Federal Aviation Administration

Ground Based Augmentation System

Performance Analysis and Activities Report

Reporting Period: April 1 – June 30, 2014

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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, United Airlines has conducted GBAS approaches 250 times as of May 31, 2014

Figure 1 - EWR SLS-4000 Configuration

2.1.1 Outages and Prediction Performance

- There is a predictable reoccurring outage each day lasting approximately twenty minutes that should be alleviated by the planned Block II update to the SLS-4000 currently targeted for approval in Spring 2015

2.1.2 Real Time Performance Data

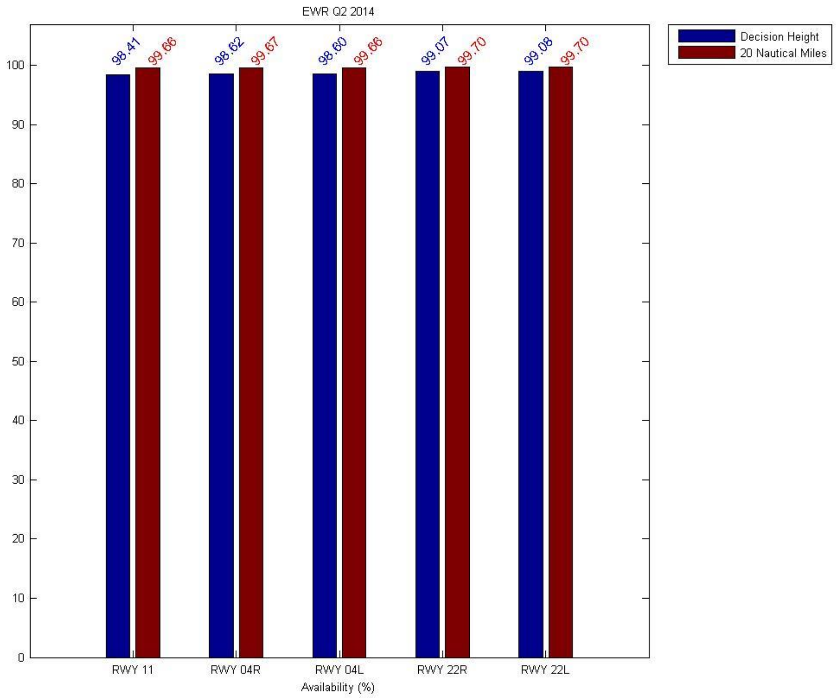

Figure 2 - EWR Availability for Q2 of 2014

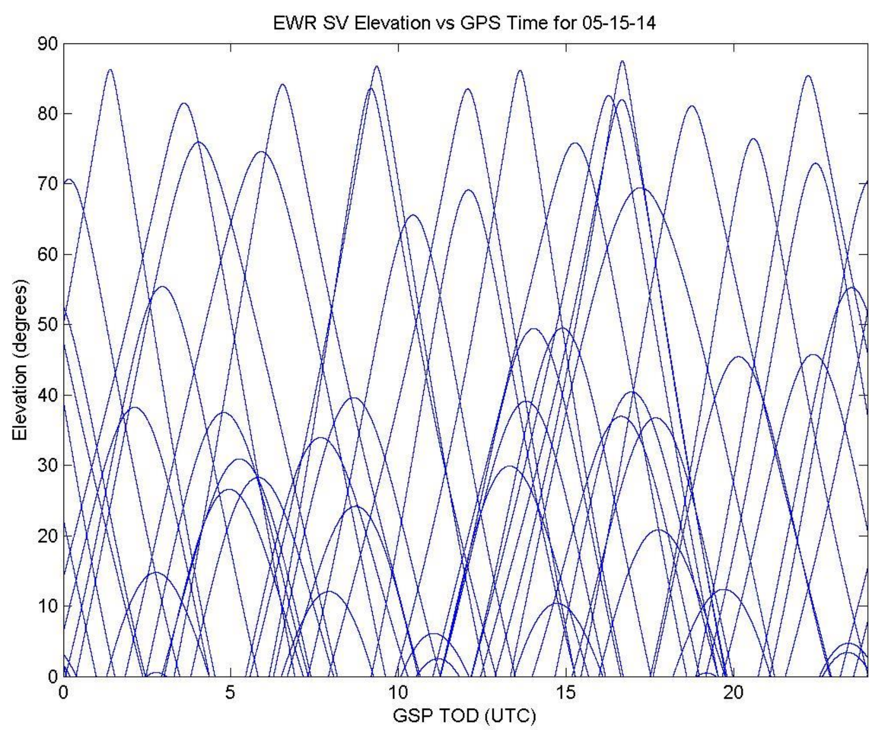

Figure 3 - EWR SV Elevation vs GPS time 5/15/14

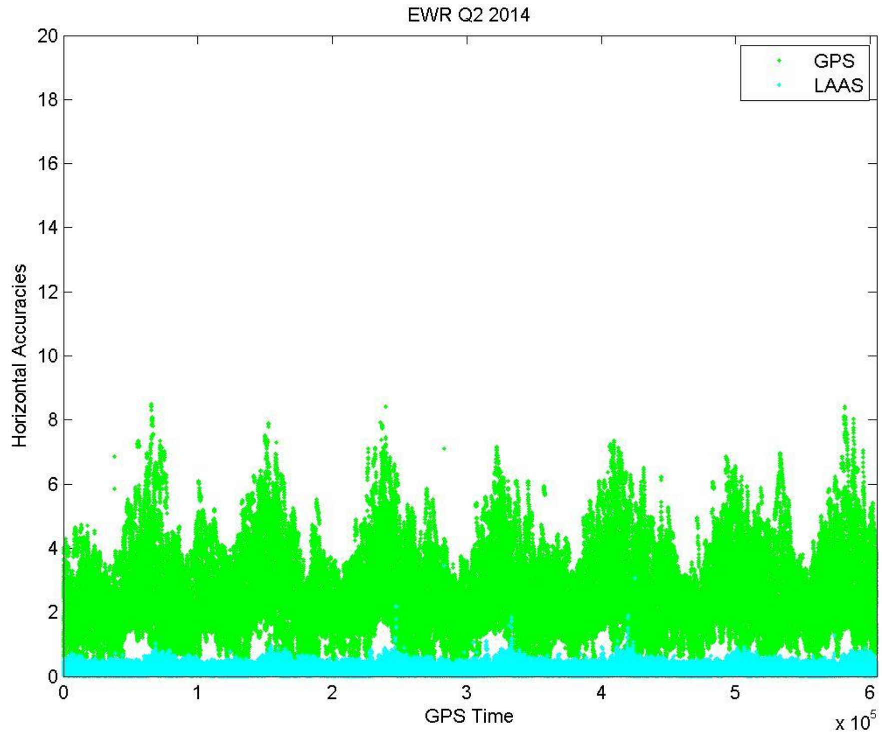

Figure 4 - EWR Horizontal Accuracy Plot

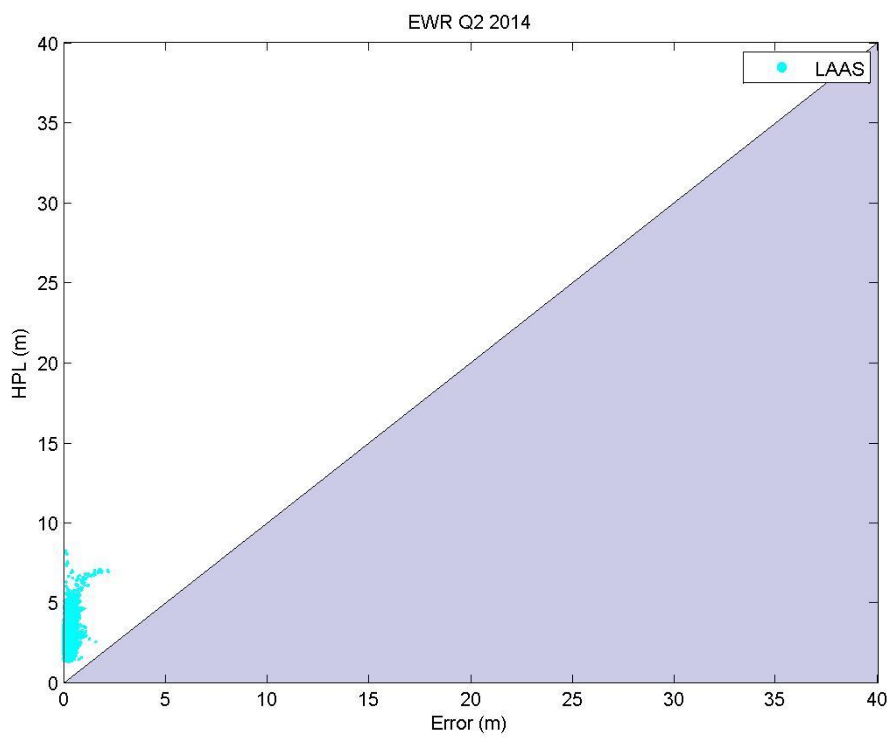

Figure 5 - EWR Horizontal Accuracy vs. Error

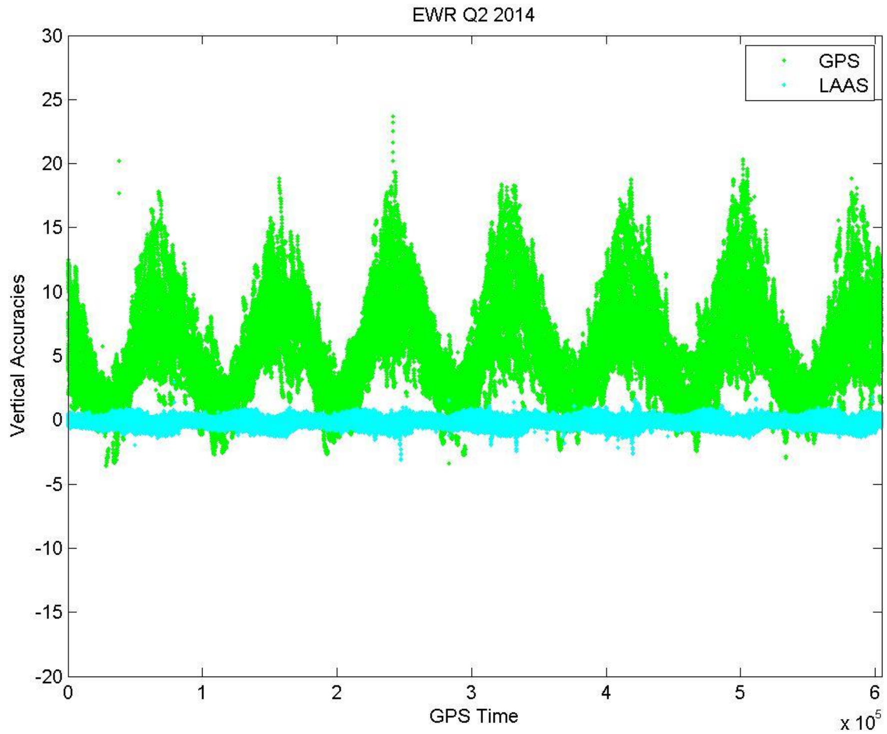

Figure 6 - EWR Vertical Accuracy

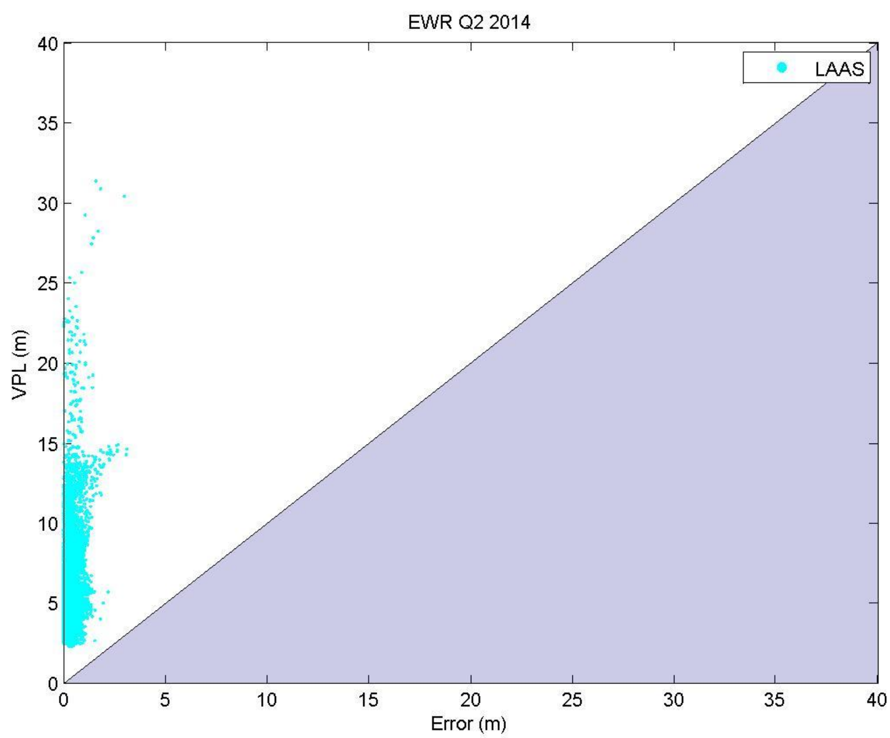

Figure 7 - EWR Vertical Accuracy vs. Error

2.2 IAH SLS

- Houston has a Honeywell SLS-4000 that was granted operational approval on April 22, 2013
- Since IAH went live, United Airlines has conducted GBAS approaches 389 times as of May 31, 2014

Figure 8 - IAH SLS-4000 Configuration

2.2.1 Outages and Prediction Performance

- There is a predictable reoccurring outage each day lasting approximately eight minutes that should be alleviated by the planned Block II update to the SLS-4000 currently targeted for approval in Spring 2015

2.2.2 Real Time Performance Data

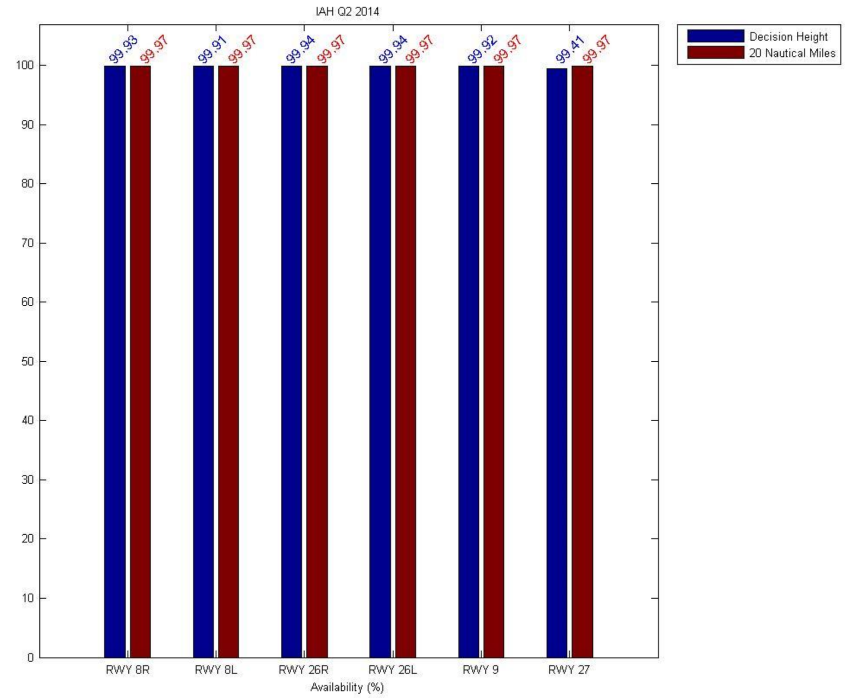

Figure 9 - IAH Availability for Q2 of 2014

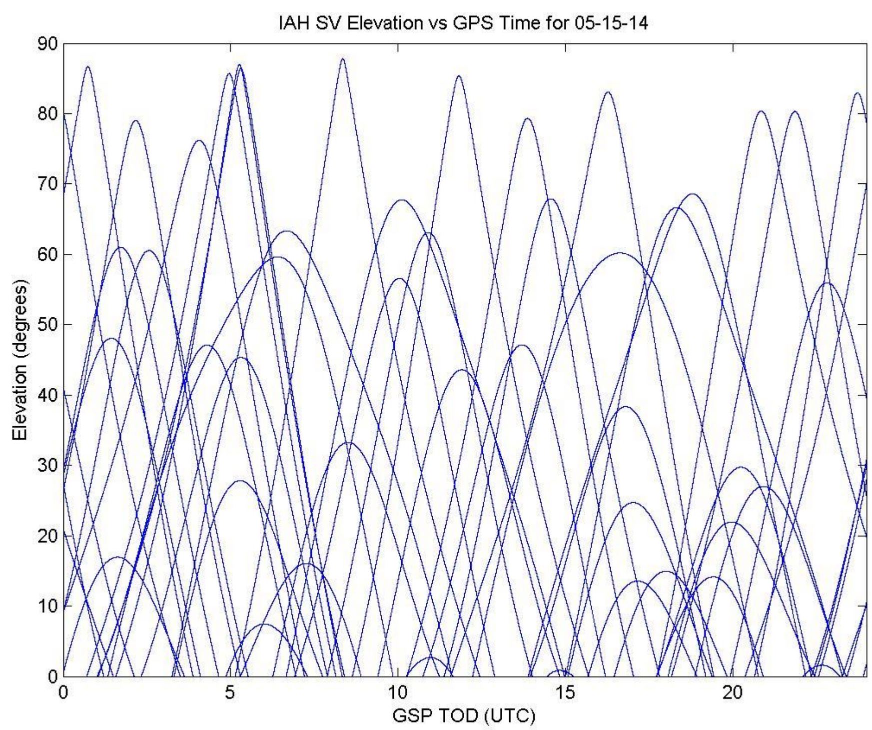

Figure 10 - IAH SV Elevation vs GPS time 5/15/14

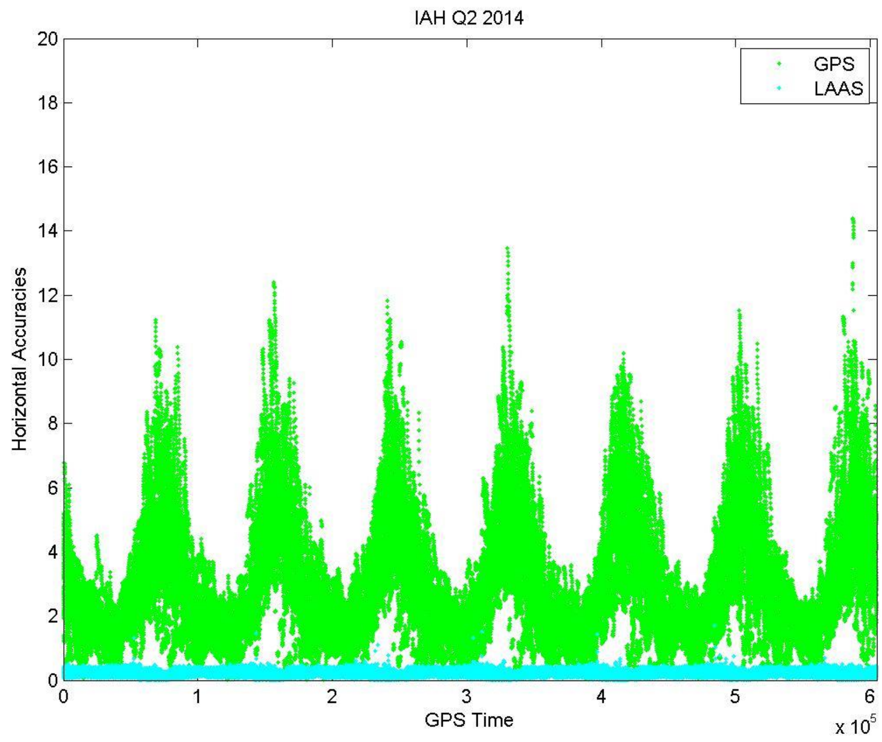

Figure 11 - IAH Horizontal Accuracy Plot

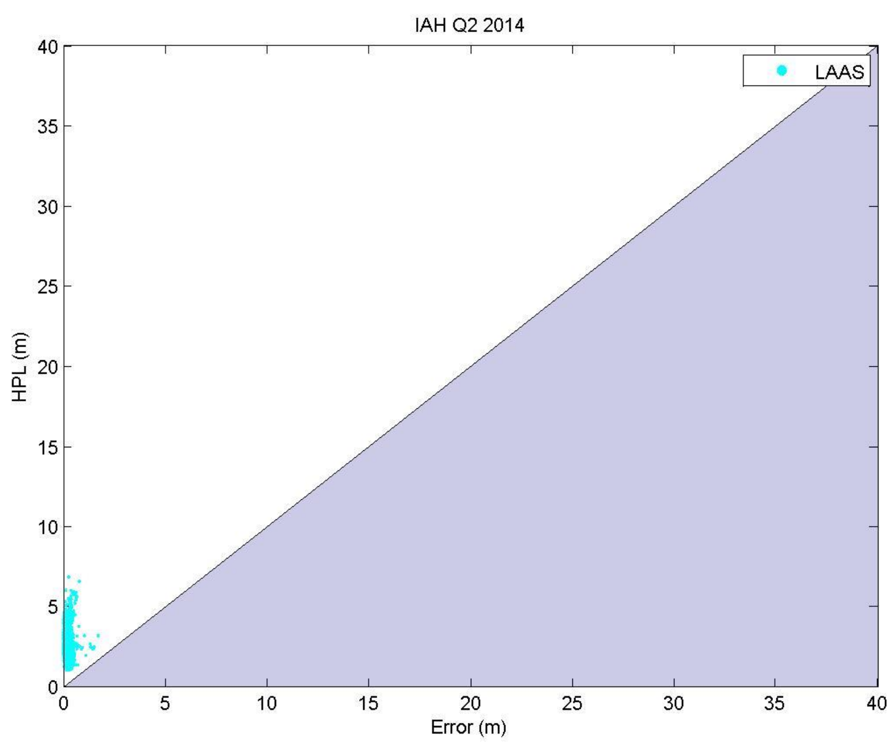

Figure 12 - IAH Horizontal Accuracy vs. Error

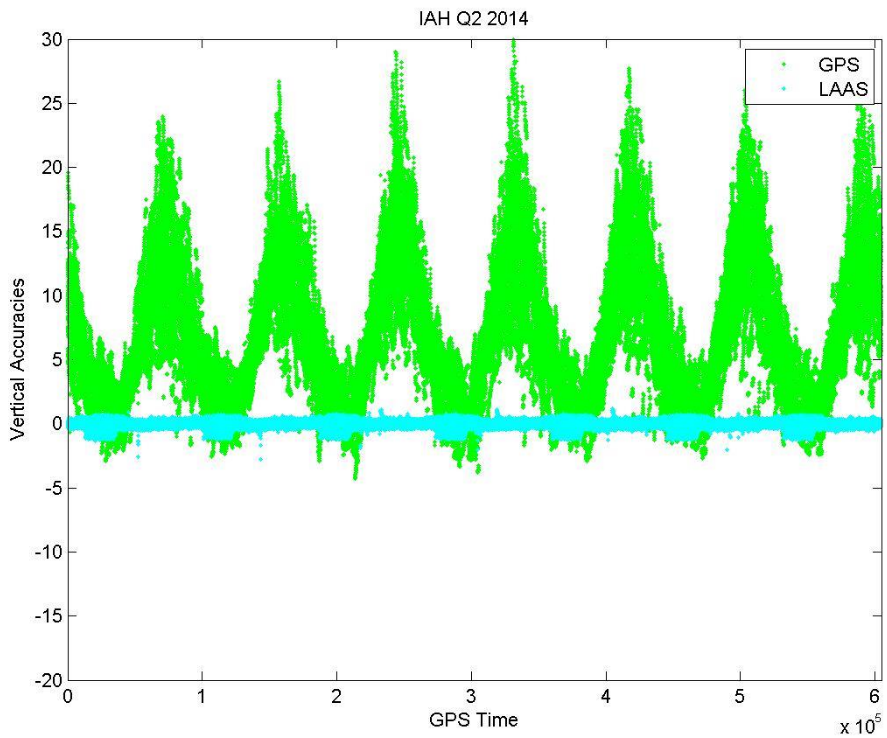

Figure 13 - IAH Vertical Accuracy

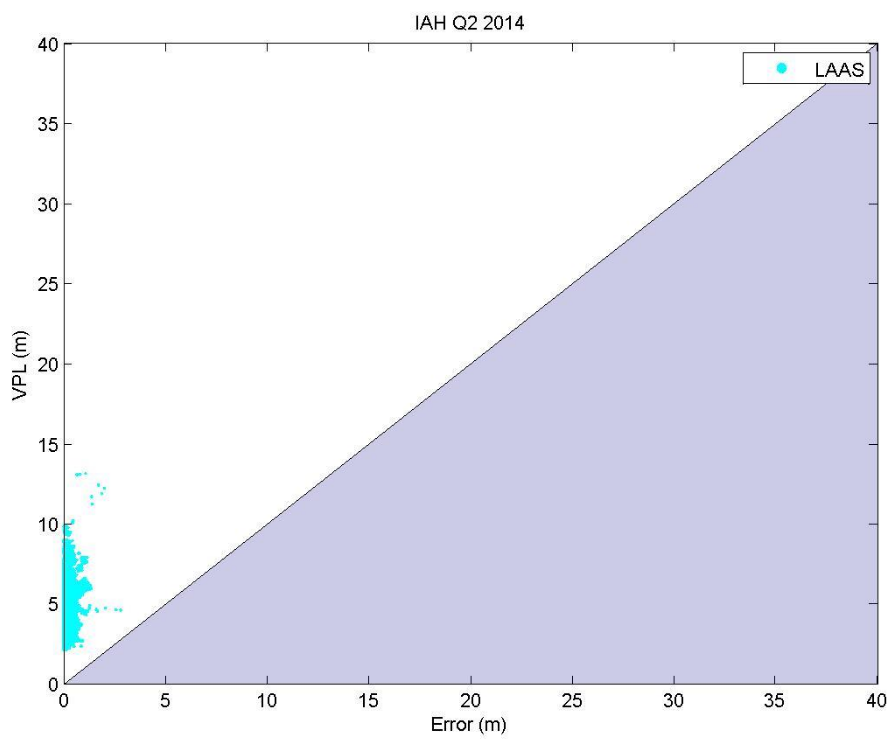

Figure 14 - IAH Vertical Accuracy vs. Error

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
- From date to current MWH is operating with a Honeywell “Porta-BAS” as the SLS-4000 is shut down due to construction activities in the surrounding area
- Repairs were done to the GBPM system in MWH, after computer/network issues caused the system to be unable to be sustained. Resolution included updates to computer, as well as to system software changes

2.3.1 Real Time Performance Data

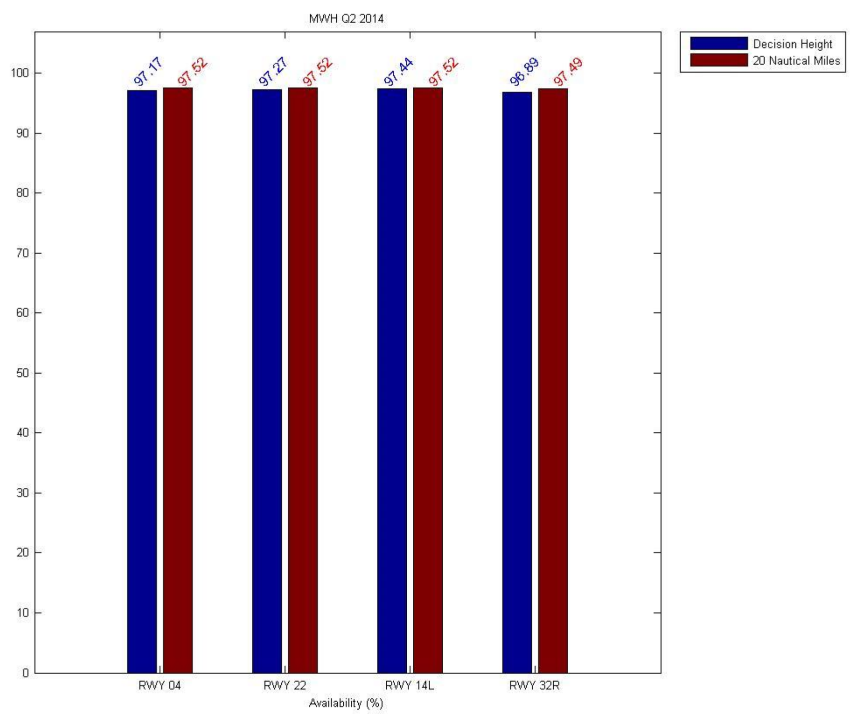

Figure 15 - MWH Availability

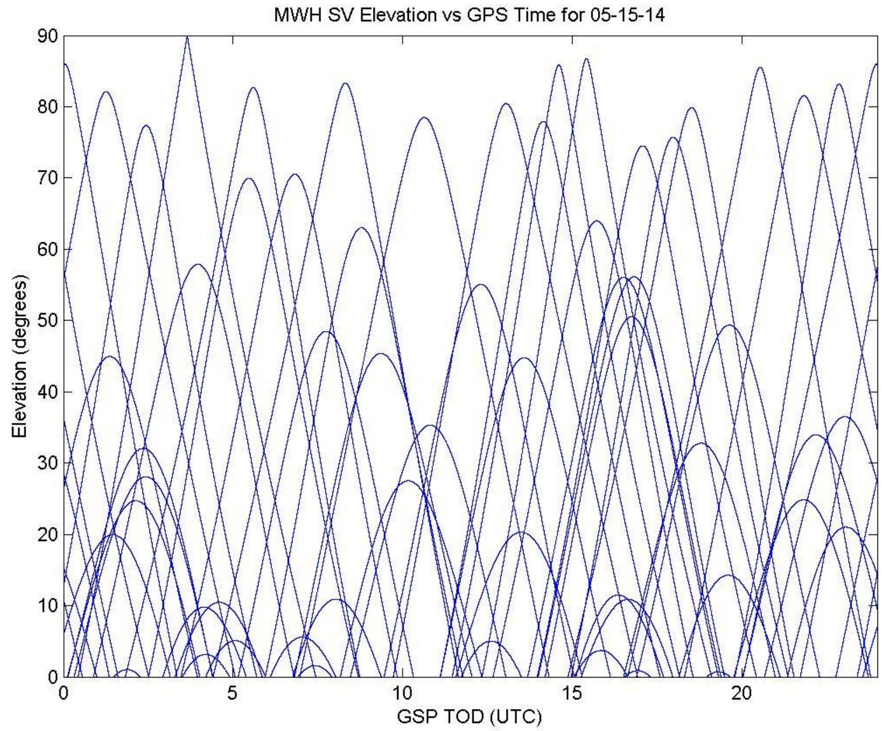

Figure 16 - MWH SV Elevation vs GPS time 5/15/14

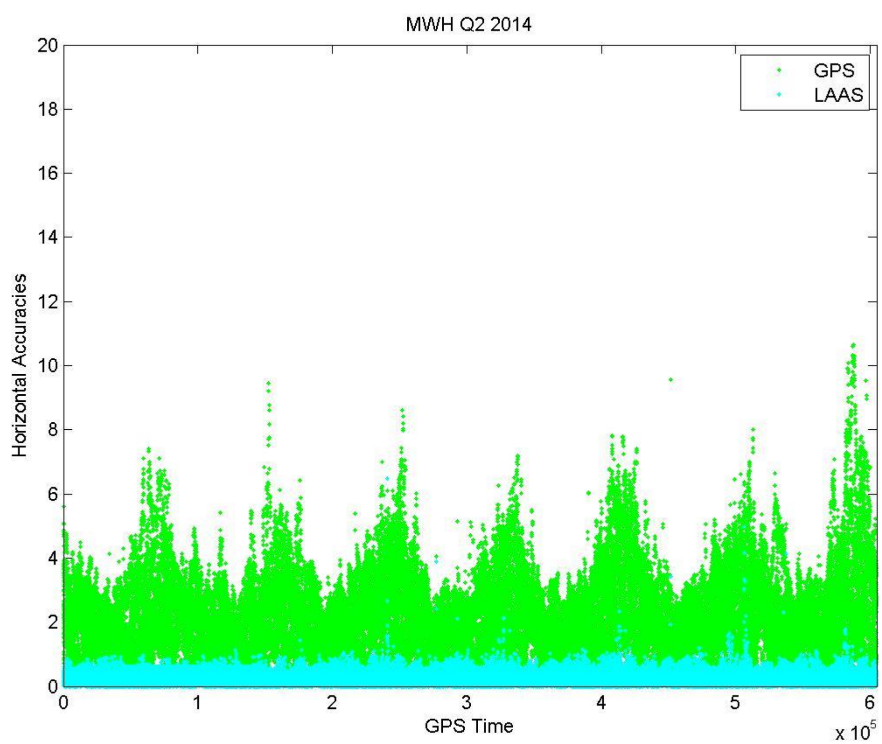

Figure 17 - MWH Horizontal Accuracy Ensemble Plot

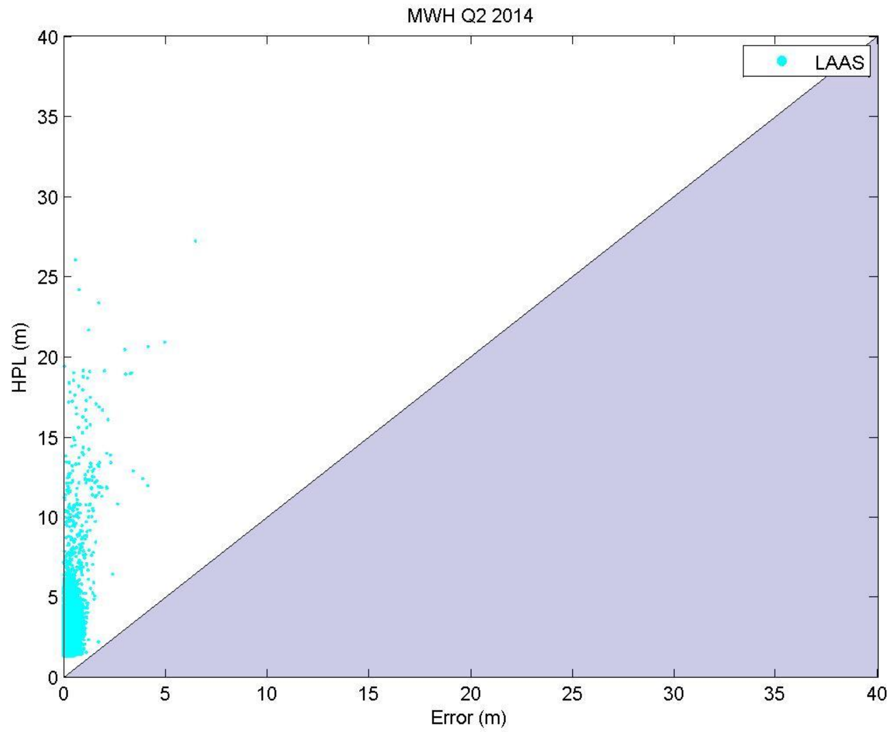

Figure 18 - MWH Horizontal Accuracy vs. Error Bounding Plot

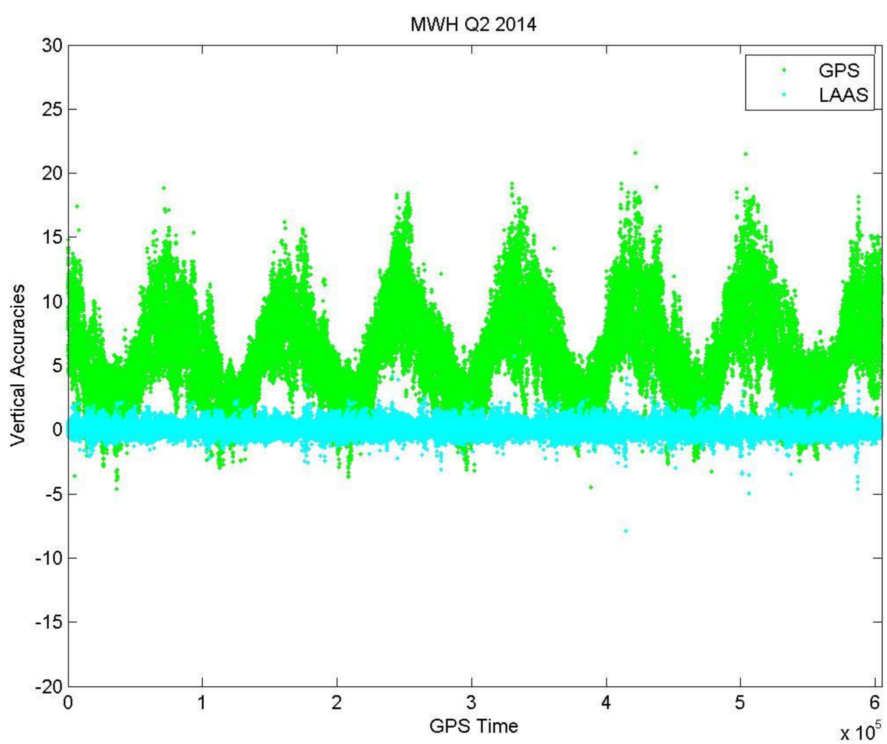

Figure 19 - MWH Vertical Accuracy

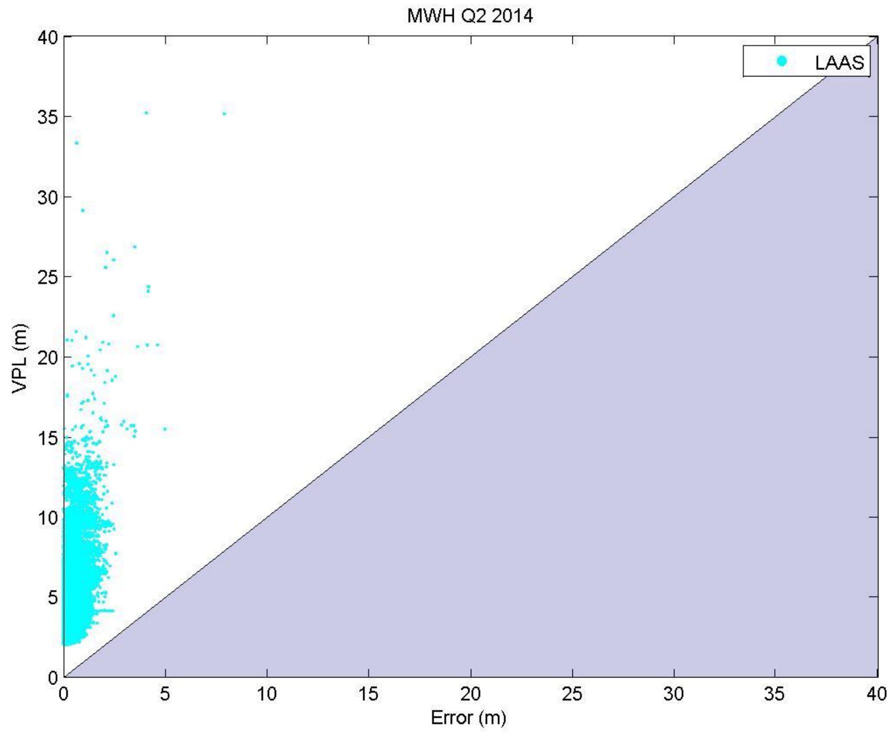

Figure 20 - MWH Vertical Accuracy vs. Error Bounding Plot

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

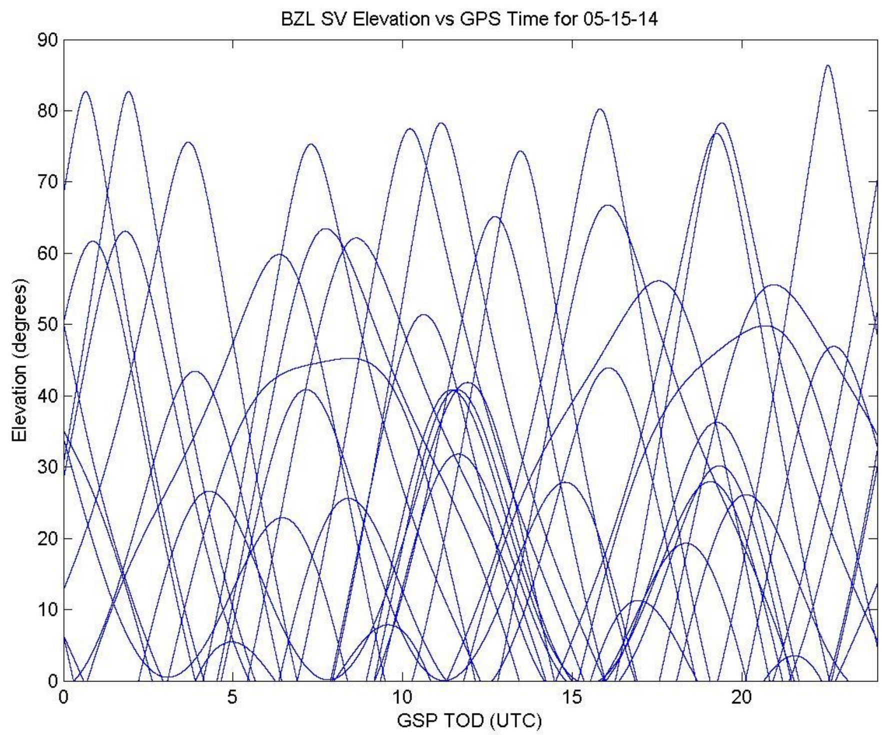

Figure 21 - BZL SV Elevation vs GPS time 5/15/14

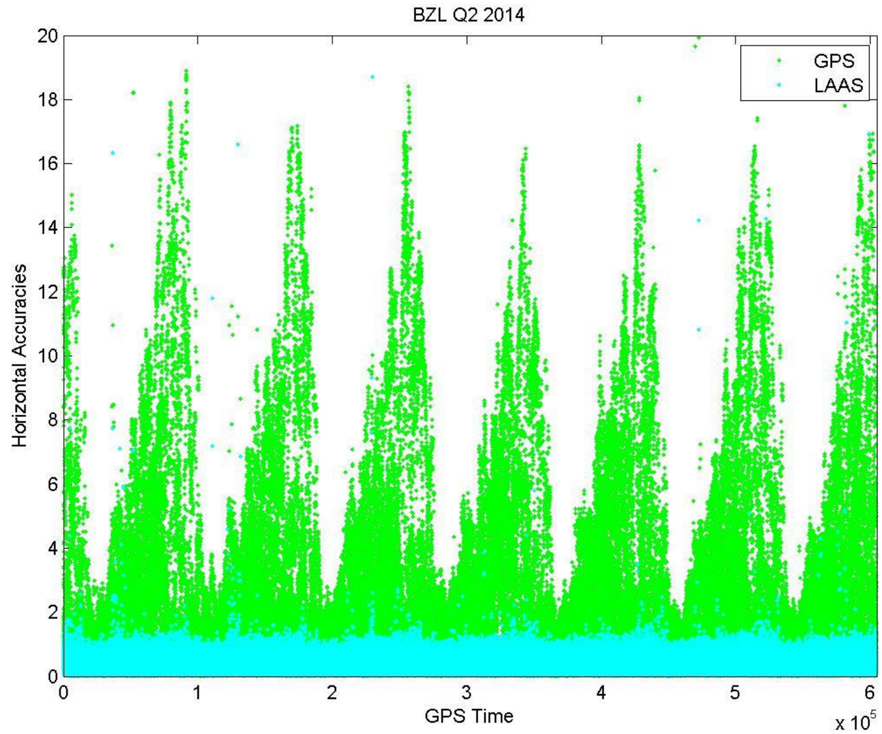

Figure 22 - BZL Horizontal Accuracy Ensemble Plot

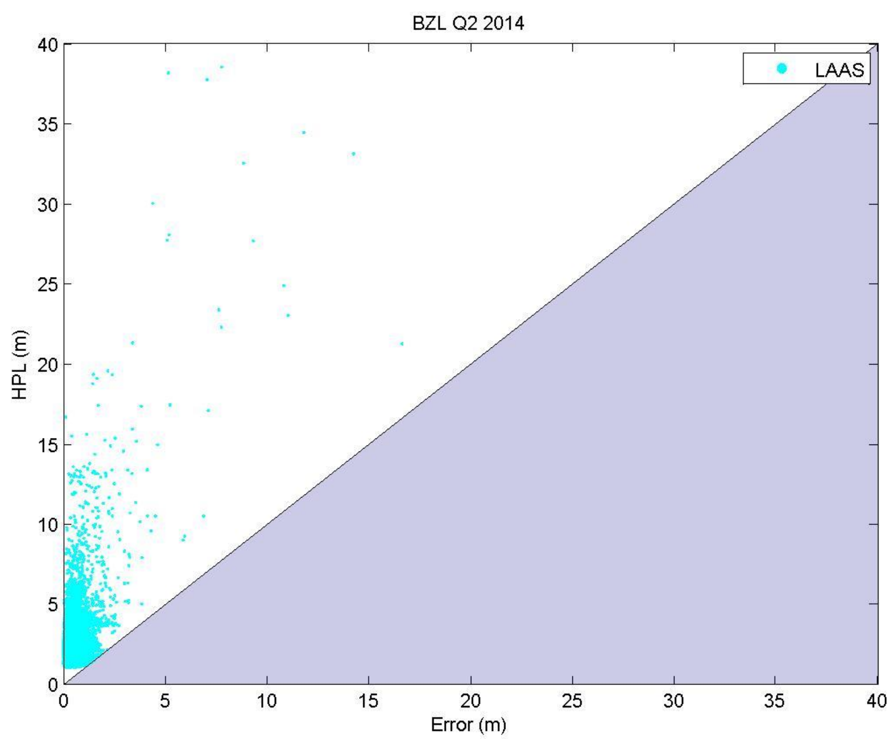

Figure 23 - BZL Horizontal Accuracy vs. Error Bounding Plot

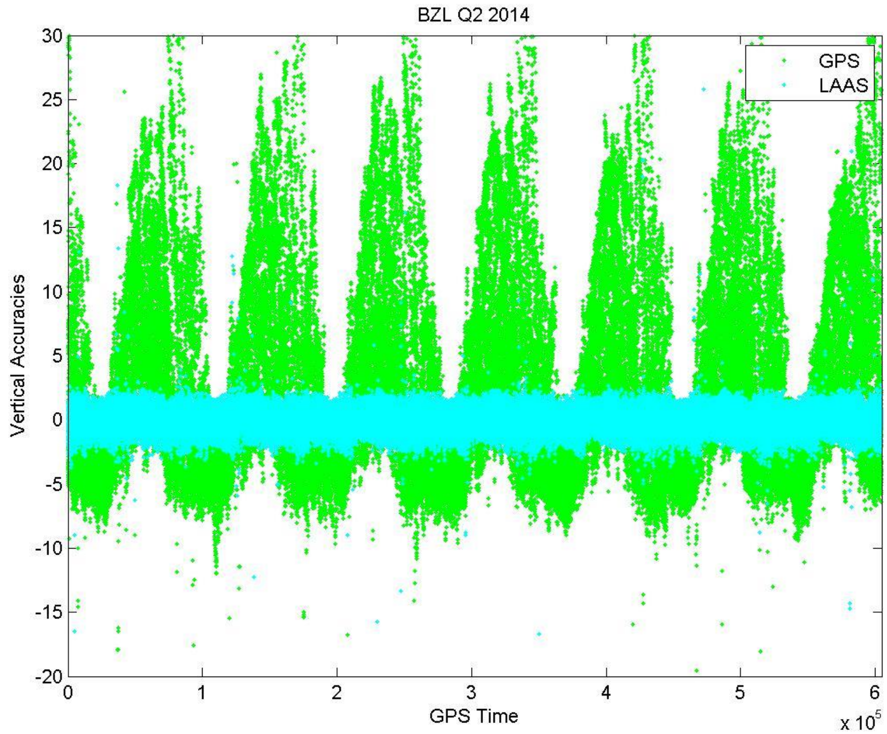

Figure 24 - BZL Vertical Accuracy

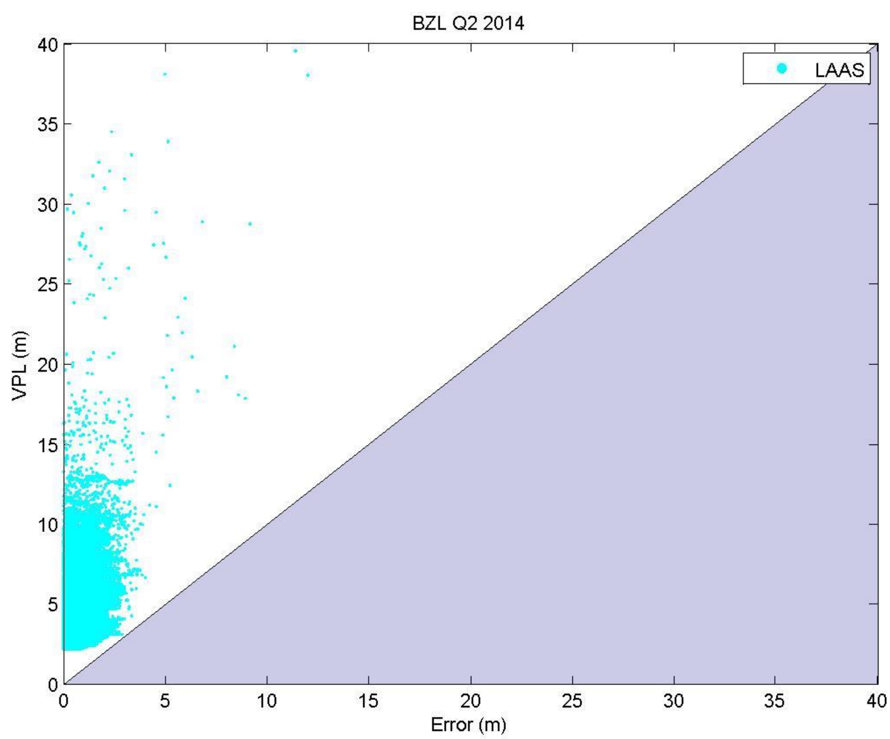

Figure 25 - BZL Vertical Accuracy vs. Error Bounding Plot

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

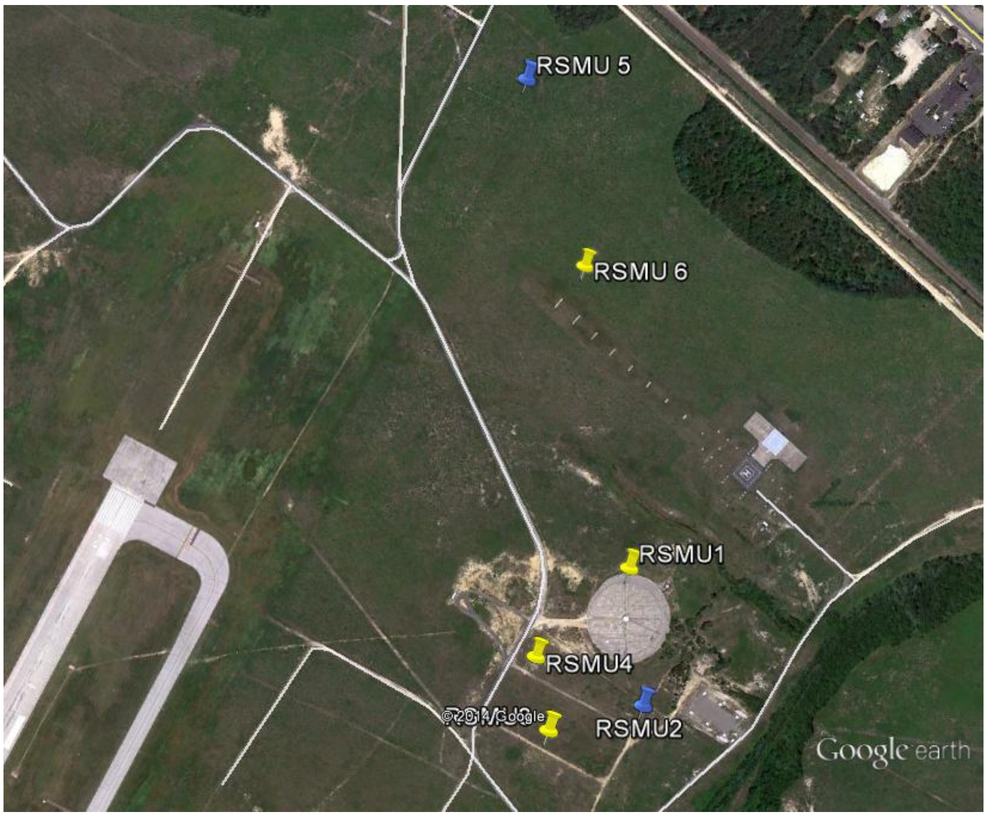

Figure 26 - ACY GAST-D Configuration

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 Graident 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

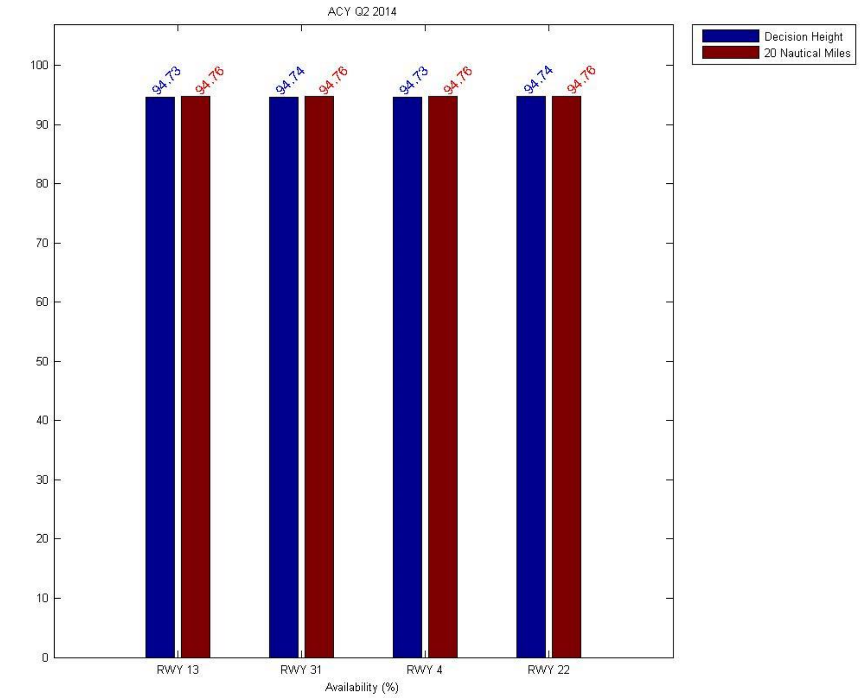

Figure 27 - ACY Availability

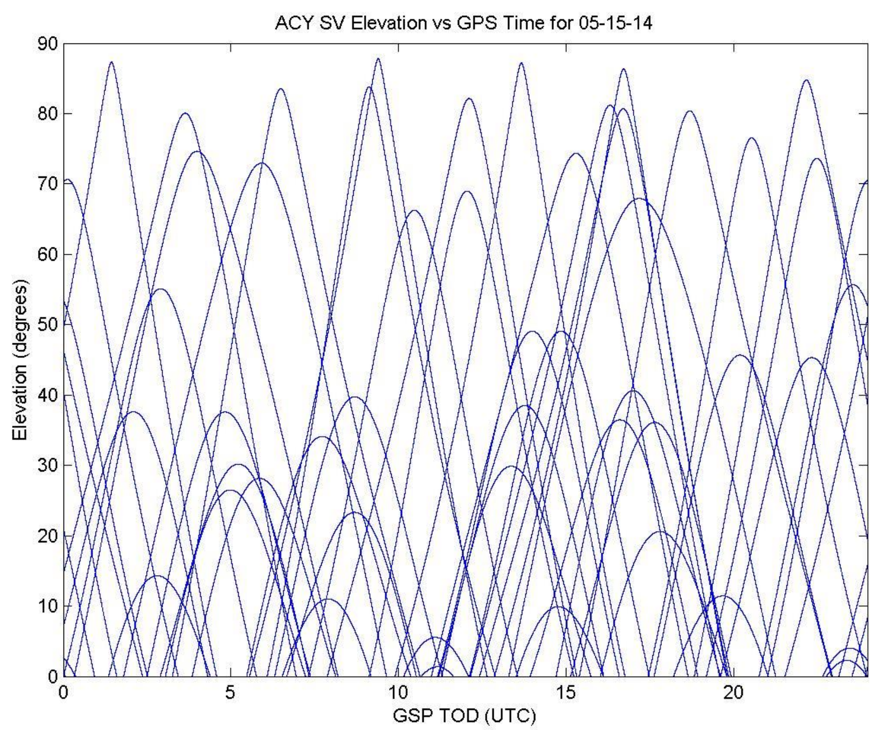

Figure 28 - ACY SV Elevation vs GPS time 5/15/14

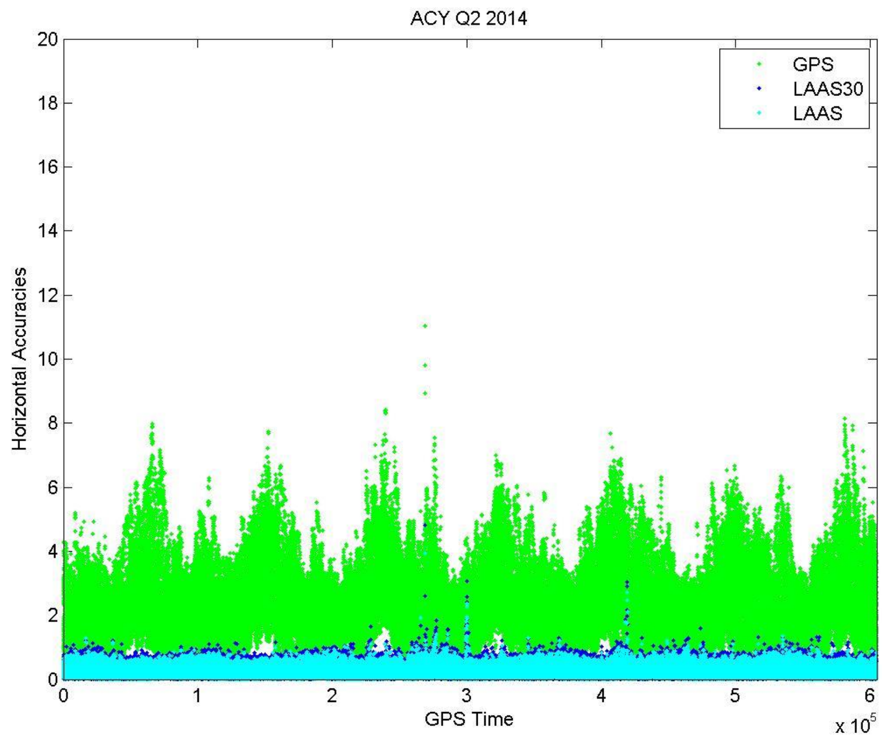

Figure 29 - ACY SLS Horizontal Accuracy Ensemble Plot

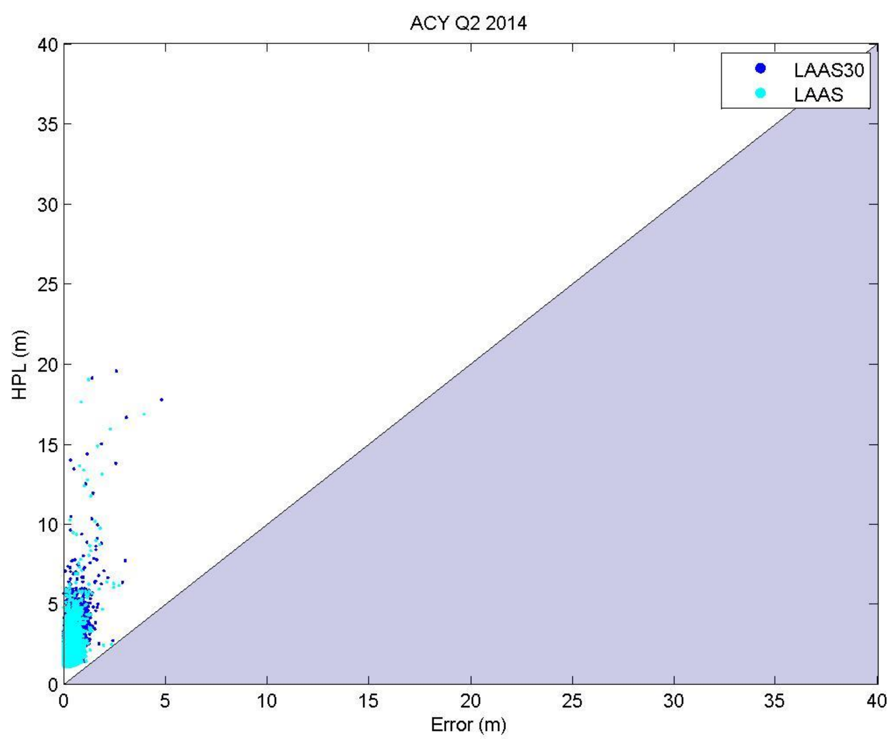

Figure 30 - ACY SLS Horizontal Accuracy vs. Error Bounding Plot

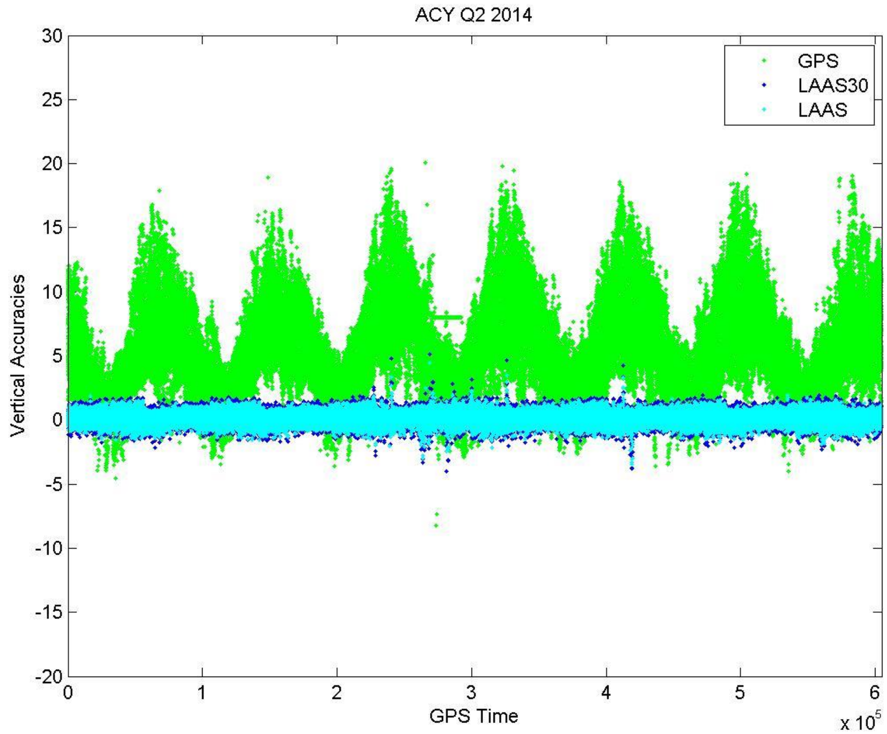

Figure 31 - ACY SLS Vertical Accuracy Ensemble

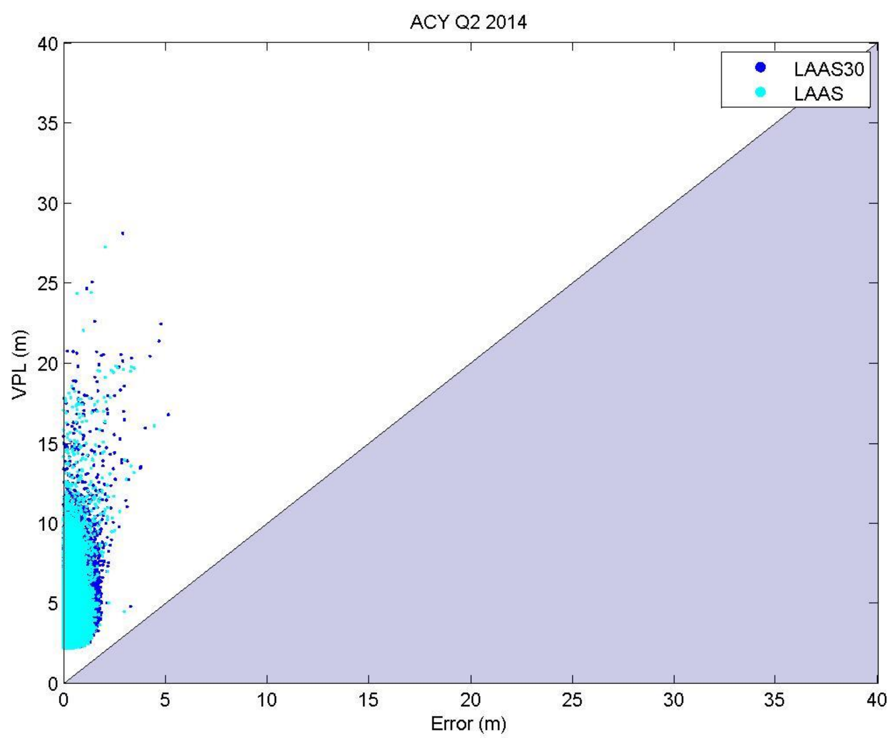

Figure 32 - ACY SLS Vertical Accuracy vs. Error Bounding Plot

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 33 - Aerial View of LTP Configuration

3. Research, Development, and Testing Activities

3.1 FAA Long-Term Ionospheric Monitoring (LTI) Activity

Large spatial variation in Ionosphere delay of Global Positioning Systems (GPS) signals occurs during severe Ionosphere storms. A threat model was developed to access and search for the maximum error possible. This allows GBAS to provide the appropriate corrections to an aircraft should an Ionosphere wave front (modeled as a spatially linear semi-infinite wedge parameterized by the gradient or "slope" of the ramp and its width moving with a constant speed) overtake that aircraft while on precision approach, even under the most detrimental conditions.

The current threat model for the mid-latitude Continental United States (CONUS) was derived by processing data corrected from local clusters of Continuously Operating Reference Stations (CORS) and Wide Area Augmentation System (WAAS) reference stations. This threat model was used for safety assessment and System Design Approval (SDA) of the Honeywell SLS-4000 by the Federal Aviation Administration for use in CONUS.

The bounds of the threat model (**Figure 34**) were determined by processing the worst anomalous days during the last solar maximum in 2000-2003. Continued monitoring of the Ionosphere to ensure gradients larger than those included in the threat model are not present is imperative to GBAS operations, as we are now in the next solar maximum period (14 year cycle). From 2011-2014, we expect to see an increase in solar activity, which may include but is not limited to Coronal Mass Ejections (CMEs), Solar Flares, and other space weather phenomenon. Figure 29 illustrates the current mid-latitude CONUS threat model, which includes confirmed gradients (in mm/km) from the 2003 solar cycle.

Max. Front slope (mm/km)	Low elevation (<15°)	375
	Medium elevation (15° <el<65°)	375+50(el-15)/50
	High elevation (>65°)	425
Front width (km)	25 – 200	
Front speed (m/s)	0 – 750	
Max. differential delay (m)	50	

Figure 34 - Parameters for Mid-latitude CONUS Threat Model

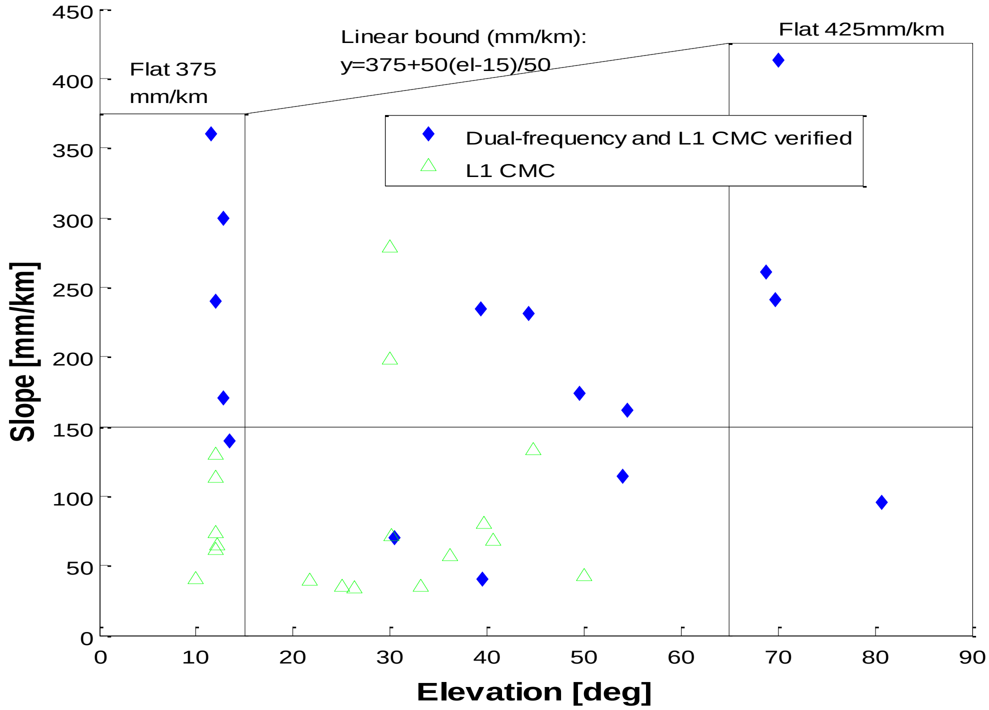

Figure 35 - Mid-latitude Conus Threat Model with confirmed gradients (mm/km) from 2003

Scope of Work:
The tool/software package being used to validate Ionospheric data is identified as the Long-Term Ionosphere Anomaly Monitor (LTIAM) and was originally developed by Dr. Jiyun Lee of the Korean Advance Institute of Science and Technology (KAIST), Dr. Sam Pullen of Stanford University, and their respective teams. The LTIAM consists of MATLAB code that will detect and report Ionospheric anomalies with data collected from NOAA, CORS, and WAAS. Our ultimate goal is to insure that Ground-based Augmentation systems that enhance the performance of GPS are robust to Ionospheric anomalies and irregularities. With regards to CONUS, we also want to continue population of the threat model, evaluate its validity over the life cycle of the system, and to continuously update the threat model if necessary.

The LTIAM tool contains two primary modules: Ionospheric Event Search (IES) and GPS Data Process (IACS). The Ionospheric Event Search block is used to check for potential occurrences of an Ionosphere storm based on space weather indices Kp and Dst (Planetary K and Disturbance Storm Time respectively). The GPS Data Process block is used to read input data (in RINEX format) and derive Ionospheric delay and gradient estimates, as well as generate Ionospheric anomaly candidate pairs. Station pairs are determined by the baseline distance (maximum separation between any two stations), which can be manually entered by the user. As a GBAS model, the first station represents an aircraft on approach and the second station simulates the GBAS ground station.

The LTIAM is capable of producing plots that include slant Ionosphere delay, L1 L2 dual-frequency gradient estimation, L1 CMC gradient estimation, and SV elevation track. We define slant Ionosphere delay as an estimation of GPS measurement caused by the Ionosphere between the receiver and the SV. Gradient estimation, or slope (in mm/km), is the difference of slant Ionosphere delay between the candidate station pair, divided by the baseline distance. LTIAM estimates slope using both L1 L2 dual-frequency (L1 carrier – L2 carrier) and L1 code-minus-carrier (L1 code – L1 carrier) measurements. Due to the low amount of noise in the dual-frequency measurement, we expect the dual-frequency gradient estimation to be our "best guess". The L1 CMC measurement is "more noisy", due to the nature of L1 code (large multipath). However, the L1 CMC measurement is not affected by normal L2 tracking anomalies and errors, which gives a good comparison against the dual frequency measurement. The most crucial aspect of manual validation comes from the comparison of these two different measurements. If the trends of both measurements match well, then this is a good indication of how trustworthy, and ultimately how real, the gradient estimation is. When processing CORS data, a baseline distance of < 100 km for GBAS operations is used (larger baselines are used for Brazil, see background information below).

Progress Report:
As of December 2013, the FAA team has entered into a cooperative project with the Brazilian Team (DECEA) to build an equatorial-based Ionosphere threat model. Although experience gained from the CONUS threat model is valuable, the exact process will differ for developing a threat model in the equatorial region (within 25 degrees latitude of the geomagnetic equator) due to the more variable and more extreme Ionospheric behavior, specifically, those of plasma bubbles and depletions that do not apply to mid-latitude regions (such as CONUS).

Brazilian data is collected from the Instituto de Geografia e Estatística (IBGE), which includes the Rede Brasileira de Monitoramento Contínuo dos Sistemas GNSS (RBMC), which covers Brazil with about 100 receiver stations as of 2010. Other networks include the widespread (but less dense) networks of IGS and LISN in South America. Selected days of high scintillation are retrieved for study and processed using LTIAM, which has been modified to process Brazilian data (referred to as LTIAM_Brazil Patch). As of March 2014, we have identified two major groups of data, which are as follows:

- Group 1: December 29-31, 2013 January 01-02 2014
- Group 2: October 21-24, 2013

This data has been processed by LTIAM and manual validation of these results is completed. An additional 100 days of data has been identified and is ready for processing with LTIAM. This large data set will be divided among the various organizations of the project, which includes: FAA, KAIST, Stanford University, Boston College, Mirus, and DECEA.

As noted above, a significant amount of work has been completed thus far, with contributions from the FAA, KAIST, Stanford University, Boston College, Mirus, and DECEA. A working threat model for confirmed gradients (from Group 1 and Group 2 data sets) is shown below in Figure 30.

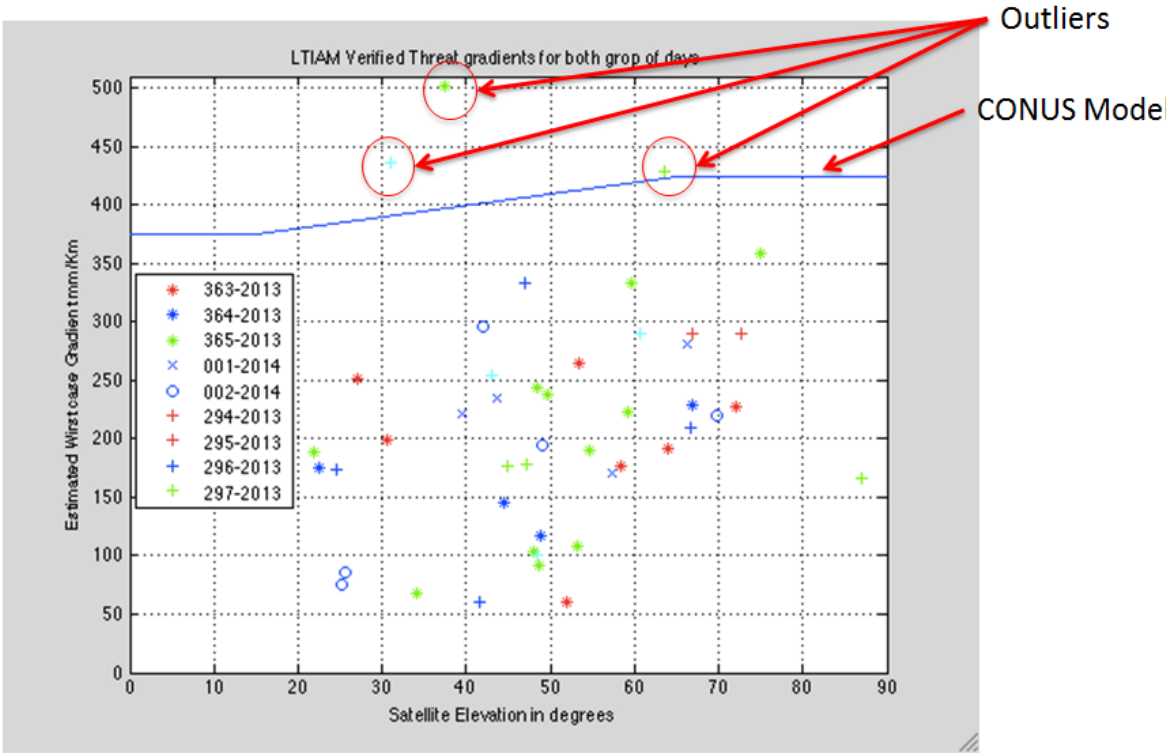

Figure 36 - Working Threat Model of Brazilian Threat Space

Additional work has been done in the mid-latitude CONUS region as well. Several days have been identified using LTIAM. These days are classified as “anomalous” based on space weather indices Kp and Dst (Planetary K and Disturbance Storm Time respectively). If these indices are found to be above a set threshold (Kp >= 6 and/or Dst <= -200), then LTIAM flags the selected days of interest as potentially experiencing severe Ionospheric activity (or as being *anomalous*). The following three days have been selected for LTIAM processing: June 1 - 2013, February 27 - 2014, and February 28 - 2014. In this LPAR report, an example gradient will be presented from June 1, 2013. LTIAM processing for February 27-28 is currently underway. Additional examples from the June 1st event are available upon request.

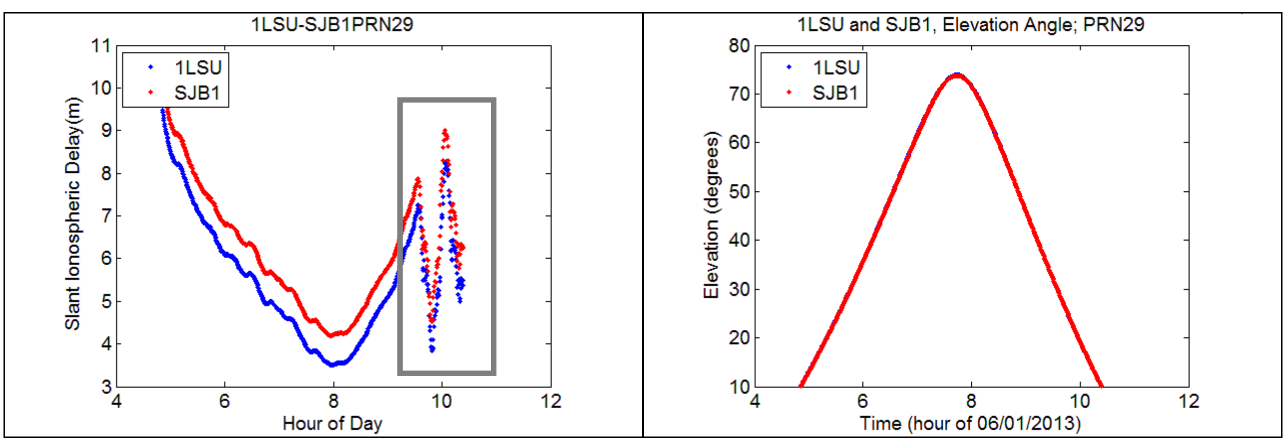

Figure 37 - Gradient: Day 152, 2013 – CORS stations 1LSU/SJB1, PRN 29, 7.10 km base

The anomaly begins approximately at Hour 9.5; notice the consistent bias between the two receivers throughout the day. This bias has an extremely long duration and is abnormal in behavior. Most likely, this bias is the cause of the -100 mm/km offset in the slope estimation (below). We can remove this offset from the final gradient estimation. Lower elevation equates to higher slant delay. As elevation increases (and LOS improved), the slant delay decreases. In the example, we can see slant delays of 3.5 - 10 meters.

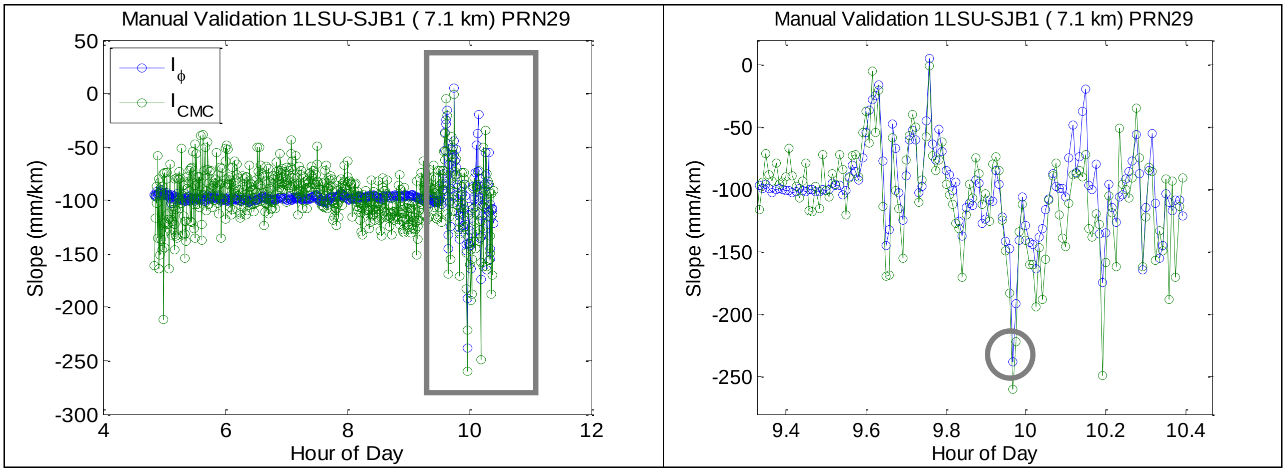

Figure 38 - Anomaly Example

The left plot (**Figure 38**) shows the dual frequency estimate (blue curve) and the L1 CMC (green curve). Notice that both curves follow a similar trend, which is more apparent at the start of the anomaly. Due to the nature of L1, we can clearly see that the green curve is estimated higher than the blue curve (L1 CMC is more noisy). We expect this, and it is our goal is to compare these two different curves based on this knowledge.

The right plot (**Figure 38**) (zoomed in on the square clearly shows how well the two curves match in trend. Green points are shown to be estimated higher than blue points in most cases (as expected). The gray circle highlights the point of highest magnitude using the dual frequency estimate (-240 mm/km, L1 CMC is slightly higher), taking into account the -100 mm/km offset, our final gradient = ~140 mm/km.

This concludes the FAA long-term Ionosphere monitoring activity for this reporting period. Additional explanation or manually validated examples are available upon request.

3.2 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 Janiero, 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.

3.3 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.

Task	INR Version	Delivery Date
Task Area I		
Delivery of 3 Baseline Receiver (INR) Units	E100	11/2010-2/2011
Delivery of Bench Test Interface Software	E100	12/2010
Delivery of CAT-I Compliance Report	E100	9/2010
Task Area II Phase I		
Implement CAT III Message Format (DO-246D LAAS ICD)	E101	3/2011
Implement 30-second pseudorange smoothing (DO-253C LAAS MOPS Section 2.3.6.6.1)	E101	3/2011
Implement dual weighing matrix (DO-253C LAAS MOPS Sections 2.3.9.2.1-3)	E102	6/2011
Implement second solution (DO-253C LAAS MOPS Section 2.3.9.2.3)	E102	6/2011
Implement DSIGMA (DO-253C LAAS MOPS Section 2.3.9.3)	E102	6/2011
Task Area II Phase II		
Activate and update software baseline from Phase 1	E200	1/2012
Implement Divergence Monitoring Function (DO-253C LAAS MOPS Section 2.3.6.11)	E201	5/2012
Implement Differential Correction Magnitude Check (DO-253C LAAS MOPS Section 2.3.9.5)	E202	5/2012
RAIM Algorithm, Analysis & Test Report	N/A	3/2012
Implement B-Value Monitoring (DO-253C LAAS MOPS Section 2.3.11.5.2.3)	E202	5/2012
Implement Fault Detection and Provide Results Data (DO-253C LAAS MOPS Section 2.3.9.6)	E202	5/2012
Task Area II Phase III		
Activate and update software baseline from Phase II	E300	8/2012
Implement VDB Message Authentication (DO-253C LAAS MOPS Section 2.3.7.3)	E301/E302	10/2012

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.

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

Upcoming Flight Tests

Flight testing will be conducted in the summer of 2014 by ANG-C32 at ACY. Like tests completed during the avionics prototyping contract, these flights will include numerous 3-degree ILS-lookalike approaches, with two HI GAST-D prototype INRs and a certified GAST-C Rockwell Collins GLNU-930 on board, all tuned to the same approach. However, in an effort to demonstrate the use of HI's updated six-reference design, these tests will focus on performance of the avionics during switching between primary and secondary references while the aircraft is on approach. Reference switches will be forced at the ground system by FAA personnel on the ground, coordinating with those who are airborne. It is expected that the switches should be undetectable by the avionics. Results from these tests should be available for presentation at the next ICAO CSG meeting in October 2014.

3.3.2 SARPs Validation Database

The FAA has created a SARPs online validation tool at http://laas.tc.faa.gov/sarps.html. The intent was to create a common tool for the FAA and ICAO members to populate with validation comments and material. The backend database contains an individual entry for each 'shall' in the GAST D proposed SARPs. By design, one POC will be responsible for each requirement and will have full access to the fields provided. All other users will have a comment section available to address any issues or concerns throughout the validation process of each entry.

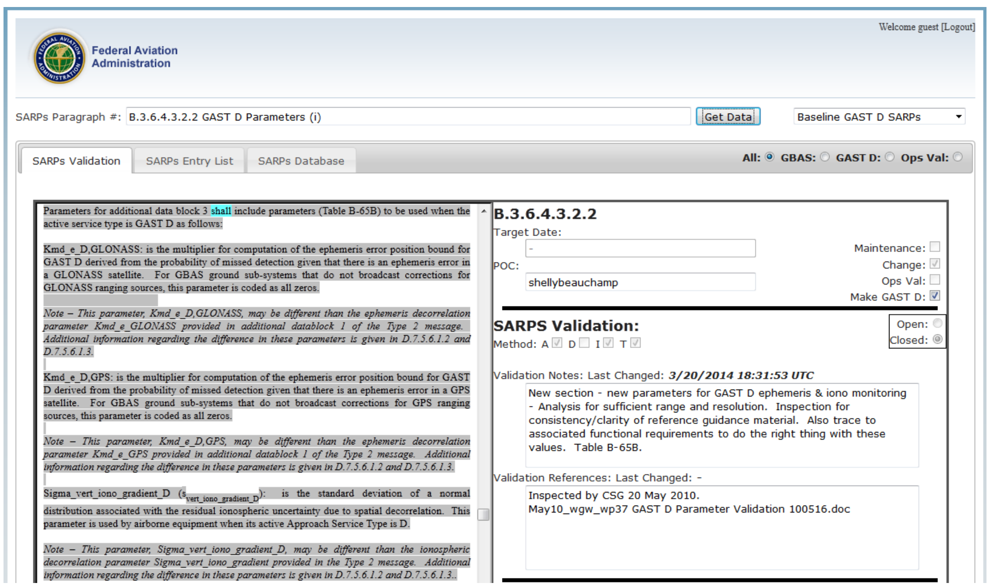

Figure 39 - SARPs Online Validation Tool Screenshot

3.3.3 GAST-D Testing at ACY

Flight tests were conducted at ACY to observe various conditional scenarios with the GBAS system, and analyze its performance based on system reference arrangements, induced failures, hardware and software changes, and various component re-admittances, during aircraft approaches. There were to be a total of 36 conditions tested, as well as basic straight-in (ILS-style) approaches to the 4 runways, and a 23nmi orbit to test the VHF Data Broadcast (VDB) coverage.

Due to the shortened availability of the aircraft, we were able to complete the straight-in approaches, the orbit, as well as one run of just over 90% of the other conditions planned. However, we were able to cover the scenarios of most interest and importance. The aircraft is scheduled in the next quarter to complete the remaining first-run scenarios, as well as to complete a secondary set.

3.4 WAAS Accuracies

On April 8th 2014, data was collected for about one hour for the Rockwell Collins MMR in WAAS mode, using the WJHTC hangar roof reference antenna. Static horizontal and vertical accuracy error plots were generated to compare and troubleshoot issues with the Rockwell Collins MMR in GBAS mode. These static accuracy error plots are generally used as a baseline for the FAA GBAS GAST-D Flight Test at KACY. These plots used the same methods used to compute errors on the GBAS monitor for static data. WAAS horizontal and vertical error averaged 1.5 meters with the maximum number of satellites being nine and the minimum being seven. The Rockwell Collins MMR mode was confirmed to be in WAAS at all times.

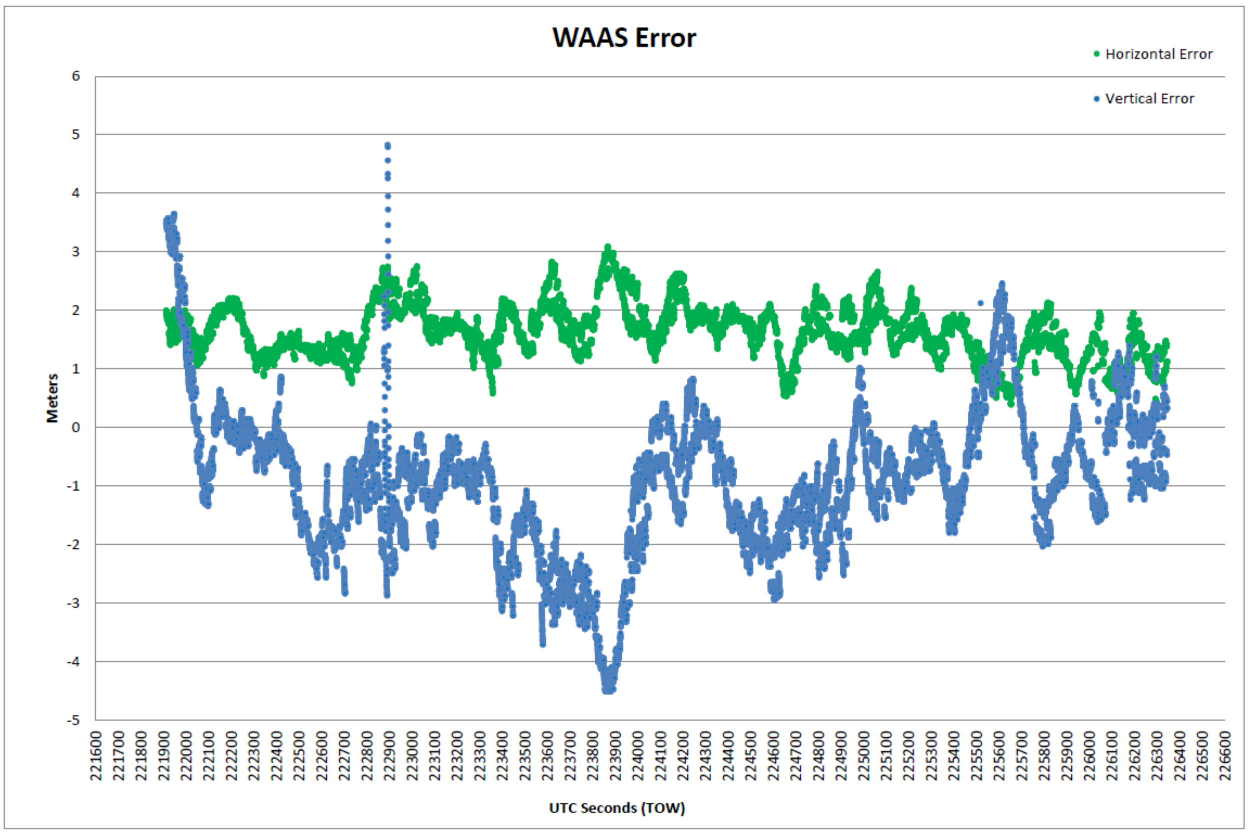

Figure 40 - FAA WAAS Static Data Test – Rockwell Collins MMR 4/8/14

3.5 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)
2014031	FCSTDV	32	04/01/2014	08:00	04/01/2014	20:00
2014032	GENERAL	06	04/03/2014	N/A	N/A	N/A
2014033	FCSTSUMM	32	04/01/2014	08:27	04/01/2014	13:48
2014034	FCSTDV	20	04/10/2014	17:00	04/11/2014	05:00
2014035	FCSTDV	31	04/15/2014	14:30	04/16/2014	02:30
2014036	FCSTSUMM	20	04/10/2014	17:41	04/10/2014	23:33
2014037	FCSTSUMM	31	04/15/2014	14:43	04/15/2014	20:21
2014038	GENERAL	N/A	04/28/2014	N/A	N/A	N/A
2014039	GENERAL	N/A	04/28/2014	N/A	N/A	N/A
2014040	FCSTDV	23	05/08/2014	17:00	05/09/2014	05:00
2014041	FCSTSUMM	23	05/08/2014	17:18	05/08/2014	23:05
2014042	FCSTUUFN	09	05/16/2014	14:30	N/A	N/A

2014043	FCSTDV	08	05/15/2014	09:00	05/15/2014	21:00
2014044	FCSTSUMM	08	05/15/2014	09:46	05/15/2014	16:37
2014045	LAUNCH	06	05/17/2014	00:03	N/A	N/A
2014046	DECOM	09	05/19/2014	14:35	N/A	N/A
2014047	USABINIT	30	05/30/2014	18:35	N/A	N/A
2014048	FCSTDV	04	06/12/2014	14:00	06/13/2014	02:00
2014049	USABINIT	06	06/10/2014	17:10	N/A	N/A
2014050	GENERAL	09	06/13/2014	N/A	N/A	N/A
2014051	FCSTSUMM	04	06/12/2014	14:20	06/12/2014	22:40

Table 5 - NANU Summary

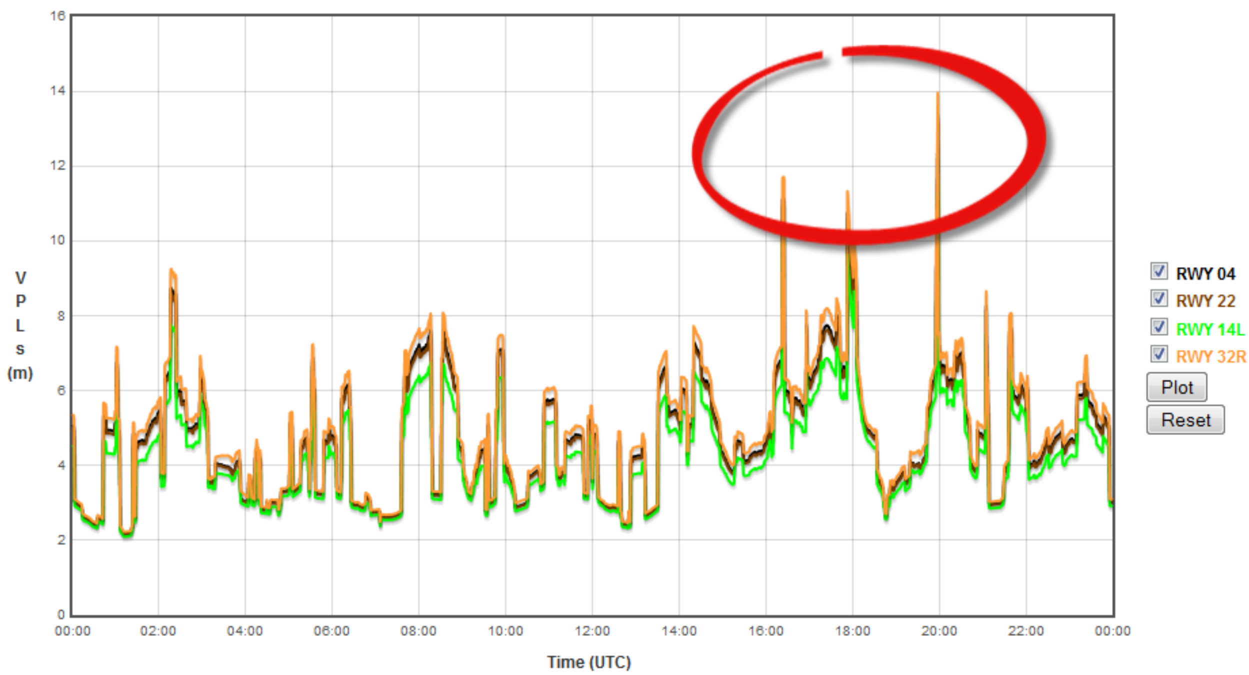

Figure 41 - MWH FCSTDV on PRN 32 4/1/2014

4. GBAS Meetings

4.1 ICAO Navigation Systems Panel (NSP)

The International Civil Aviation Organization (ICAO) Navigation Systems Panel (NSP) met in May 2014 at the ICAO headquarters in Montreal, Canada. GBAS was addressed during the Category II/III Sub-Group (CSG) meeting, May 19 – 21. The primary focus of the CSG is validation of the proposed GAST D (Category II/III) standards, as defined in the Annex 10 Standards and Recommended Practices (SARPs).

As part of the validation activity the FAA (ANG-C32) created a GAST D SARPs online validation tool. The FAA plans to use this tool in tracking the validation status of the GAST D SARPs. The tool and the associated database will be available on a website. A working paper describing the tool was presented to the CSG. The tool was offered for use by the CSG as part of its validation activities.

A topic that was the subject of several papers presented at the meeting concerned the validation of GAST D SARPs requirements related to the mitigation of anomalous ionospheric induced errors. The FAA presented three working papers on this topic. One paper, prepared by ANG-C32, was titled “Background on Mitigation of GAST-D Anomalous Ionospheric Conditions.” The paper reviewed the background of the mitigations defined in the standards for anomalous ionospheric conditions as related to GAST D. It also reviewed the various operational scenarios affected by ionospheric gradients, and how they are detected by ground and airborne monitors.

A second paper was prepared by Honeywell based on work performed under a contract with the William J. Hughes Technical Center. The paper described atmospheric activity observed at multiple mid-latitude GBAS Prototype installations based on data analysis of the Honeywell GAST D Ionosphere Gradient Monitor. During warm, mostly clear days, unexpected gradients have been observed which are believed to be attributed to abnormal components of the troposphere. The paper summarized the observations from various installation sites, described the potential impact this phenomenon may have on mitigation of anomalous ionosphere gradients for GAST D, and highlighted the impact this has on the current ICAO SARPS requirements.

A third paper was also prepared by Honeywell which identified a work plan to modify and validate changes to the GAST D ionospheric gradient monitoring requirements. Included in this work plan was a discussion of how additional time between monitor detection and annunciation of an alert (time to alert) may enable mitigation of the issues raised in the second paper. In addition, this paper identified optional formats which the new requirement may adopt.

Another paper that was presented by Boeing addressed the IGM time to alert requirement, currently 1.5 seconds. Since the IGM is required only for detection of very large ionosphere gradients that are travelling very slowly relative to the airborne and reference station lines of sight to the satellites, the potential to allow a larger time to alert was identified as a means to provide enough time for the IGM to differentiate ionosphere gradients from other non-dispersive atmospheric phenomena. The paper presented the results from trade studies performed to identify the amount of margin in the required time to alert for the IGM, based on the specific gradient and aircraft approach scenarios.

4.2 International GBAS Working Group (IGWG)

Executive Summary of GBAS Working Group Meeting 15
EUROCONTROL Experimental Centre, Brétigny, France
June 3-6, 2014

The 15th International GBAS Working Group (IGWG) was hosted by EUROCONTROL at the Experimental Centre (EEC) in Brétigny, France. The meeting was chaired by FAA and EUROCONTROL (John Warburton, FAA and Andreas Lipp, EUROCONTROL). IGWG Secretaries are Dieter Guenter, FAA (ISI/NAVTAC) and Lendina Smaja, EUROCONTROL.

About one hundred (100) participants from twelve (12) nations, international service providers, industry, airlines and aircraft manufacturers attended the meeting and working sessions.

In their welcome, Pierre Andribet, the responsible of EUROCONTROL's SESAR contribution and EEC site manager and Franca Pavlicevic, head of EUROCONTROL's Navigation and CNS Research Unit both noted the progress made since the first meeting of the group, also held at the EEC in 2004 and that it was now evident that GBAS had acquired a multi-nation support, significant operational experience and was well poised to stay a element of the aviation navigation mix, as the logical follow-on to Performance Based Navigation in the approach phase of flight.

This meeting marked the operational approval of GBAS in Sydney by Airservices Australia and Malaga by AENA, the Spanish service provider. 15 GBAS locations in Russia have been flight checked and are awaiting publication of the approach charts in the AIP before starting regular operations by regional air carriers.

The commitment to GBAS development and implementation by participants was impressive, and visible by new airline interest like Delta Airlines, TUIfly and Swiss Airlines. An increased number of GBAS acquisition plans like Zurich/Switzerland, Oslo/Norway, London Heathrow/UK, Dubai/UAE, as well as additional GBAS at Frankfurt/Germany and multiple GBAS at different locations in Australia were reported.

The national updates and SESAR project briefings demonstrated strong continued commitment and activities in implementation of GBAS CAT I as outlined above; GBAS CAT II/III validation activities and increased research in the potential impact of future multi constellation and dual frequency environment are ongoing. All of the nations represented have GBAS related activities in one form or another from concept development, research prototype activities to actual implementation.

Boeing and Airbus remain strongly committed to GLS and reported an increasing GLS customer base and increased number of GLS equipped aircraft sales, with the number of GLS aircraft having nearly doubled with respect to 2013.

Airline operations are steadily increasing, United Airlines flies an average of 70 GBAS operations per month at the Houston and Newark facilities (with a total of 639 approaches as of May 2014). TUIfly and Air Berlin fly GLS at Bremen/Germany and Malaga/Spain. In Sydney, Qantas and other operators using GLS completed 24 operations within the first 2 hours of public operation. Lufthansa is expected to be the first flying GLS approaches to Frankfurt when that station becomes operational in August 2014, while Swiss airlines is planning to do the same in Zurich. A EUROCONTROL flight-plan analysis shows that over 3% of European traffic is now GBAS equipped.

The status reports of service provider plans, users and manufacturer updates as presented on the first day of the meeting were important and informative. The key value of the GBAS working group continues to reside in the parallel strings of technical and operational sessions on day two and three, where data collection and evaluation, siting experience and interference mitigation, ionospheric activities, operational plans and future operations are not only exchanged but actively coordinated.

The trend toward operational aspects noticed during the last meeting continued. More than 2/3 of the participants attended the operational working sessions in this meeting. The presence of representatives of regulatory organizations was noted as beneficial to the discussions.

In the operational sessions (CAT I Post Approval Activities and Future Operations) all aspects of use of the GBAS signals were discussed. A recurring topic was the RNP-GLS transition which is key to address operational improvements and the needs of airports and operators in terms of flight efficiency and environment while maintaining the precision approach capability. Two topics from the previously developed value chart received the most attention, Extended Service Volume (ESV) and CAT II operations on a GAST-C system. For ESV, joint operational/technical teleconferences and a common working session were conducted after last year's discussions and concepts and a working paper presented to ICAO NSP early 2014.

Several presenters underscored the need to go beyond ILS capabilities rapidly to exploit GBAS potential in noise reduction and shorter approach paths. The capability to provide steeper and multiple approach paths for runway ends possible with GBAS can be immediately beneficial for noise reduction and wake turbulence avoidance.

The technical sessions (Data and testing, Ionosphere, Siting, Interference and Ground Monitoring) focused on the still ongoing improvements in the technical understanding of GBAS implementation and the advances in the tools used for GBAS performance assessment. The investigation in effects of ionospheric events was an important subject, with intensive discussion of GAST-D ionospheric monitoring SARPs validation. In several areas the work will be continued between I-GWG sessions to progress on the exchange of methods and experiences on more detailed subject matters.

SESAR reported significant progress on its technical and operational efforts with extensive validation results from the GAST-D prototypes as well as intensifying of work on GBAS dual frequency and multi constellation architecture that had begun in Spring 2013. The SESAR work now comprises two installed GBAS prototypes and significant efforts on operations validation and safety assessments. A new SESAR project on advanced procedures using GBAS has just been launched.

All participants were extremely satisfied with the outcome of the working group meeting, especially with first time participants who noted the high quality of work presented and the significant amount of ongoing projects. I-GWG visibly fulfils a recognized function in GBAS implementation and its format seems well adapted to the participants' needs. This working group addresses relevant issues for the development and implementation of GBAS, and exchanges data and information, which can effectively be used by the participants in formulating their business strategies and implementation plans.

The exact location of the next meeting is still open, multiple options are being reviewed and need to be confirmed, it is targeted for March 2015.

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.

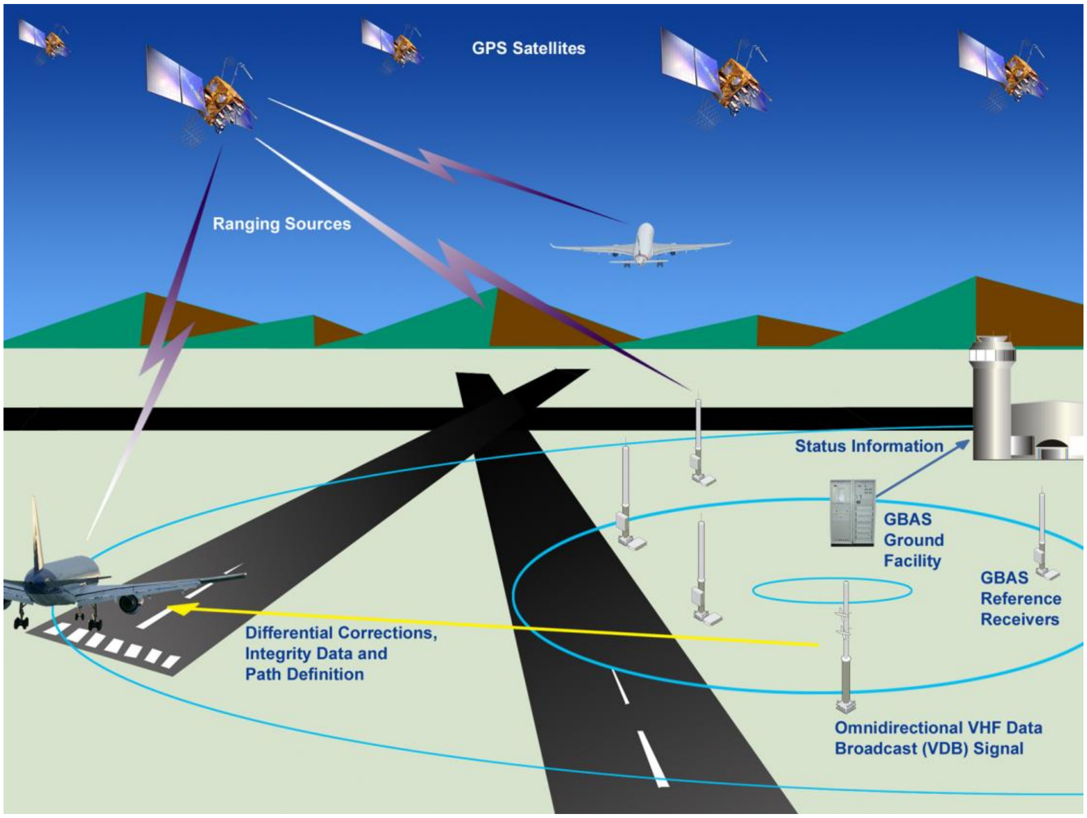

Figure 42 - GBAS Architecture Diagram

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 43 - 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.

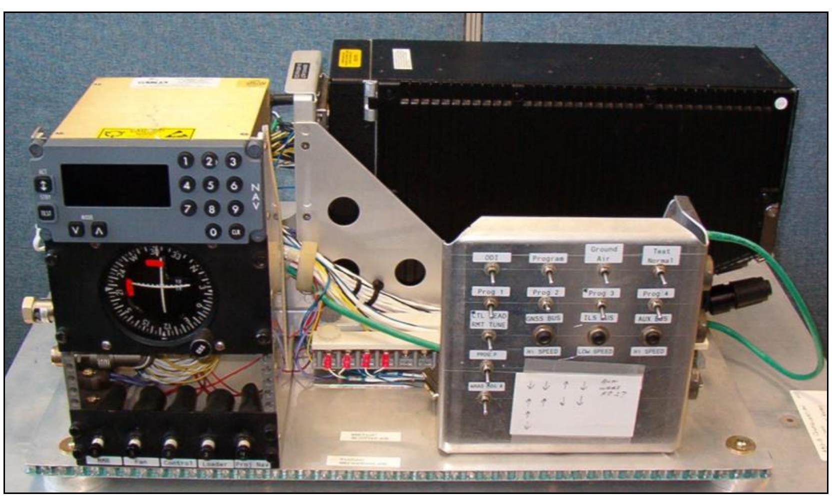

Figure 44 - MMR User Platform

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.

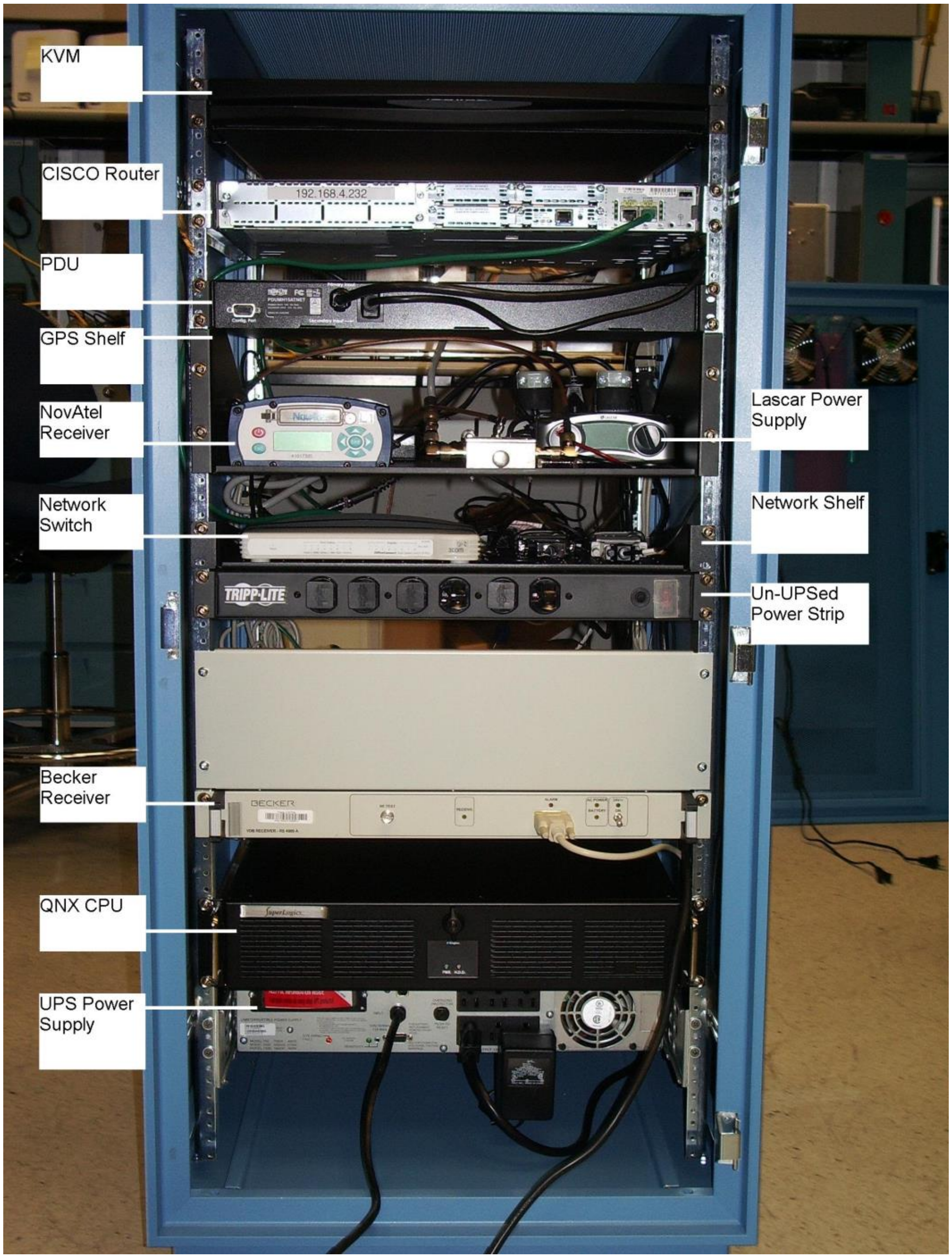

Figure 45 - Ground Based Performance Monitor (GBPM)

Glossary of Terms

—A—

ACY
Atlantic City International Airport 3, 4

—C—

CCD
Code Carrier Divergence 30
CDI
Course Deviation Indicator 47
CMEs
Coronal Mass Ejections 24
CONUS
Continental United States 24
CORS
Continuously Operating Reference Stations 24
CPU
Central Processing Unit 45
CSG
Category II/III Sub-Group 37

—D—

DECEA
Department of Airspace Control 26

—E—

EEC
Experimental Centre 38
ESV
Extended Service Volume 39
EWR
Newark Liberty International Airport 4

—F—

FAA
Federal Aviation Administration 3
FD
Fault Detection 31

—G—

GBAS
Ground Based Augmentation System 3
GBPM
Ground Based Performance Monitor 3
GIG
Galeão International Airport 4
GNSS
Global Navigation Satellite System 47
GPAR
GBAS Performance Analysis Report 3
GPS
Global Positioning System 24
GSL
GBAS Service Level 44

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