Local Area Augmentation System
Performance Analysis/Activities Report

Report #10

Reporting Period: April 1 to June 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 tenth 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)	7.273	1.409
Horizontal Protection Level (HPL)	2.358	1.183
Clock Error	19.492	2.428
Dilution of Precision (DOP) (VDOP) (HDOP)	 5.141 1.655	 0.884 0.736

Table 1: Key Performance Summary

[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.

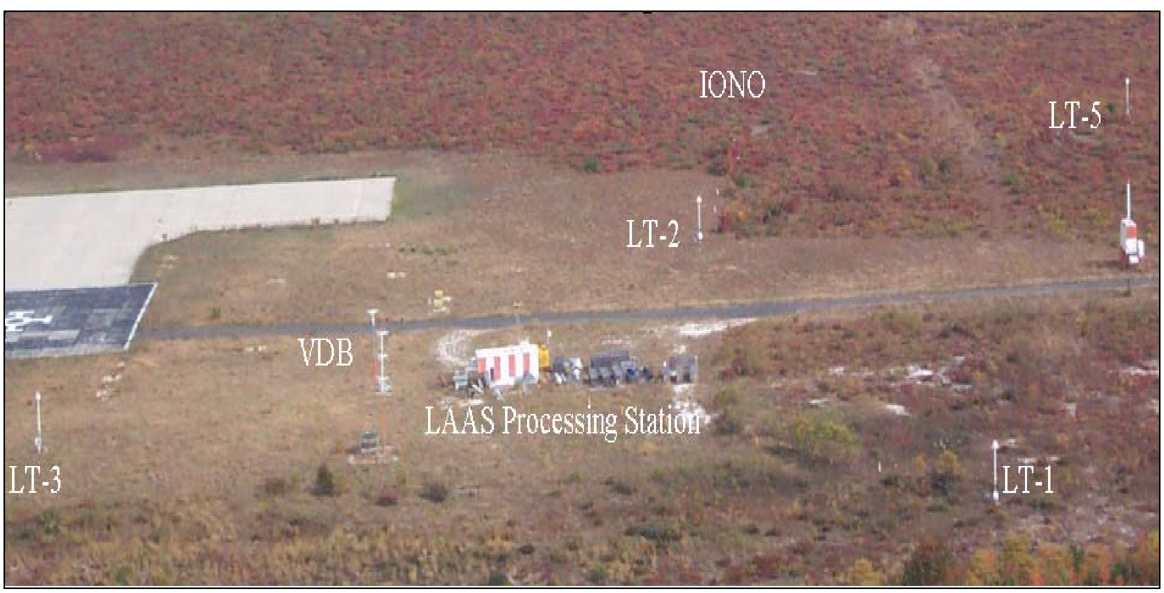


Figure 1: Aerial of LTP at ACY

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 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.

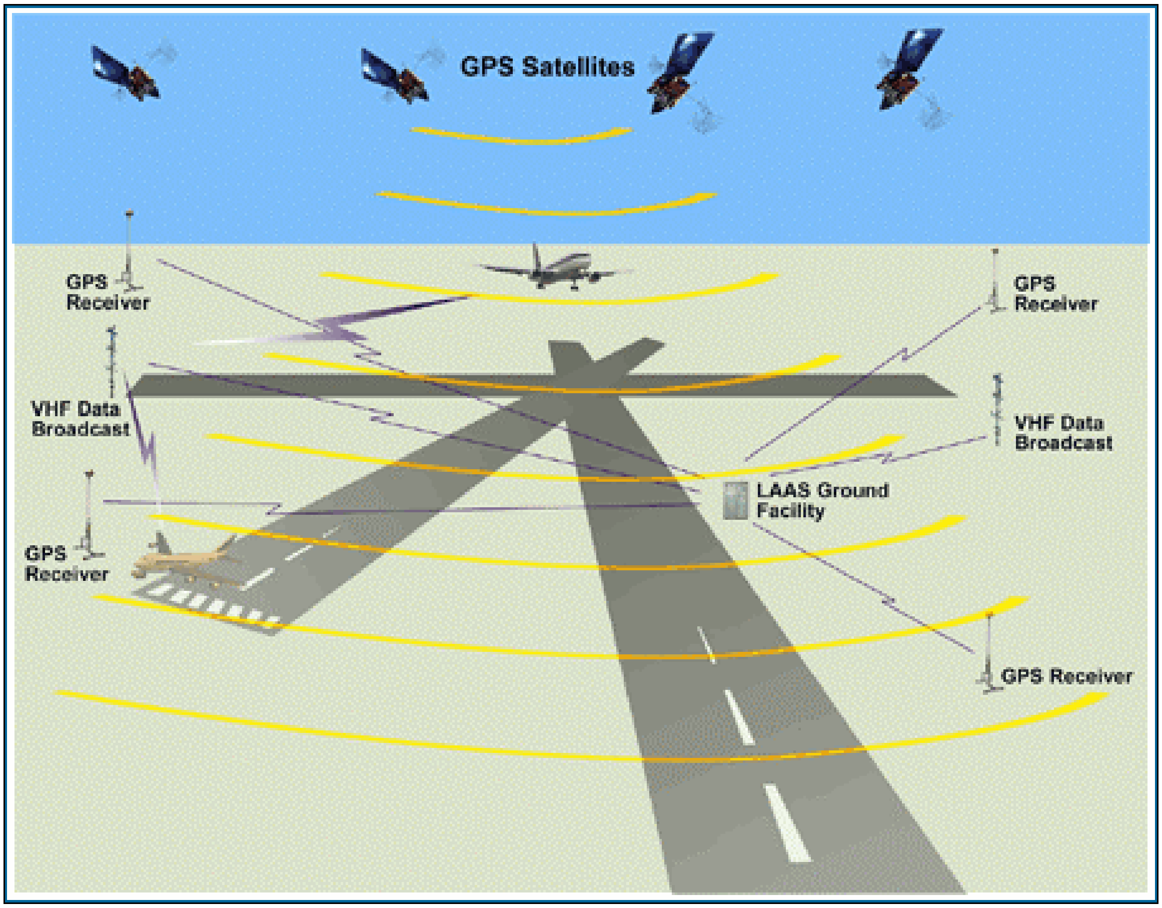


Figure 2: LAAS Simplified Architecture Diagram

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.

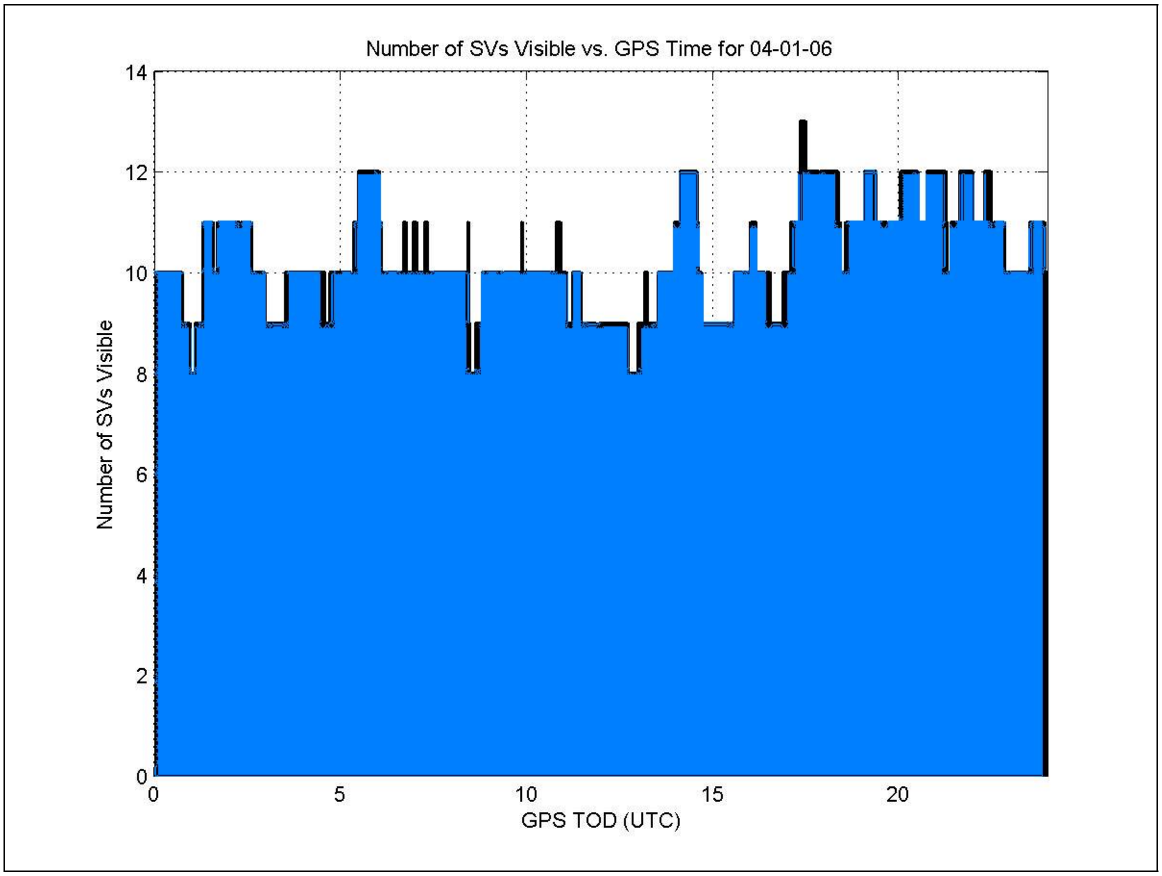


Figure 3: SV Availability at ACY

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).

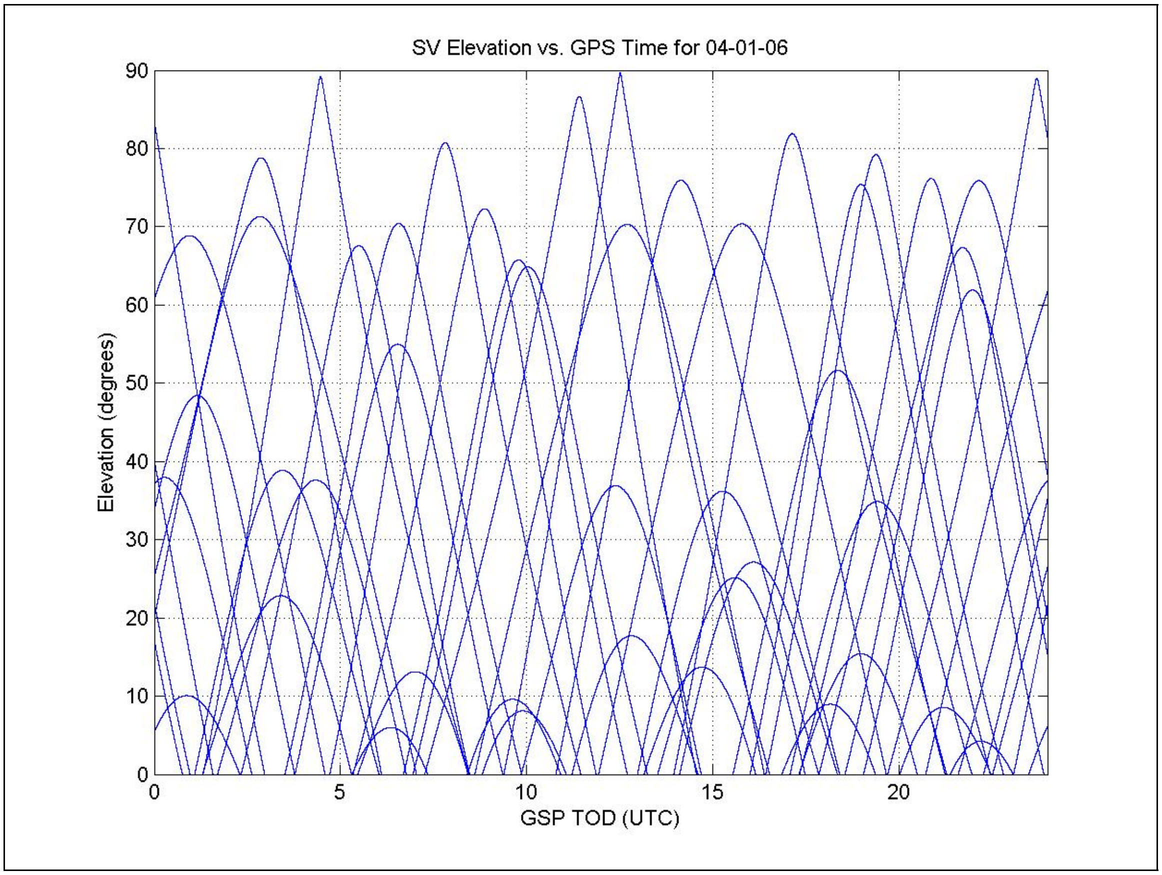


Figure 4: SV Elevations at ACY

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" or "Unusable UFN". 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 Ended
2006034	Outage Summary	PRN-10	04/06/06	14:16	04/06/06	15:14
2006035	Outage Summary	PRN-07	04/07/06	09:30	04/08/06	01:17
2006036	Outage Summary	PRN-06	04/11/06	14:18	04/11/06	20:11
2006038	Outage Summary	PRN-24	04/20/06	15:46	04/20/06	19:47
2006040	Outage Summary	PRN-07	04/27/06	15:04	04/27/06	23:24
2006044	Outage Summary	PRN-25	05/09/06	21:20	05/09/06	23:25
2006045	Outage Summary	PRN-23	05/16/06	20:15	05/17/06	02:49
2006058	Unusable	PRN-25	05/18/06	06:47	06/28/06	UFN
2006050	Outage Summary	PRN-13	05/25/06	21:11	05/26/06	04:13
2006054	Unusable	PRN-30	06/02/06	20:14	06/07/06	18:42
2006060	Unusable	PRN-03	06/18/06	15:26	06/29/06	17:29
2006062	Unusable UFN	PRN-06	06/29/06	11:05	07/17/06	16:48

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 (1 through 5) but #4 was abandoned in favor of the remaining four LT sites (see **Figure 1**).

Each reference station consists of 2 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.

Figure 5: The IMLA Antenna

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. This pseudorange error will translate directly in to the position solution.

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

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.

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.

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 a 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 PL to exceed the AL. 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 Truth). 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

6.2.1.1 Terminal Area Path and Procedures (TAP) Development

The LAAS T&E software team modified the existing LTP (Heliport System) software to transmit TAP data for two runways at Atlantic City International Airport. TAP data for R/W 13 and R/W 4 was imported into the LTP database and tested using a Rockwell Collins MMR. New Runway Path Data Selector (RPDS) numbers were assigned to these approaches so that the pilot could "tune" in the approach. Now, because of the unlinked

TAP procedures, the ground system closely resembles the new version of the MOPS (DO-246C). Flight tests were conducted at ACY with astonishing results.

TAP information greatly improves the National Airspace System (NAS), by allowing the ATC/Pilot to utilize waypoints for an approach, which may or may not consist of a curved approach procedure.

Figure 8 is an “approach plate” from which the runway 04 curved approach is derived. Used as a pictorial representation of the approach, an approach plate it utilized by air traffic control and pilots for “at a glance” identification and familiarization of a given procedure, automated or otherwise.

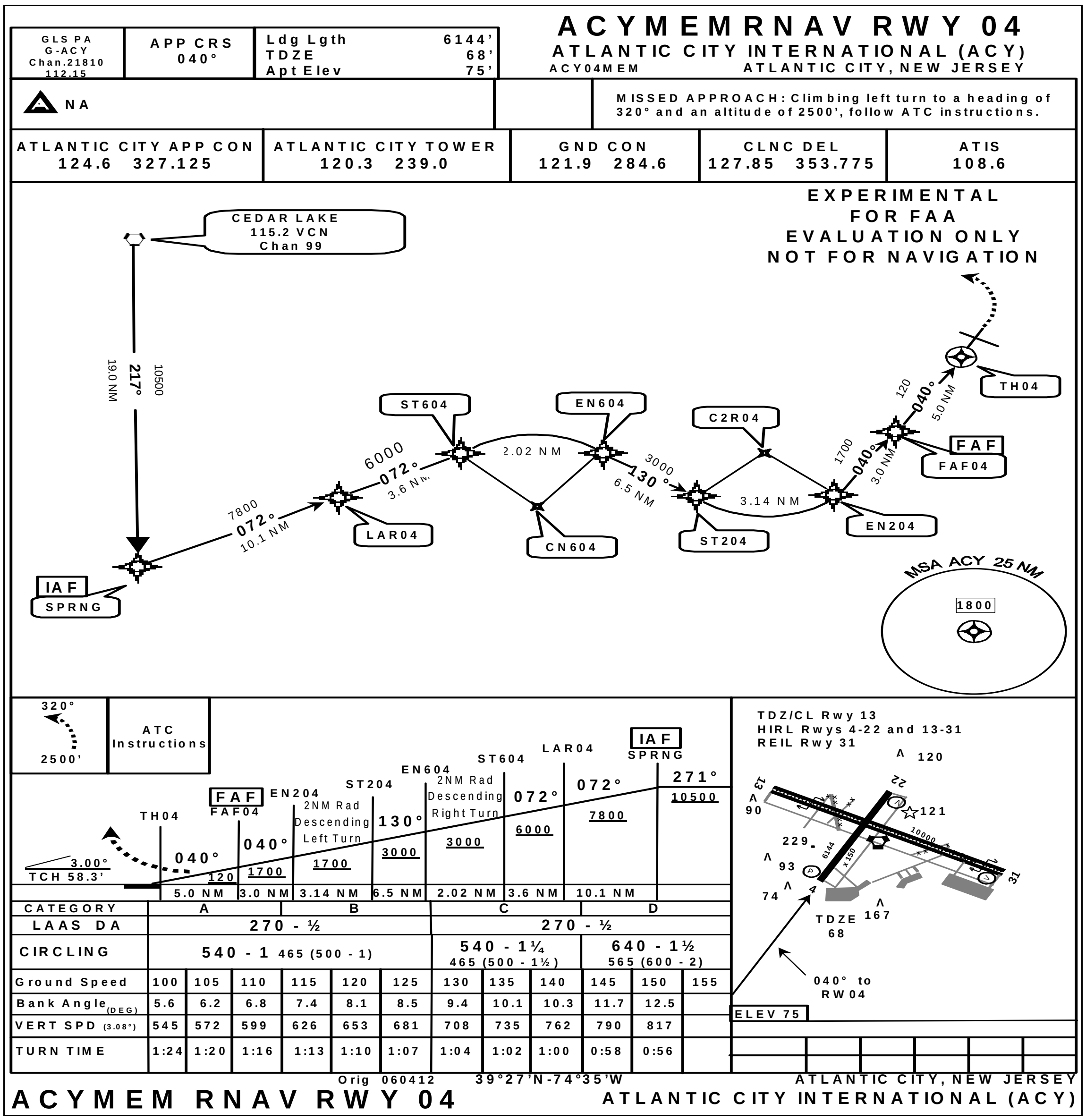


Figure 8: Approach Plate of ACY Runway 04 Curved LAAS Procedure

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.

The receiver in reference station LT1 began to falter in the mid April time frame. This caused the amount of satellites being tracked to be less than the actual number of satellites available. LT1 is the primary reference station and is used for receiving the ephemeris data, which is critical to calculating the pseudorange corrections. The problem was initially intermittent and did not become immediately evident until the number of SV's with corrections dropped to a critical level. Once the receiver was repaired it was also decided to make LT2 the primary reference station since LT1's southern view has become obstructed by flora up to 15 degrees since it was originally established. This operation was performed on June 7th 2006. It's important to note that this type of failure mode is unique to the LTP, and would not be manifested in a fully spec complaint station.

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, 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

[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).

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.

The data presented for April 2006 (04/14/06) is interesting because it is evidence of the primary reference (LT1) receiver's intermittent behavior just before it's hard failure later that month. Although this event did not cause the system to become un-flyable, it did cause an uncharacteristic rise in the vertical domain (VDOP and VPL) values. The prototypical nature of the LTP, versus a completely spec complaint LAAS system, does make it more vulnerable to these types of events. The system being developed by Honeywell for the FAA, in contrast, would not rely on a single reference station for it's ephemeris data and would not be affected in this way.

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.

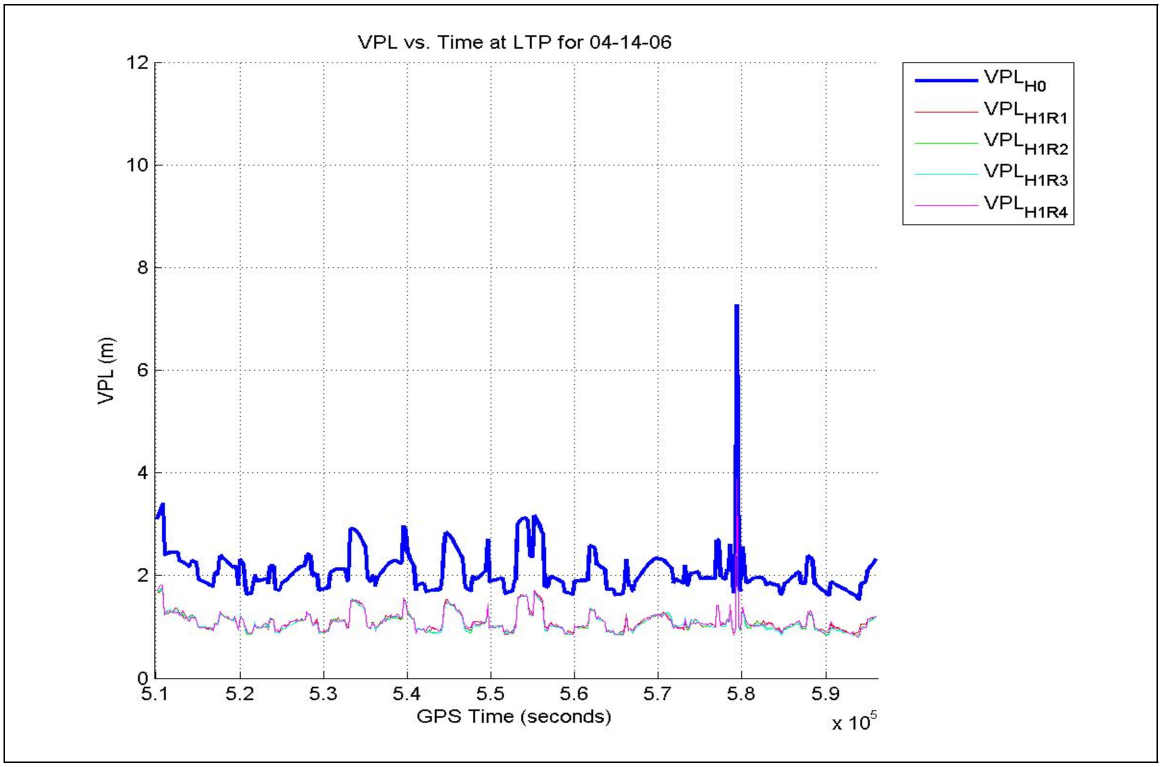
The content and organization of the LTP system performance plots, contained in the remainder of this report, are outlined below.

Reporting Period Month and Year

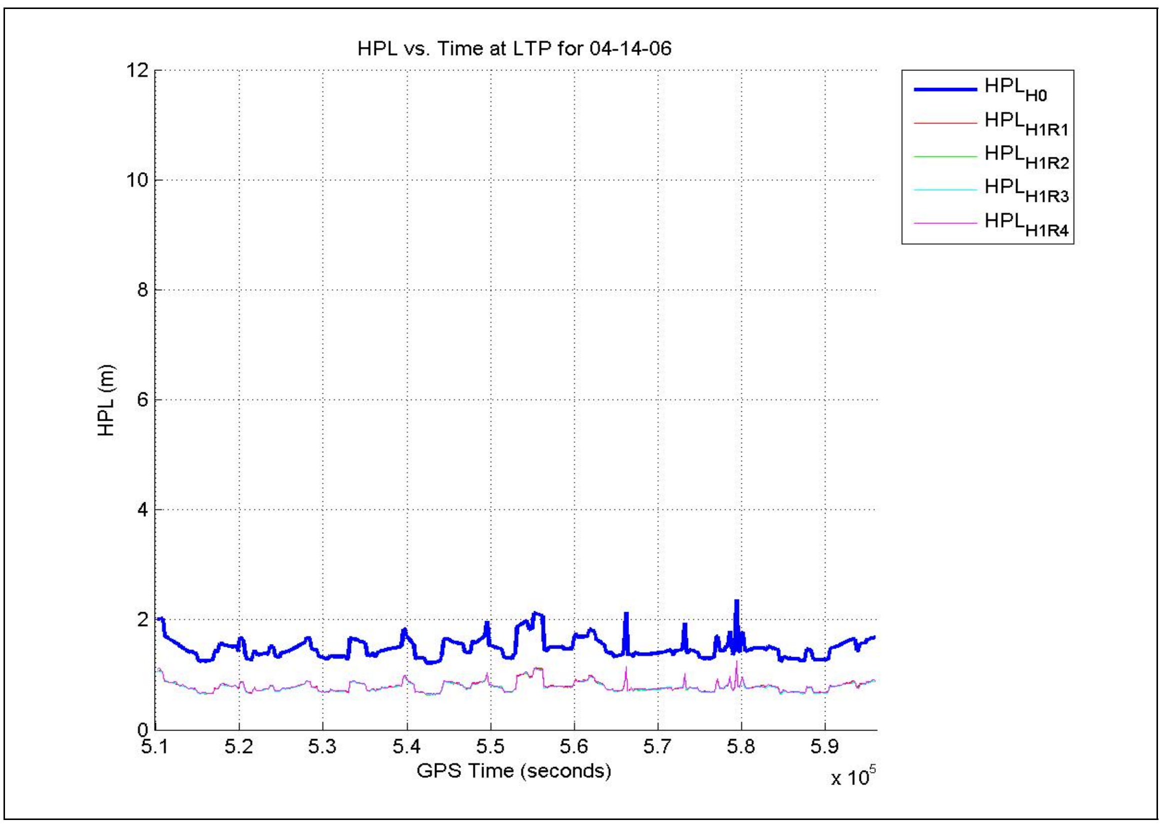
1) **VPL versus Time**
2) **HPL (LPL) versus Time**
3) **VDOP and Number of SV Observations versus Time**
4) **HDOP and Number of SV Observations versus Time**
5) **Clock Error versus Time**
6) **Dipole Status and CMC (System Average) (multiple)**
    - **System Dipole CMC Standard Deviation and Mean 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 April 2006 Performance Plots

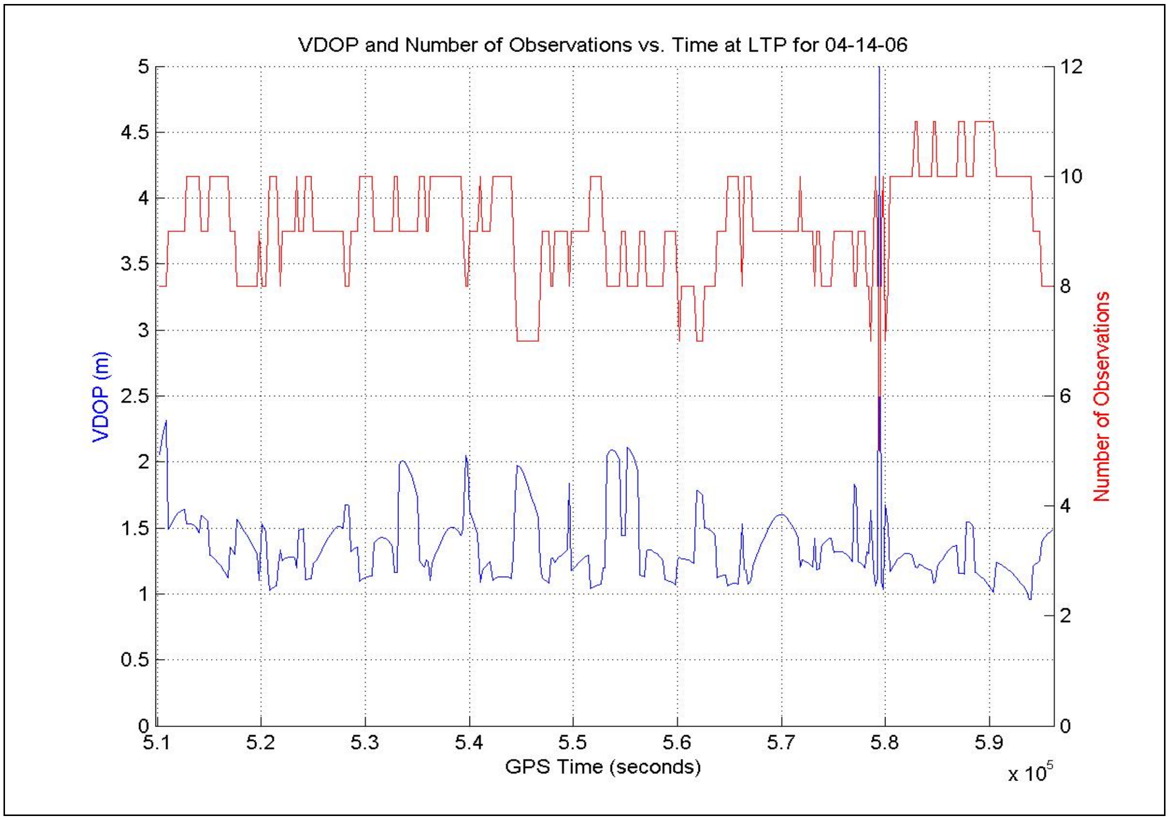
9.1.1 April VPL versus Time



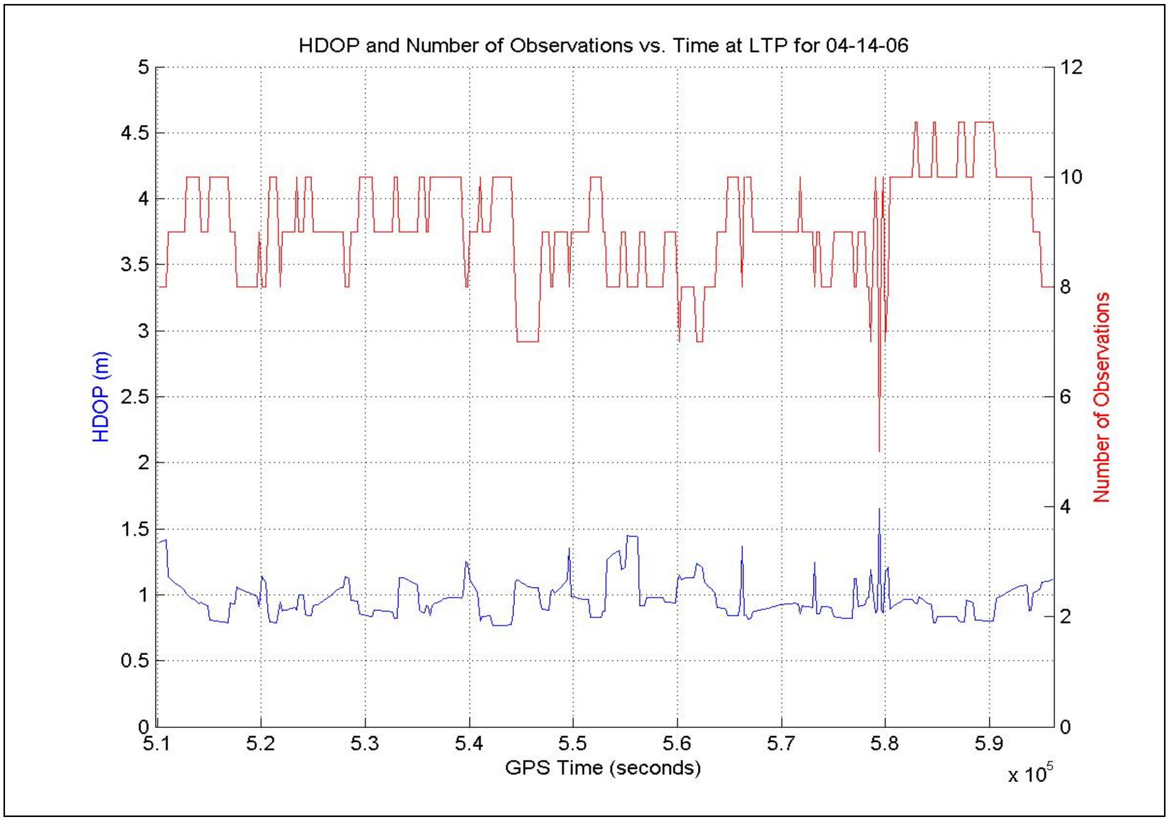
9.1.2 April HPL versus Time



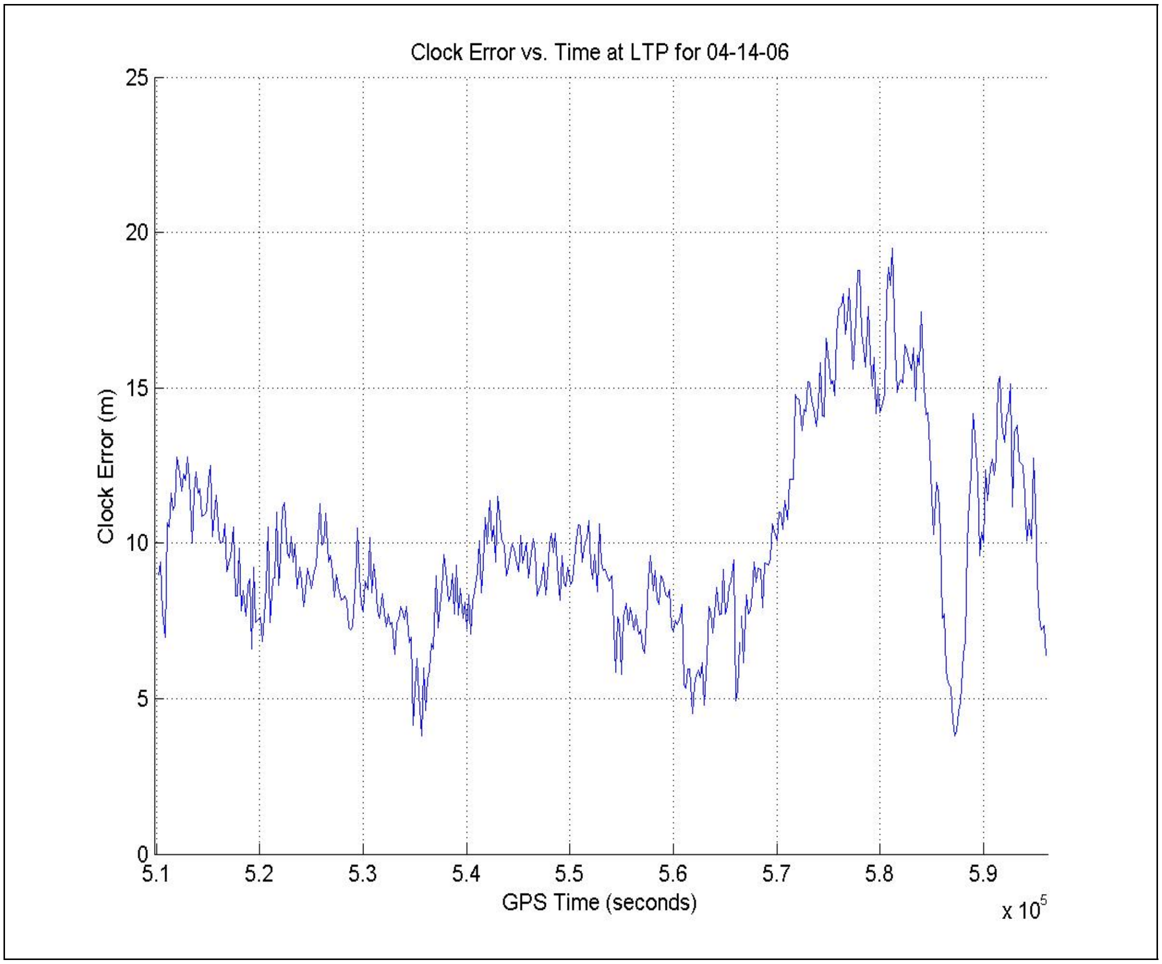
9.1.3 April VDOP and # of SV Observations versus Time



9.1.4 April HDOP and # of SV Observations versus Time

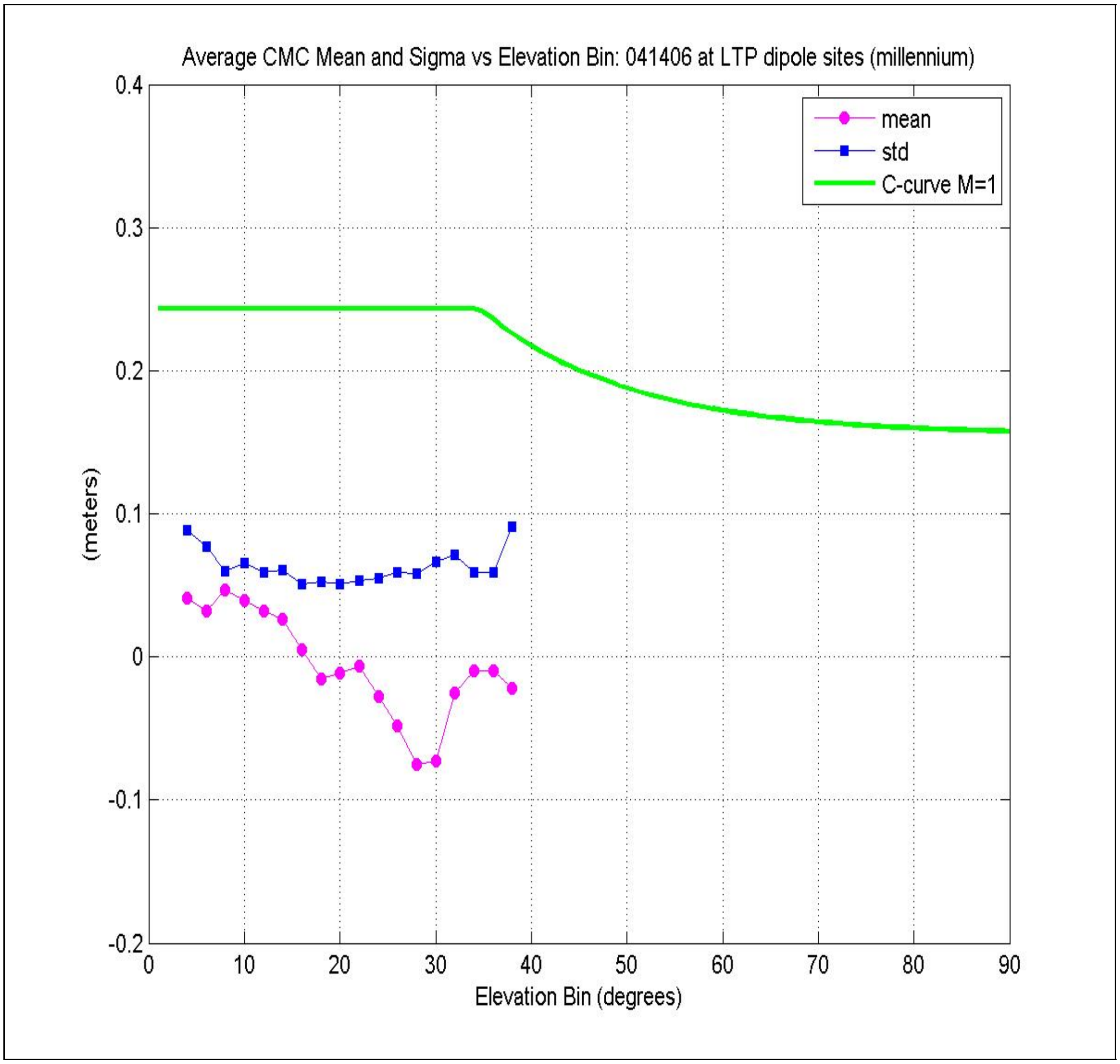


9.1.5 April Clock Error versus Time

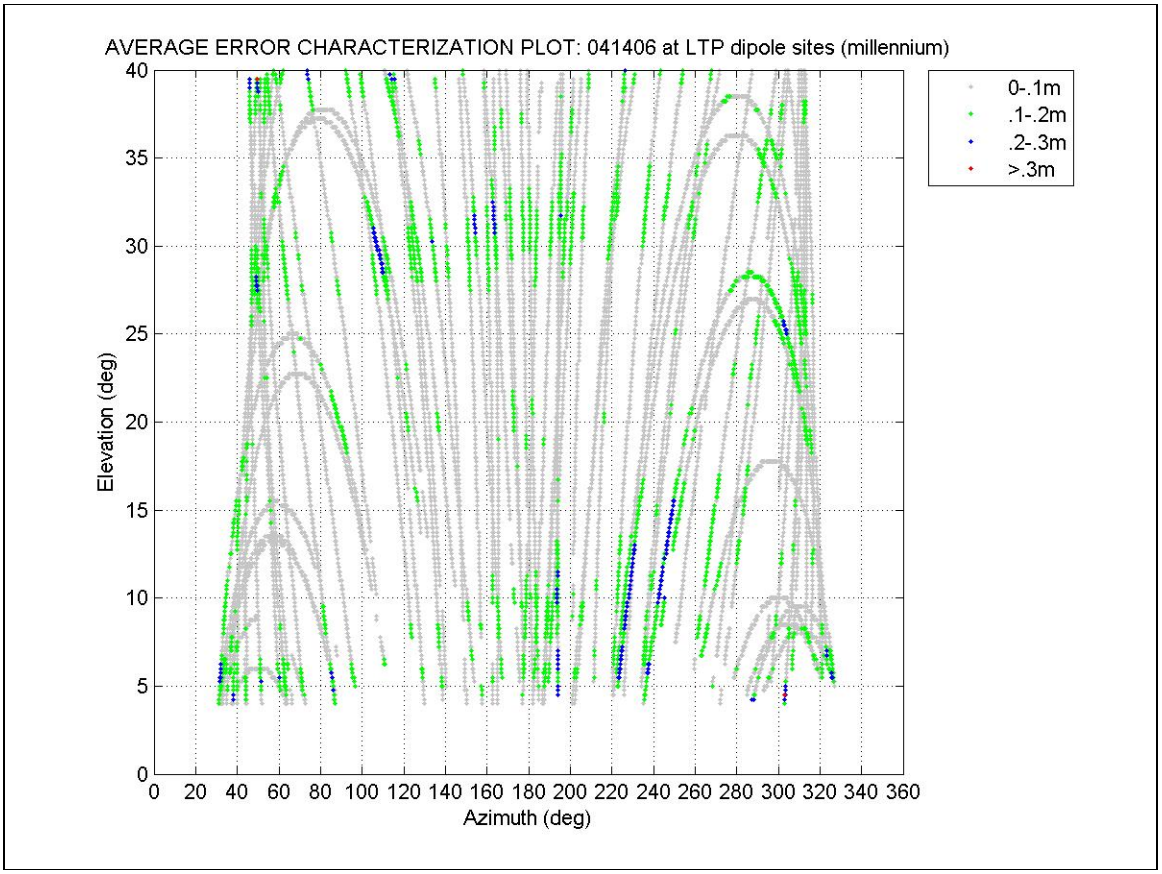


9.1.6 April Dipole Status and CMC (System Average) (multiple)

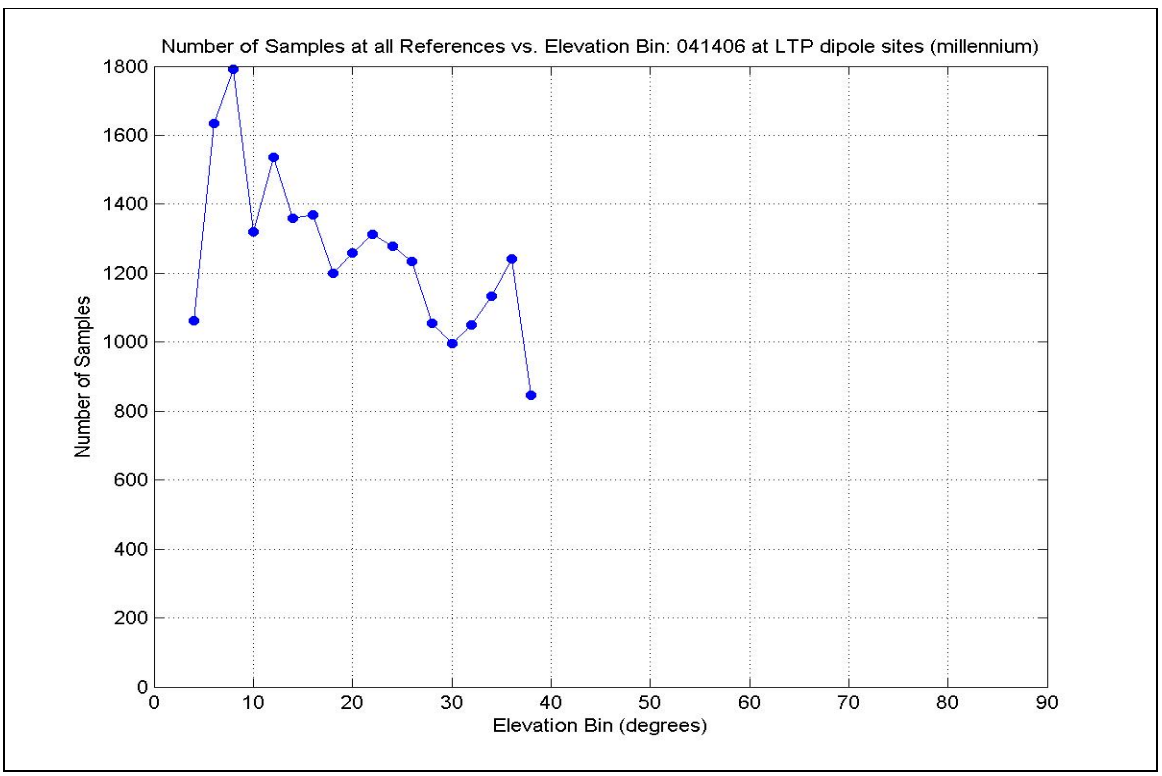
9.16.1 April System Dipole CMC Standard Deviation and Mean versus Elevation



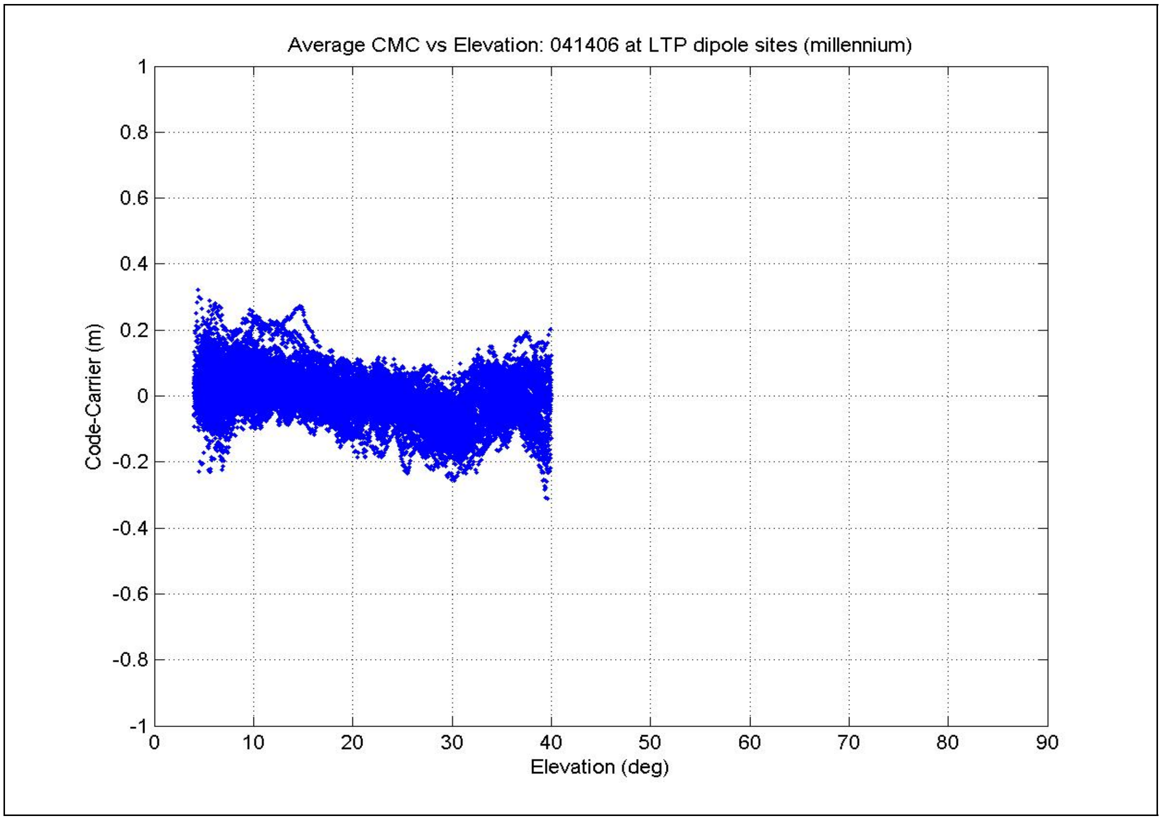
9.1.6.2 April System Dipole Error Characterization vs Azimuth and Elevation



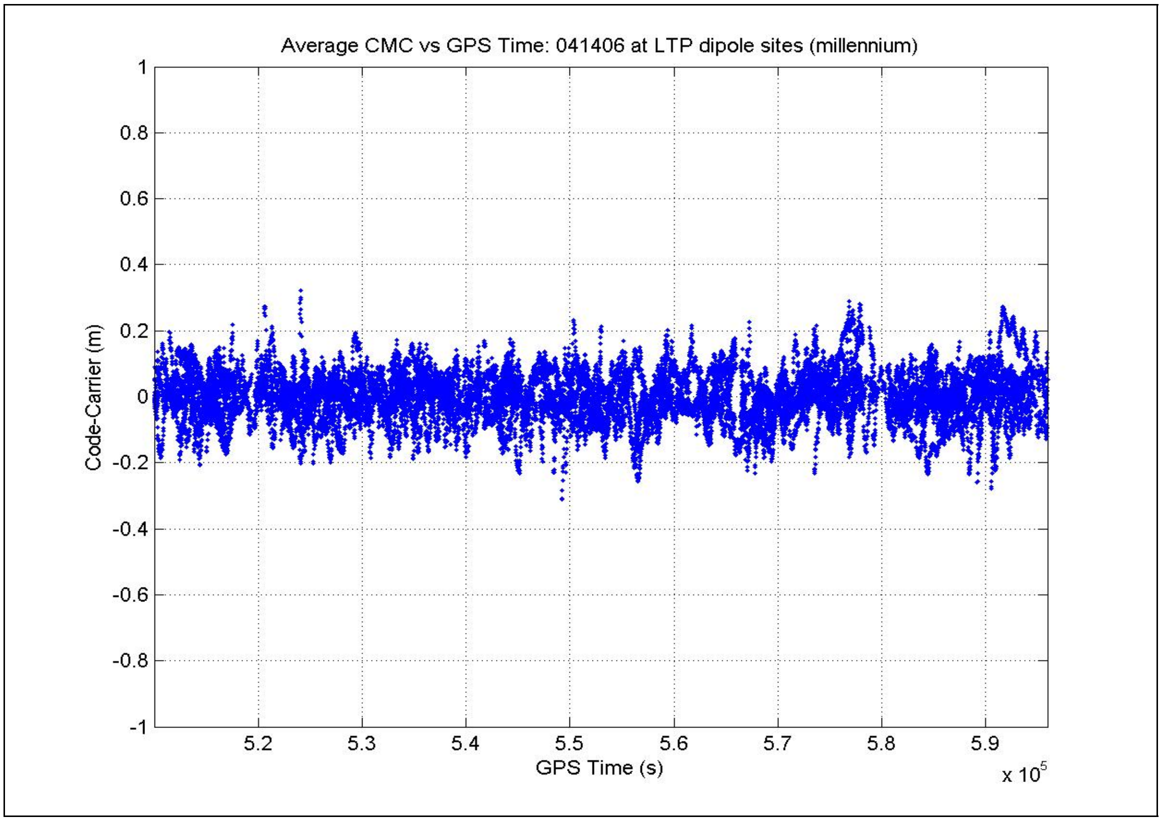
9.1.6.3 April System Dipole Number of Samples versus Elevation



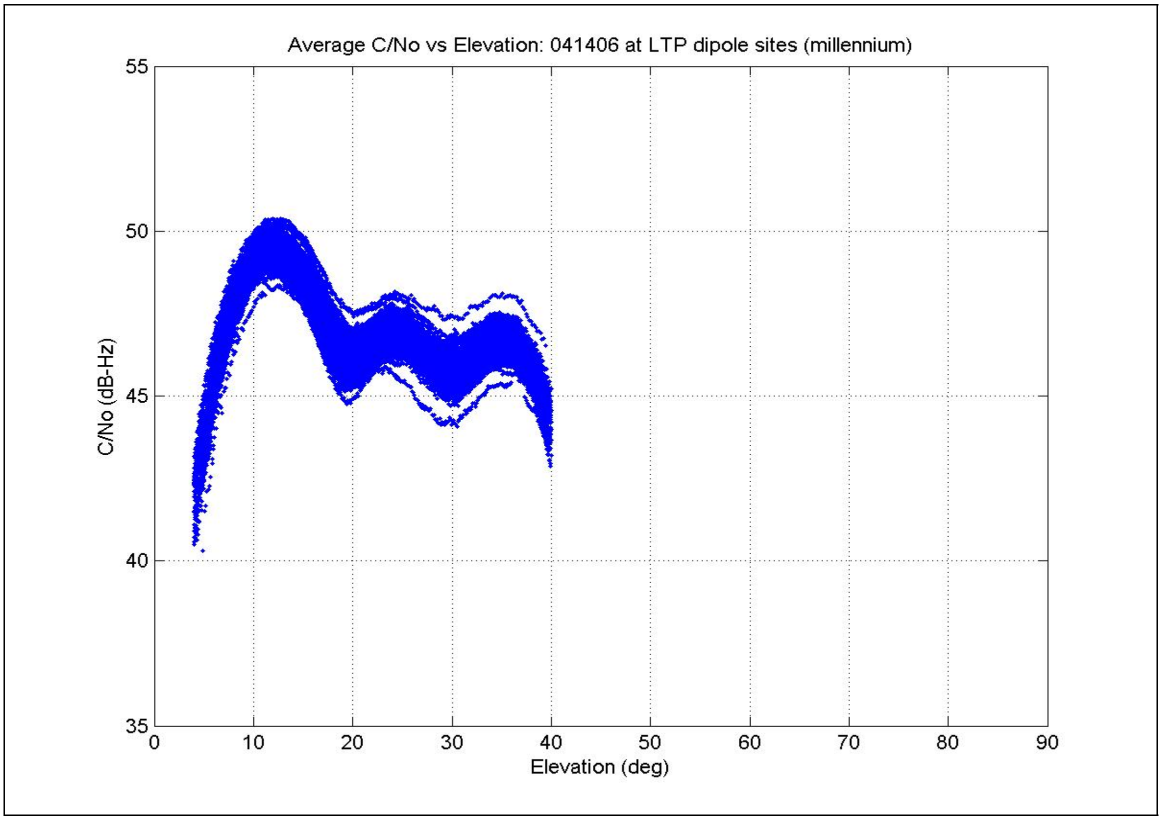
9.1.6.4 April System Dipole CMC versus Elevation



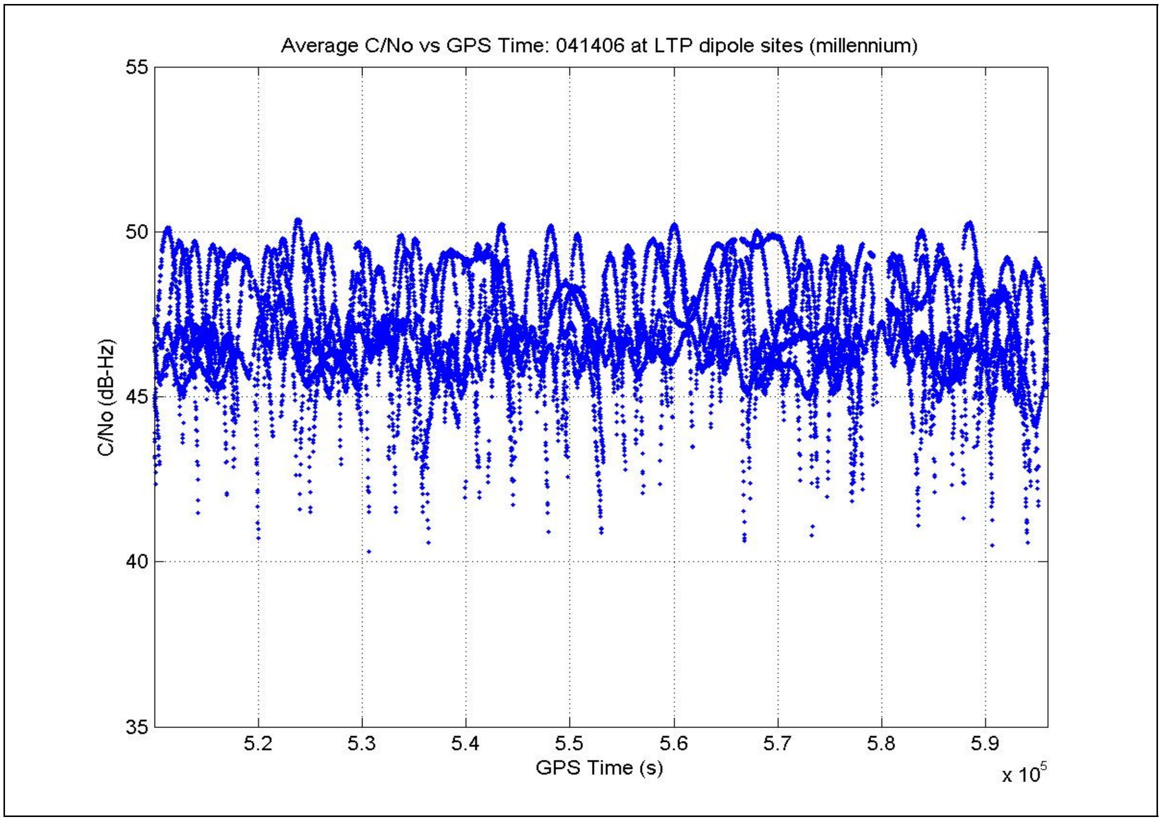
9.1.6.5 April System Dipole CMC versus Time



9.1.6.6 April System Dipole Carrier to Noise versus Elevation

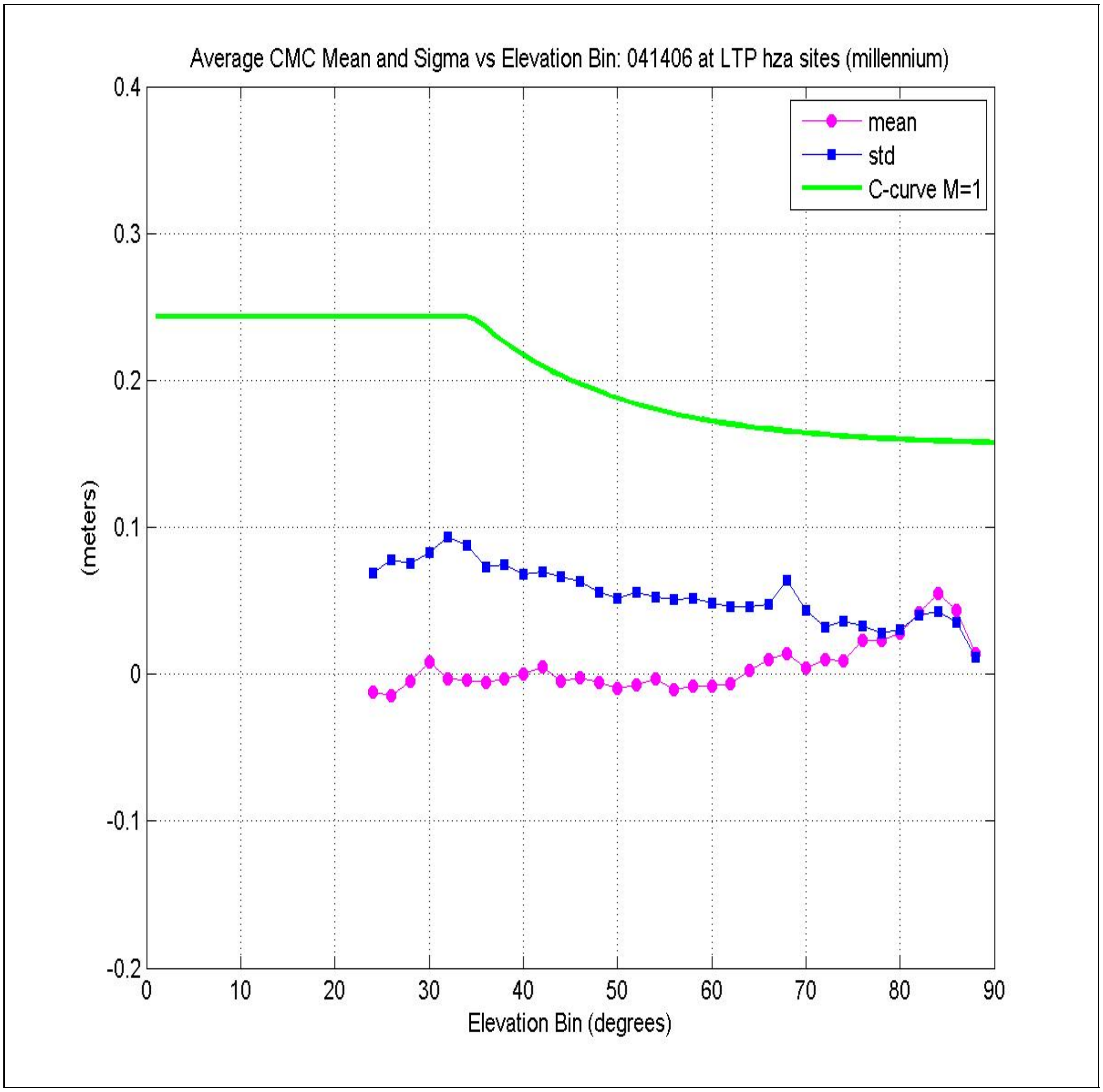


9.1.6.7 April System Dipole Carrier to Noise versus Time

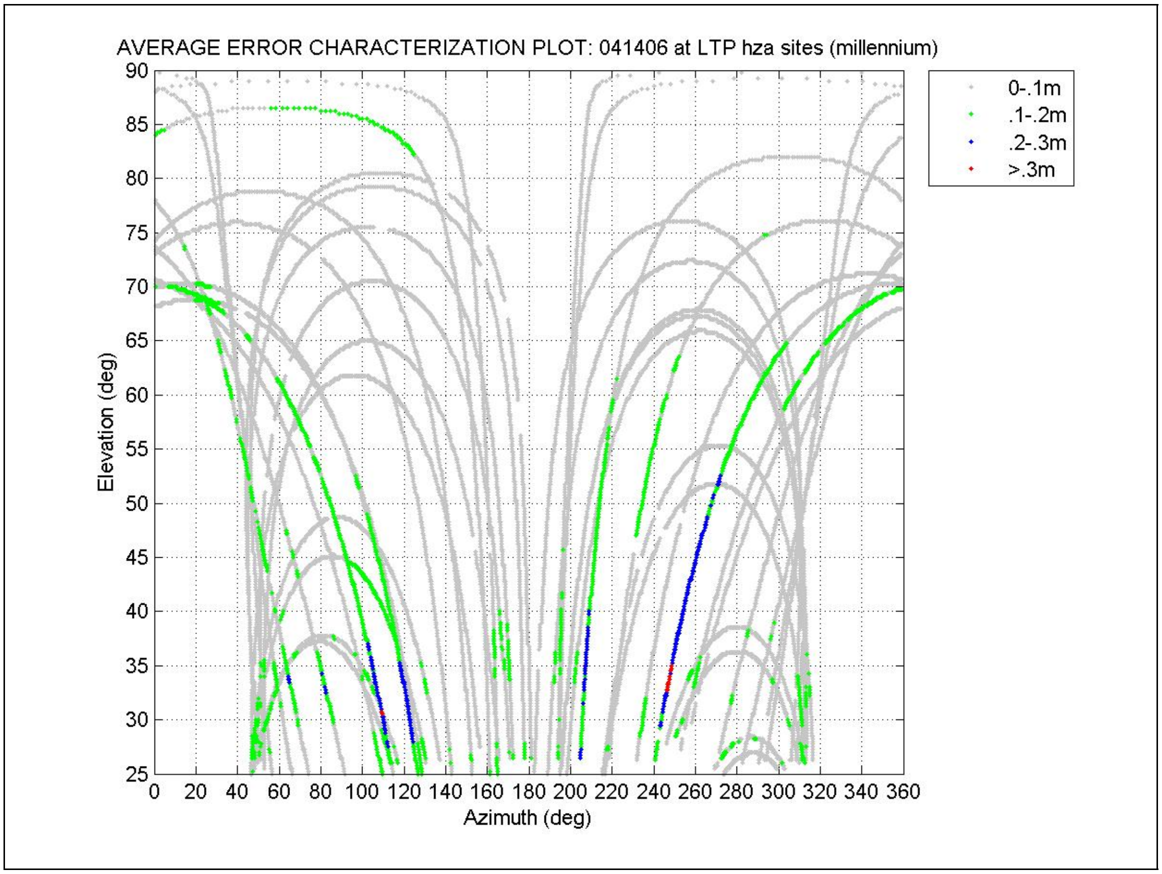


9.1.7 April HZA Status and CMC (System Average) (multiple)

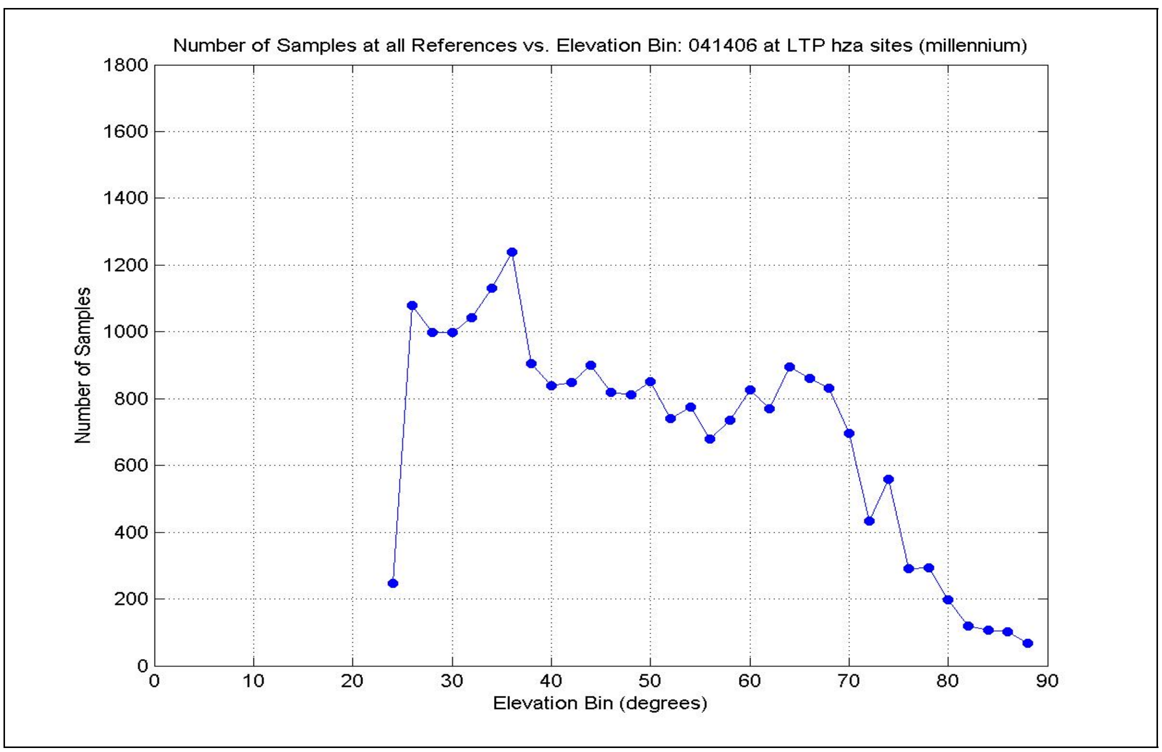
9.1.7.1 April System HZA CMC Standard Deviation and Mean versus Elevation



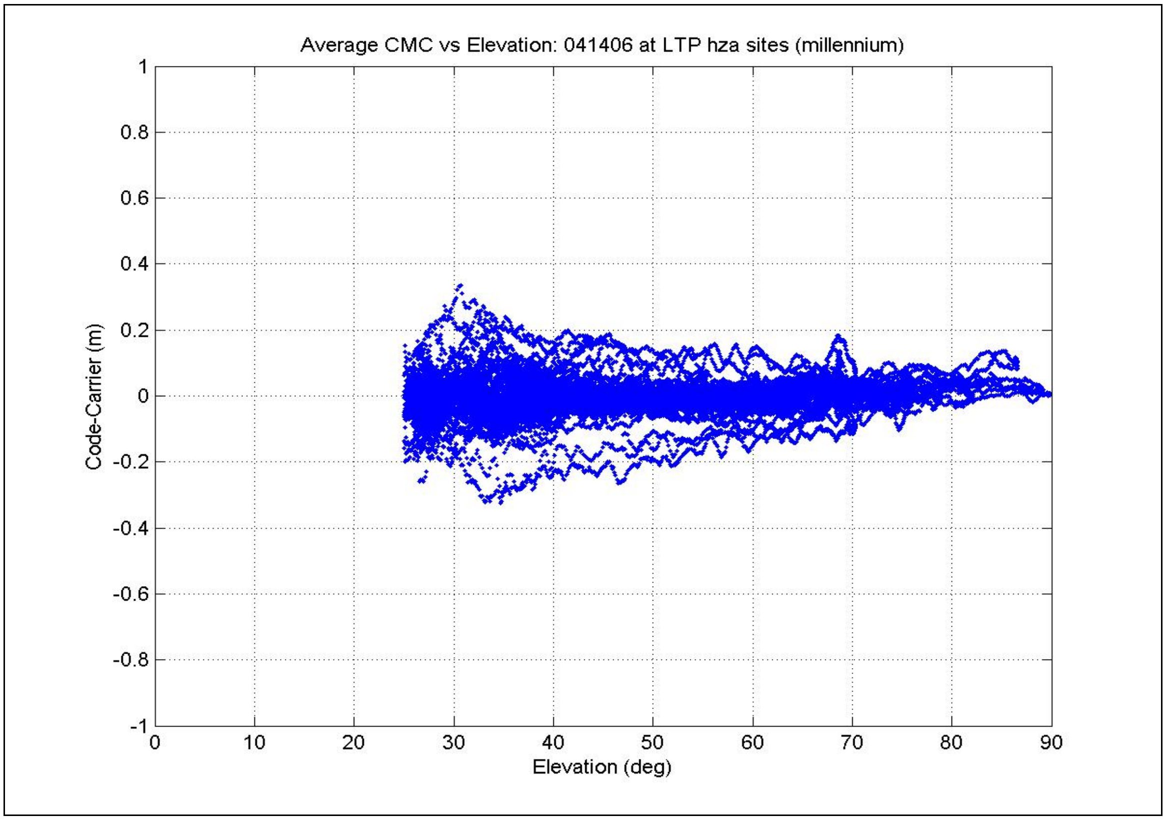
9.1.7.2 April System HZA Error Characterization versus Azimuth and Elevation



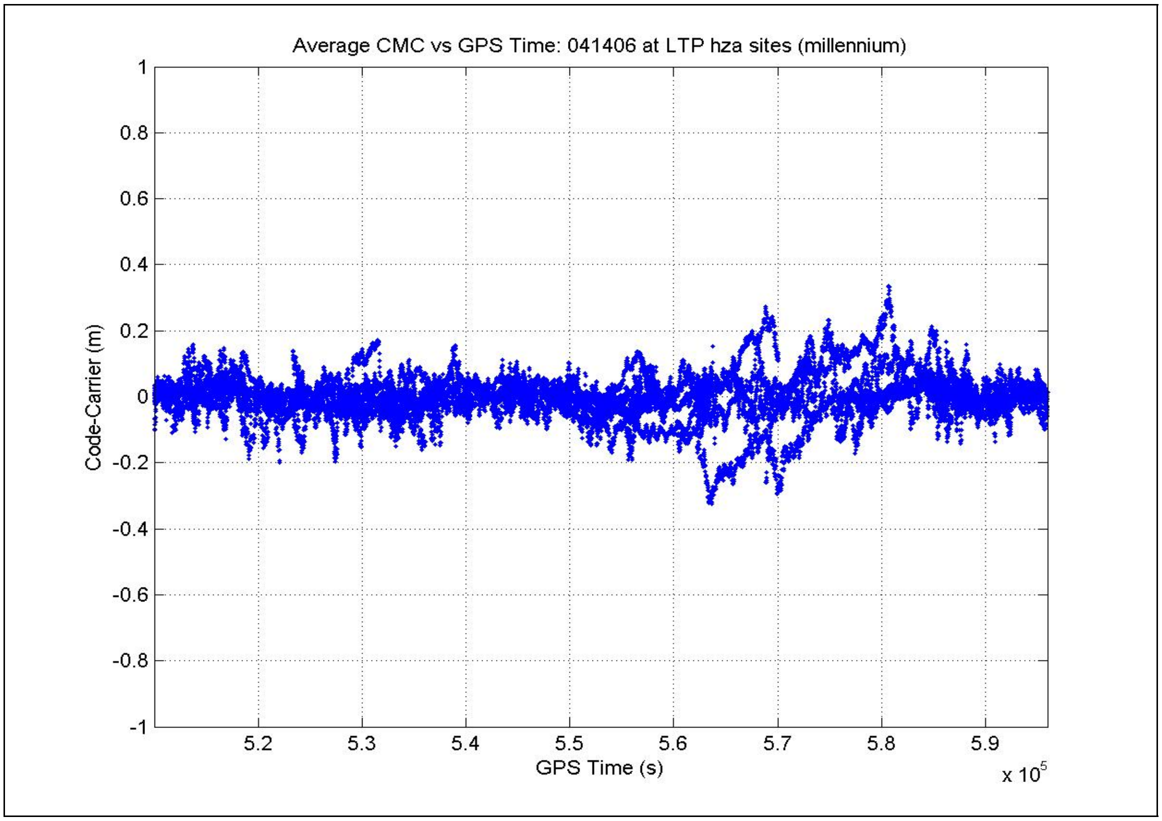
9.1.7.3 April System HZA Number of Samples versus Elevation



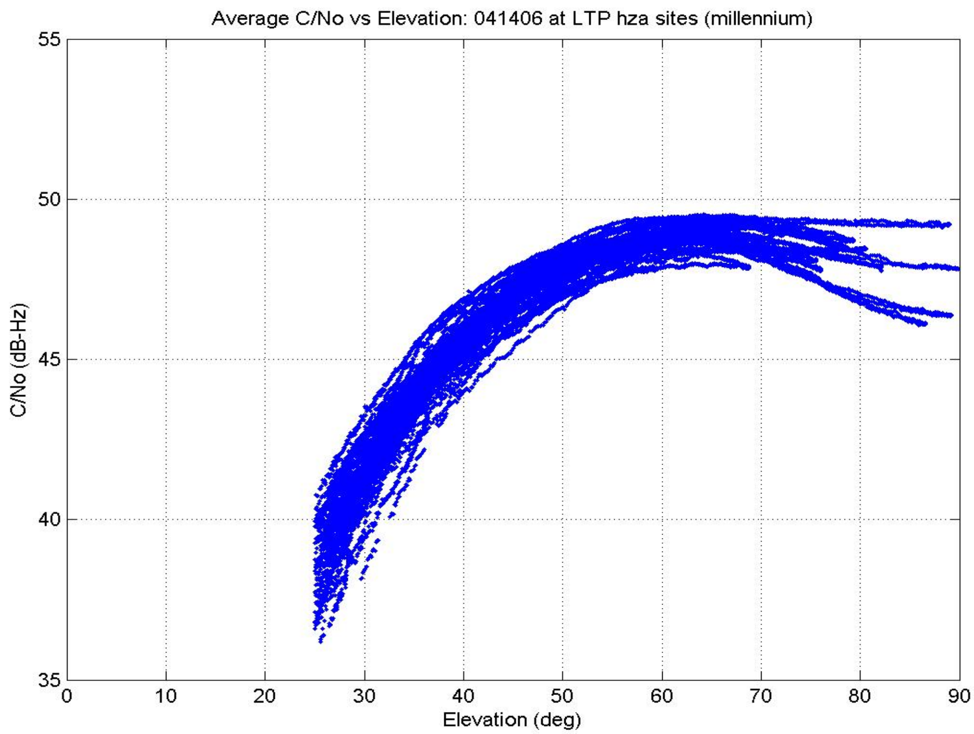
9.1.7.4 April System HZA CMC versus Elevation



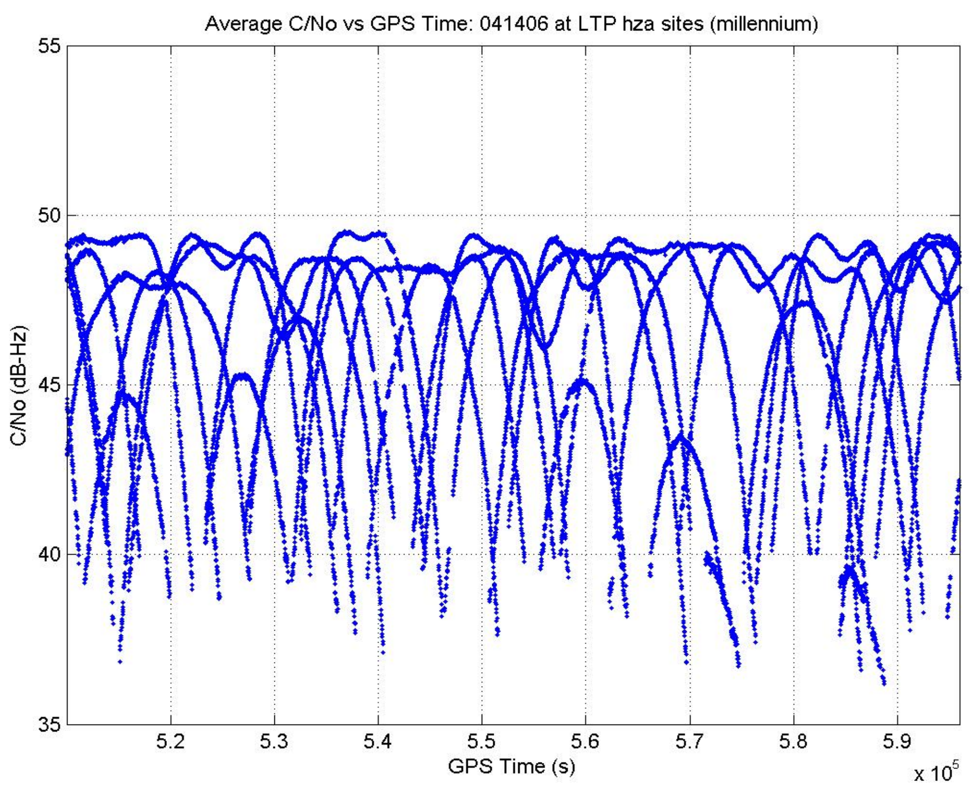
9.1.7.5 April System HZA CMC versus Time



9.1.7.6 April System HZA Carrier to Noise versus Elevation

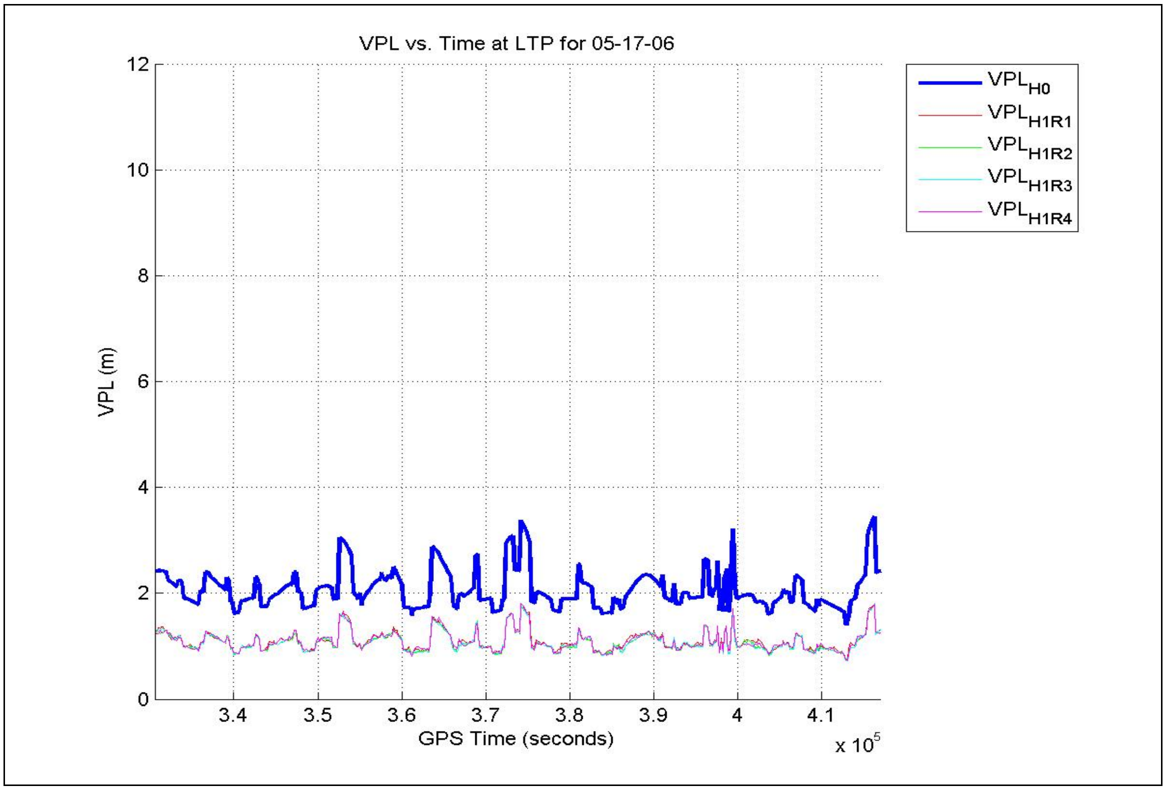


9.1.7.7 April System HZA Carrier to Noise versus Time

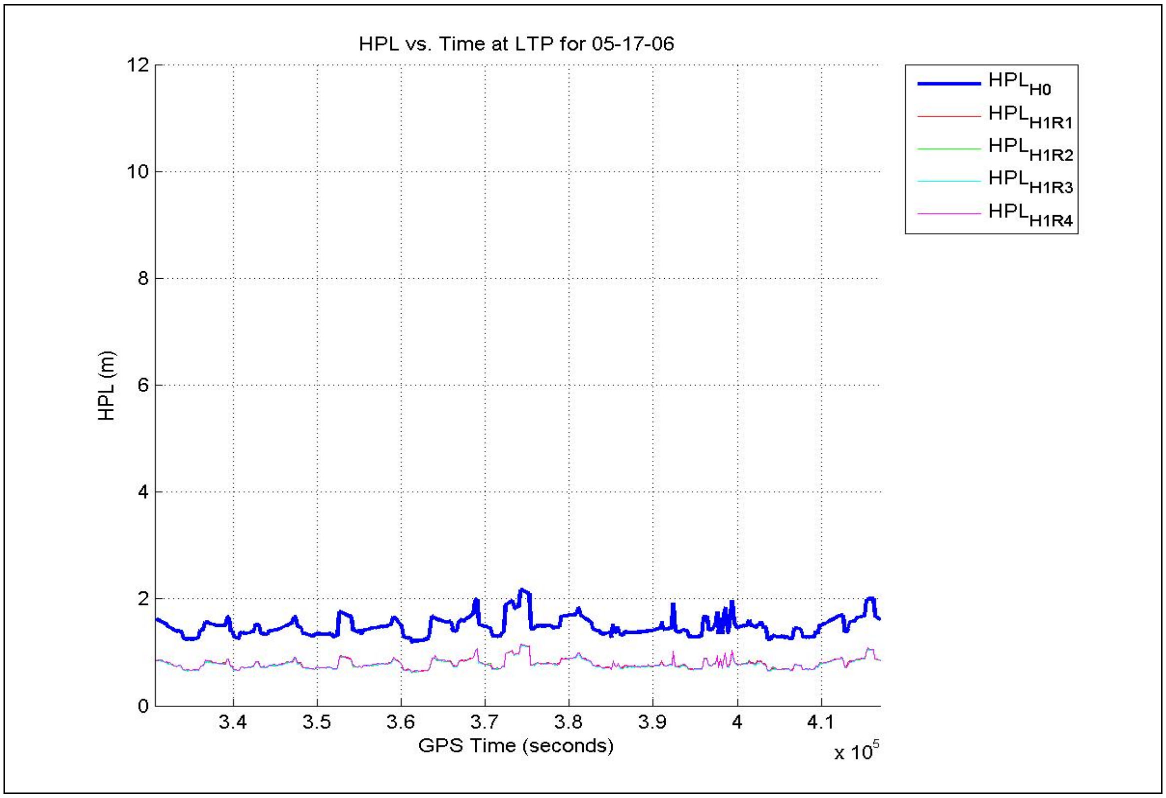


9.2 May 2006 Performance Plots

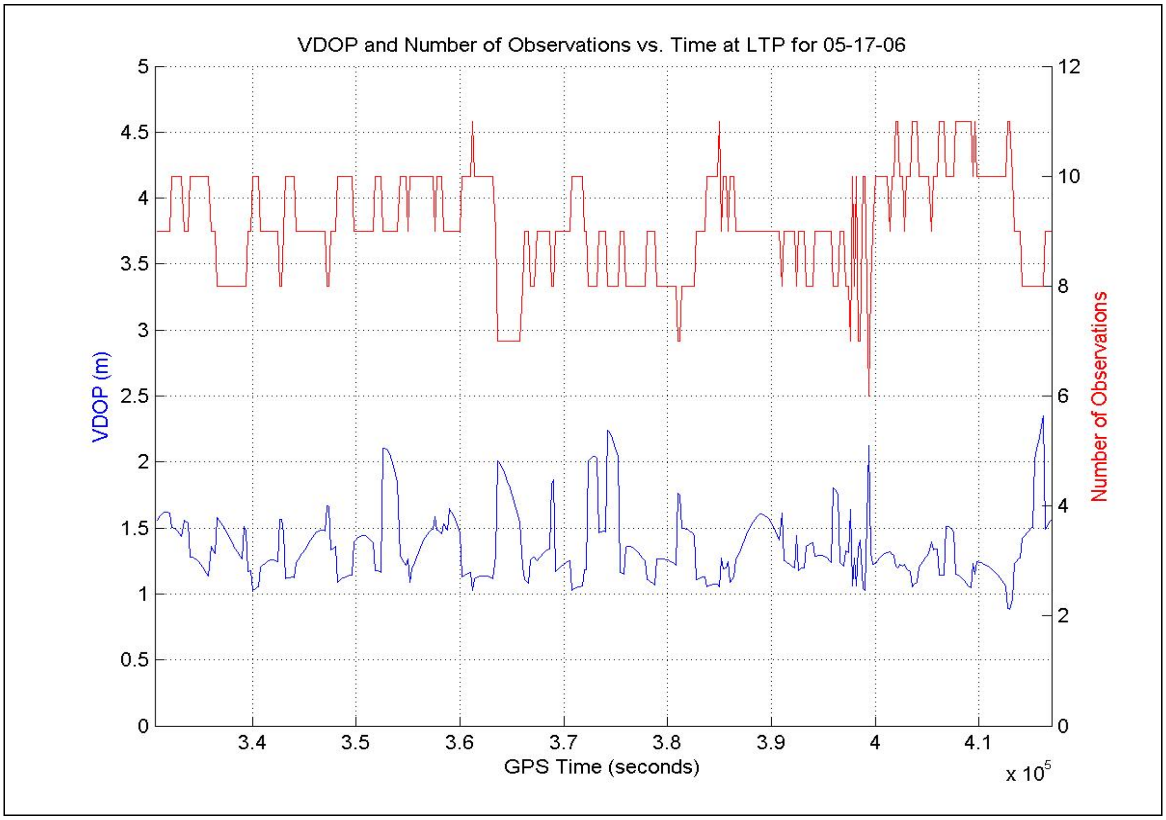
9.2.1 May VPL versus Time



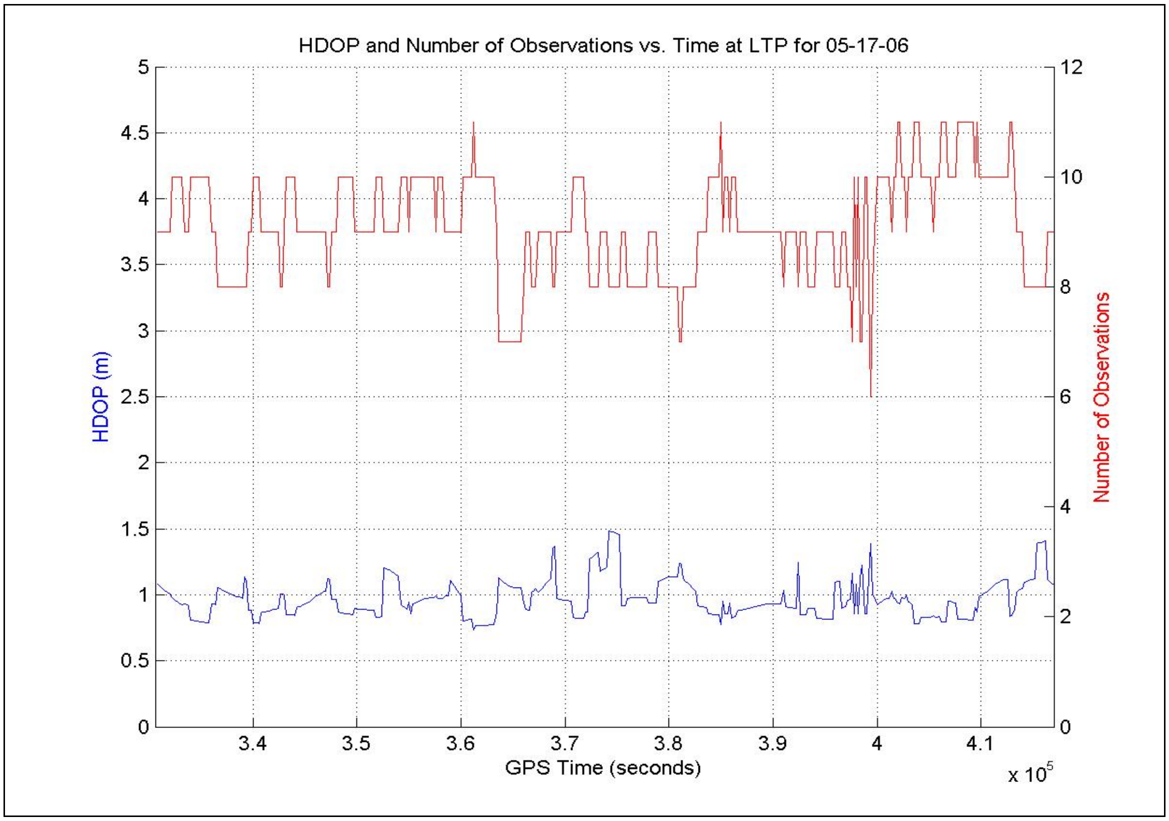
9.2.2 May HPL versus Time



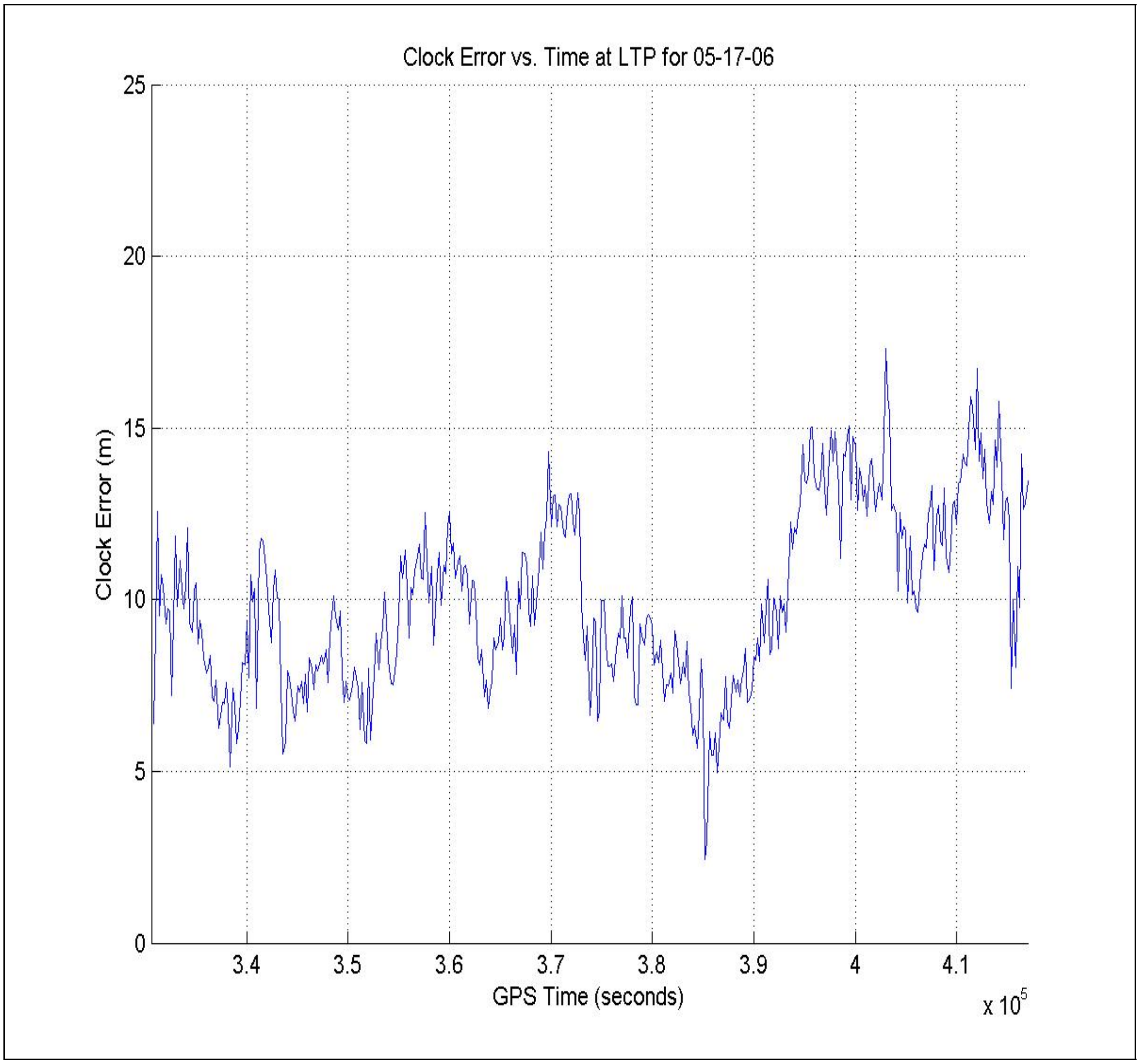
9.2.3 May VDOP and # of SV Observations versus Time



9.2.4 May HDOP and # of SV Observations versus Time

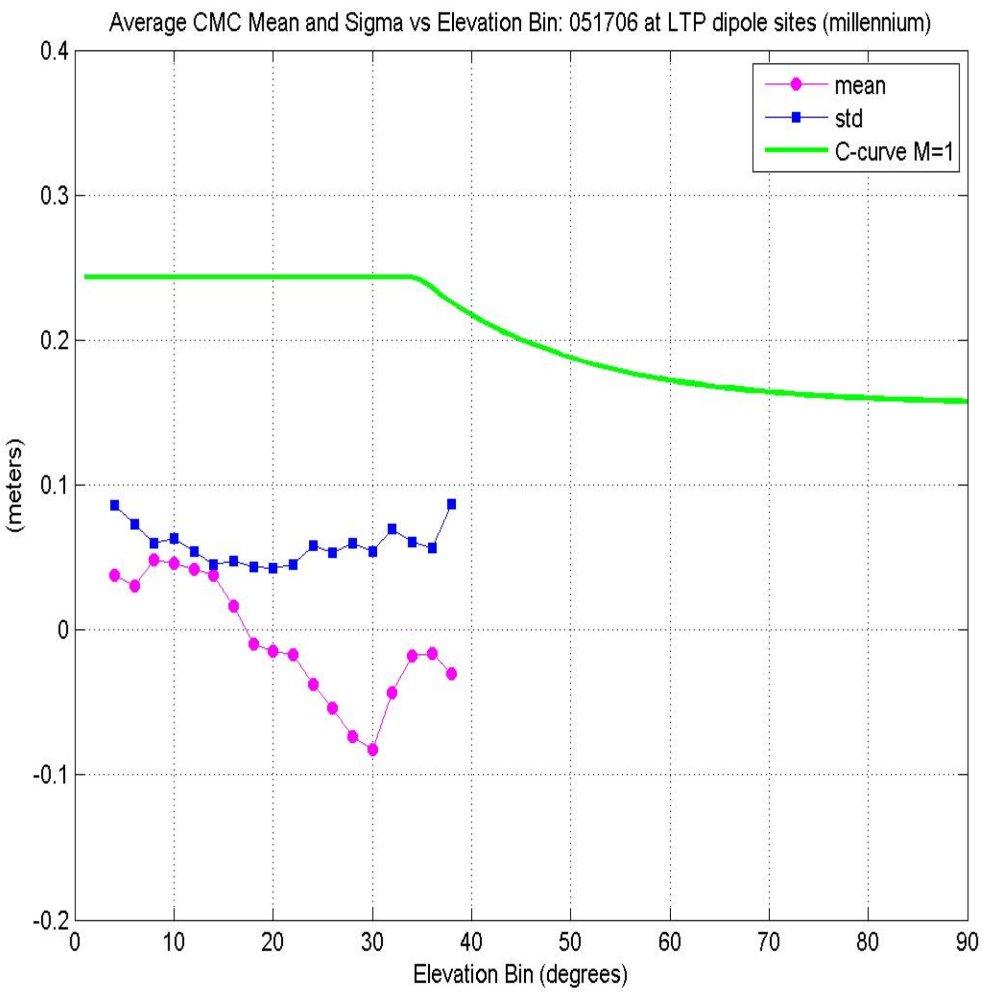


9.2.5 May Clock Error versus Time

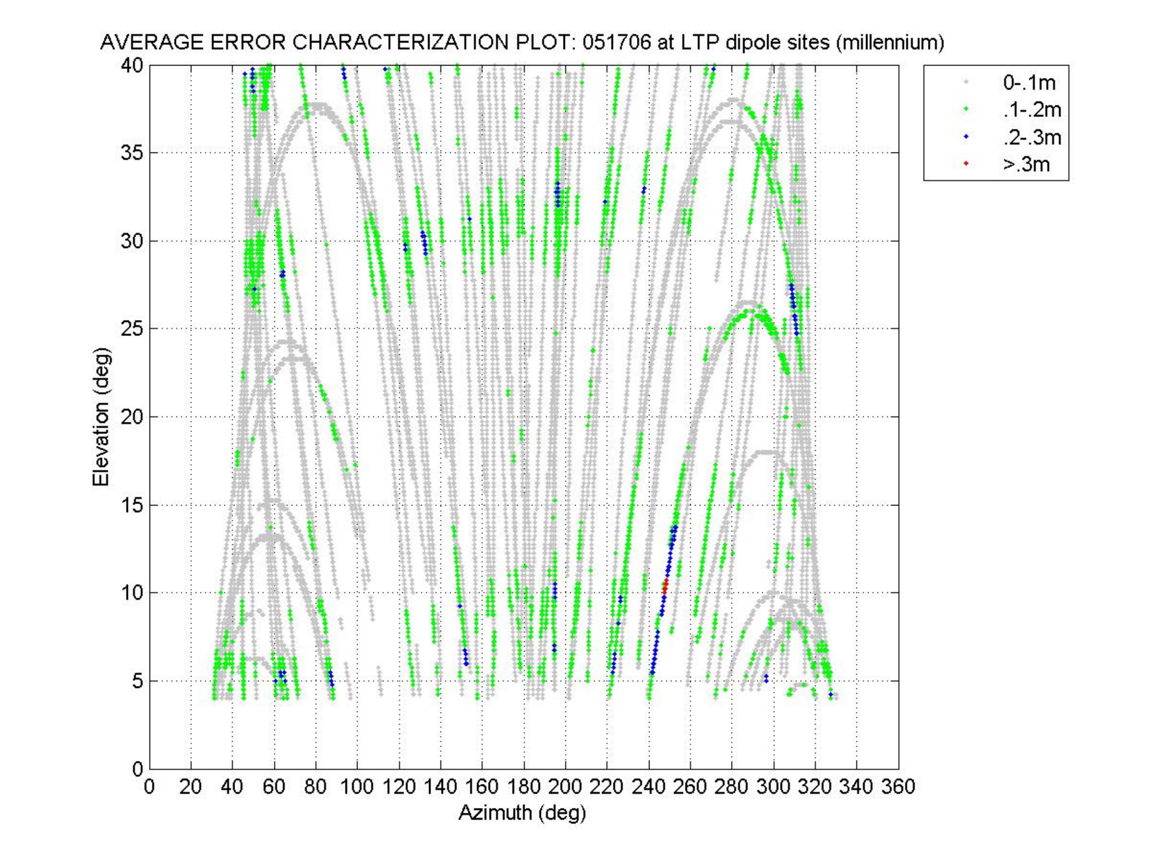


9.2.6 May Dipole Status and CMC (System Average) (multiple)

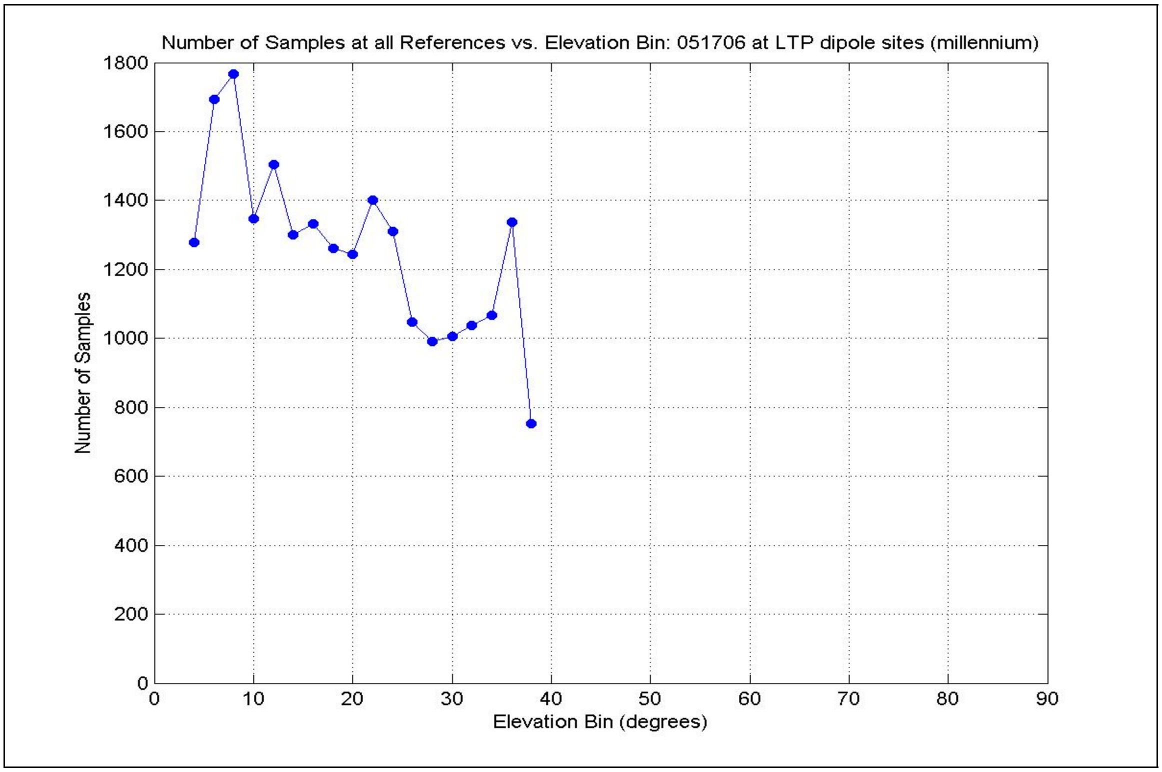
9.2.6.1 May System Dipole CMC Standard Deviation and Mean vs Elevation



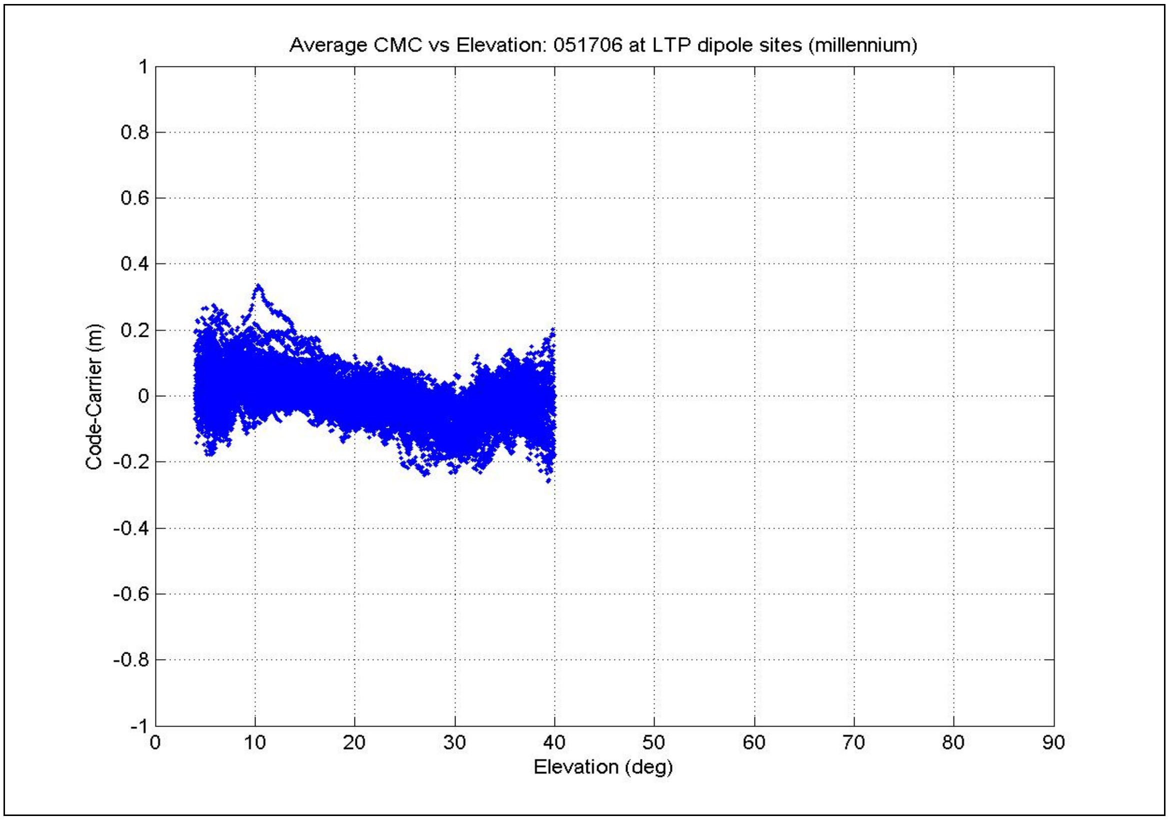
9.2.6.2 May System Dipole Error Characterization vs Azimuth and Elevation



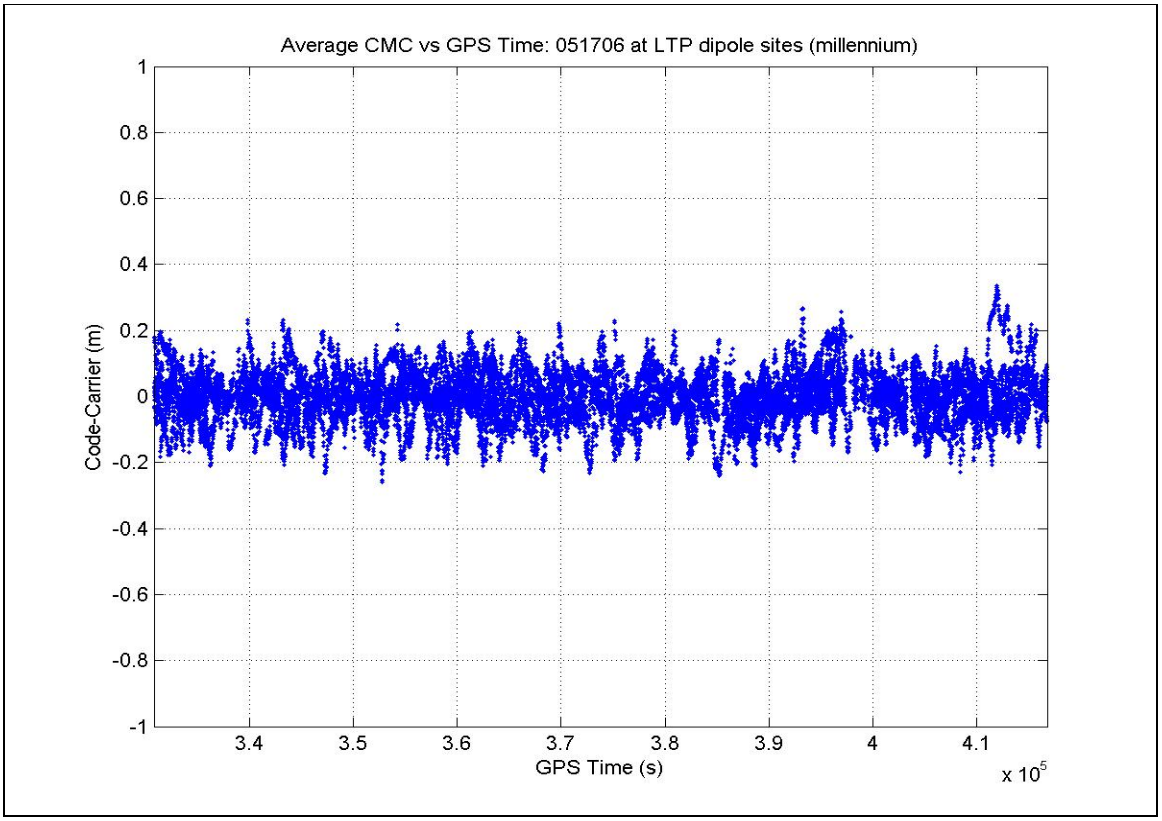
9.2.6.3 May System Dipole Number of Samples versus Elevation



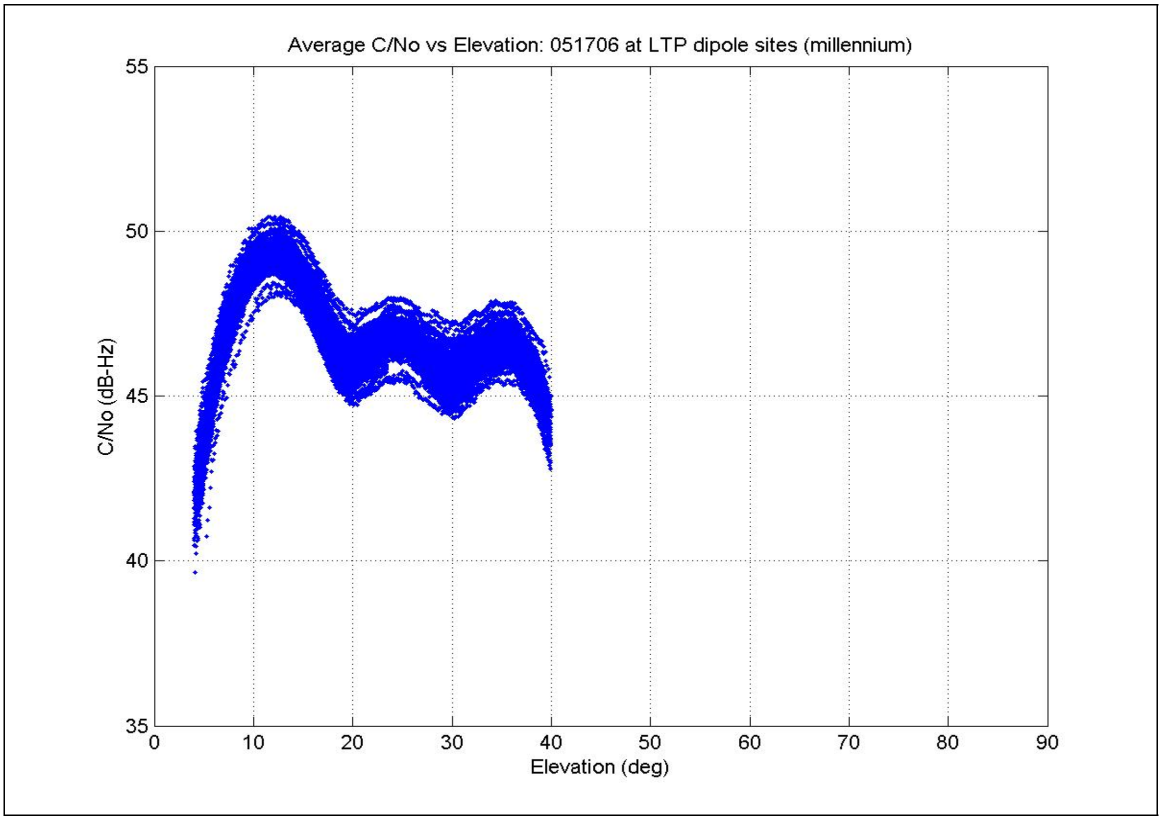
9.2.6.4 May System Dipole CMC versus Elevation



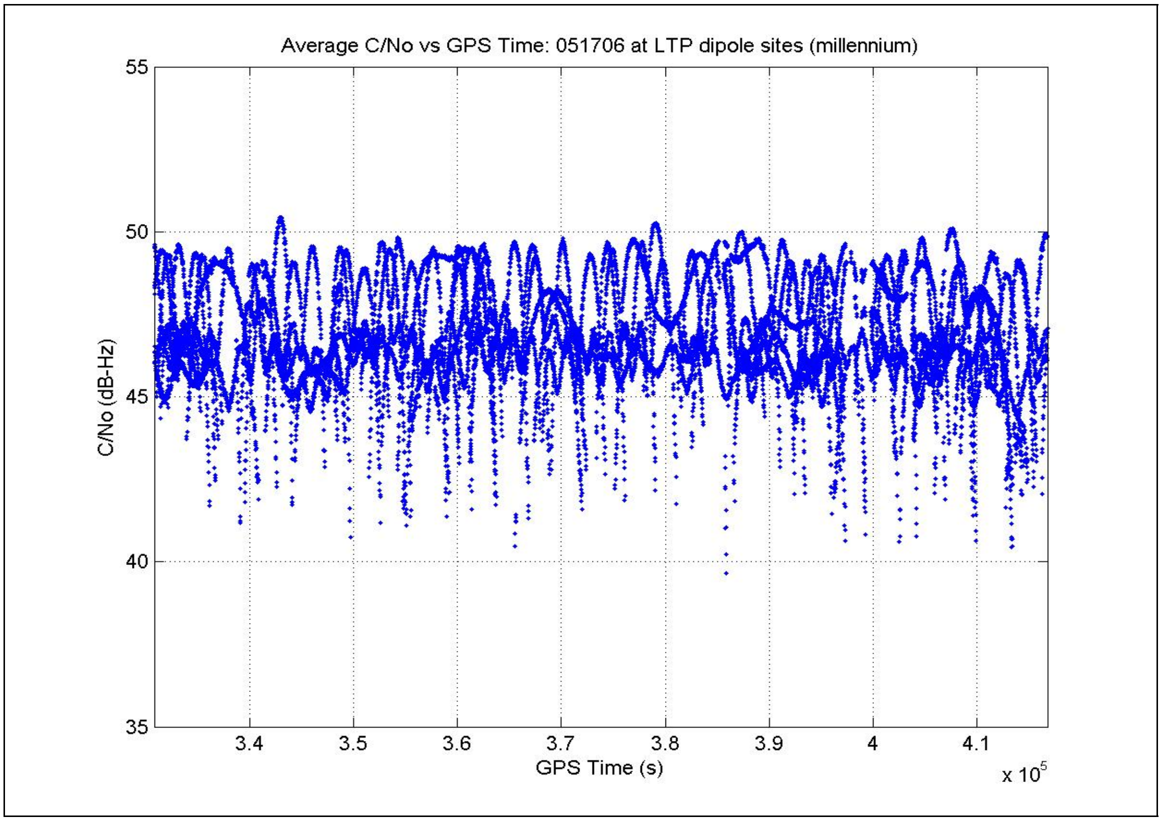
9.2.6.5 May System Dipole CMC versus Time



9.2.6.6 May System Dipole Carrier to Noise versus Elevation

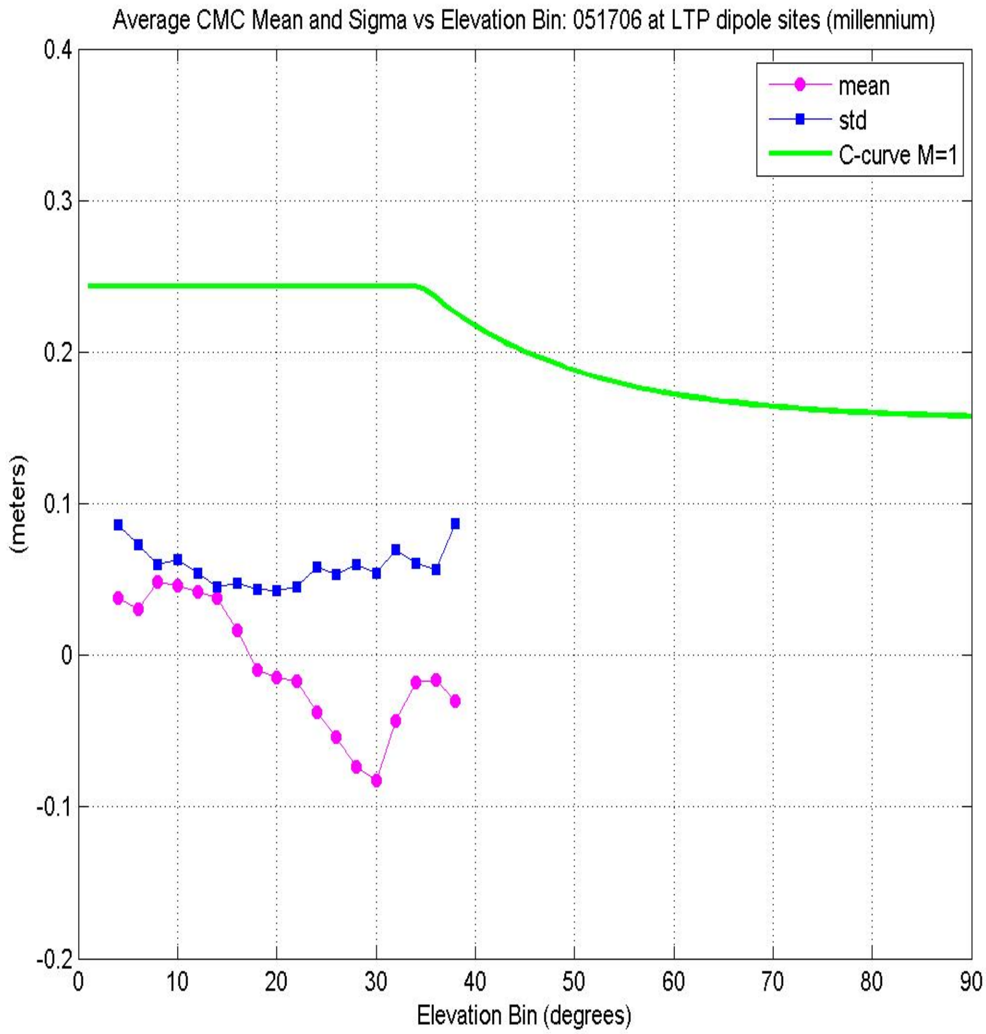


9.2.6.7 May System Dipole Carrier to Noise versus Time

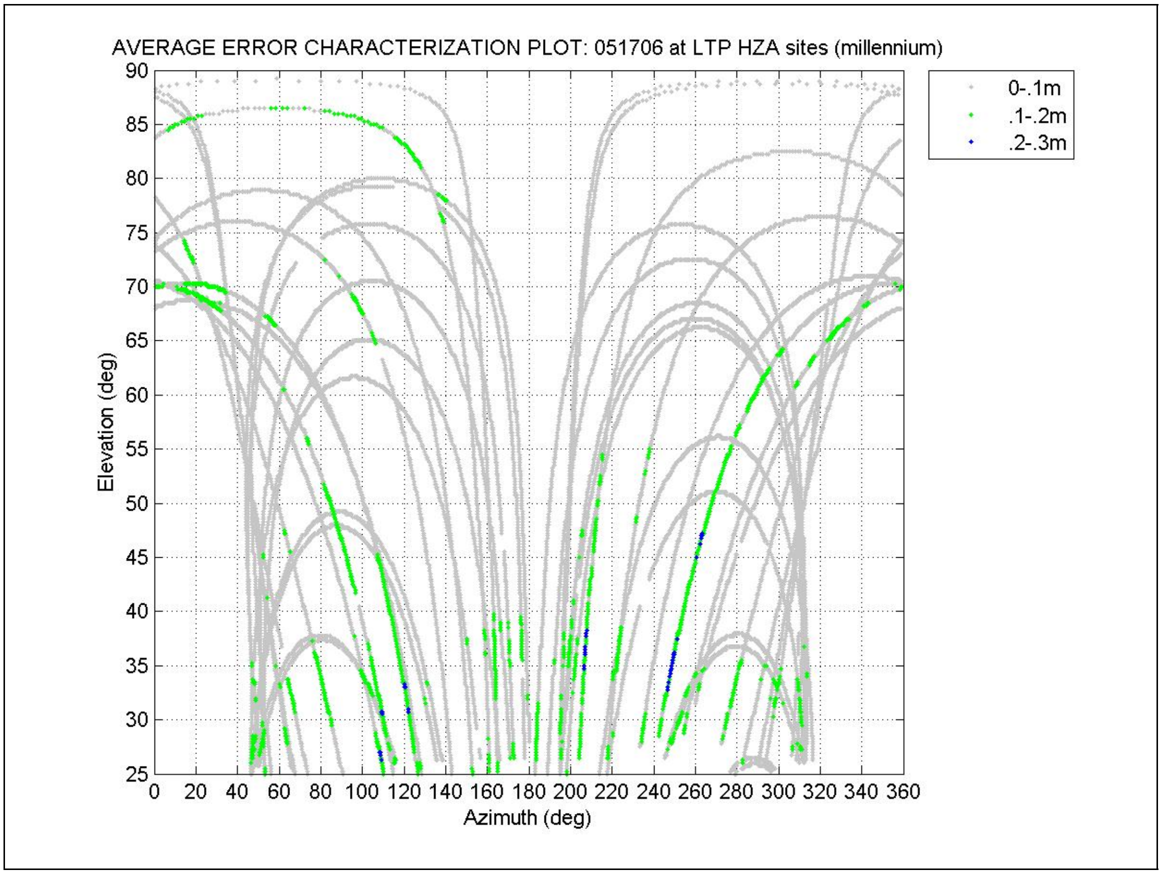


9.2.7 May HZA Status and CMC (System Average) (multiple)

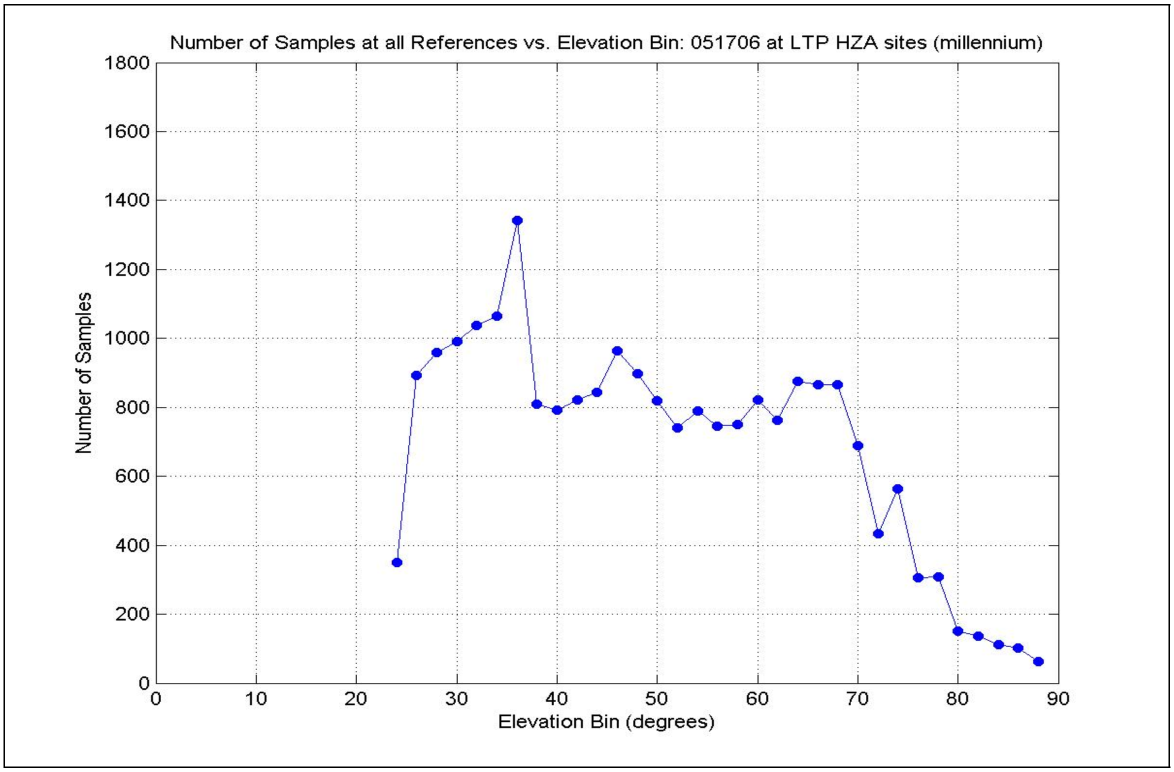
9.2.7.1 May System HZA CMC Standard Deviation and Mean vs Elevation



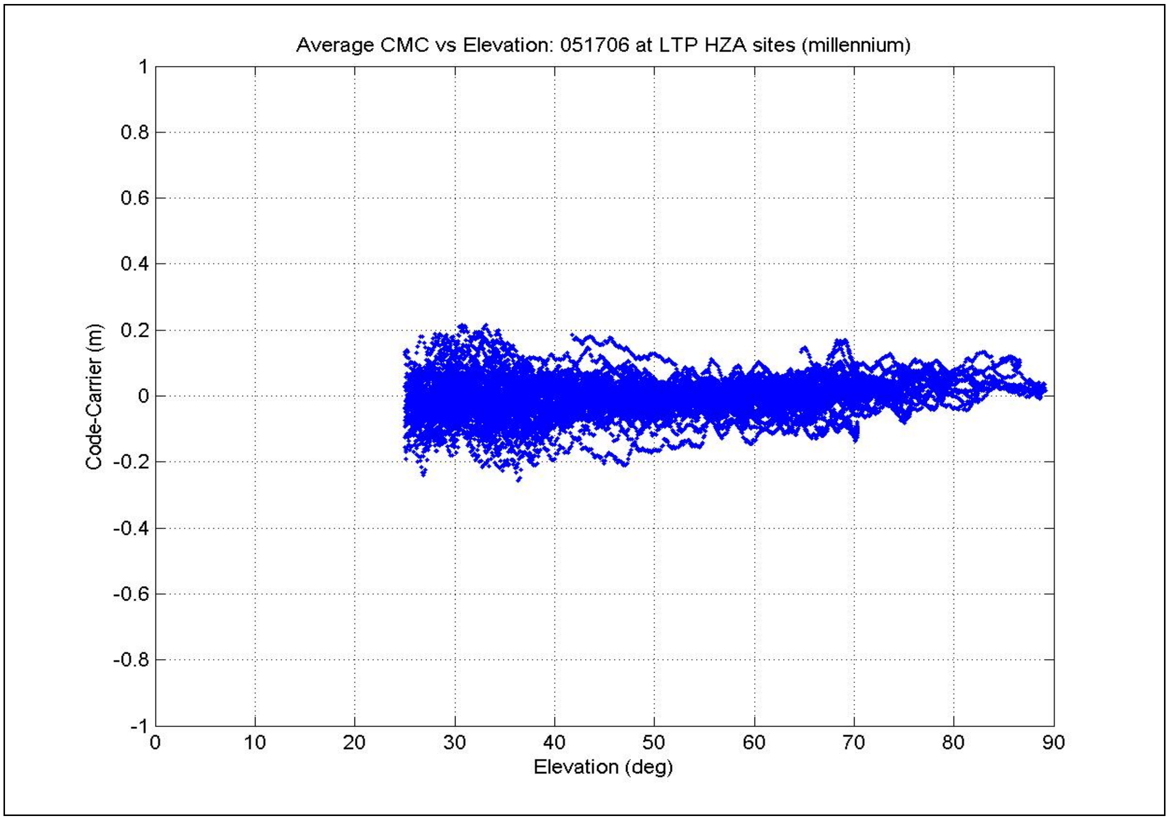
9.2.7.2 May System HZA Error Characterization vs Azimuth and Elevation



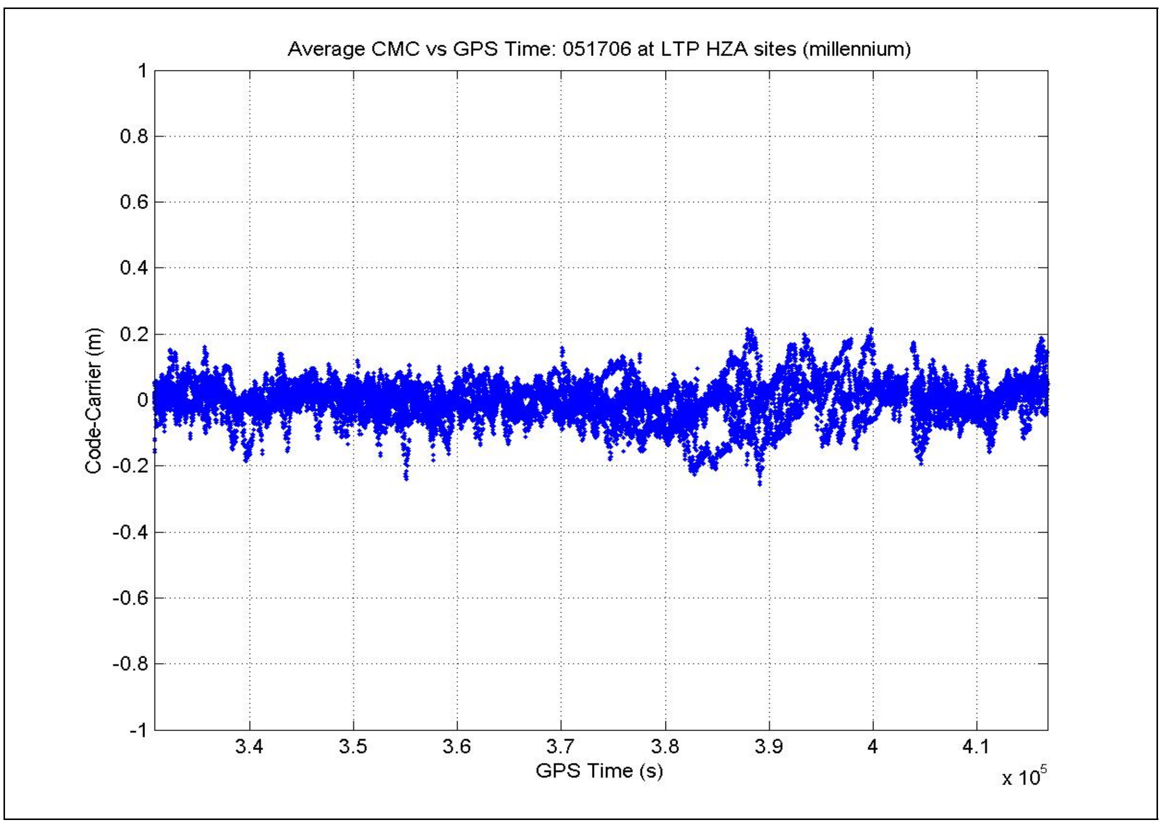
9.2.7.3 May System HZA Number of Samples versus Elevation



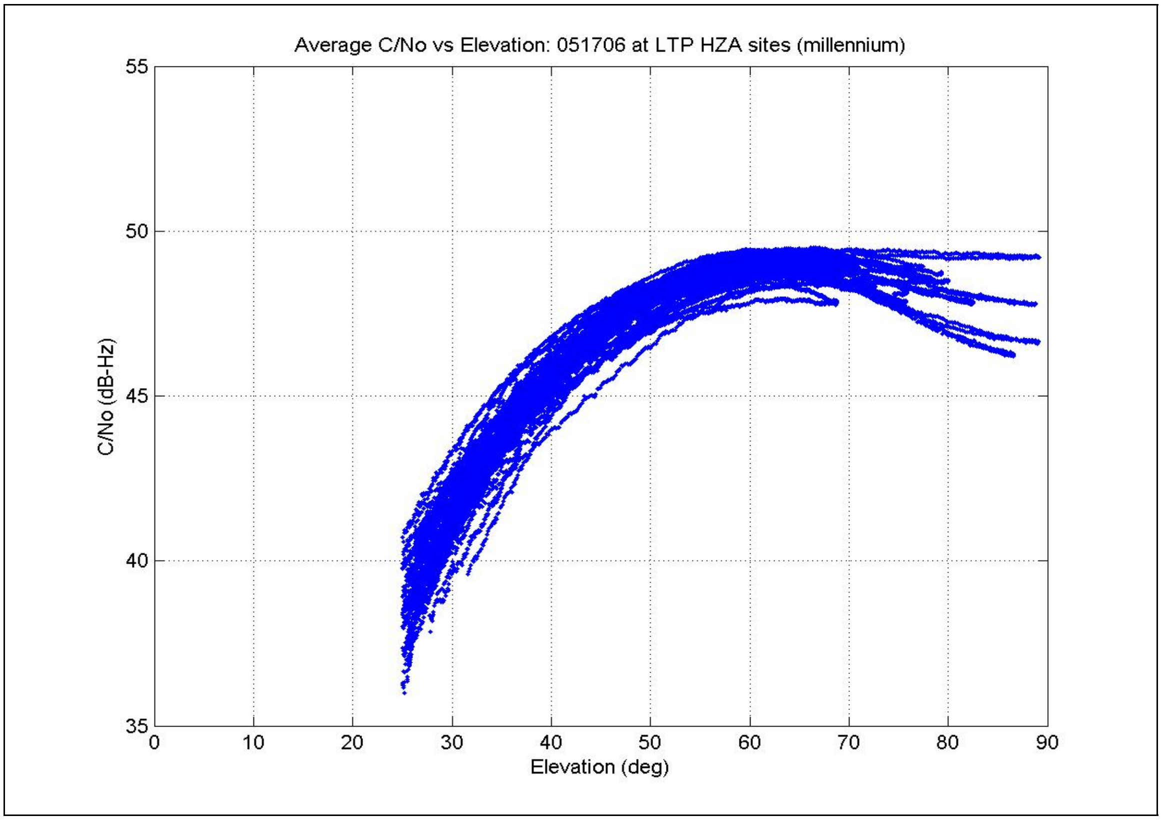
9.2.7.4 May System HZA CMC versus Elevation



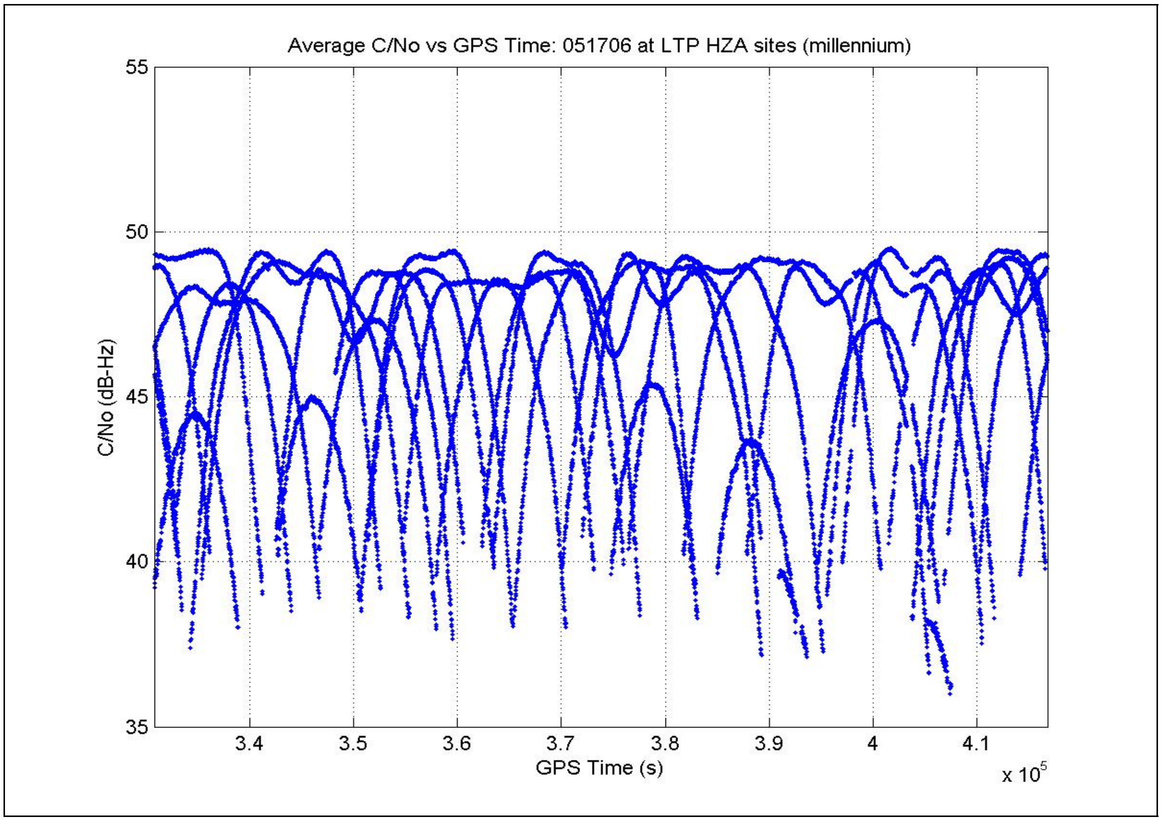
9.2.7.5 May System HZA CMC versus Time



9.2.7.6 May System HZA Carrier to Noise versus Elevation

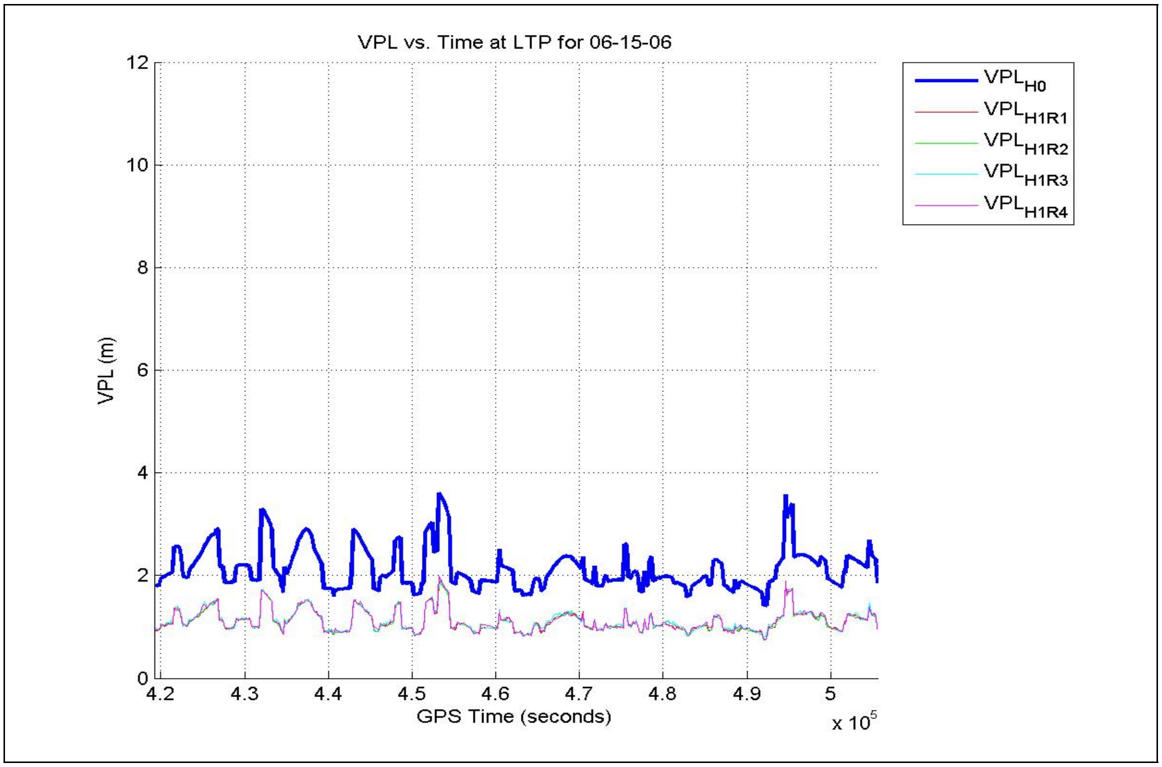


9.2.7.7 May System HZA Carrier to Noise versus Time

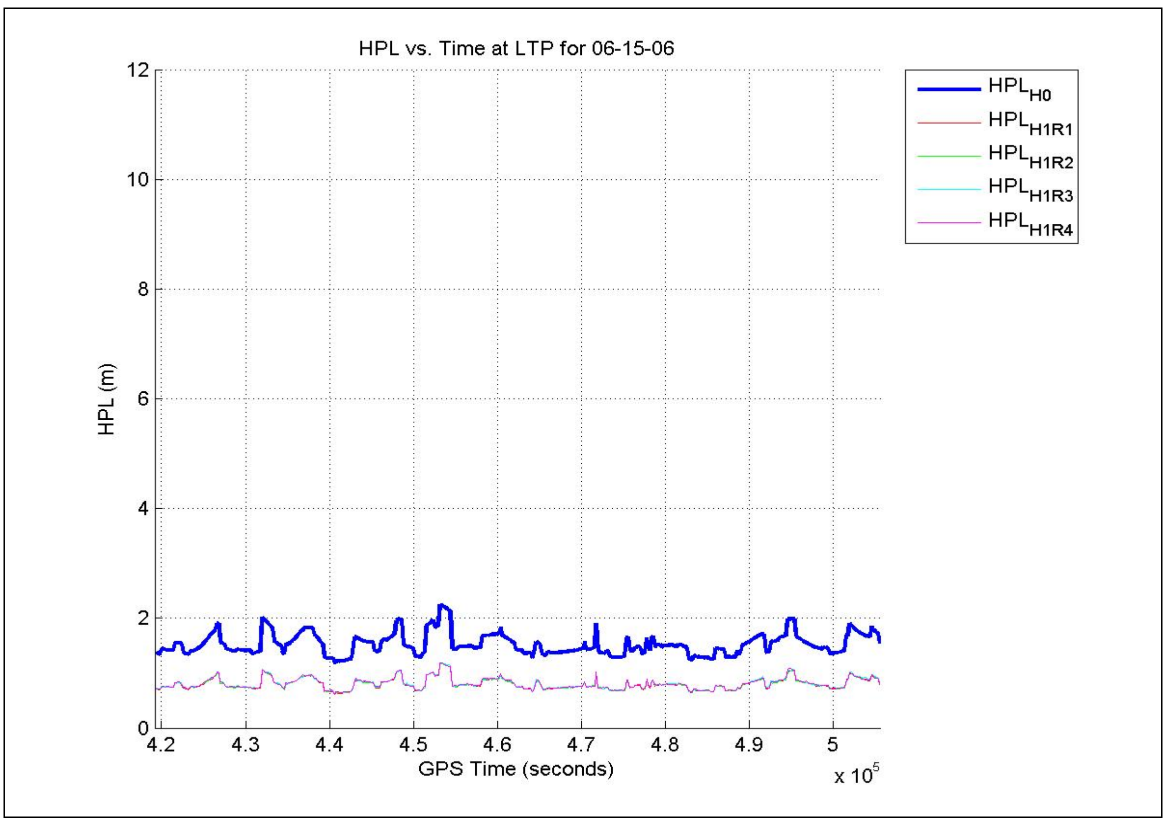


9.3 June 2006 Performance Plots

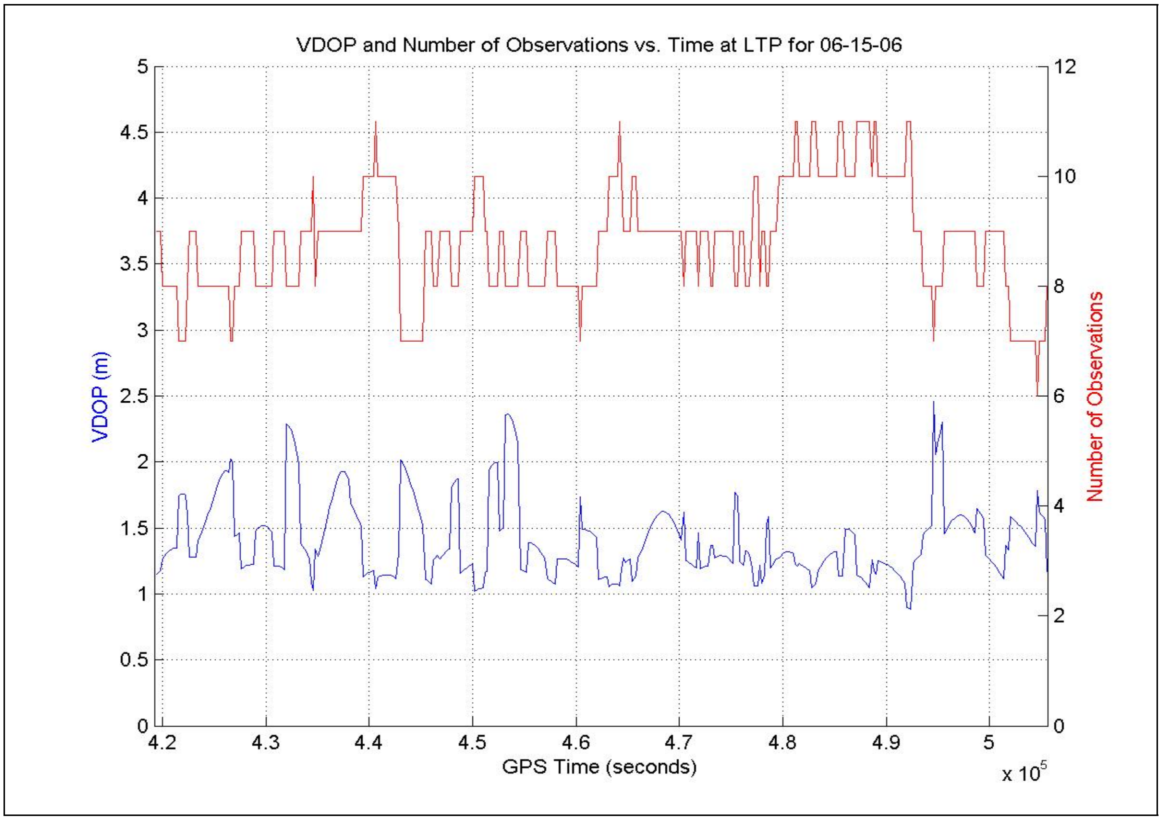
9.3.1 June VPL versus Time



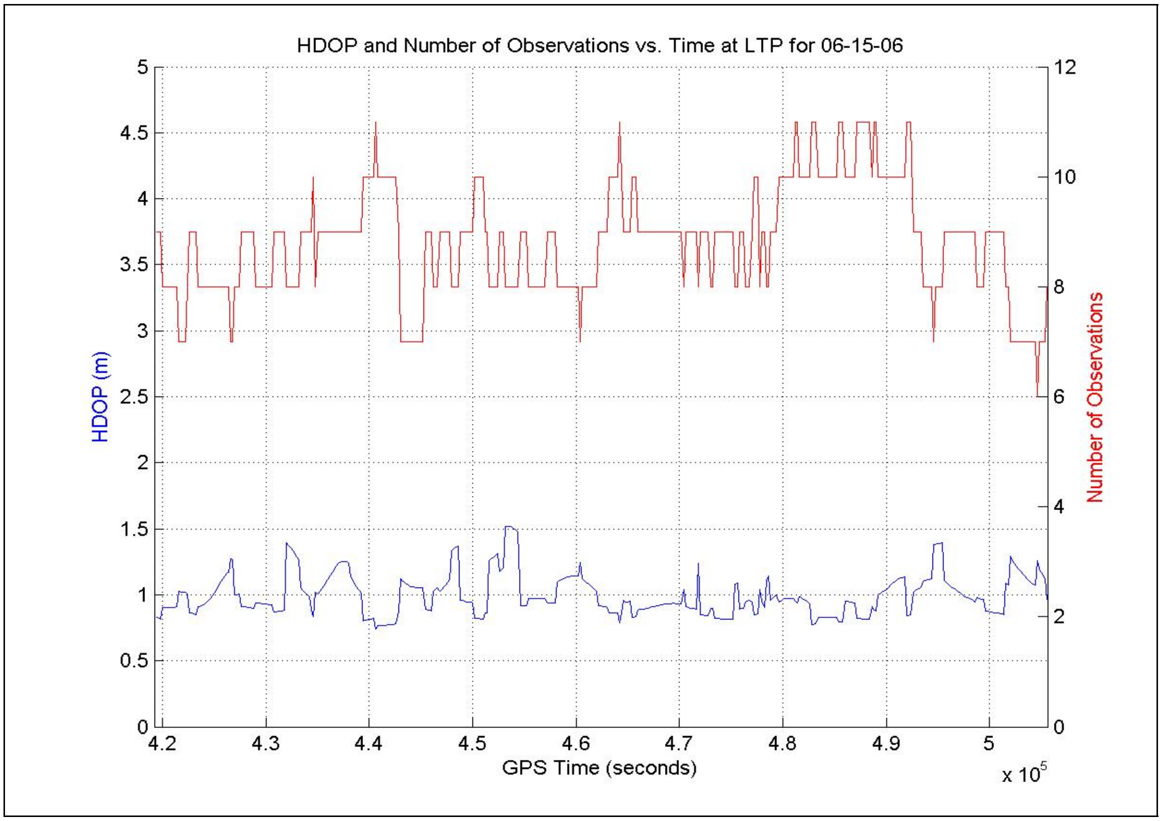
9.3.2 June HPL versus Time



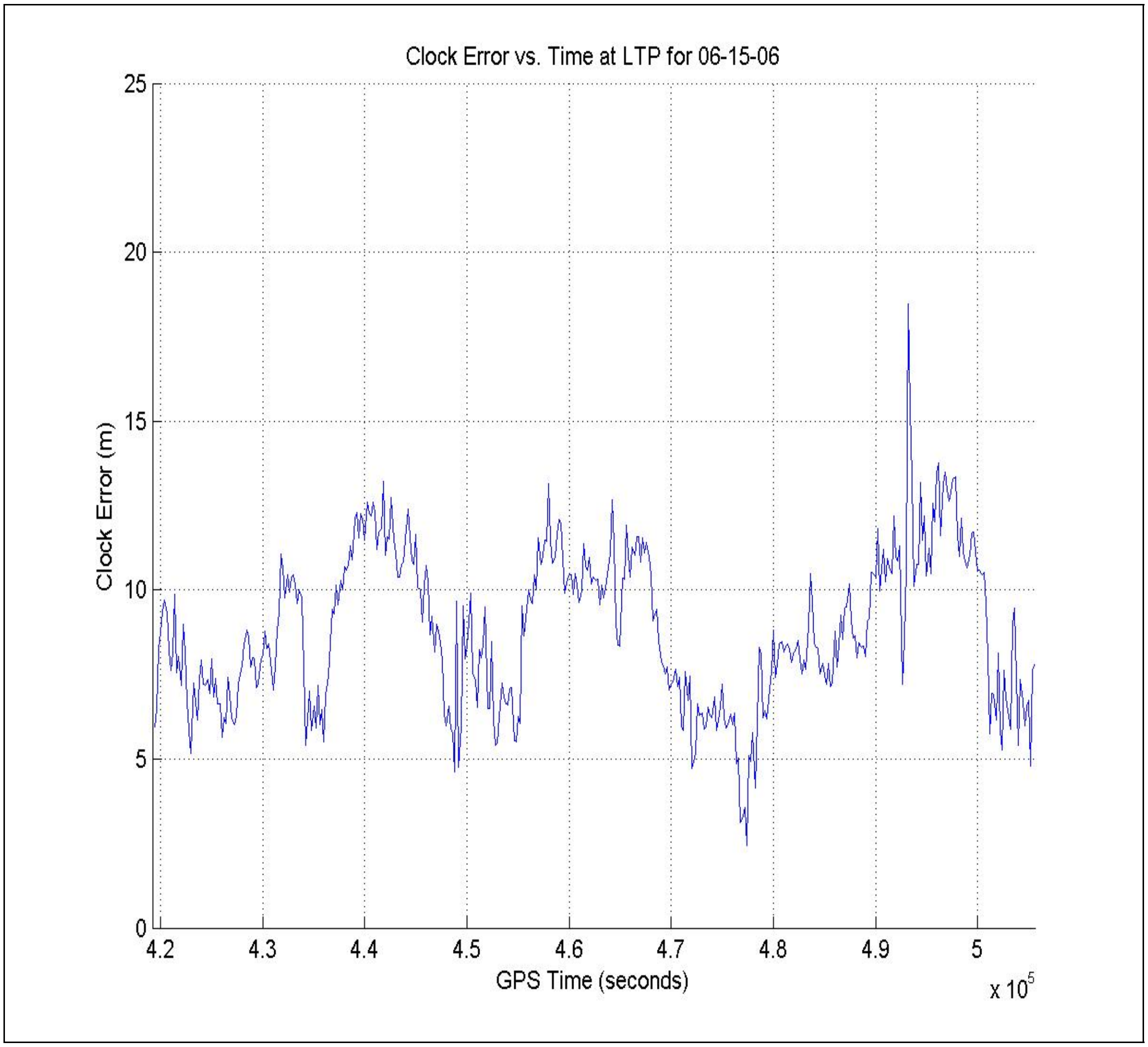
9.3.3 June VDOP and # of SV Observations versus Time



9.3.4 June HDOP and # of SV Observations versus Time

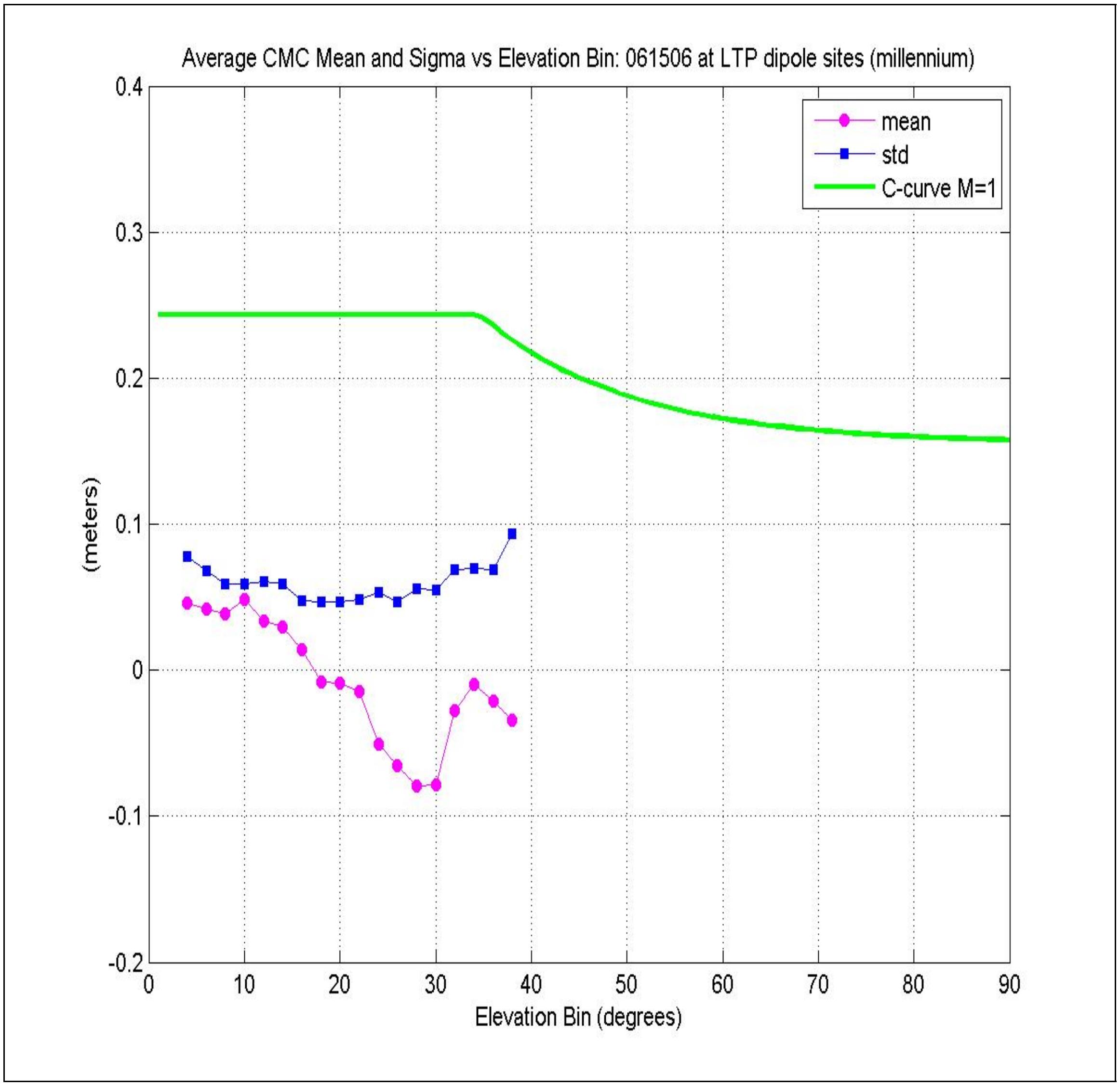


9.3.5 June Clock Error versus Time

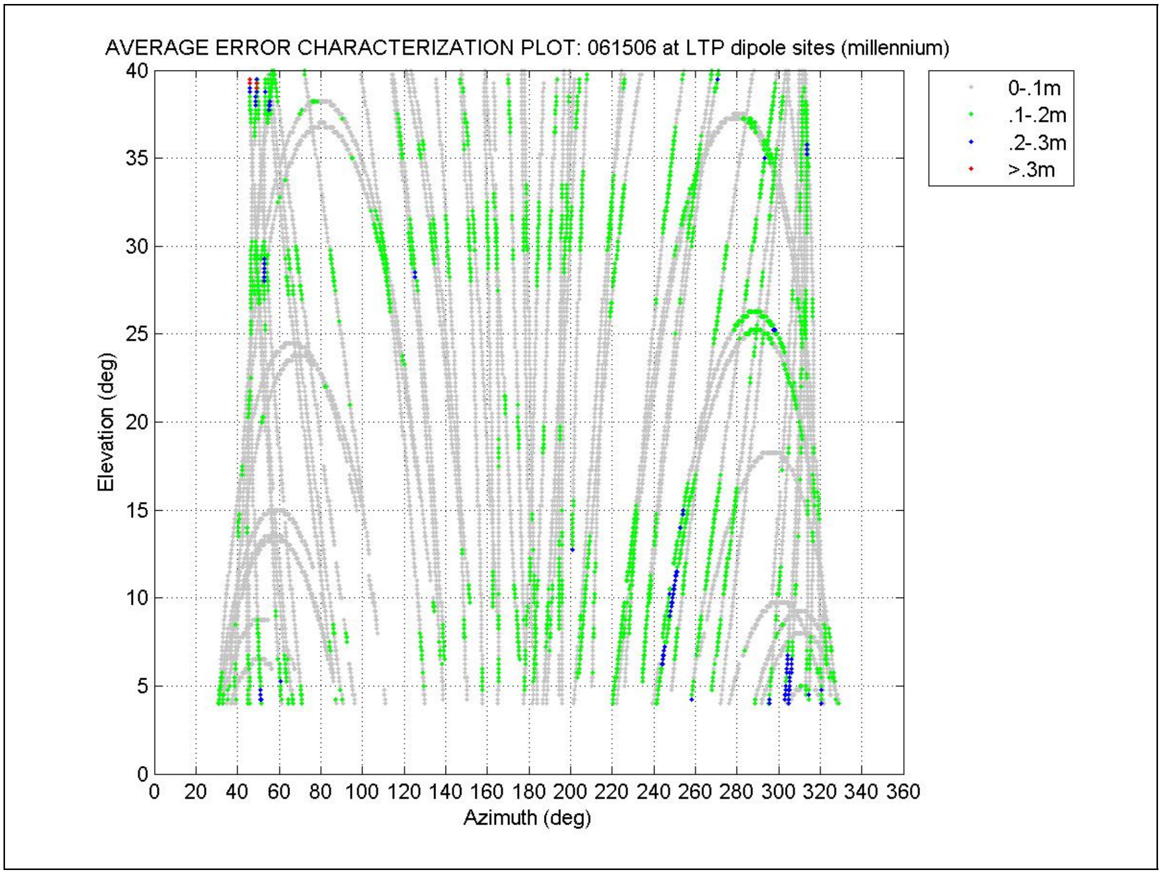


9.3.6 June Dipole Status and CMC (System Average) (multiple)

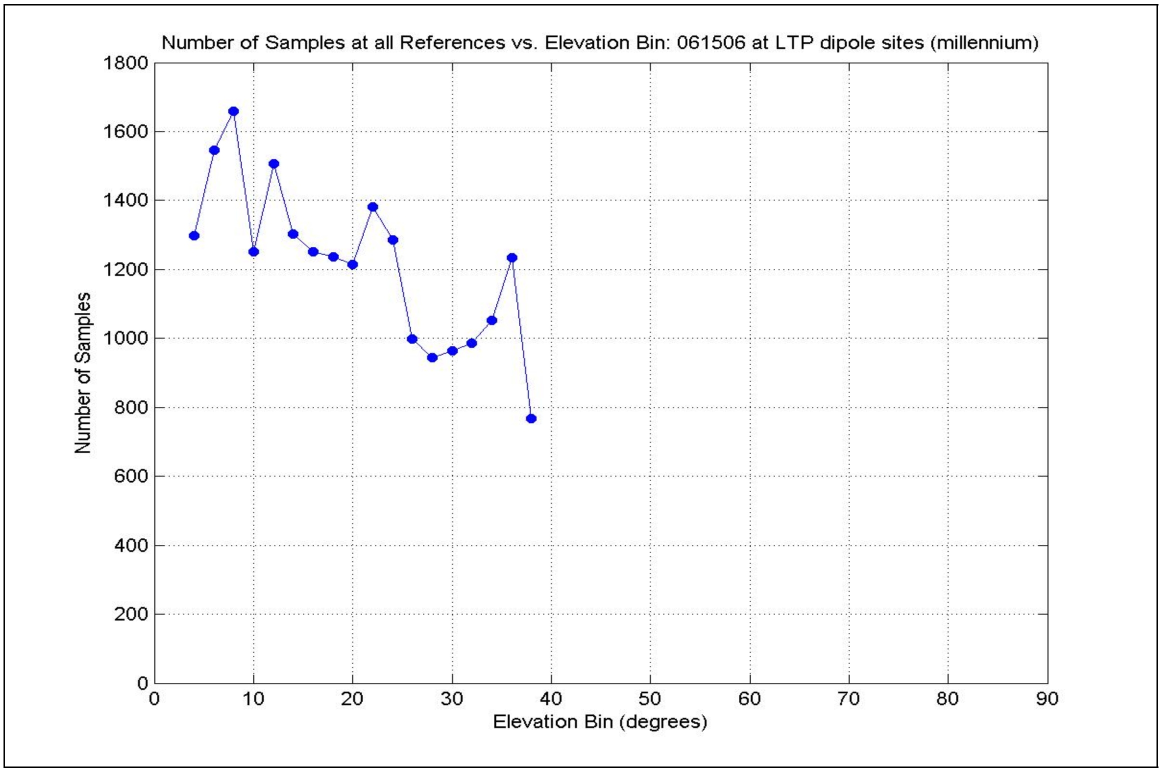
9.3.6.1 June System Dipole CMC Standard Deviation and Mean vs Elevation



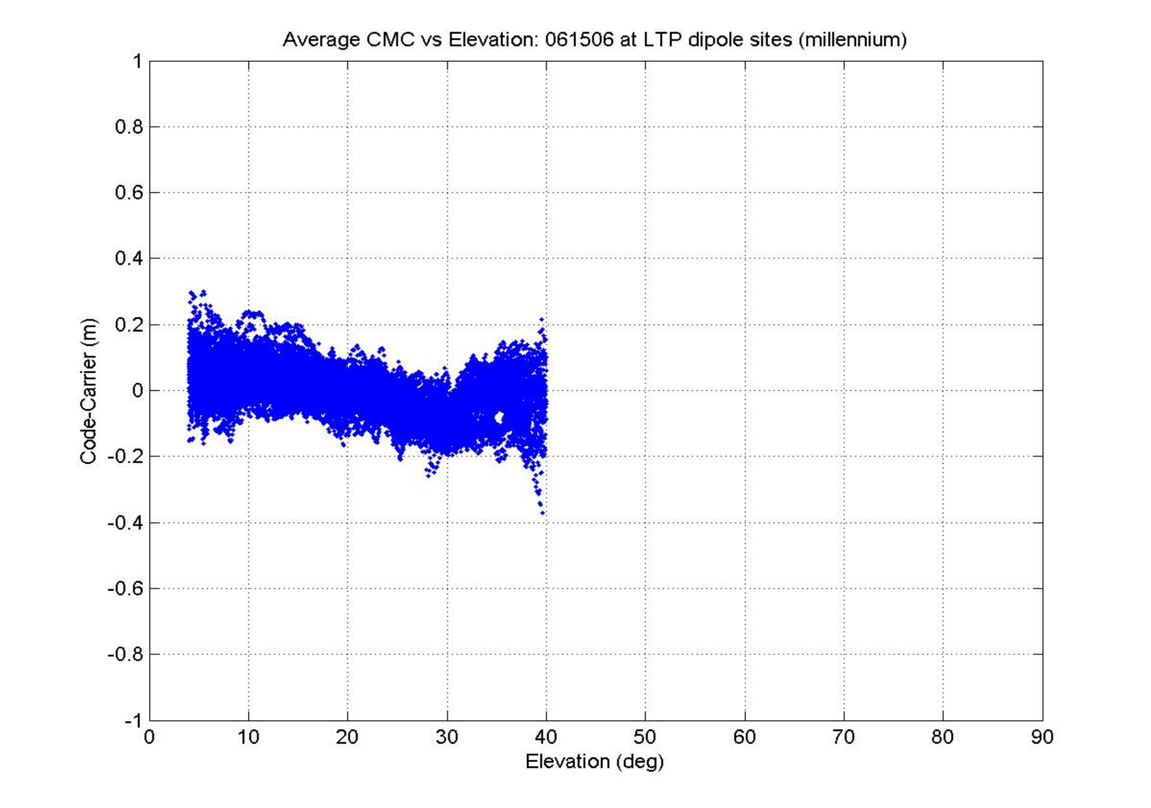
9.3.6.2 Dipole Error Characterization versus Azimuth and Elevation



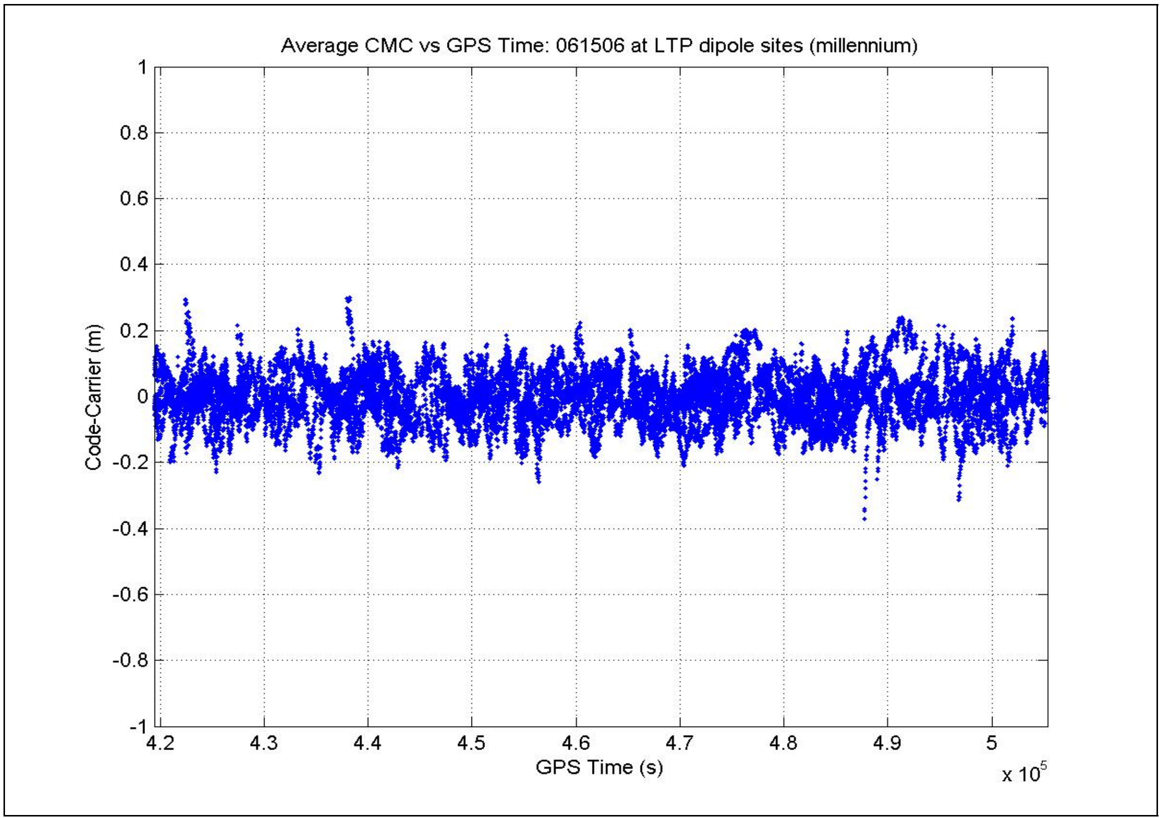
9.3.6.3 June System Dipole Number of Samples versus Elevation



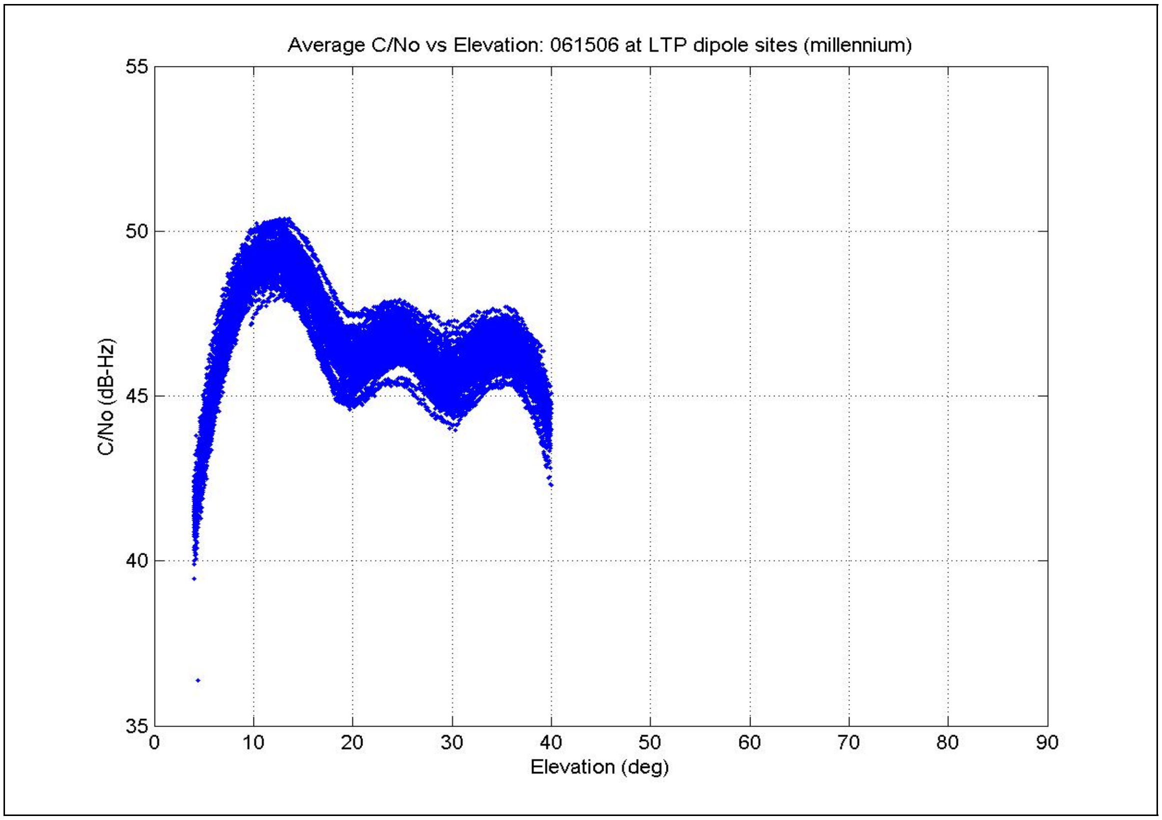
9.3.6.4 June System Dipole CMC versus Elevation



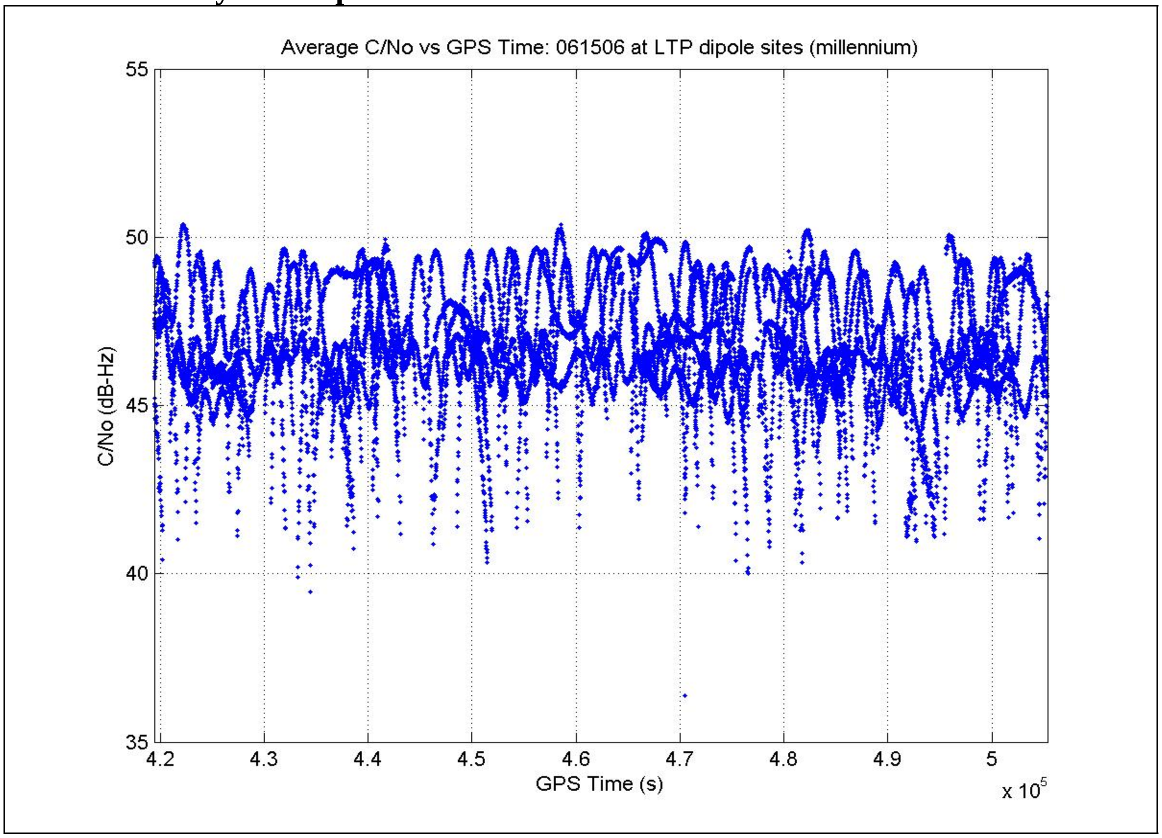
9.3.6.5 June System Dipole CMC versus Time



9.3.6.6 June System Dipole Carrier to Noise versus Elevation

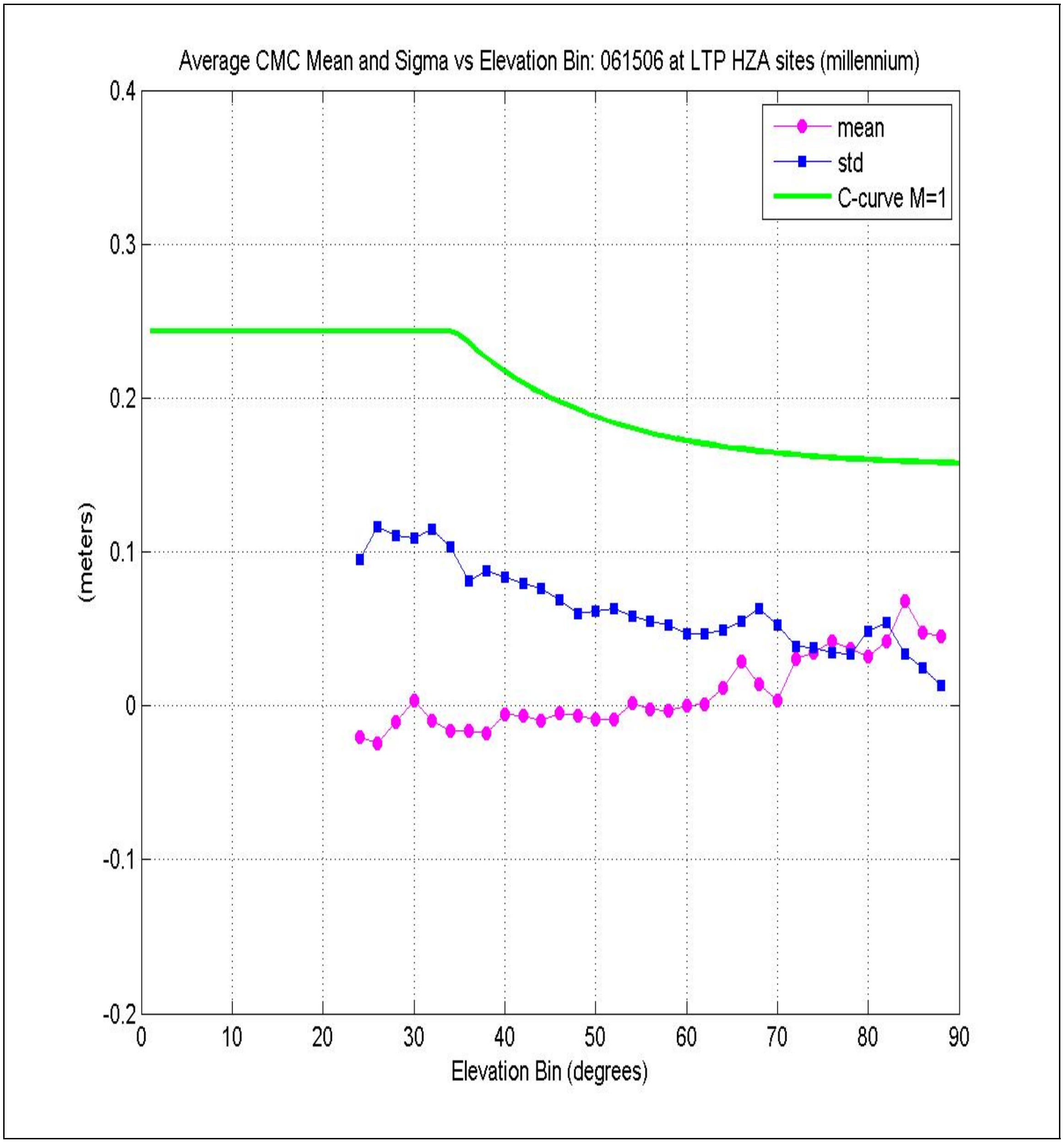


9.3.6.7 June System Dipole Carrier to Noise versus Time

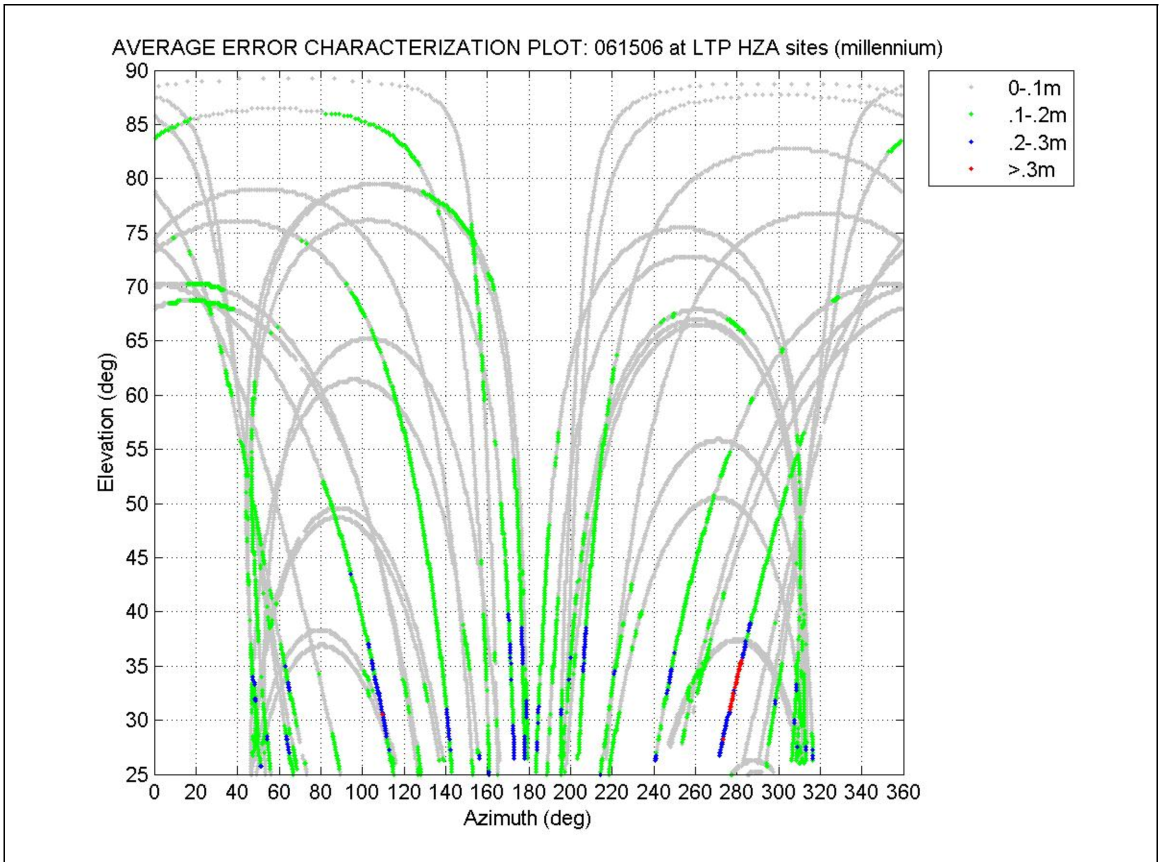


9.3.7 June HZA Status and CMC (System Average) (multiple)

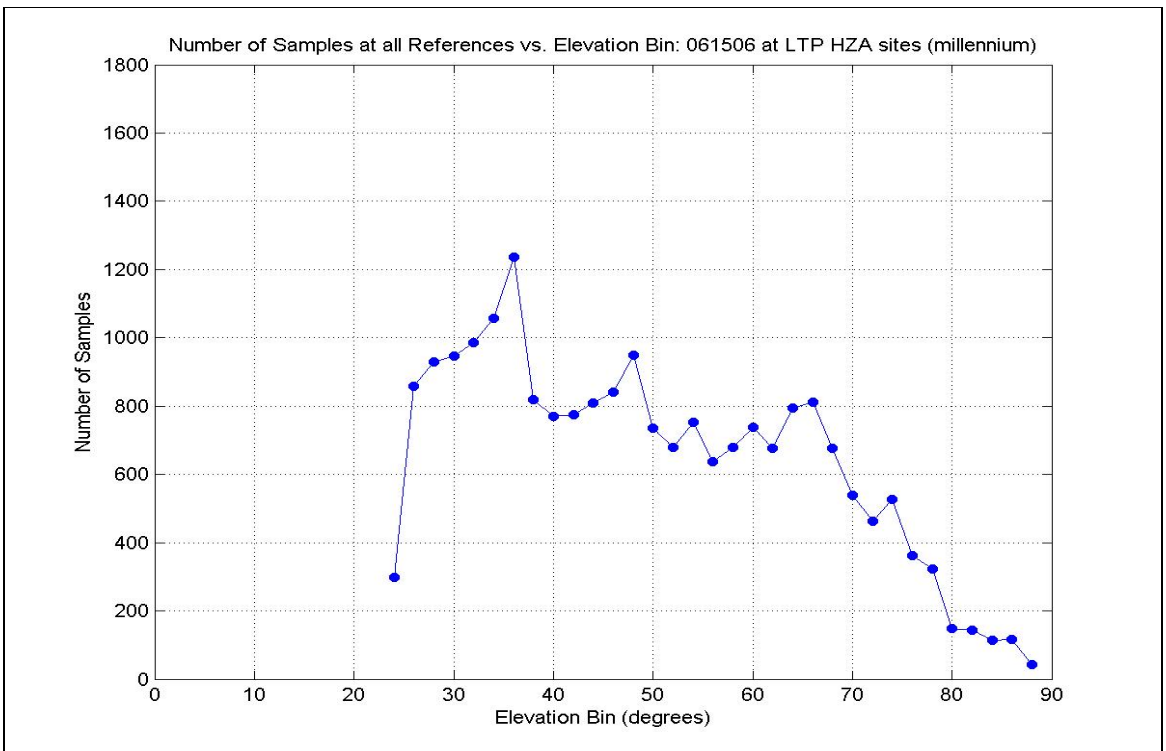
9.3.7.1 June System HZA CMC Standard Deviation and Mean vs Elevation



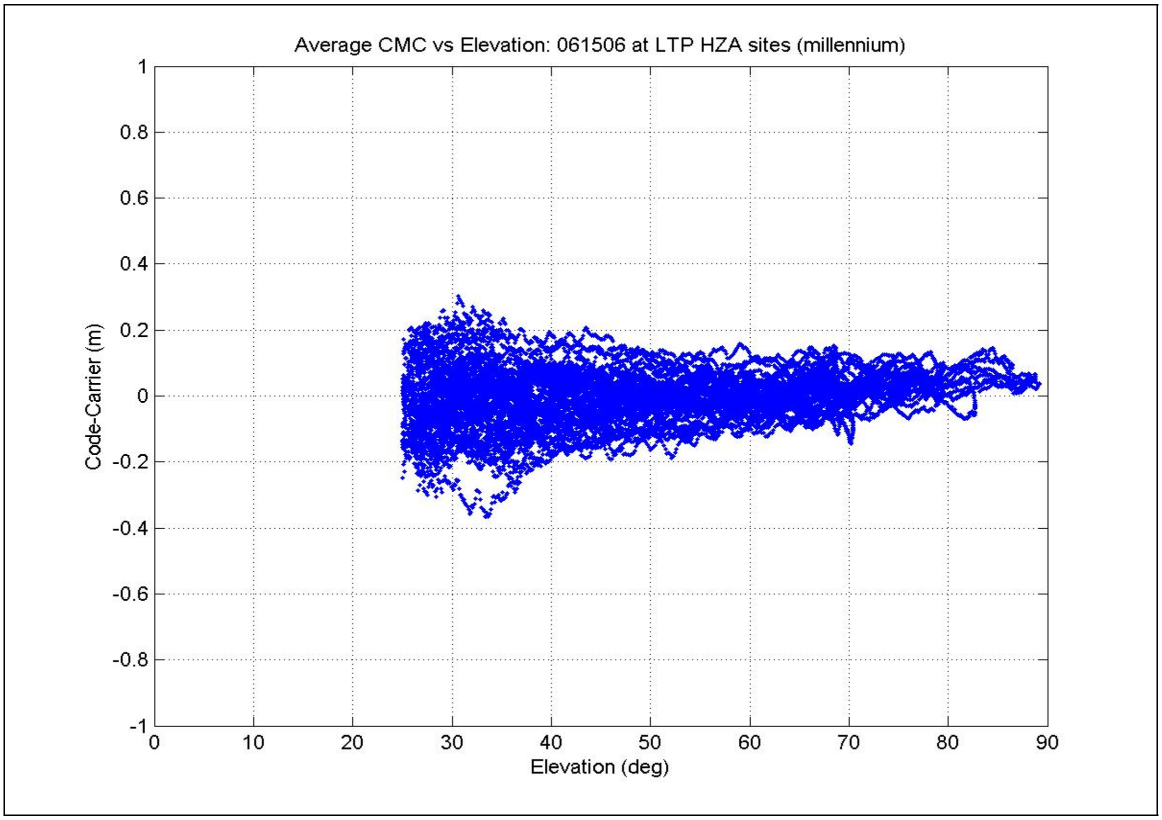
9.3.7.2 June System HZA Error Characterization vs Azimuth and Elevation



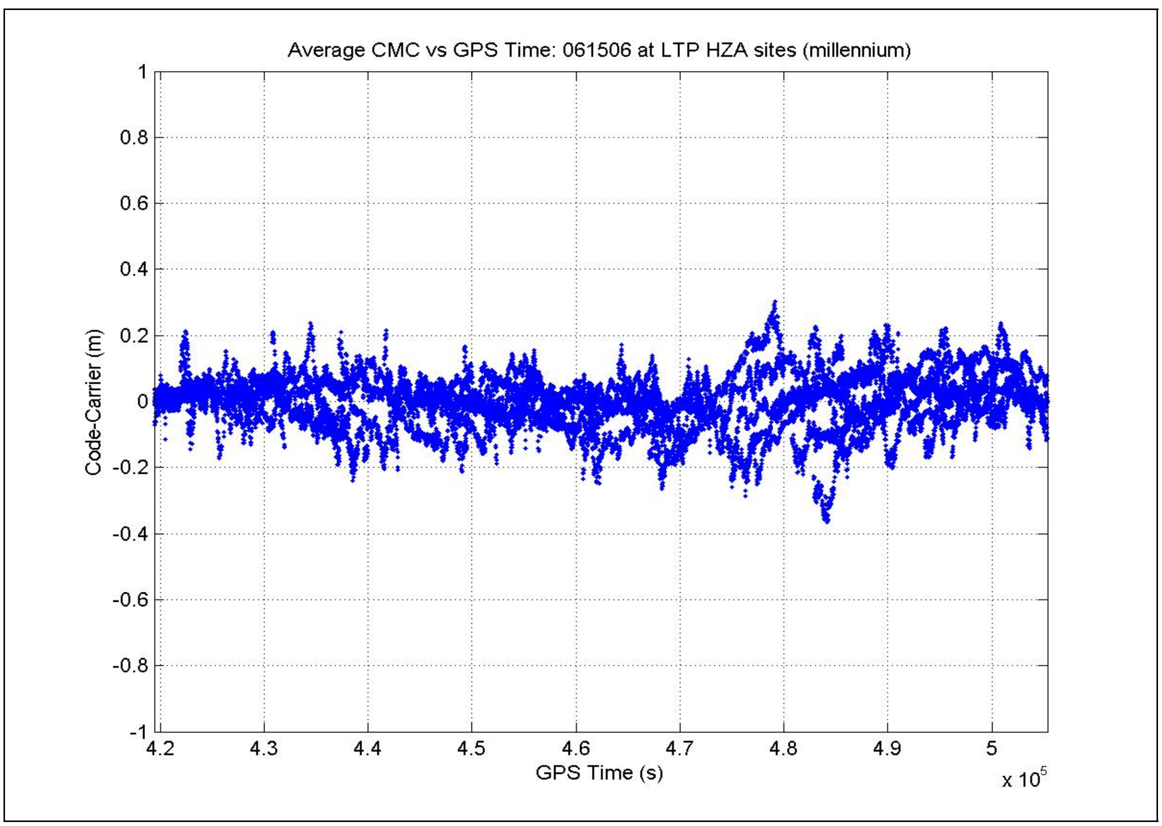
9.3.7.3 June System HZA Number of Samples versus Elevation



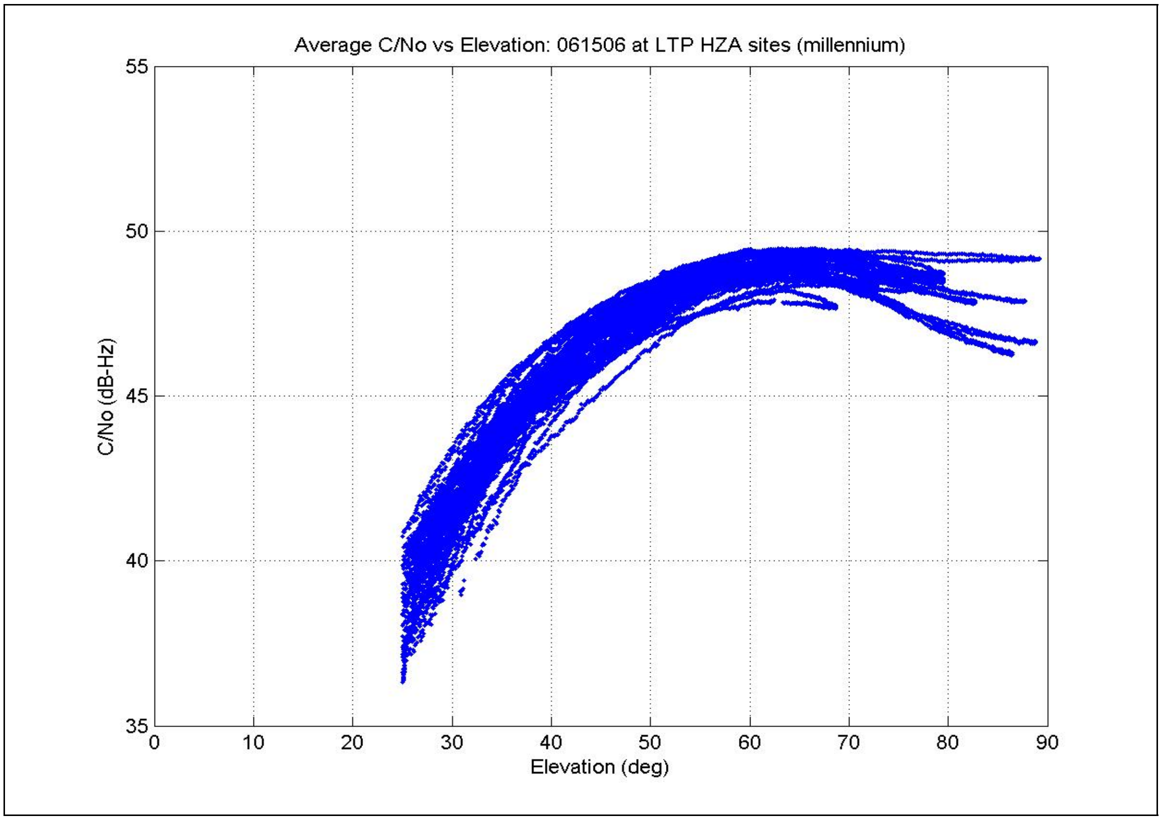
9.3.7.4 June System HZA CMC versus Elevation



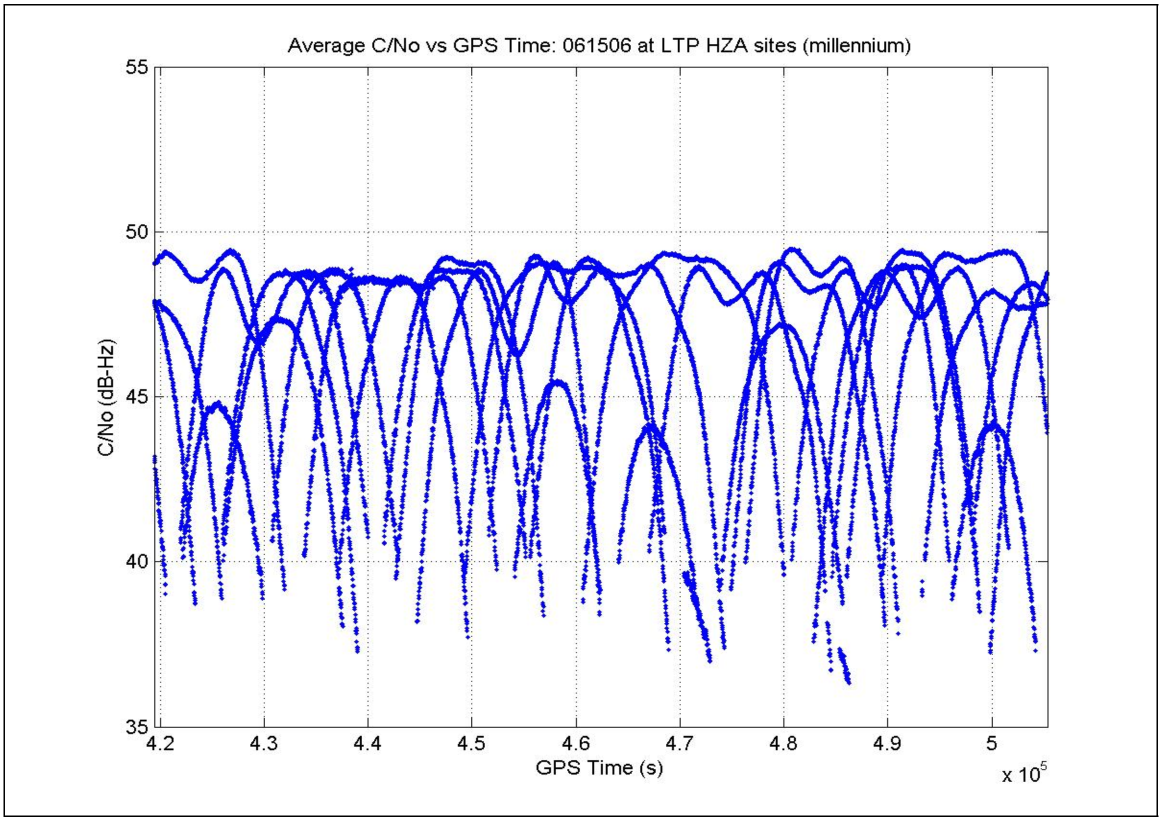
9.3.7.5 June System HZA CMC versus Time



9.3.7.6 June System HZA Carrier to Noise versus Elevation



9.3.7.7 June 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

10.1 Terminal Area Path/Procedure (TAP) Flight Testing

The LAAS, as a precision RNAV system, has built in specifications and standards for the capability of executing complex procedures and approaches. These types of procedures include, but are not limited to, curved approaches, approaches other than ILS look-alike (3 degree straight-ins), and ground based navigation (taxiing).

This flight test was the culmination of several years of planning and work going back to specific congressional language that mandated the LAAS program to pursue the implementation of complex terminal area procedures. The first step was to go to RTCA SC-159 and develop the necessary standards. This was completed in 2005 with the publication of DO-246C. This document along with the companion document, DO-245B, provides the guidance needed to implement basic terminal area procedures. To the extent possible, DO-236, Required Navigation Performance for Area Navigation, was referenced (and adhered to). DO-246C provides for the following leg types: Initial Fix, Track to Fix, Radius to Fix, and Dynamic Downwind-Track to Fix. Each leg type is broadcast by the LAAS ground station, along with precise coordinates, and a waypoint name. Through an existing contract with Rockwell-Collins, the LAAS MMR was modifed to accept the RNP/RNAV procedure and provide guidance to a CDI or Flight Director, similar to an ILS. Because the ILS is an angular system and LAAS is not, the exact sensitivity with respect to deviation display at the CDI or Flight Director must be included in the broadcast message for each leg type. All of this information is broadcast from the LAAS Test Prototype, operating at the William J. Hughes Technical Center. Approach plates were designed in-house, but were intended to mimic a RNP/RNAV procedure at Memphis International Airport. The TAP can be used to safely guide non-FMS equipped aircraft to the ground along a repeatable path, thereby conserving fuel and easing air traffic concerns. Additionally, the waypoints were computed in-house with help from the avionics group (Mike Magrogan) and the military liason, Lt. Col. Philip Fittante. Over 100 hundred approach were flown in the FAA Boeing 727, N40, with the flight operations group providing the pilots, including Keith Biehl, Larry Van Hoy, John Geyser, Mark Earhart, and Lori Farber. Flight engineers were Armando Gaetano or John Tatham. Titan provided flight test support, and a number of other LAAS project people were involved including, Dean Joannou, Ruben Velez, John Warburton, and Victor Wullschleger. Observers from FAA HQs included Dave Peterson and Pete Magarelli. FedEx provided line pilots who observed the testing over a two-day period as well.

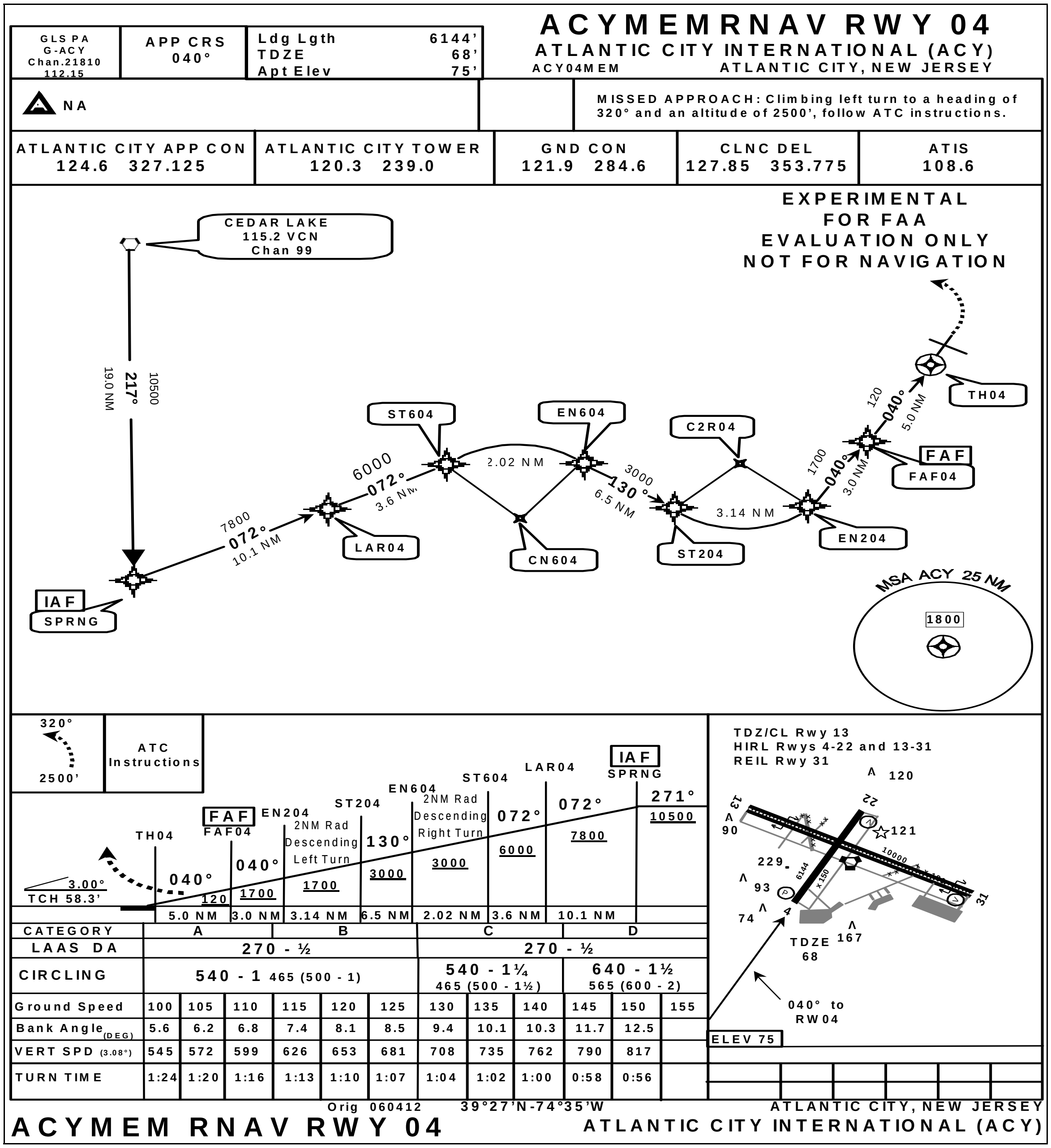


Figure 9: ACY (Memphis Overlay) LAAS Curved Approach Plate

The primary test approach plate used is shown above in **Figure 9,** and flight test data is given below in **Figure 10**. In general the results were very encouraging from a fly-ability standpoint, and the fact that the navigation sensor error was minimal. More information will be forth-coming in a flight test report. Also, more work is needed for this standard to be available in a TSOed box. The plan is for FedEx to fly experimental procedure in September/October 2006 time-frame and provide a report and recommendations on the outcome.

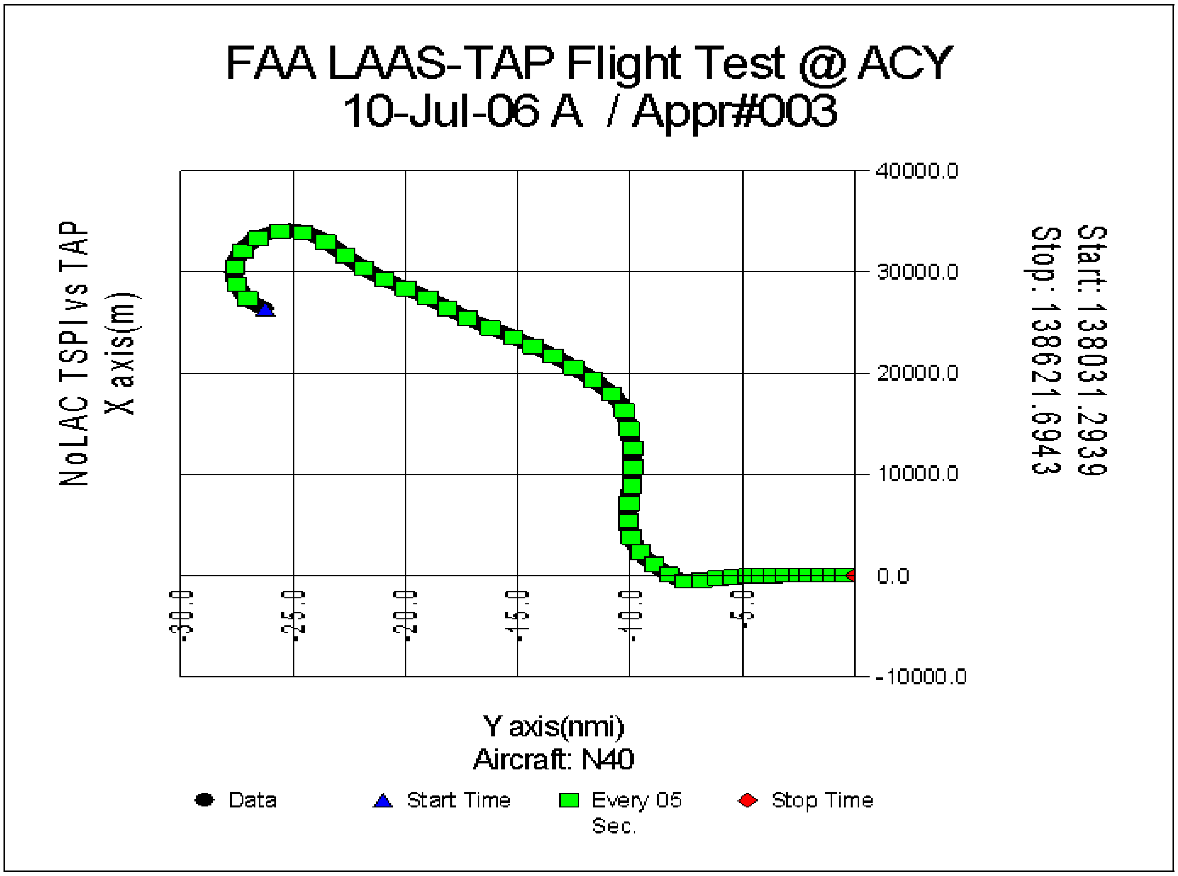


Figure 10: TAP Flight Test – Result Data

10.2 The Honeywell LAAS Program - ADD review

The FAA Technical Center continues to support the LAAS contract with Honeywell International, located outside of Minneapolis, MN, at their Coon Rapids facility. The primary, near term, goal has been the creation and approval of 11 Algorithm Description Documents (ADDs), one of which the FAA Technical Center has direct responsibility for is termed "Non Zero Means".

The ADDs had to pass through 4 gates for final approval from the LAAS Integrity Panel (LIP). Gate 1 is a thorough description of the threat and proposed mitigation. Gate 2 is validation of the mitigation technique. Gate 3 is the algorithm and description of all requirements and reference to the fault tree for the hazard. Gate 4 is the test case description and methodology.

Mr. John Warburton, Manager of the Navigation Branch at the Technical Center, is the Technical Director of the LAAS program. He has responsibility for the direct oversight of each ADD and coordinates with the government POCs as needed to resolve any issues. One outstanding issue is with the ionospheric storm monitor, which is ADD 4. The LAAS ICD allows for the broadcast of a sigma term to "bound" the nominal case. Since the Iono storm of 2003, the FAA has taken a closer look at the potential for storms that may create a hazardous situation, if not properly monitored, for an aircraft on approach.

Working in conjunction with Stanford University, a key LIP member, there have been several strides taken to describe the Iono threat as best as we understand it, for CONUS operations, and to come up with several monitoring schemes. As it is with most threats, some corner cases can be the most troublesome. In the case of the ionosphere, a slow moving storm with a steep gradient can overtake an aircraft on approach before the ground station can react.

The FAA Technical Centers' Test-Bed for WAAS and LAAS has proven to be an effective tool and analyzing these storm conditions. The ADDs are currently scheduled to be implemented in non-certified software for testing this fall, at the Memphis International Airport. There is follow-on work planned with Honeywell and the Memphis station to upgrade processors and to approve the software. A LAAS system developed by Honeywell is planned for the FAA Technical Center in 2008. The system will support testing and certification efforts that may arise. Currently the FAA Technical Center has a certified Rockwell airborne receiver that is used in flight test against the Ohio University/FAA Technical Center built prototype.

The 11 HI ADD's (including the FAA prepared "non-zero means") were submitted to the FAA for final review during this reporting period. A brief summary of the ADD's title and purposes are provided in the following text:

- ***Computation of Broadcast σ_{pr_gnd}***
  The PSP must have an algorithm in place to be used for computing a broadcast σ_{pr_gnd}. σ_{pr_gnd} is the standard deviation of the error in the differential correction for a given ranging source. Since this error distribution is generally non-Gaussian in the tails, an overbounding Gaussian distribution is broadcast to the airborne user. This Gaussian distribution must effectively bound the tails of the true error distribution.
- ***Non-Zero Means***
  The issue of non-zero mean errors must be addressed by the PSP. The main source of such errors are IMLA (integrated multipath limiting antenna) code and carrier phase center biases. These biases must be characterized through antenna modeling and the resulting calibrations implemented in the LAAS system.
- ***The Sigma Monitor***
  Reference receiver failures are classified as the occurrence of a differential correction not characterized by B-values and σ_{pr_gnd}. An assumption of LAAS is that the reference receiver is unable to detect these failures at a failure rate of 10^{-5} per approach or less. The Sigma Monitor must prevent an undetected failed reference receiver rate of greater than 10^{-5} per approach, as well as ensure that the broadcast σ_{pr_gnd} provides the required correction error bounding for changes in the environment.
- ***Ionosphere Anomaly Monitor and Variable Inflation Algorithm***
  Ionospheric Gradient Monitor and Inflation Factor Determination algorithms must be implemented in the PSP. The ionospheric gradient monitor detects anomalous ionospheric conditions that could be hazardous to the airborne user. Each satellite's ionosphere delay gradients are measured at the LGF site, and satellites with excessive gradients are excluded. The inflation factor determination

algorithm assures that the VPL bounds the vertical error induced by the ionospheric storm front while optimizing system availability by determining the sigma of each broadcast differential correction in real time.

- ***Troposphere***
  The PSP must compute a troposphere correction. This value affects each differential correction, and thus system integrity. Both the vertical correlation component of the troposphere and the component caused by weather differentials between aircraft and LGF must be considered.
- ***The Ephemeris B Monitor***
  Errors in the ephemeris data used to calculate satellite position can lead to errors in the differential corrections broadcast to an airborne user. The PSP is required to protect against all differential range errors. Ephemeris errors will be negated by assuring that the broadcast P-Value and K-factor properly bound the minimum detectable ephemeris error for Type B data broadcasts.
- ***The Signal Deformation Monitor***
  The Signal Deformation Monitor screens the correlation function of each satellite, and informs the airborne user of the integrity threat if a fault is detected. This fault occurs on the C/A code generated by a satellite. When this corrupted C/A code is correlated with receiver generated code, the resulting correlation function is deformed, and cannot be cancelled by differential GPS operation if the ground and airborne receivers are not of the same configuration.
- ***The Low Signal Power Monitor***
  The Low Signal Power Monitor must ensure that conditions that could result in misleading information are detected. These conditions are low C/N_o values and cross-correlation above a given level. Since this fault has a low probability of occurrence, the affected measurements are simply removed from the LGF broadcast.
- ***The Code-Carrier Divergence (CCD) Monitor***
  Differences in filter implementations between the ground and air systems, as well as differences in start time of ground and air filters can cause differential ranging errors due to divergence. The Code-Carrier Divergence Monitor will consist of a divergence rate estimator and a detection test to determine whether or not the rate exceeds a given threshold, and cause to alarm.
- ***The Excessive Acceleration Monitor***
  The Excessive Acceleration Monitor must detect situations in which due to satellite malfunction, signal accelerations exist such that linear extrapolation using the broadcast pseudorange is no longer valid. The accelerations are not bounded and can also be a step. The monitor screens smoothed pseudorange values on a per ranging source basis.
- ***The Executive Monitor***
  The PSP Executive Monitor must take appropriate action for all fault conditions. When a fault condition requiring that a measurement, ranging source, or reference receiver be excluded is detected, the monitor must reintroduce the resource when the fault no longer exists.

10.3 Memphis PSP Flight Test Plan Development

This reporting period saw the creation of the Memphis Flight Test Plan. Flight-testing is necessary to establish the safety and integrity of the Honeywell International (HI) β-LAAS station installed at the Memphis-Shelby County International Airport (MEM) in Memphis, Tennessee. This provably safe prototype (PSP) system includes upgraded reference receivers and antennas, as well as the implementation of 11 algorithm description documents (ADDs) created to safeguard system integrity.

The William J. Hughes Technical Center is scheduled to conduct flight testing in Memphis September 18th through 29th of 2006. A test plan including descriptions of the various systems in place at MEM, approaches to be flown, and data analysis to take place has now been completed.

Eight runway ends are available at the Memphis-Shelby County International Airport. These, as well as the locations of the four HI ground reference stations and FAA ground-based performance monitor (GBPM) and GPS Anomalous Event Monitor (GAEM) are shown in the photograph below (Figure 9).

Figure 11: Memphis International - Google Earth View

During flight-testing at MEM, 100 straight-in 3-degree ILS-like approaches will be flown. These will include 20 approaches beginning 20nmi from threshold and 45 approaches beginning 10nmi from threshold to the designated primary runway end, 18C. One 20nmi approach and 4 10nmi approaches will be flown to each of the remaining seven runway ends. These approaches will be completed over an estimated 12 flights. Data acquired during these flights will be used to assess the accuracy and integrity of the PSP. As well, any events leading to a loss of system availability will be noted and checked against the events recorded by the GAEM in order to verify the correct functioning of the HI ground station

10.4 Memphis Beta LAAS Ground Based Performance Monitor (GBPM) Station

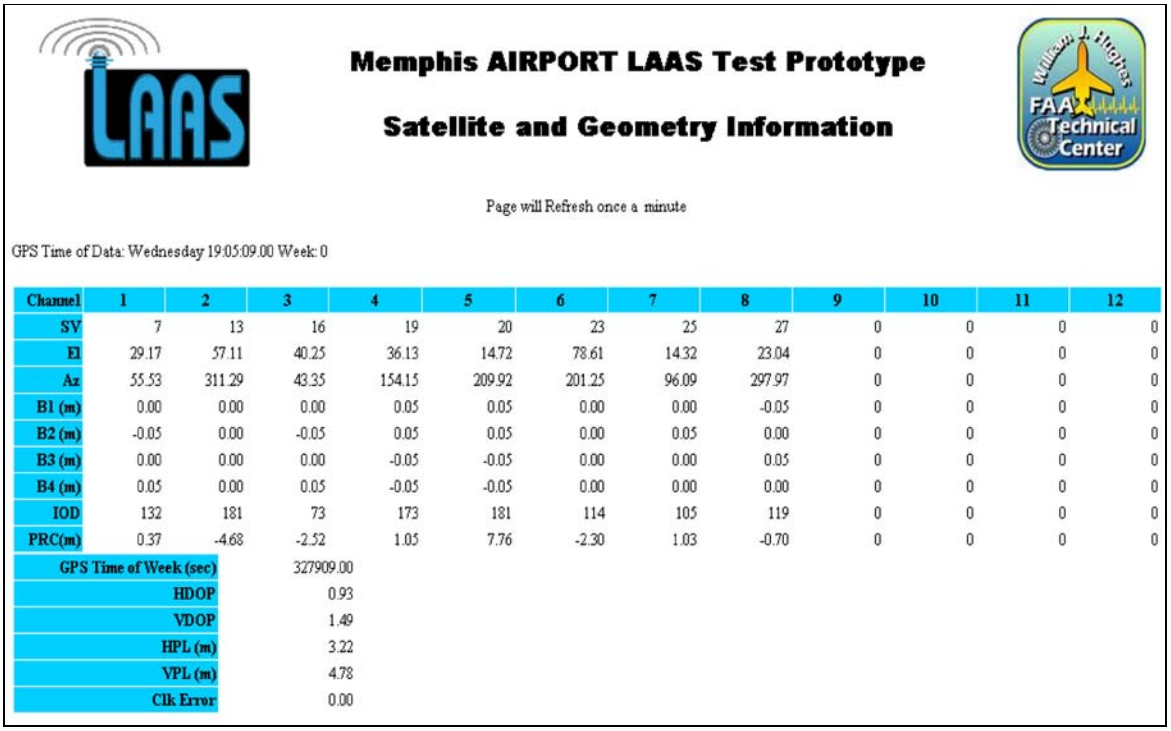
The LAAS T&E team decided early on in the planning of the Memphis effort that a dedicated fixed LAAS SIS performance monitoring station was required at Memphis. The Monitoring station is basically a stationary user platform (airborne type user) with enhanced data collection, and streaming data capabilities (for live web based performance outputs). Several requirements needed addressing before deployment, which included: a suitable AOA characteristic installation site (Hangar 12), a dedicated T1 installation, host organization (FedEx) and support personnel coordination, detailed specifications/ agreement, and permission to install such a system from the airport and FedEx.

Deployment of the Memphis monitoring station began during the week of July 11th 2005, and was fully installed (T1/Network portion) by August 17th 2005. The infrastructure installation for the monitor system (stable GPS antenna/feed and platform, tuned VHF antenna/feed, power, etc), installation of the support hardware (GPS receiver, computer peripherals, power protection, RF feeds/filters, etc), and a precision survey of the GPS antenna was conducted in July '05. The monitor CPU/VDB, and networking hardware was installed and configured in August '05.

Development of a web-based display, which gives a once-a-minute output of the Memphis LAAS Satellite and Geometry information, and calculated user position error (based on difference from the GPS antenna's true position), began during September'05. This live service is available at http://www.gps.tc.faa.gov/memlaas.asp. **Figure 12** provides a screen shot example of the web page, which displays the reported overall performance (titled "Satellite and Geometry") of the Honeywell LAAS station in its current configuration. **Figure 13** provides a screen shot example of the "at a glance" scrolling graphic of the Memphis Positioning Performance available through the "Position Monitor" button at the bottom of the "Satellite and Geometry" web page.

Detailed raw monitoring station data analysis also began in September '05. The FAA has developed custom data plot generating software to display all relevant data collected by the performance monitoring station in Memphis. These plots are numerous and include; ECEF X-Y-Z error, clock error, HPL and HDOP, VPL and VDOP, horizontal error, vertical error, SVs available (air/ground), and various VDB parameters.

As anticipated, HI has improved performance form the previous reporting period. **Figure 13** is a screenshot example of the live web FAA position monitoring of the Honeywell



Memphis AIRPORT LAAS Test Prototype

Satellite and Geometry Information

Page will Refresh once a minute

GPS Time of Data: Wednesday 19:05:09.00 Week: 0

Channel	1	2	3	4	5	6	7	8	9	10	11	12
SV	7	13	16	19	20	23	25	27	0	0	0	0
El	29.17	57.11	40.25	36.13	14.72	78.61	14.32	23.04	0	0	0	0
Az	55.53	311.29	43.35	154.15	209.92	201.25	96.09	297.97	0	0	0	0
B1 (m)	0.00	0.00	0.00	0.05	0.05	0.00	0.00	-0.05	0	0	0	0
B2 (m)	-0.05	0.00	-0.05	0.05	0.05	0.00	0.05	0.00	0	0	0	0
B3 (m)	0.00	0.00	0.00	-0.05	-0.05	0.00	0.00	0.05	0	0	0	0
B4 (m)	0.05	0.00	0.05	-0.05	-0.05	0.00	0.00	0.00	0	0	0	0
IOD	132	181	73	173	181	114	105	119	0	0	0	0
PRC(m)	0.37	-4.68	-2.52	1.05	7.76	-2.30	1.03	-0.70	0	0	0	0

GPS Time of Week (sec)	327909.00
HDOP	0.93
VDOP	1.49
HPL (m)	3.22
VPL (m)	4.78
Clk Error	0.00

Figure 12: Memphis Performance Monitor Web Page

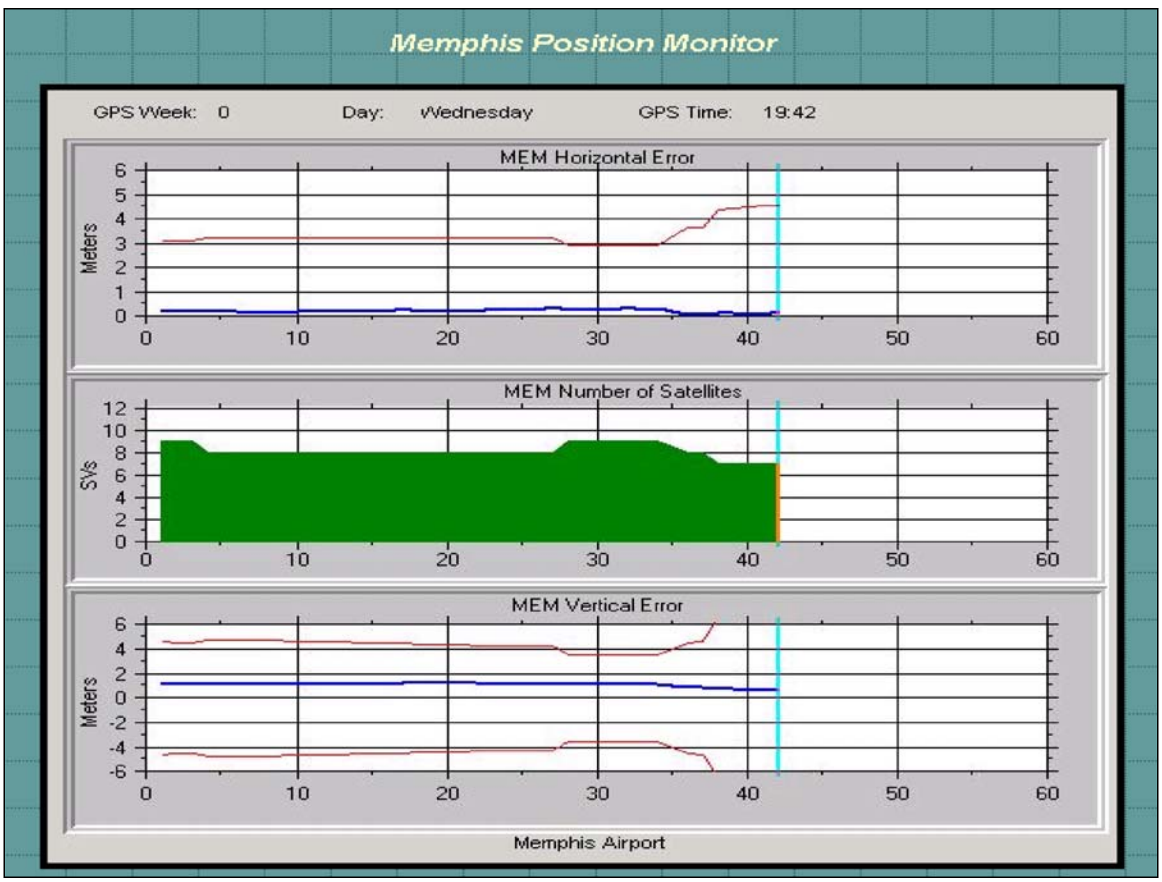


Figure 13: Memphis Position Monitor – Scrolling Web Display

-beta LAAS in Memphis. The blue traces are the calculated horizontal and vertical position error versus survey, while the red traces are the calculated horizontal and vertical protection levels (not Alert Limits). The green field in the center is the number of SVs available with corrections. Cat I performance is clearly indicated at the time this screen shot was generated.

10.5 The GPS Anomalous Event Monitor (GAEM) – FAA Delivery

Supplemental performance and integrity monitoring systems are currently being finalized to verify the effectiveness of the Memphis Honeywell Beta LAAS system upgrades as the system approaches "provably safe integrity prototype system" status. One such system is referred to as a 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 are currently in collaboration to develop the latest version of the GAEM for the FAA's use in Memphis. **Figure 14** is a rudimentary block diagram of the functional units in the GAEM system.

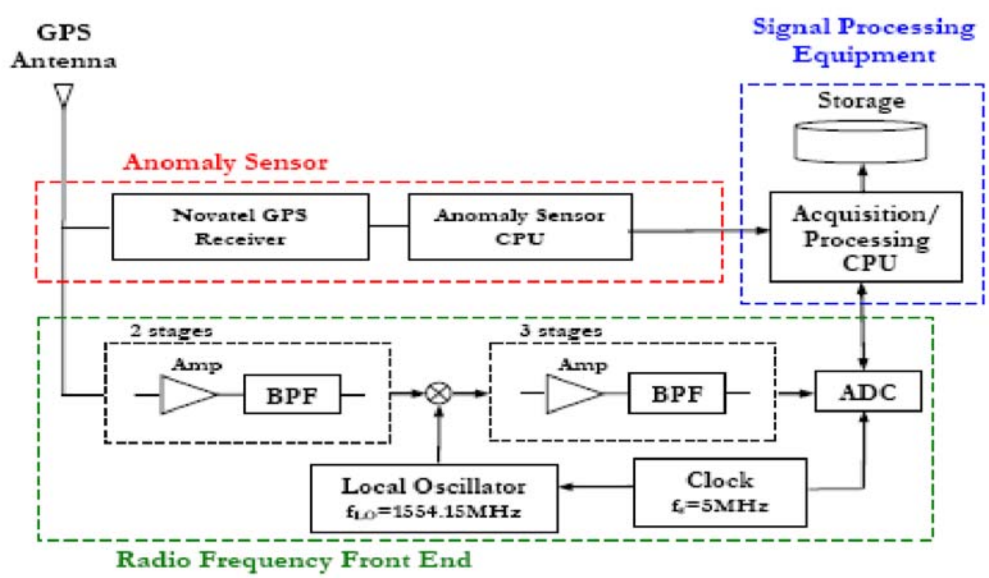


Figure 4, Ohio University GPS Anomalous Event Monitor

Figure 14: 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, yet to be implemented, integrity monitors for the Honeywell LAAS system. Later this year these integrity monitors will be active, and will need 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 when it should not.

Development of the actual GAEM system to be used in Memphis began during the summer of '05 with the specification and procurement of the over 260 individual components. The first batch of technical materials was provided to the AEC during September '05, and during this reporting period development continued as FAA and AEC resources became available.

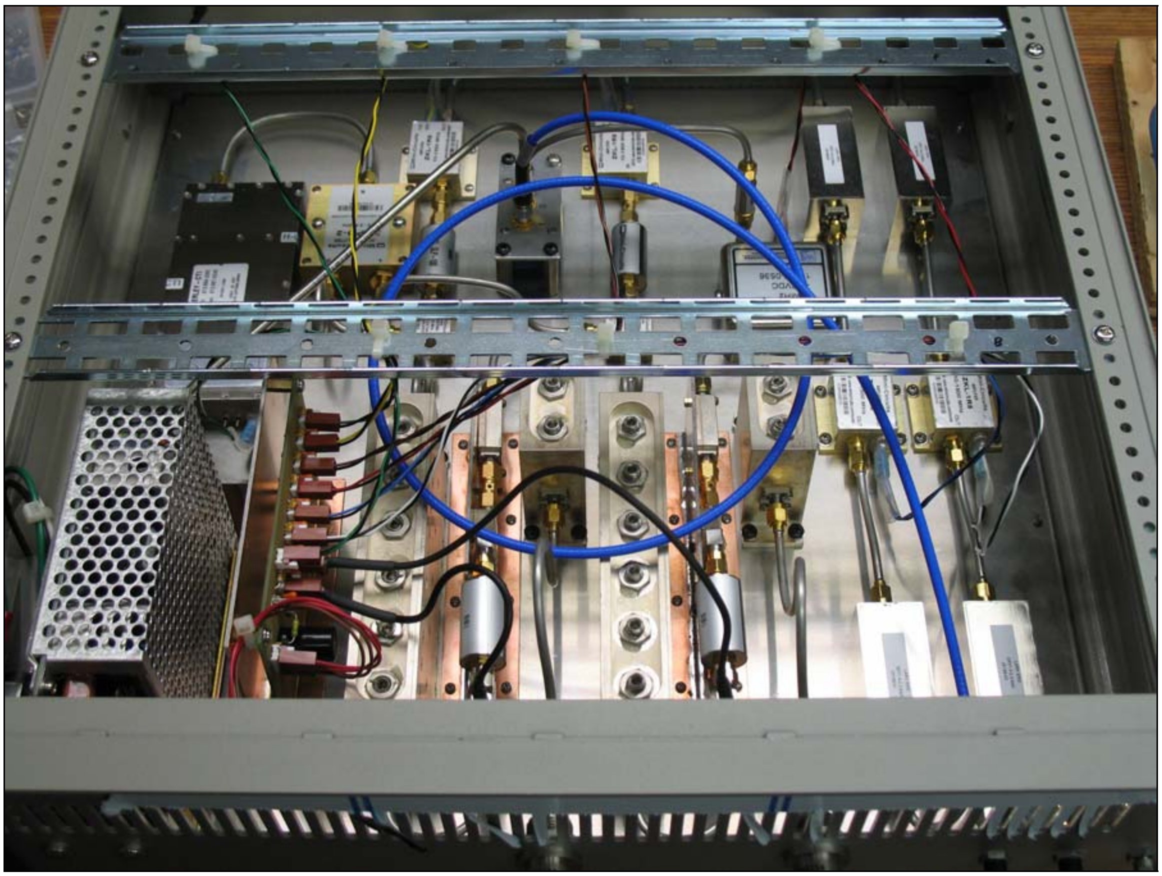


Figure 15: RF Front End for GAEM System

A working meeting with OU was held at the Technical Center the week of April 18th. The GAEM system (CPU/Server, RF front-end (**Figure 15**), and Trigger/Anomaly Detector) intended for Memphis was available for use during these meetings and at the conclusion was left in the possession of the FAA along with some items for finalization. The FAA and OU will continue the GAEM collaboration remotely to finalize the system to deployable capability with a team installation expedition planned for Memphis during early July '06.

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
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End of report