplies precede the team's arrival and was staged by FedEx who is hosting the FAA's monitoring systems at their Hangar 12.

The GAEM system, as an anomaly detector, is best configured with a Multipath Limiting Antenna (MLA) that can be sited in a GPS friendly reception environment. Hangar 12's roof provided the friendly environment, and BAE's ARL-1900 acted as the chosen MLA. The FAA had previously installed the mounting hardware required to support such an antenna, and was able to swap the ARL-1900 for the originally installed Novatel Choke-Ring that populated the mount, and serviced the Ground Based Performance Monitor (GPBM). The BAE was chosen due to its single feed design, L1/L2 capability, as well as its MLA characteristics.

Immediately following the BAE's physical installation a precision differential survey was performed using MEM's Primary Airport Control (PAC) point. **Figure 9** shows the field survey equipment setup on the PAC monument, and **Figure 10** shows the BAE antenna on the roof of Hangar 12. A precision survey position for the antenna is required for the GBPM's reference (or known) position for comparison to the calculated position solution derived from the PSP's correction information. The BAE antenna, with its steady survey position, and L1/L2 capability, can also be utilized for Time Space Position Information (TSPI) data for tracking project aircraft during flight-testing.

The GAEM system was meanwhile hoisted into position on Hangar 12's catwalk, and secured next to the GBPM. Existing and newly introduced networking equipment was configured, and immediately tested for communication and GAEM system operability from the FAA Tech Center. The GPS signal input level was then carefully adjusted to obtain adequate tracking strength, and also to allow for interference events that could exceed normal GPS signal levels. This signal headroom is required to permit interference signals to be properly replicated for recording without deforming or saturating the shape of the original waveform.

Figure 9: Survey on MEM PAC

Figure 10: BAE on Hangar 12

10.2 Brazilian Expedition - LTP Support, TAP testing, and Personnel Training

10.2.1 Background and Project Brazil Overview

The FAA LAAS program office and DECEA (Brazil Department of Air Space Control) of Brazil entered into a "Memorandum of Cooperation" (NAT-I-0801) agreement during 2003. The FAA was interested in pursuing an agreement with the Brazilians to fulfill an international leadership goal, and for the opportunity to gather raw data and perform LAAS test operations in a worst-case ionosphere environment. Areas near the Equator are most effect by dynamic variations in the ionosphere often referred to as "bubbles".

The agreement is broad in scope and involved the training of DECEA personnel of LAAS concepts and operations and ionosphere error mitigation concepts. This training was done at the FAA Technical Center in the late summer of 2003 using the actual LAAS Test Prototype (LTP) system intended for deployment in Rio de Janeiro. This LTP #2 had been developed and tested by the FAATC LAAS team the previous year. Immediately following the Brazilian visit the FAA disassembled, and packed the system for shipment, which was handled by the Brazilian air force.

John Warburton and Carmen Tedeschi of the LAAS T&E team traveled to Rio in the fall of 2003 to perform the LTP #2 installation with the Brazilians. The ten-day endeavor included the LTP installation, local software and networking configuration, airborne systems installation on DECEA's Hawker 800, and preliminary flight testing for performance verification, and adjacent airport coverage. DECEA then took possession of the systems with the FAA's pledge for continued support.

Additional expeditions to Rio by the FAA for both technical and coordination purposes have been conducted over the past three years to fulfill the support commitment. A sizable technical mission was conducted in the fall of 2004 to site and install five independent L1/L2 IONO stations in the area immediately surrounding Rio International where Brazil's LTP is resident. These stations formed an approximate 20-mile ring around their LTP, and are being used to study the ionosphere with painstaking detail.

10.2.2 Brazilian Work Details

FAA and L3-Titan personnel traveled to Rio De Janeiro Brazil the last two weeks of August 2006 to update the Brazilian LTP #2, and to fly LAAS TAP experimental approaches for the first time in the southern hemisphere. The mission also entailed an updated precision survey of the LTP's reference receiver antennas (RRAs), and training the DECEA LTP personnel with the latest techniques for airborne data processing.

An updated precision survey was required to minimize key value inflations, which were apparent when observing the dynamic B-Values on the LTP's master CPU display. The likely cause was the technique utilized for the original survey conducted in 2003. This was a known compromise due to a equipment failure when the FAA was present in Rio. The original survey, although accurate, was not as exact as obtainable. To remedy this situation, without disturbing the IMLA antennas, a previously unutilized technique using the IMLA antenna's HZA as the L1/L2 survey sensor was tested and verified for accuracy at the FAA Technical Center in preparation for the deployment. The HZA's survey accuracy and repeatability was verified as acceptable, and specialized survey kits were prepared for the re-survey mission. The re-survey mission at Rio International also tied in a nearby runway threshold (runway 33 **– Figure 11**) to act as a representative checkpoint for the accuracy of the final survey network adjustment. The primary Rio International Airport Reference Point (ARP **– Figure 12**) was used as the control station. The survey numbers generated from the survey were then plugged into the LTP's CPU program, and subsequently reduced the B-Values to CONUS typical levels.

Figure 11: Threshold 33 Survey - Rio

Figure 12: Rio Intl. ARP Control

The Brazilians have long had a strong interest in completing LAAS complex, or TAP, approaches. LAAS enabled TAP curved approaches are most beneficial at busy airports, or at airports that have challenging terrain and other obstacles in the local area. Santos Dumont International (SBRJ) in downtown Rio is a prime example of an airport that can benefit from LAAS's TAP capabilities. The two parallel northward heading runways at Santos have a significant terrain obstruction (Sugar Loaf Mountain) directly to the south at a distance of approximately 2 miles. The proximity, position, and height of Sugar Loaf Mountain makes traditional approaches from the south (and departures from the north) dangerous in fair weather, and treacherous in poor weather.

Figure 13: View of Sugar Loaf Mountain from SBRJ

Figure 13 is a view of Sugar Loaf Mountain from a building directly on the edge of Santos' primary tarmac. The FAA/DECEA team collaborated to create a curved approach to avoid the mountain with a shorter than average final approach segment. The FAA/DECEA team made the required updates the DECEA's Hawker flight inspection craft, and to the LTP's CPU program to uplink the new procedure with corrections. This textbook case specialized TAP approach was attempted for the first time during this visit, with an updated version being evaluated by DECEA for testing during our next visit. **Figure 14** is an approach plate depiction of the original procedure as designed by the Brazilians. The mountain's location is not depicted here, but would be present in the lower right hand corner of the graph. There are currently three preliminarily flight-tested TAP approaches broadcast in the Brazilian LTP station available for use.

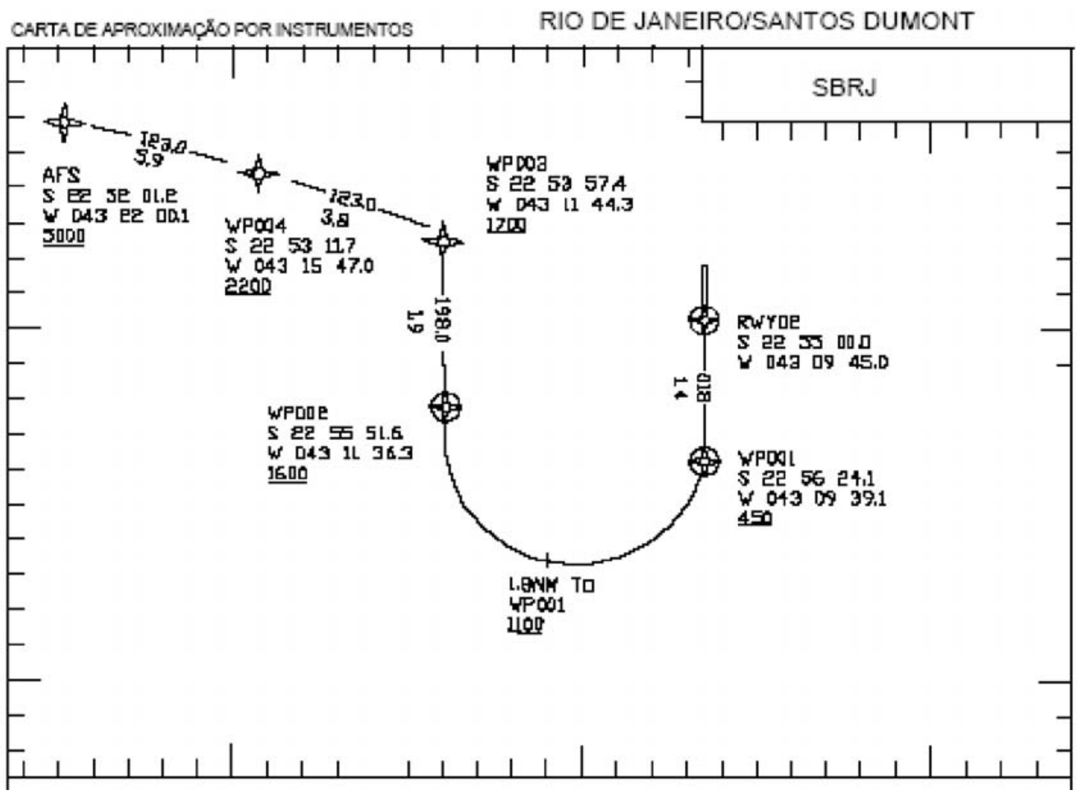


Figure 14: Experimental TAP Approach Plate - RWY 02R SBRJ

Training for the DECEA personnel included detailed hands-on instructional units for updated processing software packages for both the airborne LAAS/MMR position data, and TSPI (Time Space Positional Information) truth positioning data. These custom instructionals were created and conducted by Ruben Velez of the FAA, and Chad Kemp of L3-Titan.

The TSPI processing package is a commercially available program made by WayPoint Consulting and is titled GrafNav. The FAA has utilized and proven this English-only program's effectiveness for multiple projects, so a detailed instructional for the primarily Portuguese speaking audience was decided necessary for rapid familiarization and effective utilization. TSPI data since processed by the Brazilians using GrafNav has been provided to the FAA for method verification.

The LAAS/MMR data processing package is a FAA proprietary collection of custom programs designed specifically for merging the "unknown" or test LAAS positional airborne data, with the "known" or truth TSPI positional data. These programs generate multiple plots used to evaluate the accuracy, availability, continuity, and integrity of the LAAS signal in space and how it is applied to the MMR system. As a FAA created package it is the FAA's intention to maintain and update the package as needed for the Brazilian's continued and exclusive use.

A follow up technical visit to Brazil to fly the updated TAP approaches is being planned for early 2007.

10.3 Honeywell PSP Stability Testing

As part of the LAAS integrity development contract Honeywell Incorporated (HI) is required to conduct and pass a fourteen-day stability test using the Provably Safe Prototype (PSP) system installed at Memphis international airport. The stability test is intended not only to thoroughly ring out the system hardware, but also to provide an opportunity to evaluate the long-term performance of the integrity monitoring software modules (also known as ADDs or Algorithm Description Documents). System shutdowns during stability testing are to be allowed only as a direct result of one of the ADDs preventing the PSP from broadcasting Hazardously Misleading Information (or HMI) to an airborne user.

HI's first attempt at the required fourteen-day stability testing of the PSP in Memphis began on 09/01/06. As planned the FAA Ground Based Performance Monitor (GBPM), and the GPS Anomalous Event Monitor (GAEM), were installed and running at Hangar 12 in Memphis for the duration of the testing. Daily performance monitor plots have been generated, and any GAEM events recorded and available for analysis. HI had employed several workarounds for this first attempt at this test, which are to be addressed and corrected and/or implemented permanently before the next formal attempt.
There were four known restarts for the test duration. Since restarts were not to be allowed unless caused by an integrity alert shutdown, which only covers the conditions surrounding the one of the restarts, the stability test will need to be reattempted and passed to satisfy the terms of the contract.

10.4 Memphis PSP Flight Test

A FAA team conducted flight tests at Memphis International Airport during the weeks of September 18 and September 25, 2006 using the recently commissioned N47 FAA project plane (Airborne Team and N47 depicted in **Figure 15**). The purpose of this test was to collect data against the Honeywell LAAS Provably Safe Prototype (PSP). This system has incorporated the key integrity monitors required for LAAS in accordance with the ICAO SARPS and LGF Specification.

The goal was to collect data on 100 approaches that would include all runway ends. Achieved were 104 approaches to 7 of the 8 runways ends: RW 18R, 18C, 18L, 36R, 36C, 36L, and RW27 (see **Figure16** below). All approaches were flown as straight-in approaches from either 10 nmi or 20 nmi, except 1 approach that was an experimental Terminal Area Path (TAP) complex procedure. Also flown was an orbit, at 3,000 feet AGL at 20 nmi from the airport. This was to collect field strength data on the VHF data broadcast (VDB). Several radials over the airport were flown, also for the purpose of collecting VDB data. All flights were conducted aboard the FAA Bombardier Global 5000 aircraft (tail number N-47). Position data was collected from the Honeywell ground station at a remote location atop of the Federal Express Hangar building, located close to the end of RW 27. The FAA has installed a GPS anomalous event monitor (GAEM) as well, for the purpose of recording a digitized set of data surrounding a satellite anomalous event. Data processed to date indicate very low navigation sensor error in both lateral and vertical dimensions.

Figure 15: N47 and LAAS Airborne Team at Memphis

Figure 16: Memphis International - Google Earth View - Runways

FAA position monitor and anomalous event monitor data are still being analyzed, and indicate some performance issues that were present. The nature of these issues is primarily related to receiver loss-of-lock events, or satellite events that the PSP detected that need to be confirmed by the GAEM. There are some stability issues with the Honeywell PSP that are under investigation as well. Preliminary data results of the majority of the approaches, however, were encouraging and are presented below in **Figure 17**. More results of this test will be forthcoming in a FAA report to be published in the near future.

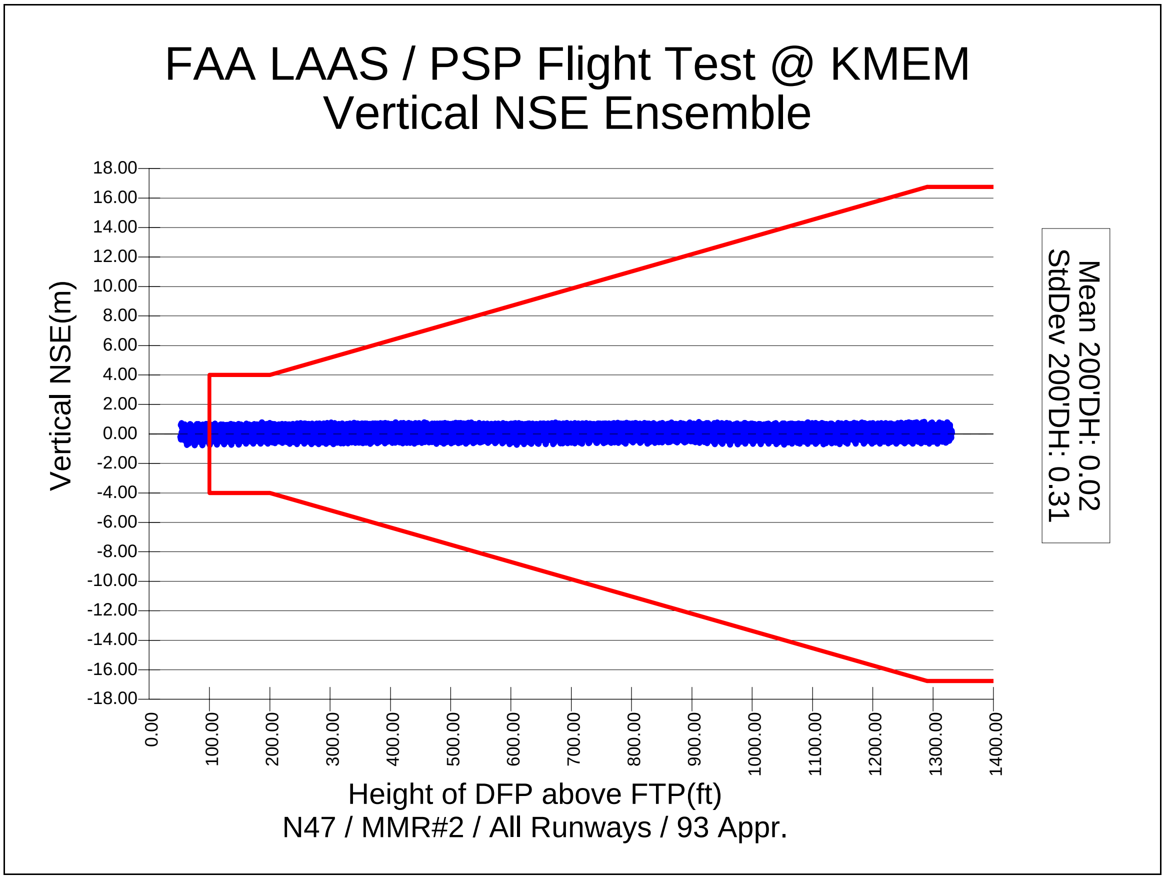


Figure 17: Preliminary NSE Results - Memphis

During the flight-testing a number of visitors from FAA Headquarters in Wash. D.C. were present, as were a number of members of the Joint Precision and Approach Landing System (JPALS) test team. The visitors were given tours of the HI PSP LAAS ground station, the GBPM/GAEM system sites at Hangar 12, and many were able to accompany the FAA airborne LAAS team on N47 for a live demonstration during actual data collection flights.

11. Glossary of Terms and Acronyms

A

ACY
Atlantic City International Airport.. i
ADD
Algorithim Description Document 60
AEC
Avionics Engineering Center (of Ohio University)…………………………………...66
AOA
Air Operations Area.. i

B

B-value
An estimation of the pseudorange correction (PRC) error 21

C

CDI
Course Deviation Indicator.. 10
CMC
Code Minus Carrier.. 1
CNO
Carrier to Noise Ratio.. 17
CPU
Central Processing Unit 7
CRC
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D

DQM
Data Quality Monitor……………………………………………………………….17

E

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Earth Centered Earth Fixed…………………………………………..…………..64
EPOL
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12.1 Tables

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In closing the author also wishes to thank the GBAS program office, and the entire LAAS Test and Evaluation Team for their inputs and contributions to ongoing software and hardware efforts. These efforts are documented and cited in detail throughout this and past reports.

End of Report