



Federal Aviation  
Administration



# Ground Based Augmentation System

## Performance Analysis and Activities Report

Reporting Period: January 1 –March 31, 2015

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## 1. Introduction

The Ground Based Augmentation System (GBAS) team under the direction of the Navigation Branch (ANG-C32) in the Engineering Development Services Division in the Advanced Concepts and Technology Development Office at the Federal Aviation Administration's (FAA) William J Hughes Technical Center (WJHTC) provides this GBAS Performance Analysis / Activities Report (GPAR).

This report identifies the major GBAS related research, testing, and validation activities for the reporting period in order to provide a brief snapshot of the program directives and related technical progress. Currently, the GBAS team is involved in the validation of the GAST-D ICAO SARPs, long-term ionospheric monitoring, supporting system design approval activities for an update to the CAT-I approved Honeywell International (HI) Satellite Landing System (SLS-4000), and observing trends and anomalies utilizing the FAA's Local Area Augmentation System (LAAS) Test Prototype (LTP) (Internationally standardized as GBAS), six Ground Based Performance Monitors (GBPM), and prototype Honeywell Satellite Landing System here at Atlantic City International Airport (ACY).

Objectives of this report are:

- a) To provide status updates and performance summary plots per site using the data from our GBPM installations
- b) To present all of the significant activities throughout the GBAS team
- c) To summarize significant GBAS meetings that have taken place this past quarter
- d) To offer background information for GBAS

## 2. GBAS Updates by Site

The GBPM was designed and built by ANG-C32 to monitor the performance of our GBAS installations. There are currently six GBPM's in use. They are located in Newark New Jersey (EWR), Houston Texas (IAH), Moses Lake Washington (MWH), Rio de Janeiro Brazil (GIG), and two in Atlantic City New Jersey (ACY). The GBPM is used to monitor integrity, accuracy, availability, and continuity of the LTP and Honeywell's SLS-4000. The plots in each of the following sections utilize a compilation of data collected at one minute intervals. For live, up-to-date data, refer to <http://laas.tc.faa.gov>. A more detailed description of the GBPM configuration can be found in Appendix D of this report.

### 2.1 EWR SLS

- Newark has a Honeywell SLS-4000 that was granted operational approval on September 28, 2012
- Since the EWR SLS-4000 went live until March 2015, United Airlines has conducted 687 GBAS approaches
- British Airways has conducted 179 GLS approaches since September 2014
- On February 18, 2015, Delta Airlines landed using the SLS-4000 for the first time



Figure 1 - EWR SLS-4000 Configuration

2.1.1 Real Time Performance Data

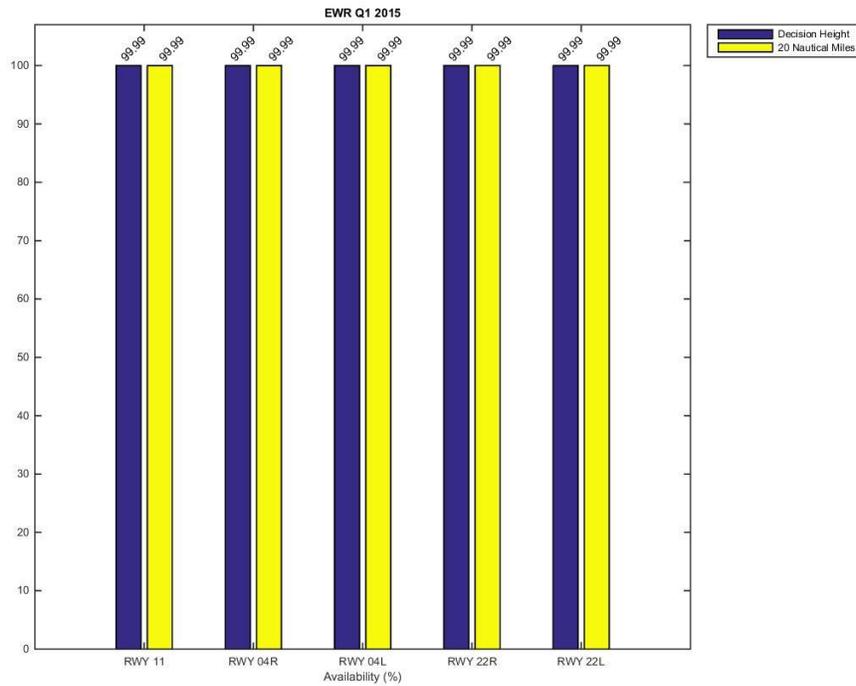


Figure 2 - EWR Availability - The data shown is based upon times when the SLS was transmitting corrections

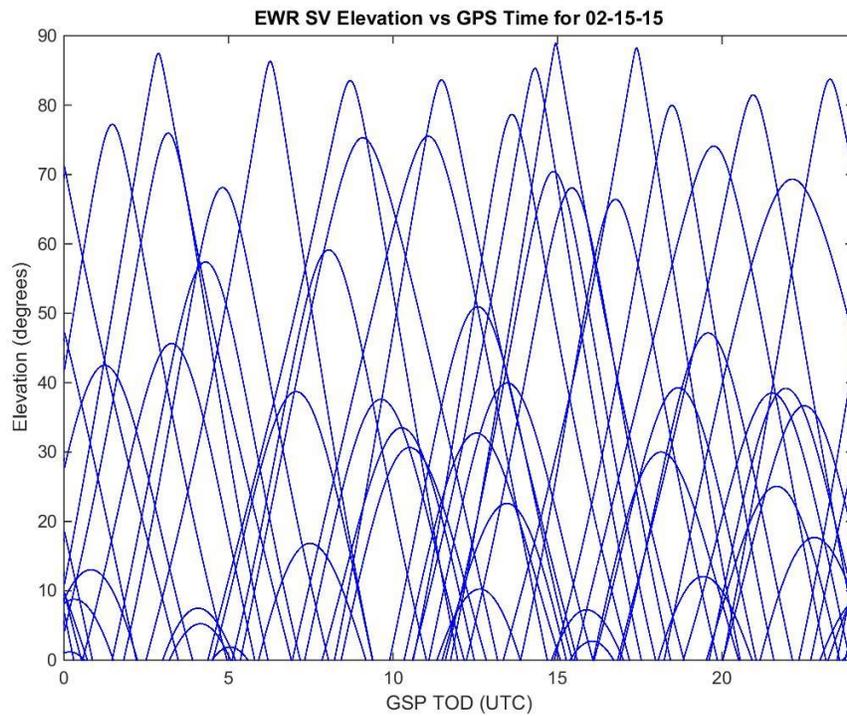


Figure 3 - EWR SV Elevation vs GPS time 02/15/15

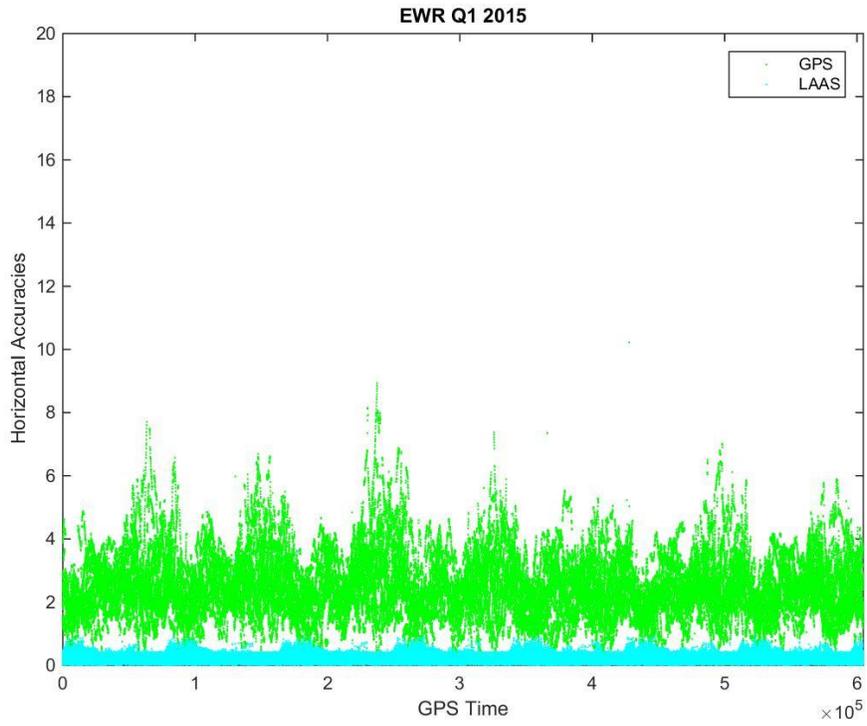


Figure 4 - EWR Horizontal Accuracy Plot

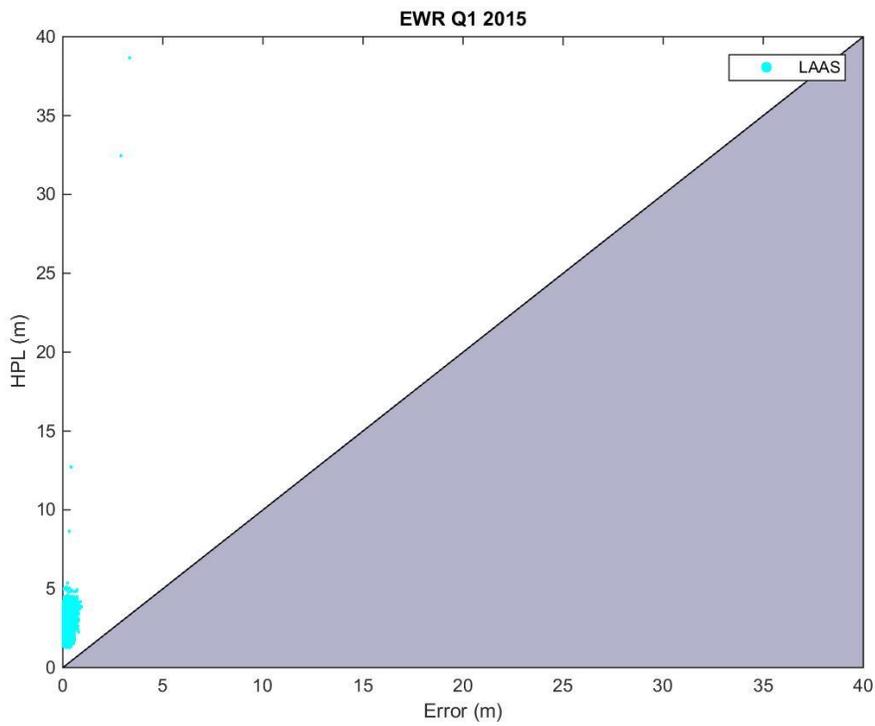


Figure 5 - EWR Horizontal Accuracy vs. Error

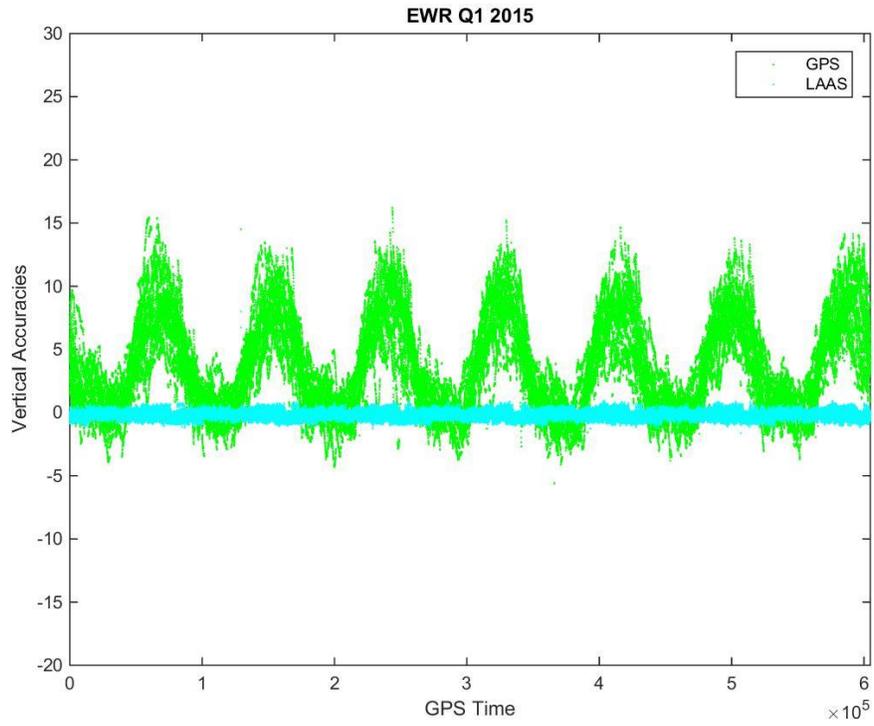


Figure 6 - EWR Vertical Accuracy

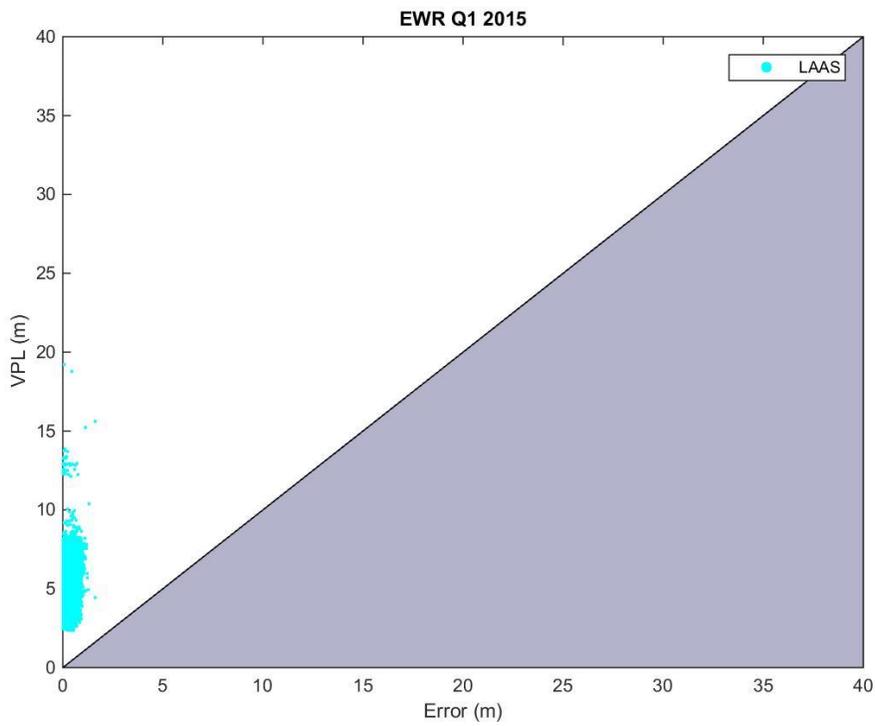


Figure 7 - EWR Vertical Accuracy vs. Error

## 2.2 IAH SLS

- Houston has a Honeywell SLS-4000 that was granted operational approval on April 22, 2013
- Since IAH went live until March 2015, United Airlines has conducted 860 GBAS approaches
- Since December 2014, Emirates conducted 18 GLS approaches, Lufthansa 9 GLS approaches, and Cathay Pacific 20 GLS approaches
- Cathay Pacific landed using the SLS-4000 for the first time on January 30, 2015
- Annual ground inspection by the FAA non-Fed Inspector and Honeywell was accomplished on January 21, 2015.



Figure 8 - Cathay Pacific first GLS landing at IAH

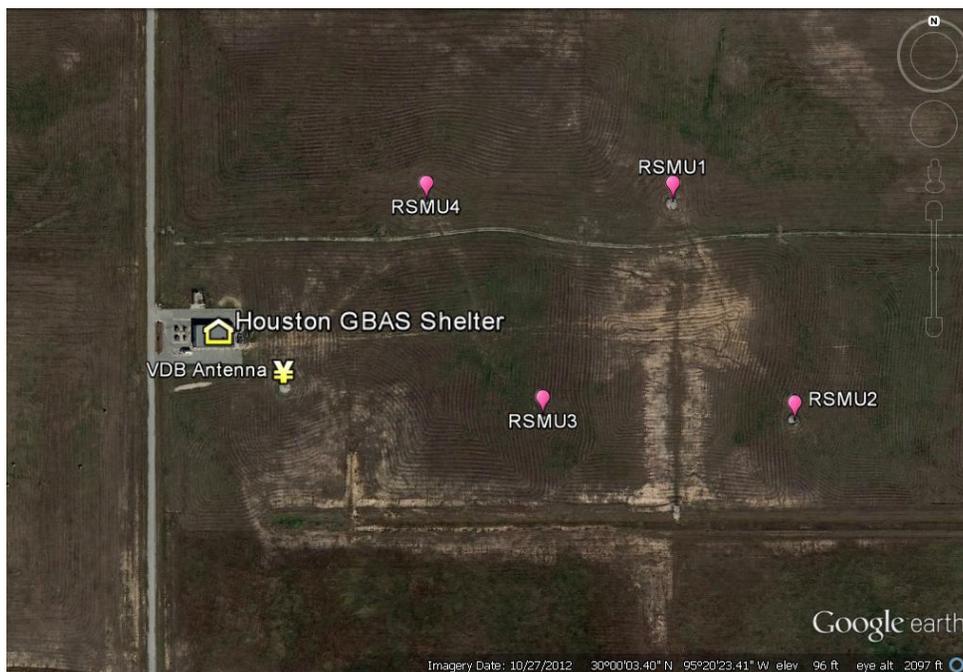
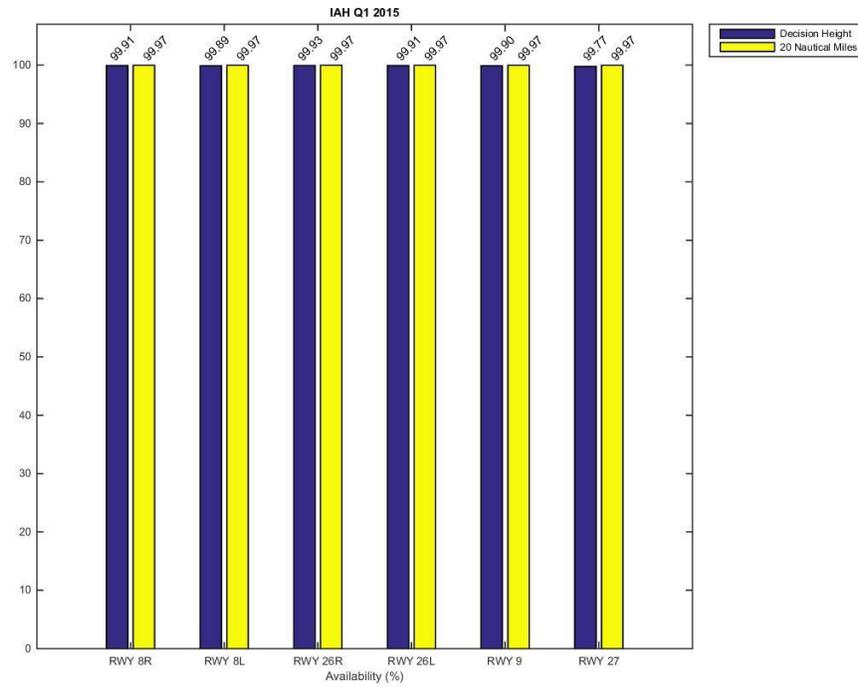


Figure 9 - IAH SLS-4000 Configuration

**2.2.1 Real Time Performance Data**



**Figure 10 - IAH Availability - The data shown is based upon times when the SLS was transmitting corrections**

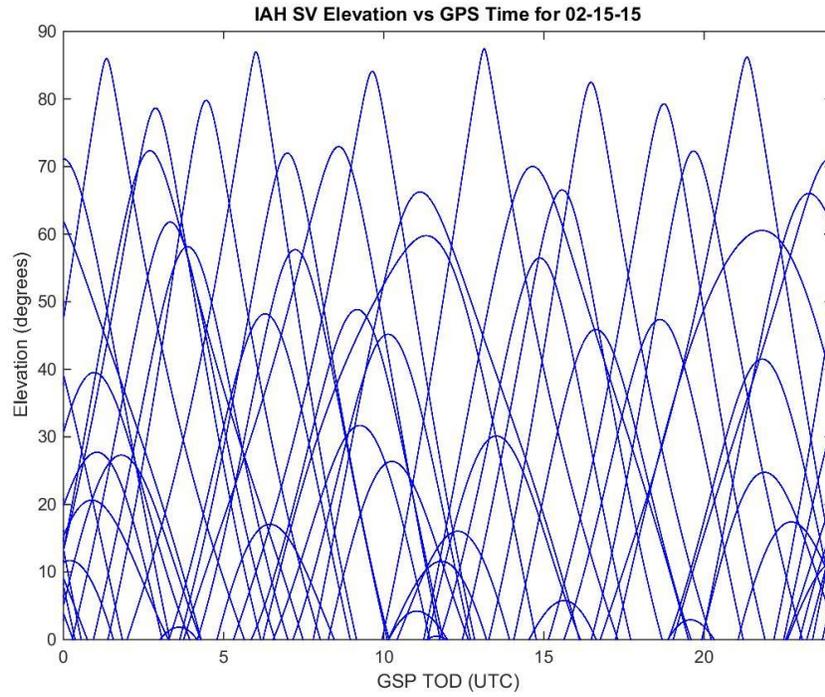


Figure 11 - IAH SV Elevation vs GPS time 02/15/15

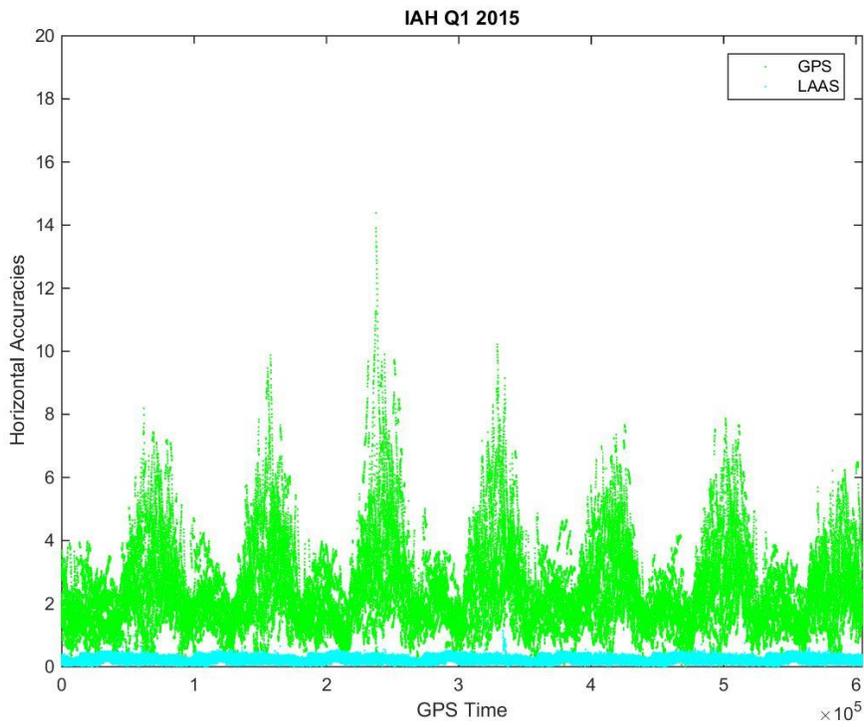


Figure 12 - IAH Horizontal Accuracy Plot

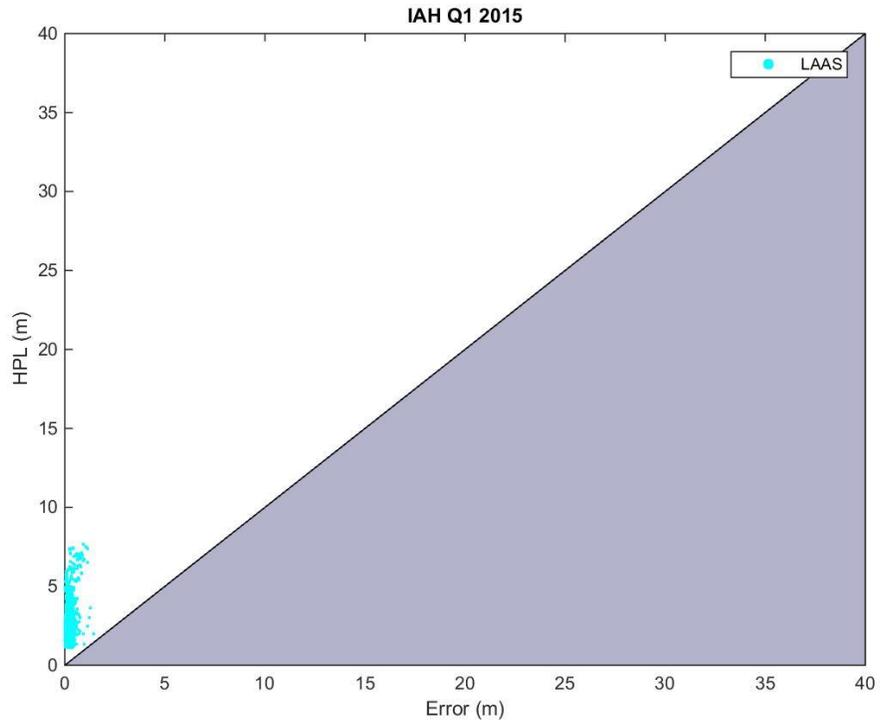


Figure 13 - IAH Horizontal Accuracy vs. Error

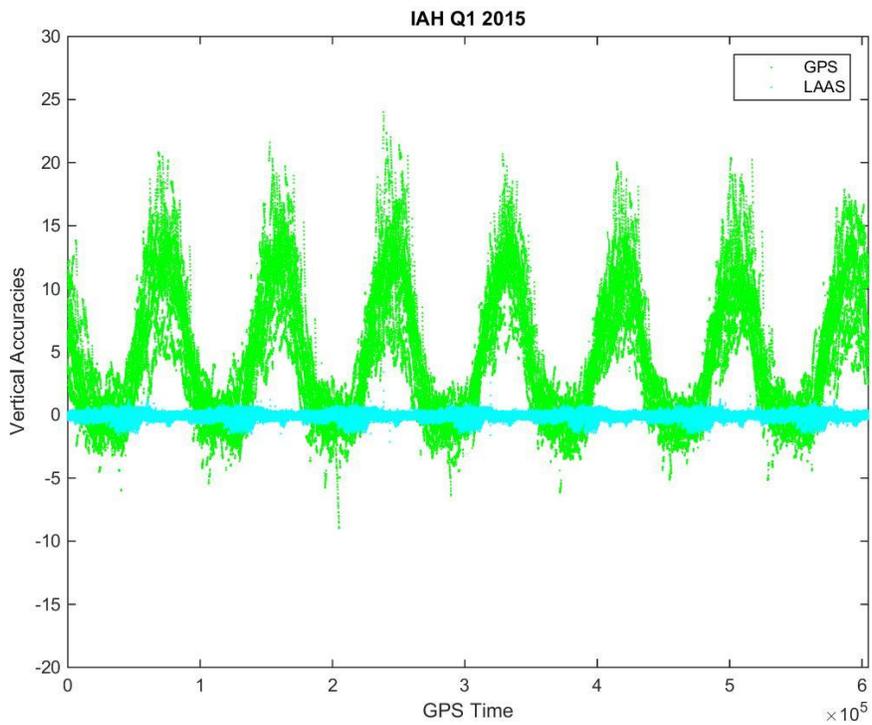
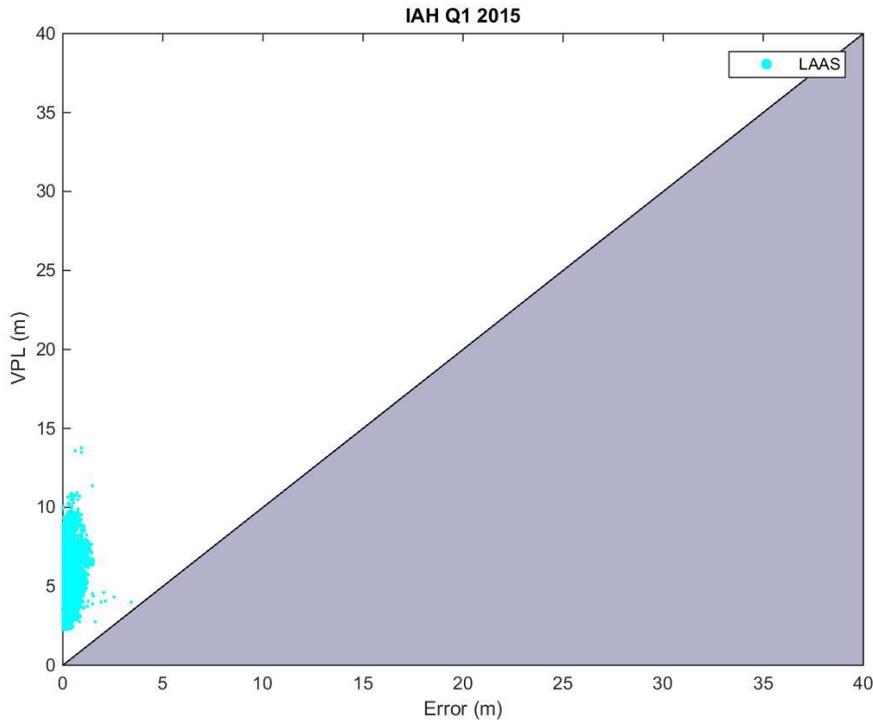


Figure 14 - IAH Vertical Accuracy



**Figure 15 - IAH Vertical Accuracy vs. Error**

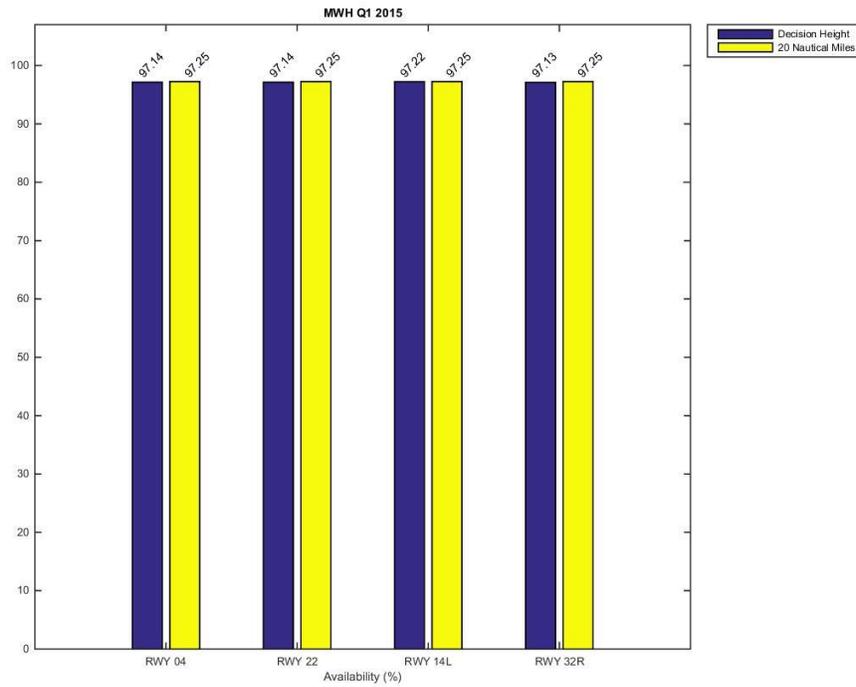
### 2.3 MWH SLS

- Moses Lake has an Honeywell SLS-4000 that was granted operational approval on January 9, 2013
- Boeing uses this site for production activities
- Boeing will also operate this site in a prototype GAST-D mode for flight test to support GAST-D validation
- While Grant Country Airport (GEG) is a public use airport, it has no commercial flights
- A GLS Category III autoland test was successfully completed at the end of the previous quarter with a prototype Honeywell GAST-D GBAS and prototype Honeywell GAST-D INR

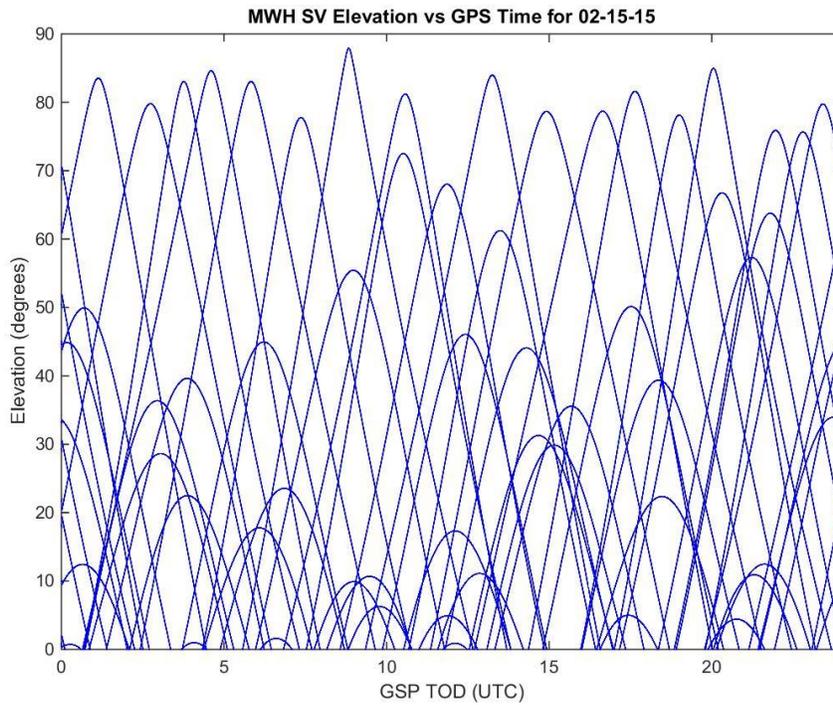


Figure 16 - MWH SLS-4000 Configuration

**2.3.1 Real Time Performance Data**



**Figure 17 - MWH Availability – The data shown is based upon times when the SLS was transmitting corrections**



**Figure 18 - MWH SV Elevation vs GPS time 02/15/15**

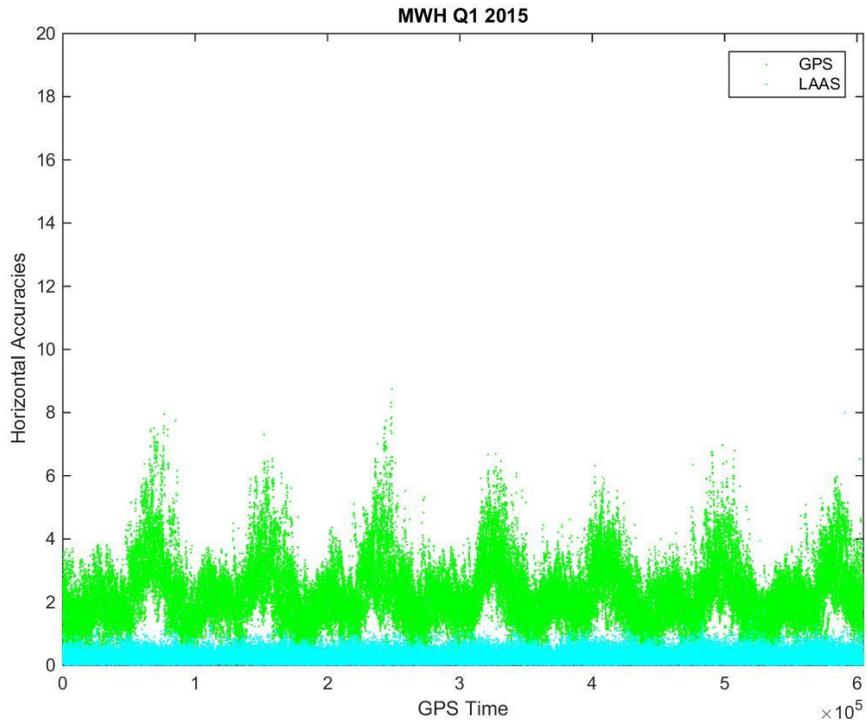


Figure 19 - MWH Horizontal Accuracy Ensemble Plot

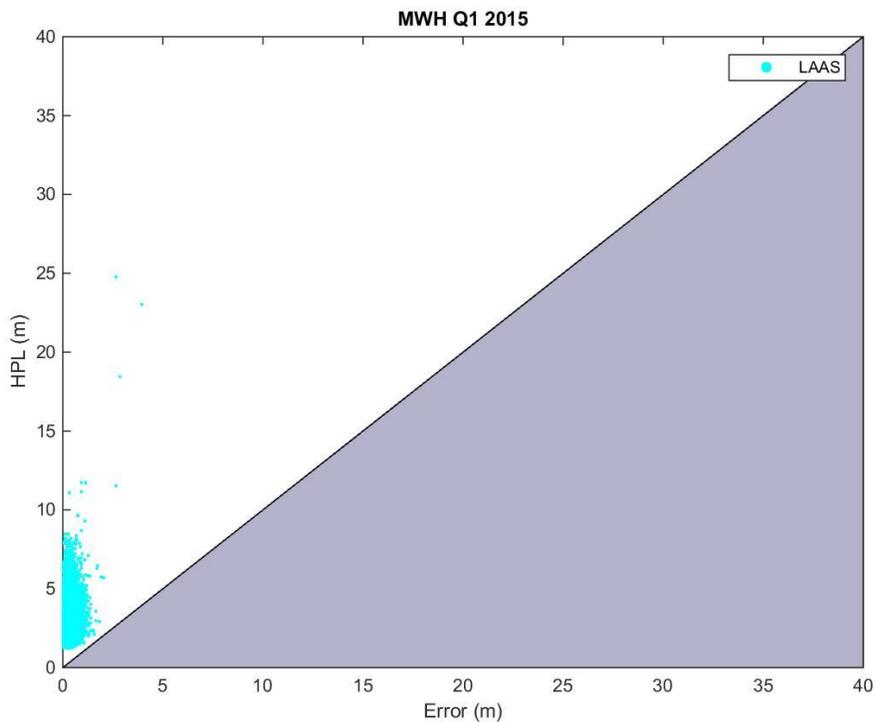


Figure 20 - MWH Horizontal Accuracy vs. Error Bounding Plot

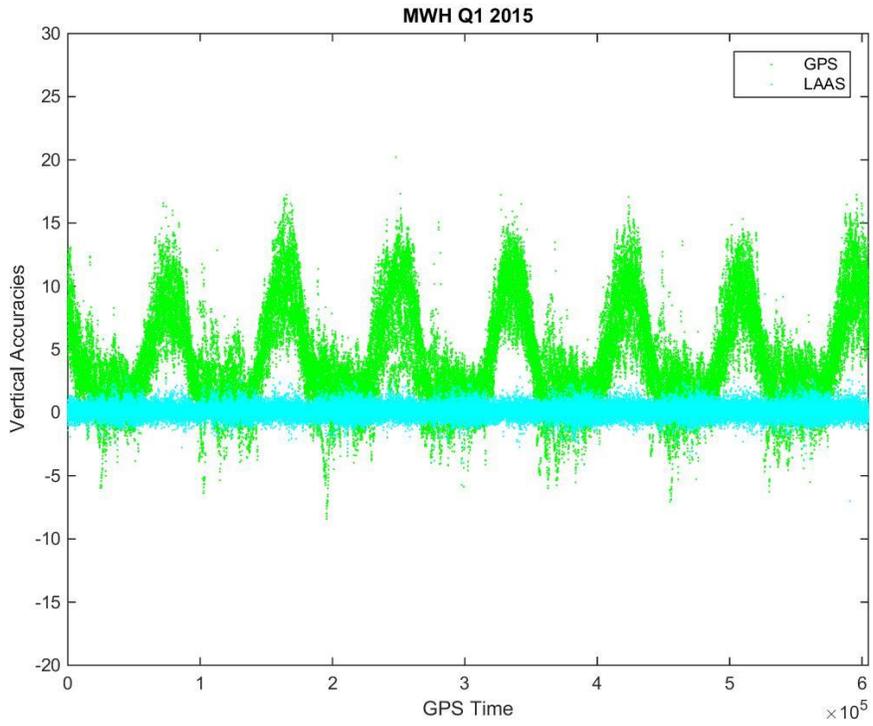


Figure 21 - MWH Vertical Accuracy

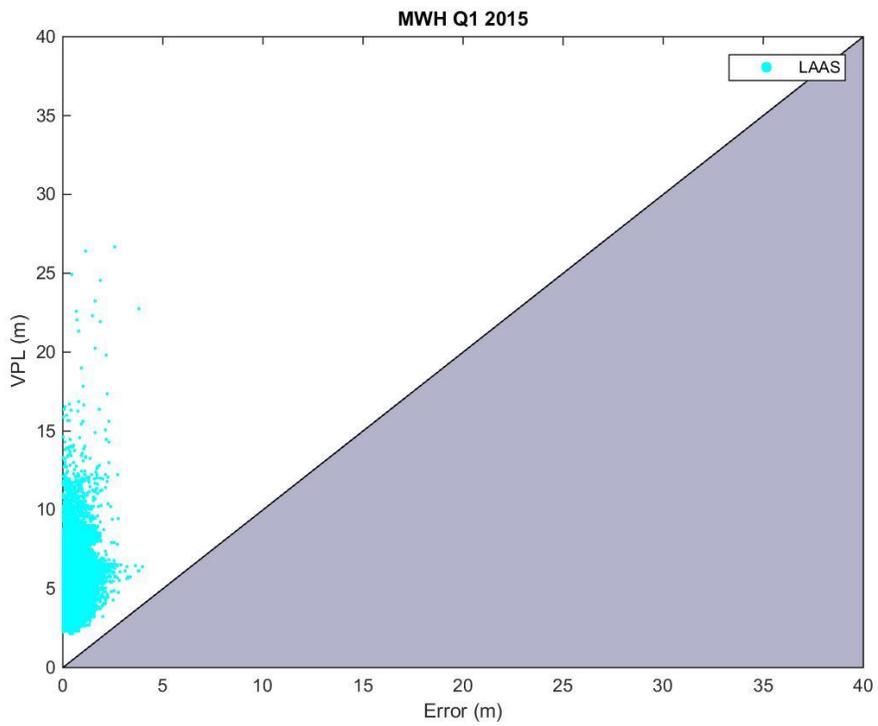


Figure 22 - MWH Vertical Accuracy vs. Error Bounding Plot

## 2.4 Rio de Janeiro Brazil

- System is a Honeywell SLS-4000 operating in a Block II prototype mode
- The antenna on the Brazil monitor is less robust than the other sites, therefore satellites below 11 degrees may not be tracked as well

### 2.4.1 Real Time Performance Data

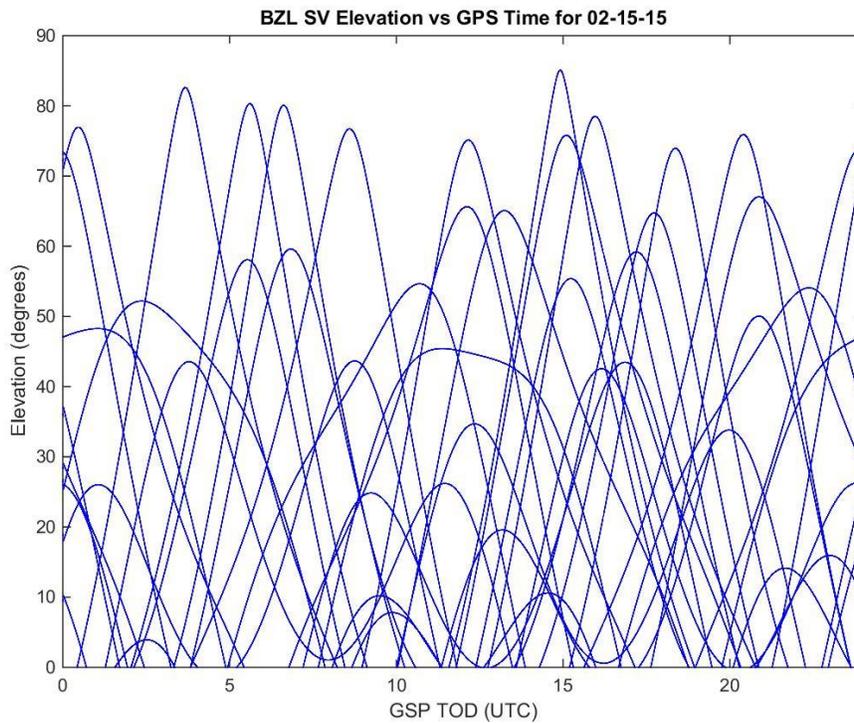


Figure 23 - BZL SV Elevation vs GPS time 02/15/15

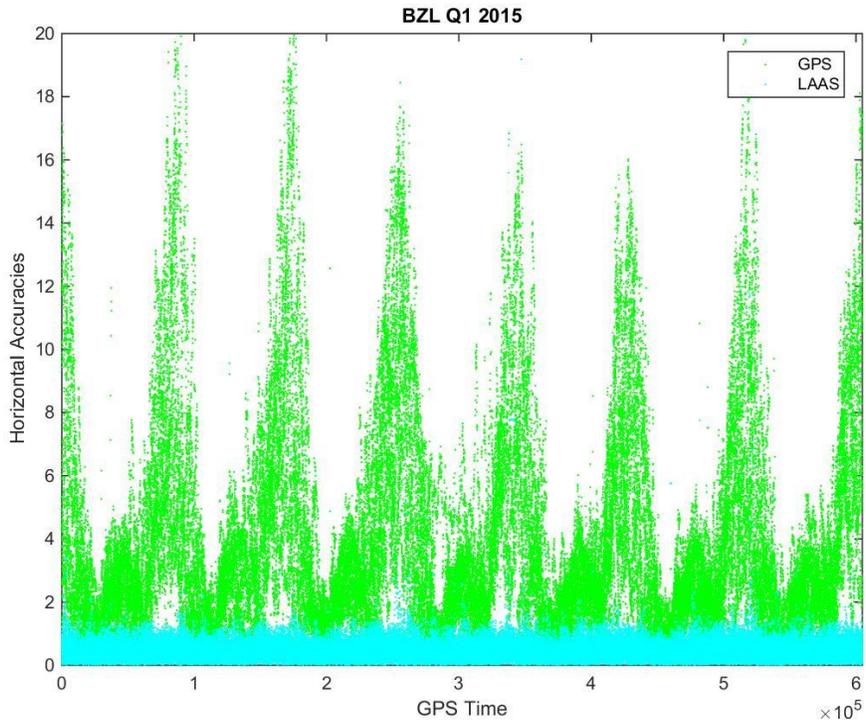


Figure 24 - BZL Horizontal Accuracy Ensemble Plot

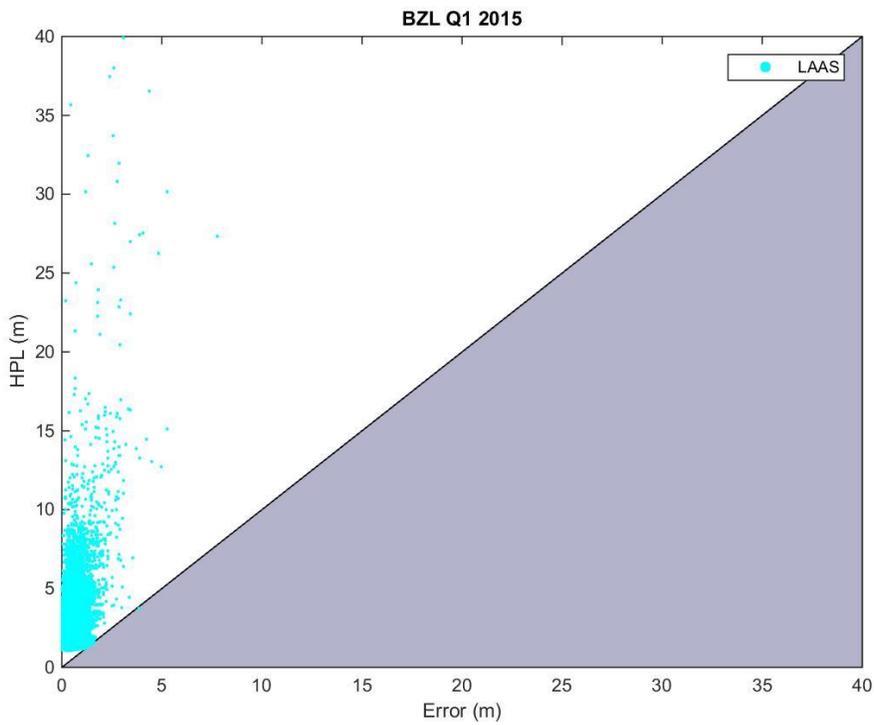


Figure 25 - BZL Horizontal Accuracy vs. Error Bounding Plot

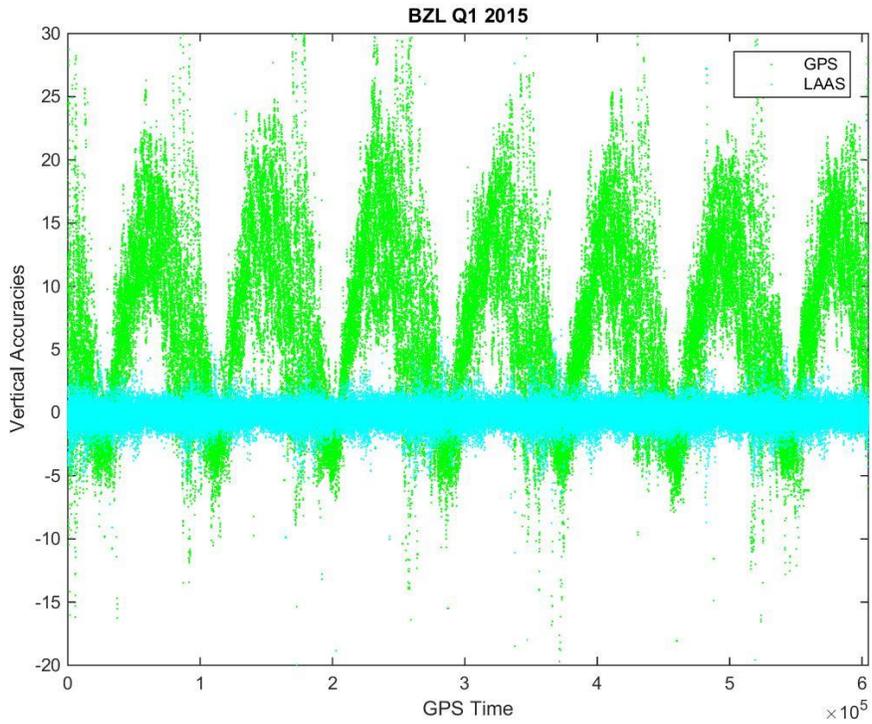


Figure 26 - BZL Vertical Accuracy

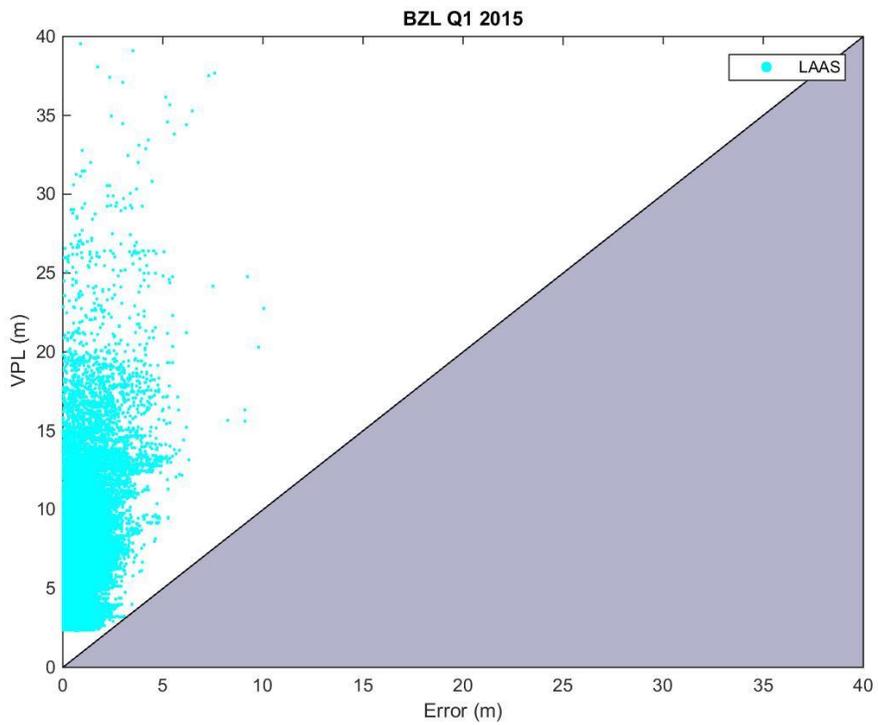


Figure 27 - BZL Vertical Accuracy vs. Error Bounding Plot

## 2.5 ACY SLS

- The SLS is currently configured for GAST-D
- See the below image and description for complete details on the configuration and testing being done

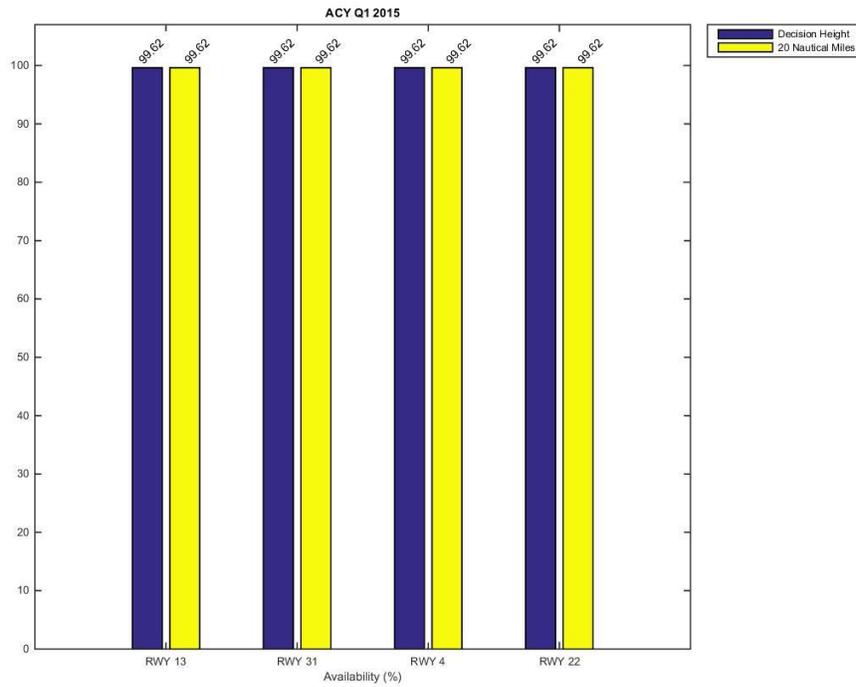


**Figure 28 - ACY GAST-D Configuration**

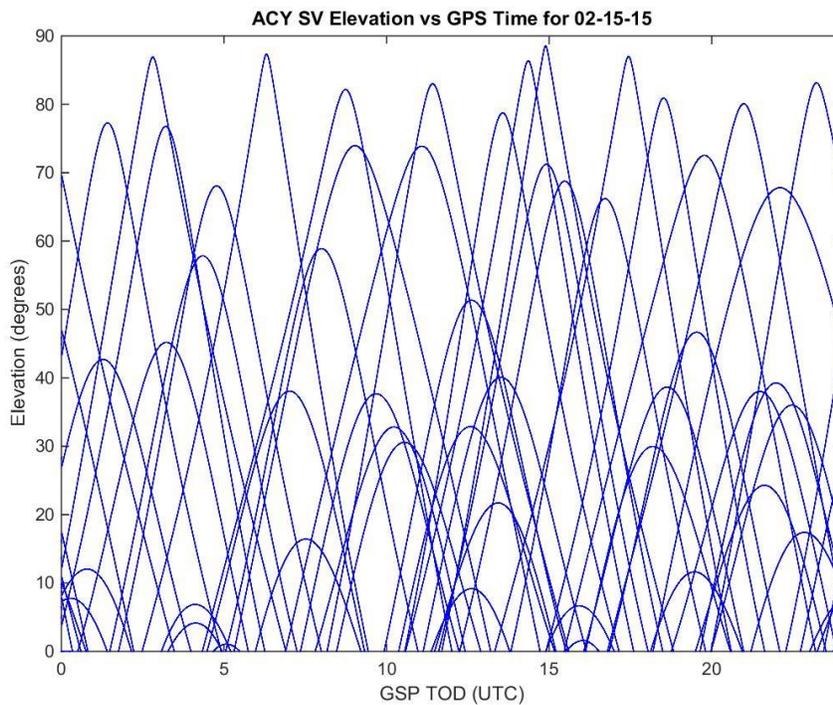
The picture above shows the current locations of all 6 reference receivers available under the newly designed GAST-D configuration. This configuration uses 4 Primary references (yellow pins), and 2 substitutes (blue pins) that can be interchanged under certain circumstances that cause one of the Primary sites to be unavailable. Monitoring, such as the Ionosphere Gradient Monitor (IGM), is also performed using the 6 reference receivers. The additional references also allow for more, and longer baselines during the various monitoring processes.

There was also the start of Ground testing of different GBAS operational scenarios, conducted to demonstrate some possible conditions that might occur with the system during normal operation. Test data was collected using the GBPM, a Rockwell MMR, and a Honeywell Integrated Navigation Receiver (INR). That data, as well as the raw GBAS station data, is currently being analyzed in preparation for Flight Tests, which are to be conducted in the late April-early May timeframe.

**2.5.1 Real Time Performance Data**



**Figure 29 - ACY Availability - The data shown is based upon times when the SLS was transmitting corrections**



**Figure 30 - ACY SV Elevation vs GPS time 02/15/15**

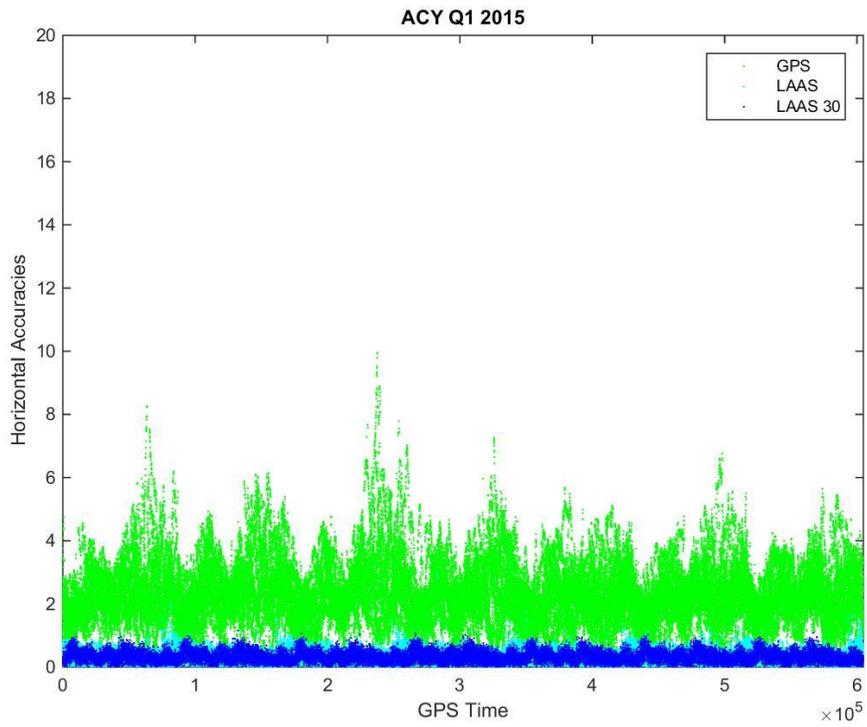


Figure 31 - ACY SLS Horizontal Accuracy Ensemble Plot

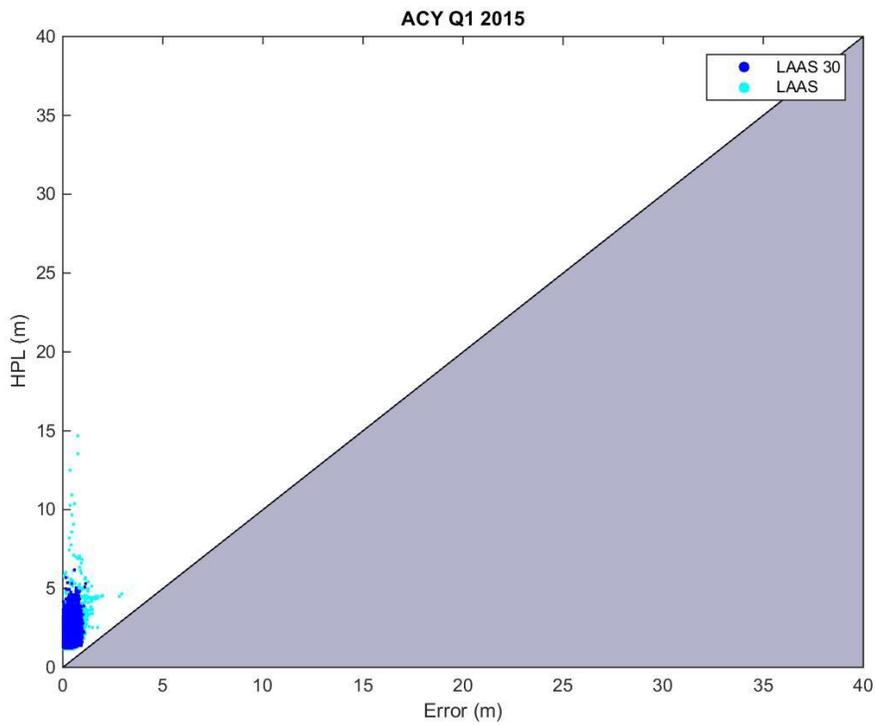


Figure 32 - ACY SLS Horizontal Accuracy vs. Error Bounding Plot

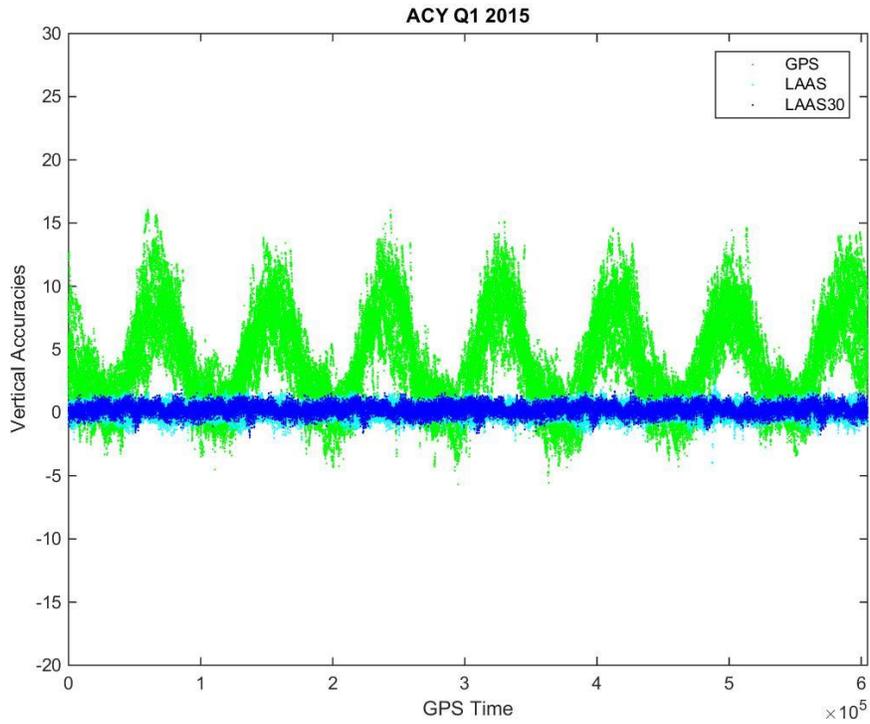


Figure 33 - ACY SLS Vertical Accuracy Ensemble

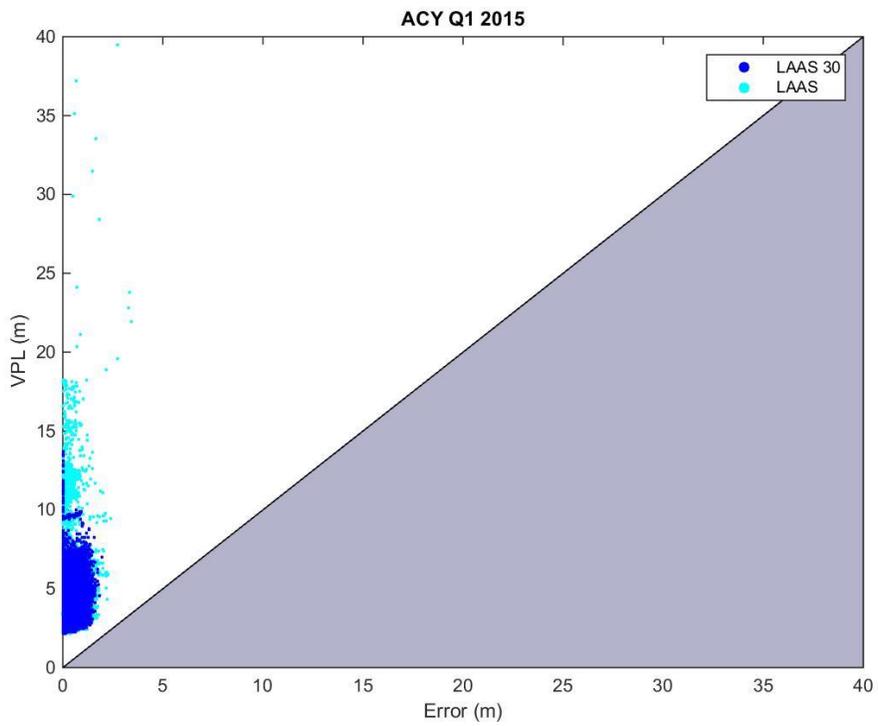


Figure 34 - ACY SLS Vertical Accuracy vs. Error Bounding Plot

## 2.6 LTP ACY

- The LTP has not been operational this quarter due to damaged fiber connections and other hardware components
- LTP hardware has been repaired, which includes repairs to fiber communication to 3 of 4 references, coaxial cable repairs to VDB antenna, as well as computer repair and network switch replacement. Software updates being conducted with various other configuration changes
- See Appendix C for a full description of the LTP configuration



**Figure 35 - Aerial View of LTP Configuration**

### 3. Research, Development, and Testing Activities

#### 3.1 CAT I Block II SDA

The FAA is currently supporting system design approval activities for an update to the CAT-I approved Honeywell International SLS-4000 system. This software update is known as “Block II” and includes changes that will improve system availability in the NAS and allow for use in low-latitude areas such as Rio de Janeiro, Brazil. The table below provides an overview of the major updates to be made in Block II from the previously approved Block I and Block 0 versions.

Configuration Attributes	GBAS Configuration		
	YG4031EA01 Block 0	YG4031EA02 Block I	YG4031EA03 Block II
CAT-I Integrity/Continuity	☑	☑	☑
Robust to Personal Privacy Devices (a.k.a., GPS jammers)		☑	☑
P-Value & Kmde moved to a site specific parameter file (facilitates extended service volume without a “code” change)			☑
SDM Natural Bias Update (Enables the use of PRN 11 and 23)			☑
Increase the number of selective masks (Improve granularity of masks to improve availability)			☑
Updates to Data Recorder and FAS Input File (Supports ED-114A compliance)			☑
Facilitates Low-latitude Operations (Scintillation monitor added, configurable scintillation thresholds, etc.)			☑
Number of Approaches Supported	26	26	48

**Table 1 - Block II Updates**

The current target date for design approval is March-April 2015, with FAA design approval limited to use in CONUS. Verification and analysis of the work done to allow operations in low-latitude regions will be left to authorities in those regions.

#### 3.2 GAST-D Validation

##### 3.3.1 GAST-D Validation Activities Overview

A key goal of the FAA’s GBAS program is validation of the GAST-D ICAO SARPS. Much of this work is being accomplished through prototyping contracts for ground and airborne systems, both with Honeywell International. Planned GAST-D avionics prototyping was completed in January 2013, while ground prototype development continues. Validation is scheduled to be officially completed by ICAO in February 2015. HI has already applied for SDA support for a GAST-D system, with a target completion date in 2018.

*Avionics*

A cost-sharing contract to create a GAST-D avionics prototype was awarded to HI in August 2010 and was complete as of January 2013. Under this contract HI implemented GAST-D algorithms and message types as described in the LAAS Minimum Operational Performance Standards (MOPS) (DO-253C) and the LAAS ICD (DO-249D) on their commercially available GAST-C platform, the Integrated Navigation Receiver. The objectives were to confirm that the various monitor thresholds set forth in the MOPS were appropriate and that all MOPS requirements were clearly and correctly defined. Incorporation of new GAST-D algorithms occurred over several software builds within three task areas, as shown in the table below.

<b>Task</b>	<b>INR Version</b>	<b>Delivery Date</b>
<b><i>Task Area I</i></b>		
<b>Delivery of 3 Baseline Receiver (INR) Units</b>	E100	11/2010-2/2011
<b>Delivery of Bench Test Interface Software</b>	E100	12/2010
<b>Delivery of CAT-I Compliance Report</b>	E100	9/2010
<b><i>Task Area II Phase I</i></b>		
<b>Implement CAT III Message Format (DO-246D LAAS ICD)</b>	E101	3/2011
<b>Implement 30-second pseudorange smoothing (DO-253C LAAS MOPS Section 2.3.6.6.1)</b>	E101	3/2011
<b>Implement dual weighing matrix (DO-253C LAAS MOPS Sections 2.3.9.2.1-3)</b>	E102	6/2011
<b>Implement second solution (DO-253C LAAS MOPS Section 2.3.9.2.3)</b>	E102	6/2011
<b>Implement DSIGMA (DO-253C LAAS MOPS Section 2.3.9.3)</b>	E102	6/2011
<b><i>Task Area II Phase II</i></b>		
<b>Activate and update software baseline from Phase 1</b>	E200	1/2012
<b>Implement Divergence Monitoring Function (DO-253C LAAS MOPS Section 2.3.6.11)</b>	E201	5/2012
<b>Implement Differential Correction Magnitude Check (DO-253C LAAS MOPS Section 2.3.9.5)</b>	E202	5/2012
<b>RAIM Algorithm, Analysis &amp; Test Report</b>	N/A	3/2012
<b>Implement B-Value Monitoring (DO-253C LAAS MOPS Section 2.3.11.5.2.3)</b>	E202	5/2012
<b>Implement Fault Detection and Provide Results Data (DO-253C LAAS MOPS Section 2.3.9.6)</b>	E202	5/2012
<b><i>Task Area II Phase III</i></b>		
<b>Activate and update software baseline from Phase II</b>	E300	8/2012
<b>Implement VDB Message Authentication (DO-253C</b>	E301/E302	10/2012

<b>LAAS MOPS Section 2.3.7.3)</b>		
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**Table 2 - GAST-D Avionics Prototype Software Builds**

During the course of the contract, several deficiencies were found in the MOPS as they were written. These have been presented at RTCA for amendment and are summarized here:

- Airborne Code Carrier Divergence Filtering (CCD) [DO253-C Section 2.3.6.11]
  - Filter output can be positive or negative, but MOPS defines the threshold as positive.
  - CCD output will be in meters, but the MOPS defines the threshold as m/sec.
  - The MOPS does not specify any re-inclusion criteria for an SV excluded by the CCD monitor. Should IN PAR and IN AIR sates be monitored?
  - Due to the 20 minute waiting period for SV inclusion, receiver start-up performance will be different for AEC-D equipment than AEC-C equipment, even when operating in GAST-C mode.
- Differential Correction Magnitude Check (HPCM) [DO253-C Section 2.3.9.5]
  - There is an extra term in the computation for the total correction to the measured PR for SV 'i'.
  - More clarity on when to use 100-second or 30-second smoothed PRs for computation of HPDCM is required.
- Reference Receiver Fault Monitoring (RRFM) [DO253-C Section 2.3.11.5.2.3]
  - Computations for the standard deviations of  $D_v$  and  $D_L$  are not defined. Acceptable assumptions for manufacturers to use when computing these values should be stated.
- Fault Detection [DO253-C Section 2.3.9.6]
  - The MOPS requires fault detection (FD) only for GAST-D systems. HI believes FD would be beneficial in detecting local conditions that could lead to faulted measurements.
- Fault Detection for Satellite Addition [DO253-C Section 2.3.9.6.1]
  - More clarity is needed on when FD for SV is required
  - How to handle situations where multiple SVs which were failed for CCD in the past 20 minutes become available at the same time
- VDB Authentication [DO253-C Section 2.3.7.3]
  - No guidance is provided for clearing a fault after an authentication failure.

Not all of the GAST-D updates found in the LAAS MOPS (DO253-C) were completed. Notably absent is the implementation of airborne geometry screening. VDB Authentication protocols were also only partially completed, as the hardware changes necessary to successfully implement those protocols which require detection of the slot a message was received in fell outside the scope of this contract. A follow-on contract to address these items has not been possible due to funding.

A complete report on the GAST-D avionics prototype contract, including detailed results of the six sets of flight testing completed by ANG-C32 during development, is available at [http://laas.tc.faa.gov/documents/Docs/INR\\_FINAL\\_REPORT.pdf](http://laas.tc.faa.gov/documents/Docs/INR_FINAL_REPORT.pdf).

*Ground System*

The FAA is currently conducting contracts with Honeywell International (HI) to implement GAST-D GBAS ground requirements on the HI GAST-C GBAS system, the SLS-4000. Tasking under the original contract is complete. This work included modifications for RFI robustness, as well as necessary updates to existing GAST-C monitors and the addition of an ionospheric gradient monitor (IGM). Modeling and system safety analysis work for the various monitors implemented was also completed.

All updates have been implemented on the FAA's SLS-4000 at Atlantic City International Airport (ACY). Hardware changes have included the switch from copper to fiber connectivity to the reference stations from the main processing unit and the addition of two 'secondary' reference receivers (RRs). These extra RRs will be used to help mitigate RFI as well as to provide longer baselines for ionospheric gradient monitoring. A description of the GAST-D software updates to the ACY SLS-4000 is provided in **Table 3**.

A new contract modification was recently awarded to HI to allow for more work, primarily on ionospheric gradient monitoring. As work progressed on the original GAST-D contract, it was found that non-ionospheric elements of the atmosphere could also cause delays that could cause blinding or false tripping of the developed gradient monitor. Further study of this issue led to concerns with the ground ionospheric gradient monitoring requirement as it is written in the current SARPS. Details on the data collected and suggested changes to this requirement are available in working papers presented by the FAA and HI at this meeting [1, 2]. Although HI led the effort to build and validate the ground IGM, this work was sponsored by the FAA. Validation material for the IGM was collected under the prototyping contract and was overseen by the FAA, and the LAAS Integrity Panel (LIP) has reviewed and concurred with the data collection.

Software Build	Updates	Date Delivered
1	Display Type 11 Msg	12/2010
2	Implement 30 second smoothing Populate Type 11 msgs Updates to Message Types 2 & 3 Incorporation of iono gradient monitor	6/2011
3	Incorporation of CAT-III Excessive Acceleration (EA) monitor	7/2012
4	Updates to manage 6 RRs	9/2012
5	Incorporation of CCD monitor updates Incorporation of Ephemeris monitor updates Incorporation of Signal Deformation Monitor (SDM) Updates	12/2012
6	Measured site data updates for 6 RRs	3/2013
7	Addition of RR selection logic RFI monitoring updates	7/2013
8	6 RR updates for SDM, CCD, IGM, and carrier rate monitors	Expected 11/2014

**Table 3 - GAST-D Ground Prototype Software Builds****3.3 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 event of GPS SV outages, and could cause concern if the SV outage(s) creates an insufficient geometry to keep the protection levels below the alert limits. See **Table 4** below for a list of NANU types.

NANUs that caused an interruption in service where Alert Limits are exceeded will be highlighted within the NANU summary (see **Table 5**). Although such an interruption is unlikely, the GBAS team closely tracks the NANUs in the event that post-data processing reveals a rise in key performance parameters.

NANU Acronym	NANU Type	Description
FCSTDV	Forecast Delta-V	Satellite Vehicle is moved during this maintenance
FCSTMX	Forecast Maintenance	Scheduled outage time for Ion Pump Ops / software testing
FCSTEXTD	Forecast Extension	Extends a referenced "Until Further Notice" NANU
FCSTSUMM	Forecast Summary	Gives exact time of a referenced NANU
FCSTCANC	Forecast Cancellation	Cancels a referenced NANU
FCSTRESCD	Forecast Rescheduled	Reschedules a referenced NANU
FCSTUUFN	Forecast Unusable Until Further Notice	Scheduled outage of indefinite duration
UNUSUFN	Unusable Until Further Notice	Unusable until further notice
UNUSABLE	Unusable	Closes an UNUSUFN NANU with exact outage times
UNUNOREF	Unusable with No Reference NANU	Resolved before UNUSUFN could be issued
USABINIT	Initially Usable	Set healthy for the first time
LEAPSEC	Leap Second	Impending leap second
GENERAL	General Message	General GPS information
LAUNCH	Launch	Recent GPS Launch
DECOM	Decommission	Removed From current constellation

**Table 4 - NANU Types and Definitions**

NANU	TYPE	PRN	Start Date	Start Time (UTC)	End Date	End Time (UTC)
2015001	FCSTDV	13	01/09/2015	0530	01/09/2015	1730
2015002	FCSTUUFN	26	01/05/2015	1600	N/A	N/A
2015003	GENERAL	08	01/07/2015	2200	N/A	N/A
2015004	UNUSUFN	26	01/05/2015	1750	N/A	N/A
2015005	DECOM	26	01/06/2015	2200	N/A	N/A

2015006	FCSTSUMM	13	01/09/2015	0544	01/09/2015	1330
2015007	GENERAL	26	02/05/2015	N/A	N/A	N/A
2015008	FCSTDV	30	02/06/2015	0030	02/06/2015	1230
2015009	FCSTSUMM	30	02/06/2015	0112	02/06/2015	0556
2015010	GENERAL	26	02/26/2015	N/A	N/A	N/A
2015011	UNUSABLE	11	02/19/2015	0450	N/A	N/A
2015012	UNUSABLE	11	02/19/2015	0450	02/20/2015	1445
2015013	FCSTDV	14	03/05/2015	1500	03/06/2015	0300
2015014	FCSTSUMM	14	03/05/2015	1512	03/05/2015	2128
2015015	FCSTDV	29	03/12/2015	0400	03/12/2015	1600
2015016	FCSTSUMM	29	03/12/2015	0431	03/12/2015	1048
2015017	FCSTDV	32	03/20/2015	0830	03/20/2015	2030
2015018	FCSTSUMM	32	03/20/2015	0906	03/20/2015	1525
2015019	LAUNCH	26	03/25/2015	1836	N/A	N/A
2015020	FCSTMX	32	03/29/2015	2200	04/11/2015	0000
2015021	GENERAL	08	03/26/2015	2200	N/A	N/A
2015022	UNUSABLE	32	03/30/2015	0005	04/11/2015	0000
2015023	FCSTSUMM	32	03/30/2015	0005	03/31/2015	2344

**Table 5 - NANU Summary**

## Appendix A – GBAS Overview

### A.1 GBAS Operational Overview

A GBAS is a precision area navigation system with its primary function being a precision landing system. The GBAS provides this capability by augmenting the GPS with real-time broadcast differential corrections.

A GBAS ground station includes four GPS Reference Receivers (RR) / RR antenna (RRA) pairs, and a Very High Frequency (VHF) Data Broadcast (VDB) Transmitter Unit (VTU) feeding an Elliptically Polarized VDB antenna. These sets of equipment are installed on the airport property where a GBAS 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 GBAS user(s) using the VDB from the ground-based transmitter. The integrity checks and broadcast parameters are based on the LGF Specification, FAA-E-3017, and RTCA DO-253D (Airborne LAAS Minimum Operational Performance Standards or MOPS).

Airborne GBAS users receive the broadcast data and use it to compute standardized integrity results. When tuning the GBAS, the user also receives the approach path for navigation with integrity assured. The GBAS receiver applies corrections to GPS measurements and then computes ILS-like deviations relative to the uplinked path providing guidance to the pilot. Airborne integrity checks compare protection levels, computed via the integrity parameters, to alert levels. Protection levels were determined based on allowable error budgets. The horizontal alert limit is 40m and the vertical is 10m at the GAST-C decision height of 200m. If at any time the protection levels exceed the alert limits, calculated deviations are flagged and the approach becomes unavailable. With the current constellation horizontal protection levels are typically 2.3m and vertical protection levels are typically < 5m with resulting availability of 100%.

One key benefit of the GBAS, in contrast to traditional terrestrial navigation and landing systems (e.g., ILS, MLS, TLS), is that a single GBAS 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.

**Figure 42** is provided as an illustration of GBAS operation with major subsystems, ranging sources, and aircraft user(s) represented.

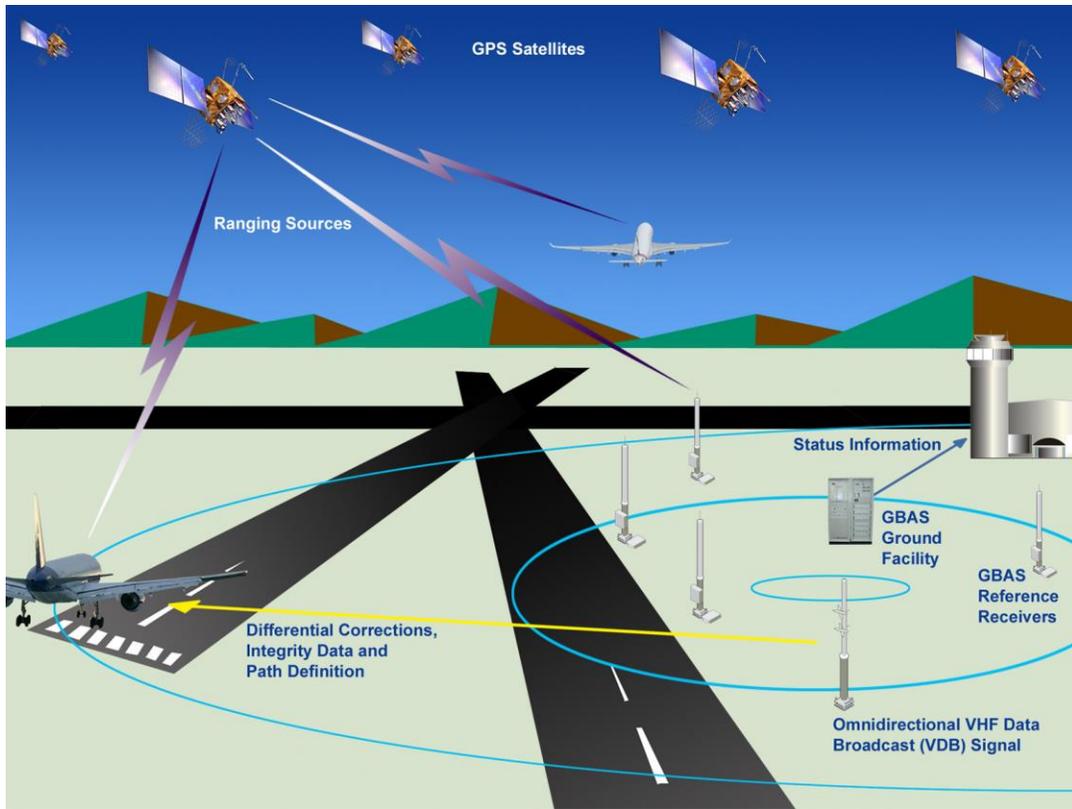


Figure 36 - GBAS Architecture Diagram

## Appendix B - GBAS Performance and Performance Type

### **B.1 Performance Parameters and Related Requirements Overview**

The GPS Standard Positioning Service (SPS), while accurate, is subject to error sources that degrade its positioning performance. These error sources include ground bounce multipath, ionospheric delay, and atmospheric (thermal) 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 differential correction, with short baselines to the user(s), is suitable to provide precision guidance.

In addition to accuracy, there are failures of the SPS that are possible, which are not detected in sufficient time and can also cause hazardous misleading information (HMI). GBAS provides monitoring of the SPS signals with sufficient performance levels and time to alarm to prevent HMI.

The relatively short baselines between the user and the GBAS reference stations, as well as the custom hardware and software, is what sets GBAS apart from WAAS. Use of special DGPS quality hardware such as employment of MLA's serves to mitigate the multipath problems, while the GBAS software monitors and corrects for the majority of the remaining errors providing the local user a precision position solution.

The LAAS Ground Facility is required to monitor and transmit data for the calculation of protection parameters to the user. The GBAS specification also requires monitoring to mitigate Misleading Information (MI) that can be utilized in the position solution. These requirements allow the GBAS 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, (i.e., 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.

### **B.2 Performance Parameters**

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

Cat I precision approach requirements for GBAS 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.

### ***B.2.1 VPL and HPL***

Vertical and Horizontal Protection Levels (VPL and HPL) parameters are actively monitored since the GBAS is required to perform with a worst case constellation and geometry scenario. VPL / HPL parameters are directly tied to constellation geometry and when combined with pseudorange errors affect the SPS position estimate and time bias. Monitoring the VPL and HPL in the GBPM gives a valid picture of what the user is experiencing. The protection levels are compared against the alert limits of the appropriate GBAS service level (GSL). In the event the protection levels exceed the alert limit, an outage will occur (See section 6 for GBAS site specific outages).

### ***B.2.2 B-Values***

B-values represent the uncorrectable errors found at each reference receiver. They are the difference between broadcasted pseudorange corrections and the corrections obtained excluding the specific reference receiver measurements. B-values indicate errors that are uncorrelated between RRs. Examples of such errors include multipath, receiver noise, and receiver failure.

### ***B.2.5 Performance Analysis Reporting Method***

For a given configuration, the LTP's 24-hour data sets repeat performance, with little variation, over finite periods. The GBAS 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 GBAS T&E team indications for closer investigation into the presence, or suspicion, of uncharacteristic performance.

Data sets from the LTP ground and monitoring stations are retrieved on a weekly basis and processed immediately. A representative data-day can then be drawn from the week of data to be formally processed. The resultant performance plots 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.

## **Appendix C - LTP Configuration and Performance Monitoring**

### **C.1 Processing Station**

The LTP Processing Station is an AOA-installed operational GBAS system. It is continually operational and is used for flight-testing, in addition to data collection and analysis summarized in this report. 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 corrections broadcast. The performance reporting of the system is represented only from GBAS standard operating configurations.

#### **C.1.1 Processing Station Hardware**

The processing station consists of an industrialized Central Processing Unit (CPU) configured with QNX (a UNIX-type real time OS). It then collects raw reference station GPS data messages while processing the data live. It also collects 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 serial card that communicates in real time with the four reference stations through a Lantronix UDS2100 serial-to-Ethernet converter. 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). The CPU then generates the GBAS corrections and integrity information and outputs them to the VDB.

The VDB Transmitter Unit (VTU) is capable of output of 80 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 112.125 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 (see Protection Level Maps at <http://laas.tc.faa.gov> for graphical representation).

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

#### **C.1.2 Processing Station Software**

Ohio University (OU) originally developed the GBAS code through an 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 GBAS T&E team since that time and has undergone numerous updates to incorporate evolving requirements, such as the inclusion of Cat III.

The software stores the precise survey data of the four GBAS reference station antennas (all RRA segments). Raw GPS data (i.e., range and ephemeris info) is received via 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 is extracted into local LTP variables. Once the system has received sufficient messages, the satellite positions are calculated in

relation to the individual reference receivers. Type 1, 2, 4, 11 messages containing differential corrections, integrity values, GS information, and approach path data are then encoded and sent to the VDB via a RS-232 connection. Each of the four message types are encoded separately and sent according to DO-246D standards.

### **C.2 Reference Stations**

There are four reference stations included in the FAA's LTP as required in the GBAS specification. The LTP's reference stations are identified as LAAS Test (LT) sites; there were originally five LT sites (LT1 through LT5), excluding LT4. LT4 was originally used for the L1/L2 site (**Figure 43**).

Each reference station consists of two major component systems. The first is a high quality, GNSS antenna (ARL-1900) manufactured by BAE Systems. The second is the reference receiver.



**Figure 37 - The BAE GNSS Multipath Limiting Antenna (MLA)**

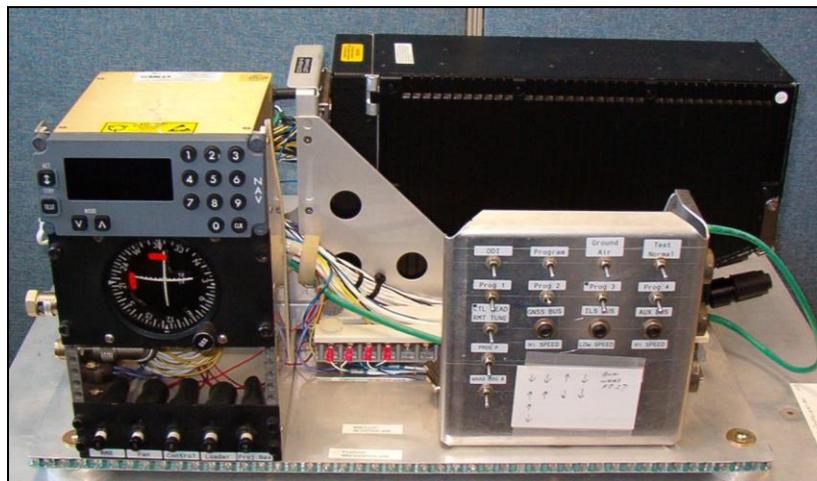
### **C.2.1 The BAE ARL-1900 GNSS Multipath Limiting Antenna (MLA)**

The BAE Systems ARL-1900 is an innovative, single feed, GNSS antenna that is approximately 6 feet high, and weighs about 35 pounds. The receiving elements are configured in an array, and when combined allow reception of the entire GNSS (Global Navigation Satellite System) band. This antenna is also capable of the high multipath rejection as required by the LAAS specification.

Multipath is a phenomenon common to all Radio Frequency (RF) signals and is of particular concern in relation to DGPS survey and navigation. It is simply a reflection of a primary signal that arrives at a user's equipment at a later time, creating a delay signal that can distort the primary if the reflection is strong. Reflected multipath is the bouncing of the signal on any number of objects including the local water table. Signals that reflect off the earth surface are 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 the signal's Time of Arrival (TOA). This causes a pseudorange error, for the SV being tracked, proportional to the signal strength. The BAE provides at least 23 dB of direct to indirect (up/down) pattern isolation above 5 degrees elevation. These multipath induced pseudorange errors can translate directly into a differential GPS position solution, which would be detrimental to applications such as GBAS. Multipath limiting antennas, such as the BAE Systems ARL-1900, were therefore developed to address the multipath threat to differential GPS and attenuate the ground multipath reducing the error. The ARL-1900 antenna characteristics also mitigate specular reflections from objects. The antenna's polarization (right hand circular polarized, or RHCP), provides a pattern advantage and reflective LHCP signals, which is left hand circular polarized.

### **C.3 Multi-Mode Receiver (MMR) Monitoring Station**

The GBAS team maintains an MMR on a precise surveyed GPS antenna to monitor ground station performance and 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. A virtual runway was constructed such that the approach path goes through the MMR GPS antenna point. With the configuration, the CDI should always be centered when the MMR is tuned to the virtual runway that coincides with the antenna's survey position. **Figure 44** is a representation of a typical FAA fabricated MMR test/flight user platform. The version of MMR firmware for this reporting period was Flight Change (FC) 31.



**Figure 38 - MMR User Platform**

## Appendix D - GBPM Configuration and

The Ground Based Performance Monitor is the primary performance monitoring tool for the LTP and the Honeywell SLS-4000 systems. The system uses the received VDB broadcast type 1, 2, 4, and 11 messages from the ground station being monitored along with raw GPS data in order to compute the position of the monitor station. The position calculated from this data is compared to the position of the precision-surveyed GBAS grade GPS antenna, which is used to identify positioning errors.

The GBPM's Novatel OEM-V receiver logs range and ephemeris messages, which provide the necessary pseudorange and carrier phase measurements, as well as satellite position information. VDL messages are then received and separated into each of the DO-246D GBAS message types and decoded.

Data is collected in 24-hour intervals and saved to a .raw file without interruption. This data is used to post-evaluate system performance. In addition to the raw file, live data is transferred from each offsite monitor once per minute to our local database. Users can then access the data through an interactive website by means of tables, charts, and graphs hosted by the Navigation Branch at the FAA. The web address for this service is <http://laas.tc.faa.gov>.

Analysis of GBPM data is critical for closely observing the LTP and SLS performance behavior. The GBPM data output package contains several plots that can quickly illustrate the overall performance picture of the GBAS. The most useful plots available for performance summary purposes are *Vertical and Horizontal User Error versus Time*. These two plots are often used for preview performance analysis because the "user" GPS sensor position is known and stationary. The known position (precision survey) of the GBPM GPS sensor is compared directly to the computed user position. Typical LTP Vertical and Horizontal user error has an average well within the +/- 1-meter range.

**Figure 45** is one of the GBPM's that was built by the Navigation Branch. Some of the major components include a retractable KVM to check the current status of the monitor, CISCO router with a T1 line back to our lab at ACY for data collection and maintenance, Power Distribution Unit (PDU) for a means remote access to bring power outlets back up if they become unresponsive, Novatel GPS Receiver, Becker VDB Receiver, QNX CPU, and an uninterruptable power supply.

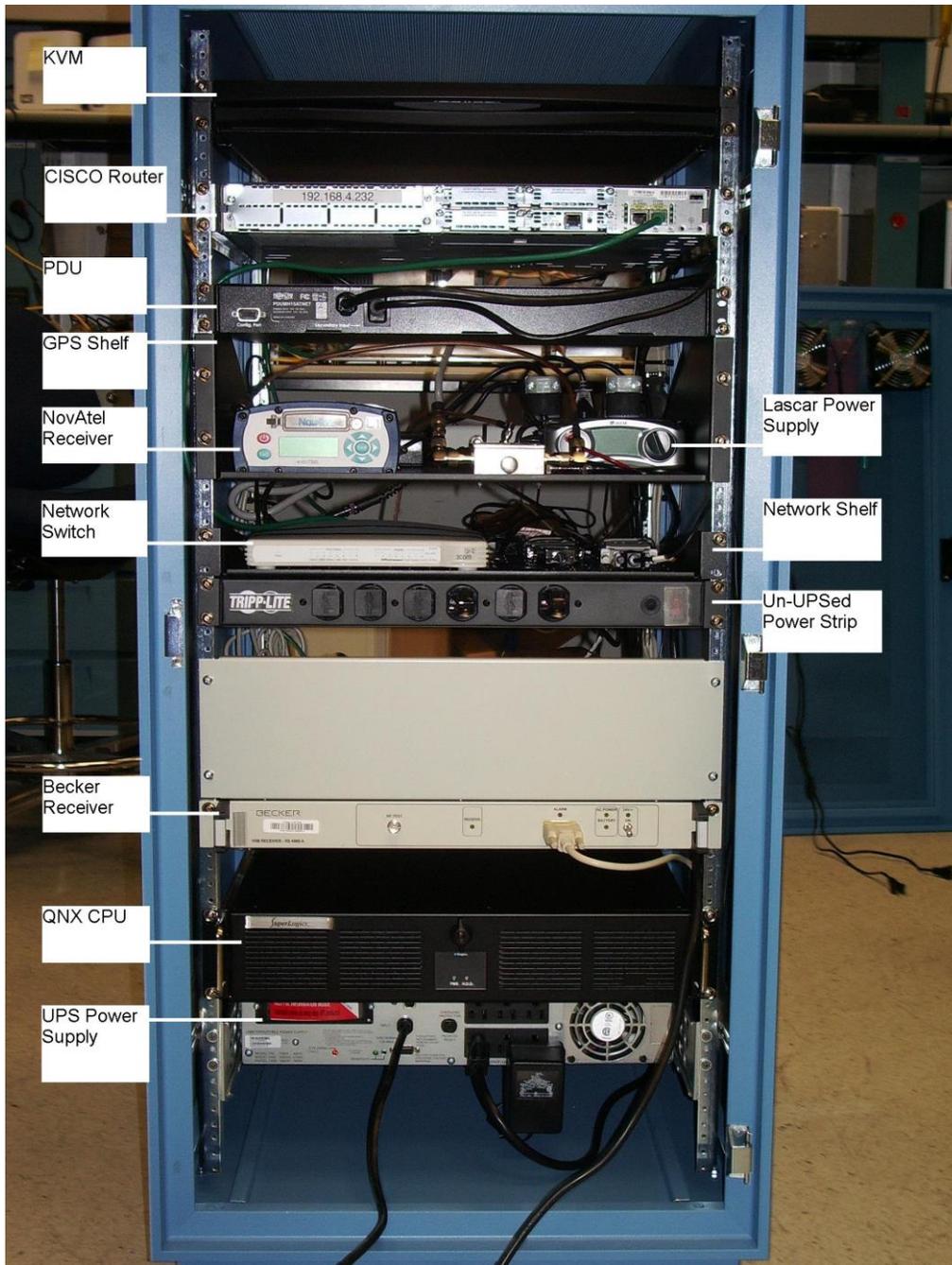


Figure 39 - Ground Based Performance Monitor (GBPM)

**Glossary of Terms**

**—A—**

ACY  
 Atlantic City International Airport ..... 3, 4

**—C—**

CCD  
 Code Carrier Divergence ..... 26

CDI  
 Course Deviation Indicator ..... 38

CPU  
 Central Processing Unit ..... 36

**—E—**

EWR  
 Newark Liberty International Airport..... 4

**—F—**

FAA  
 Federal Aviation Administration ..... 3

FD  
 Fault Detection..... 26

**—G—**

GBAS  
 Ground Based Augmentation System ..... 3

GBPM  
 Ground Based Performance Monitor ..... 3

GIG  
 Galeão International Airport..... 4

GNSS  
 Global Navigation Satellite System ..... 38

GPAP  
 GBAS Performance Analysis Report ..... 3

GSL  
 GBAS Service Level ..... 35

**—H—**

HI  
 Honeywell International..... 3

HPCM  
 Differential Correction Magnitude Check..... 26

HPL  
 Horizontal Protection Level..... 35

**—I—**

IAH  
 George Bush Intercontinental Airport..... 4, 8

IGM  
 Ionosphere Gradient Monitor..... 19

INR

Integrated Navigation Receiver..... 19

**—L—**

LAAS

Local Area Augmentation System ..... 3

LHCP

Left Hand Circular Polarized ..... 38

LIP

LAAS Integrity Panel..... 27

LT

LAAS Test ..... 37

LTP

LAAS Test Prototype ..... 3

**—M—**

MASPS

Minimum Aviation System Performance Standards ..... 34

MI

Misleading Information ..... 34

MLA

Multipath Limiting Antenna ..... 38

MMR

Multi-Mode Receiver ..... 38

MOPS

Minimum Operational Performance Standards ..... 25

MWH

Grant County International Airport..... 4

**—N—**

NANU

Notice Advisory to Navstar Users ..... 28

**—O—**

OU

Ohio University ..... 36

**—P—**

PRC

Pseudorange Correction ..... 32

PT

Performance Type..... 34

**—R—**

RF

Radio Frequency ..... 38

RHCP

Right Hand Circular Polarized..... 38

RRA

Reference Receiver Antenna ..... 32

RRFM

Reference Receiver Fault Monitoring ..... 26

**—S—**  
 SLS  
     Satellite Landing System ..... 3  
 SPS  
     Standard Positioning Service ..... 34  
**—T—**  
 TOA  
     Time Of Arrival ..... 38  
**—V—**  
 VDB  
     VHF Data Broadcast ..... 32  
 VHF  
     Very High Frequency ..... 32  
 VPL  
     Vertical Protection Level ..... 35  
 VTU  
     VDB Transmitter Unit ..... 32  
**—W—**  
 WJHTC  
     William J. Hughes Technical Center ..... 3

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