



Federal Aviation
Administration

GBAS Integrity and GBAS Key Risk Areas

Presented by:

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Overview

- **GBAS Integrity Method**
- **Key Risk Area/Algorithm Description Document Link**
- **Risk Area Details**
- **Summary**

Thanks to Zeta Associates, Ohio University, Illinois Institute of Technology who provided data and/or analysis included in this briefing



LAAS Integrity Method

- **Responsibility for LAAS Integrity resides in the LAAS Ground Facility (LGF)**
 - The user (aircraft) receives a set of integrity parameters from the LGF and applies those in a set of standardized equations to determine protection levels
 - The user must check the calculated result against the requirement
 - A protection level bound, or Alert Limit, is transmitted from the LGF with each procedure
- **The Service Provider is responsible for ensuring that the uplink integrity parameters are accurate and that they provide the required function**
 - When used in the specified equations, the protection level must always* bound the user error
 - *The probability of not bounding is the required integrity probability
 - CAT I is 2.0×10^{-7} per approach

Integrity Performance Protection Level Bounding

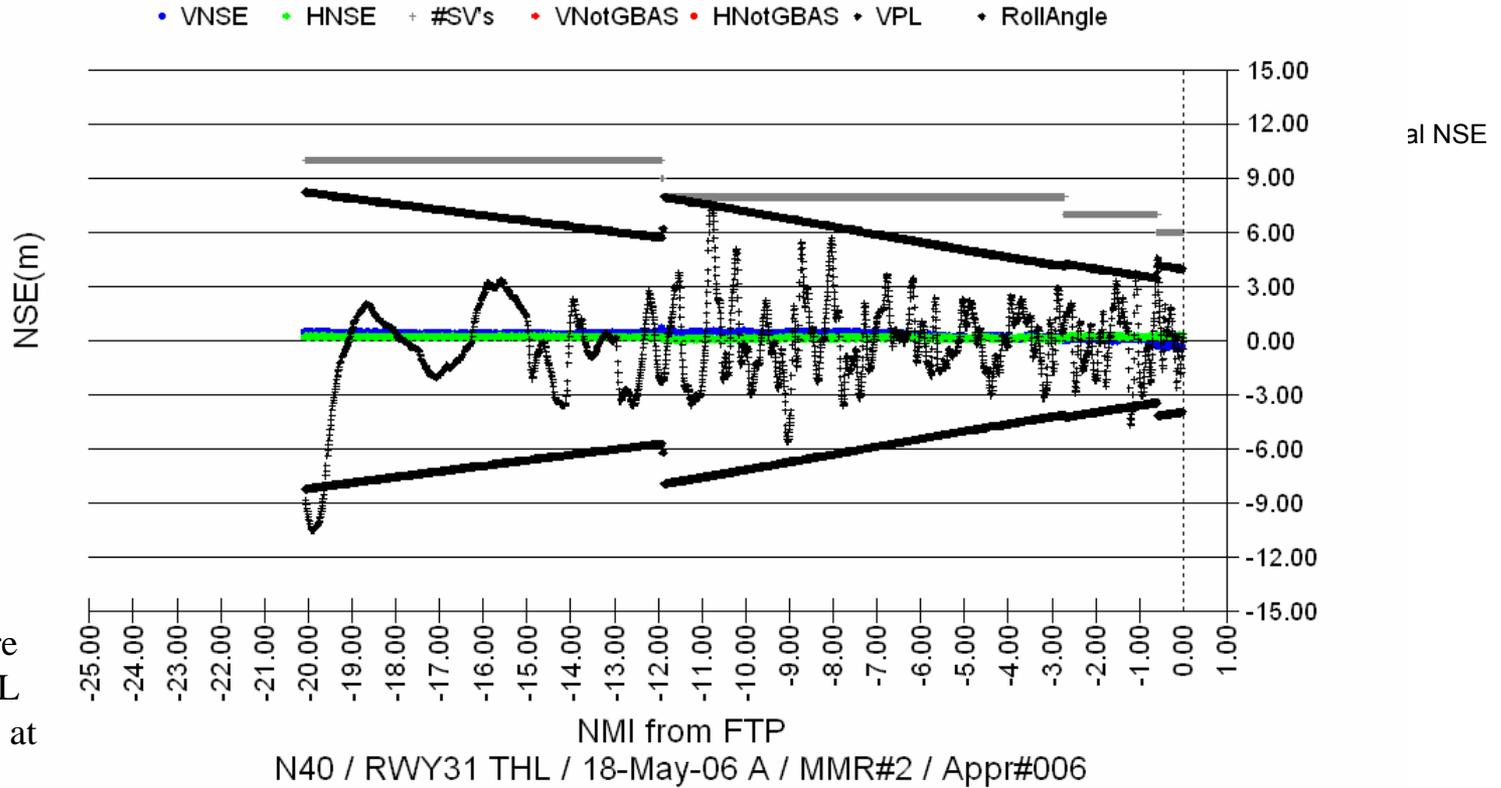
Single Approach
example of protection
level bounding

Vertical NSE and
vertical protection
Level

Vertical NSE is
always less than
the calculated
protection level

Navigation Flags are
displayed when VPL
exceeds VAL, 10M at
200 ft HAT

FAA LAAS Flight Test @ ACY Navigational Sensor Error (NSE)



Key Risk Areas

LAAS Category I

- **The FAA developed a list of the technical areas considered most challenging to both ground equipment manufacturers and certification authorities**
 - These areas are associated with integrity monitors, integrity parameter establishment, or integrity safety analysis
- **CAT I Key Risks were translated into Algorithm Design Documents (ADDs) or Preliminary System Safety Analysis (PSSA) sections**
- **All key areas were addressed in the SLS-4000 System Design Approval (SDA)**

Key Risk Areas

KRA	ADD	Priority	Description
1	PSSA		Position Domain to Range Domain Transformation
<u>2</u>	<u>PSSA</u>		<u>Per Approach Integrity (Re-scoped and renamed)</u>
3 (1)	1		Correct PR Distribution (σ_{pr_gnd}) – Temporal Variation Effects
3 (2)	1		Corrected PR Distribution (σ_{pr_gnd}) – Site Variation Effects
3 (3)	1		Corrected PR Distribution (σ_{pr_gnd}) – Time Correlation Effects (e.g., measurement sampling rate effects)
3 (4)	1		Corrected PR Distribution (σ_{pr_gnd}) – AZ/EL Correlation

Key Risk Areas (Continued)

KRA	ADD	Priority	Description
3(5)	1		RR Independence (σ_{pr_gnd})
3(6)	1		Iono Divergence (σ_{pr_gnd})
4	2		Non-Zero Mean
5	14, PSSA		RFI
6	3		Sigma Monitoring
7	4		Sigma Iono Characterization and Monitoring
8	5		Sigma Tropo Characterization and Monitoring
9	6		Ephemeris (Type B) Characterization and Monitoring

Key Risk Areas (Continued)

KRA	ADD	Priority	Description
10	6*		Ephemeris (Type A) Characterization and Monitoring
11	7		Signal Deformation Monitoring (SDM) (a.k.a., Evil Waveforms)
12	8		Low Power Monitoring
13	9		Code/Carrier Divergence Monitoring
14	10		Excessive Acceleration Monitoring
15	11		Executive Monitor (e.g., resolving RR and SV errors)
16	PSSA		Per Approach Integrity LAAS Fault Tree Analysis

KRA 3: Corrected Pseudorange Error

- **KRA 3 Covers six of the key risk areas**
 - Temporal variation, both seasonal and environmental changes
 - Site Specific installation criteria
 - Time correlation of measurements and sampling choices
 - AZ/EL Characterization, binning and masking
 - Independence of measurements between reference receivers
 - Impact of Ionospheric divergence on smoothing filter transient error behavior

KRA 3: Protection Level Equations

Fault Free Integrity

- **Primary LAAS integrity come from the measured statistical performance of the LGF**
 - Error in the calculation of pseudorange corrections
 - The uplink parameter is σ_{pr_gnd} , a one sigma estimate of the correction error
 - This parameter is set at installation using a service provider approved procedure
 - Proving the procedure is correct is the responsibility of the manufacturer
 - The LGF must continuously monitor the correction performance to ensure the broadcast σ_{pr_gnd} is still accurate
- **Method relies on range domain error analysis to represent position domain error**

KRA 3: Protection Level Equations

Fault Free Integrity

- The H_0 , or fault-free hypothesis equation, combines the ground error estimate and a similar airborne estimate and multiplies the sum by a geometry projection unit vector S_{ii} for each SV
 - S_{ii} provides the weight, or relative importance of each SV in the solution

- Given by the equation:

$$PL_{Apr_H0} = K_{ffmd} \sqrt{\sum_{i=1}^N S_{Apr,i}^2 \sigma_{i_H0}^2}$$

$$\sigma_{i_H0}^2 = \sigma_{pr_gnd}^2[i] + \sigma_{tropo}^2[i] + \sigma_{pr_air}^2[i] + \sigma_{iono}^2[i]$$

- This equation is essentially a geometry filter, that excludes certain constellations based on the capability of the ground and airborne system

KRA 3: Corrected Pseudorange Error

- **Data and analysis must show that the value selected for σ_{pr_gnd} is appropriate for any user**
 - Must include non-Gaussian characteristic present in the observed or expected distributions
 - Must include consideration of seasonal changes, environmental changes
 - May be characterized by long-term data collection with test systems
 - A methodology must be established to approve installations in a reasonable period of time
 - Sigma Monitor required (KRA 6) to protect against sudden changes
 - Must take into account changes in the orbital tracks of the ranging sources
 - A GPS signal model capable of producing predicted errors based on the installed environment is required to augment collected performance data where no SV measurements are available

KRA3: Corrected Pseudorange Error

LGF Specification σ_{pr_gnd}

3.2.1.2.8.7.1 GPS Sigma Pseudorange Accuracy

In the standard interference environment defined in appendix D of the LAAS MOPS (RTCA/DO-253A), the accuracy of the LGF shall be such that the broadcast σ_{pr_gnd} satisfies the following inequality:

$$\sigma_{pr_gnd}(\theta_n) \leq \sqrt{\frac{\left(a_0 + a_1 e^{-\theta_n/\theta_0}\right)^2}{M(n)} + (a_2)^2} \quad (6)$$

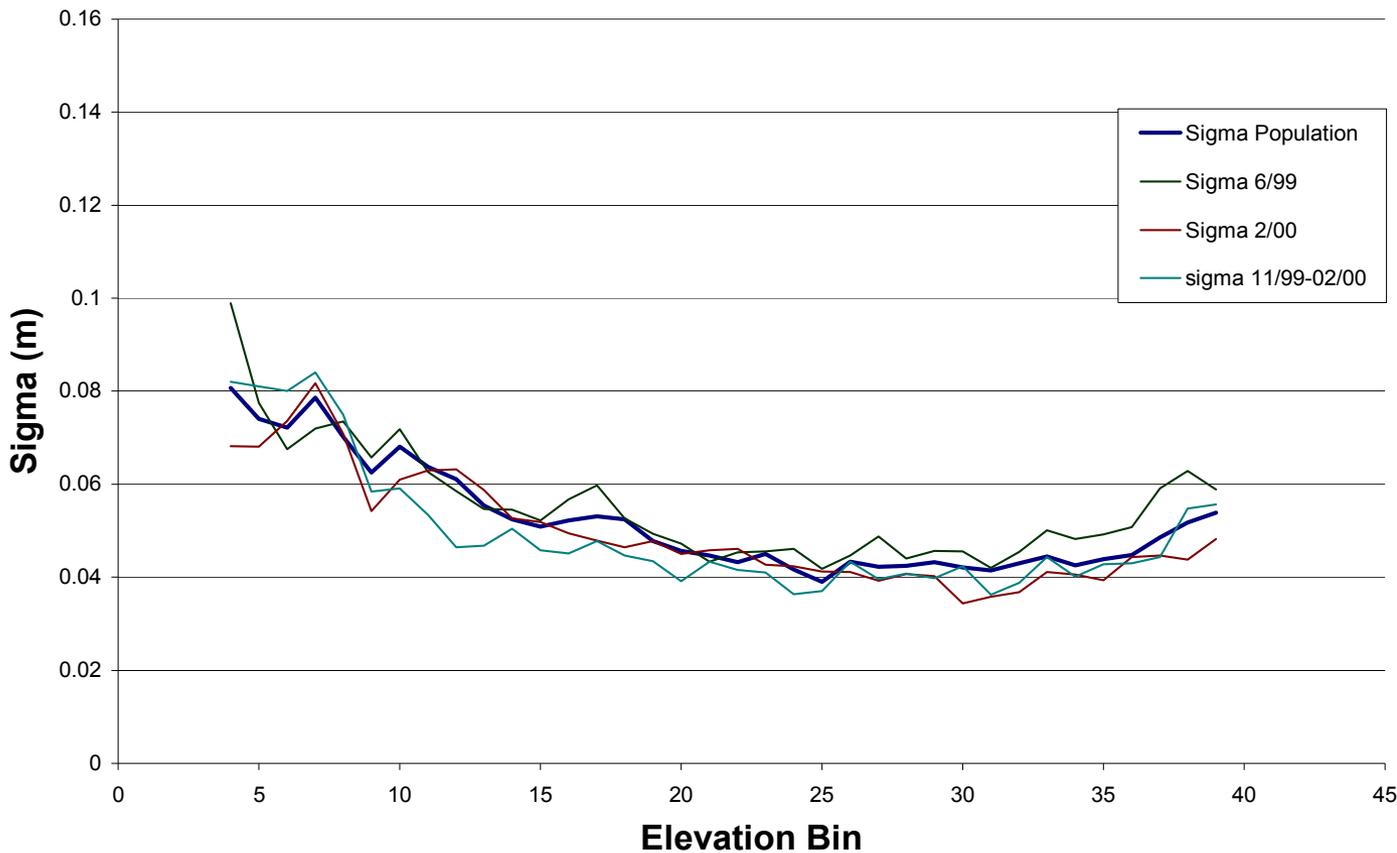
where θ_n is the n^{th} ranging source elevation angle, a_0 , a_1 , a_2 , and θ_0 are the coefficients for the applicable Accuracy Designator defined in Table 3-3.

Table 3-3. GPS Accuracy Designator C Coefficients

Accuracy Designator C	a_0 meters	a_1 meters	a_2 meters	θ_0 degrees
$\theta_n \geq 35^\circ$	0.15	0.84	0.04	15.5
$\theta_n < 35^\circ$	0.24	0	0.04	-

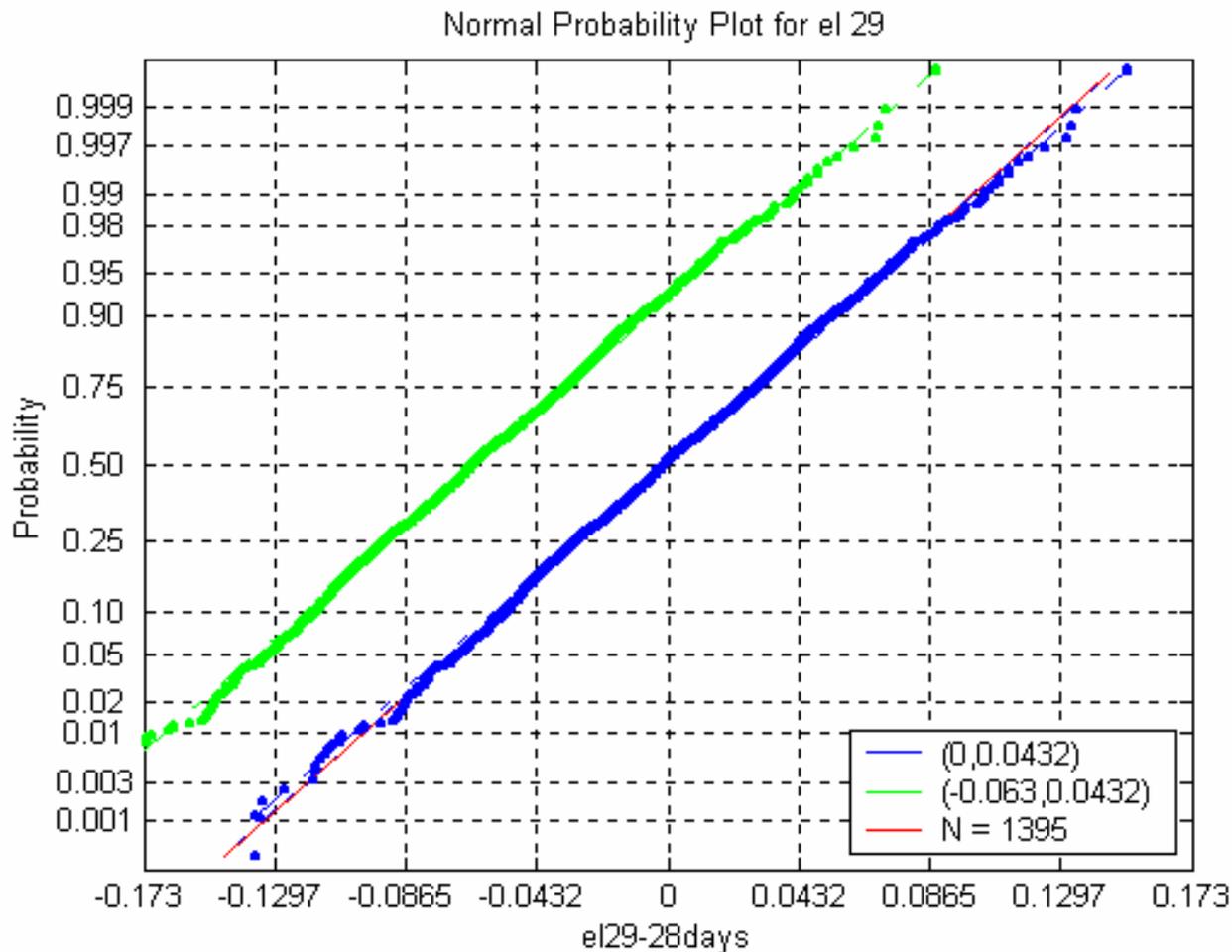
KRA 3: Corrected Pseudorange Error

Atlantic City LTP Installation
Dipole Sigma, 1° Elevation Bins



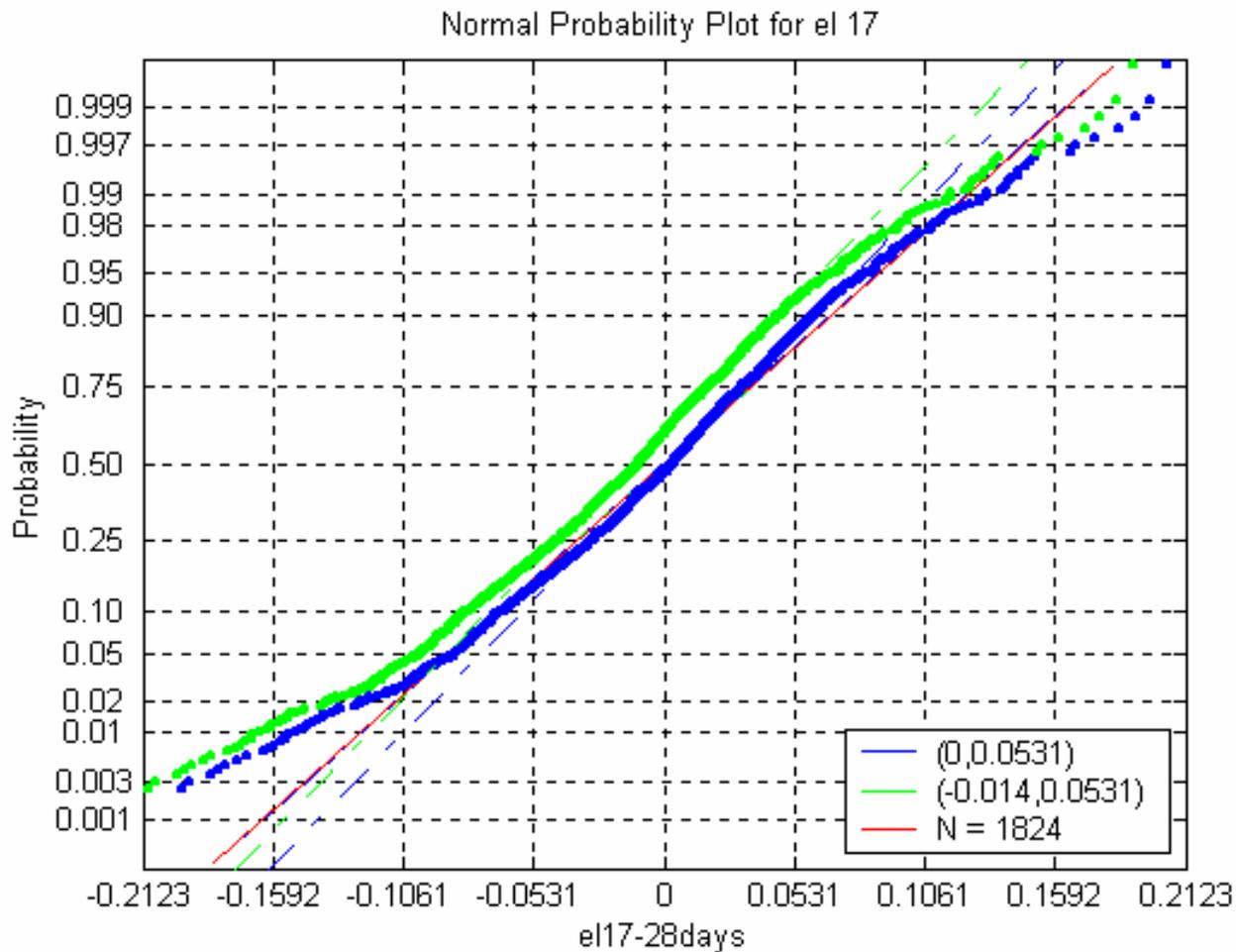
**Comparison of
short-term and
long-term statistical
correction error
performance
FAA LTP**

KRA 3: Corrected Pseudorange Error



Distribution Analysis
Gaussian nature of data
Gaussian log-normal plot
One degree elevation Bin

KRA 3: Corrected Pseudorange Error



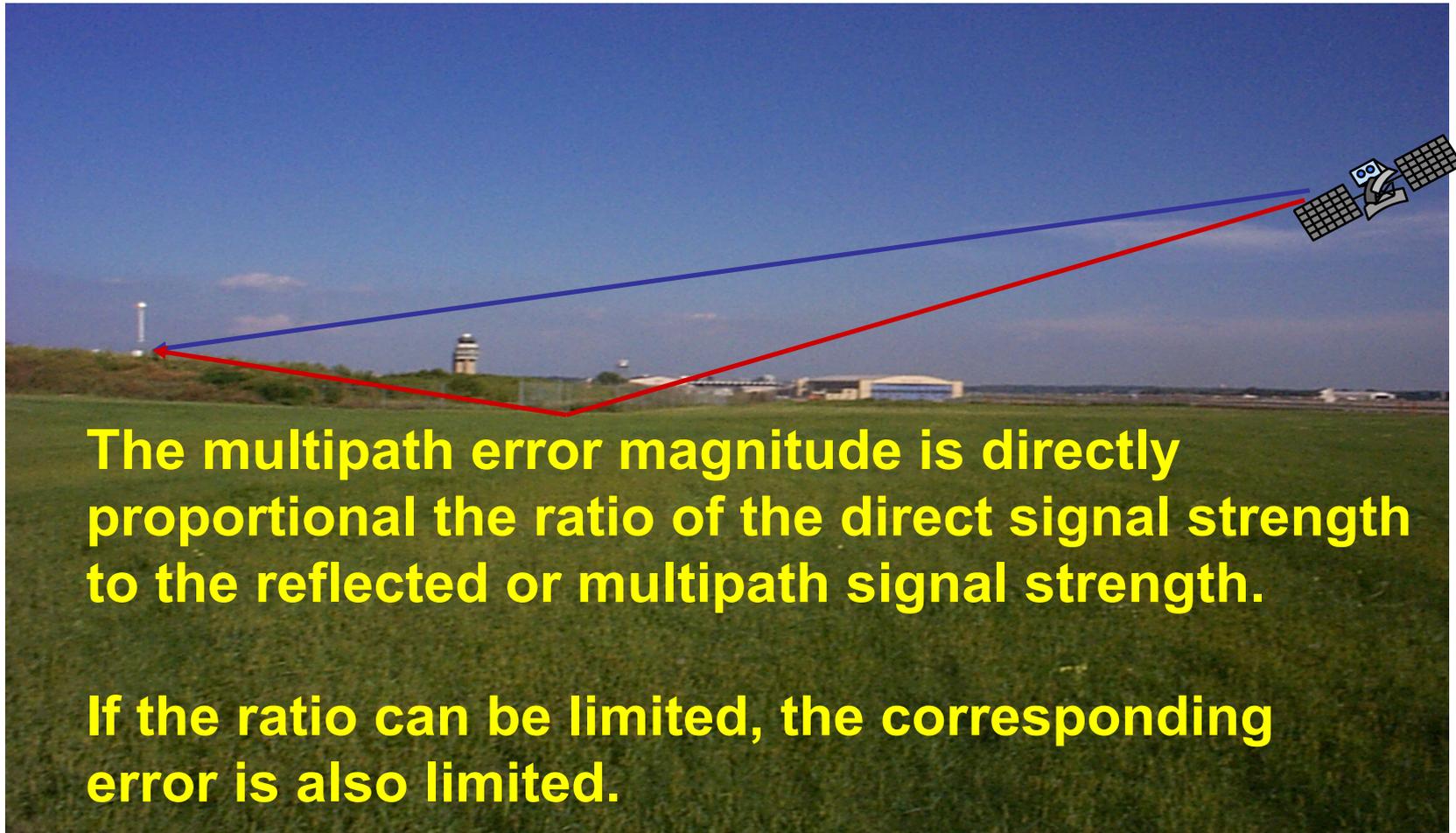
Distribution Analysis
Non-Gaussian data
Gaussian log-normal plot
One degree elevation Bin



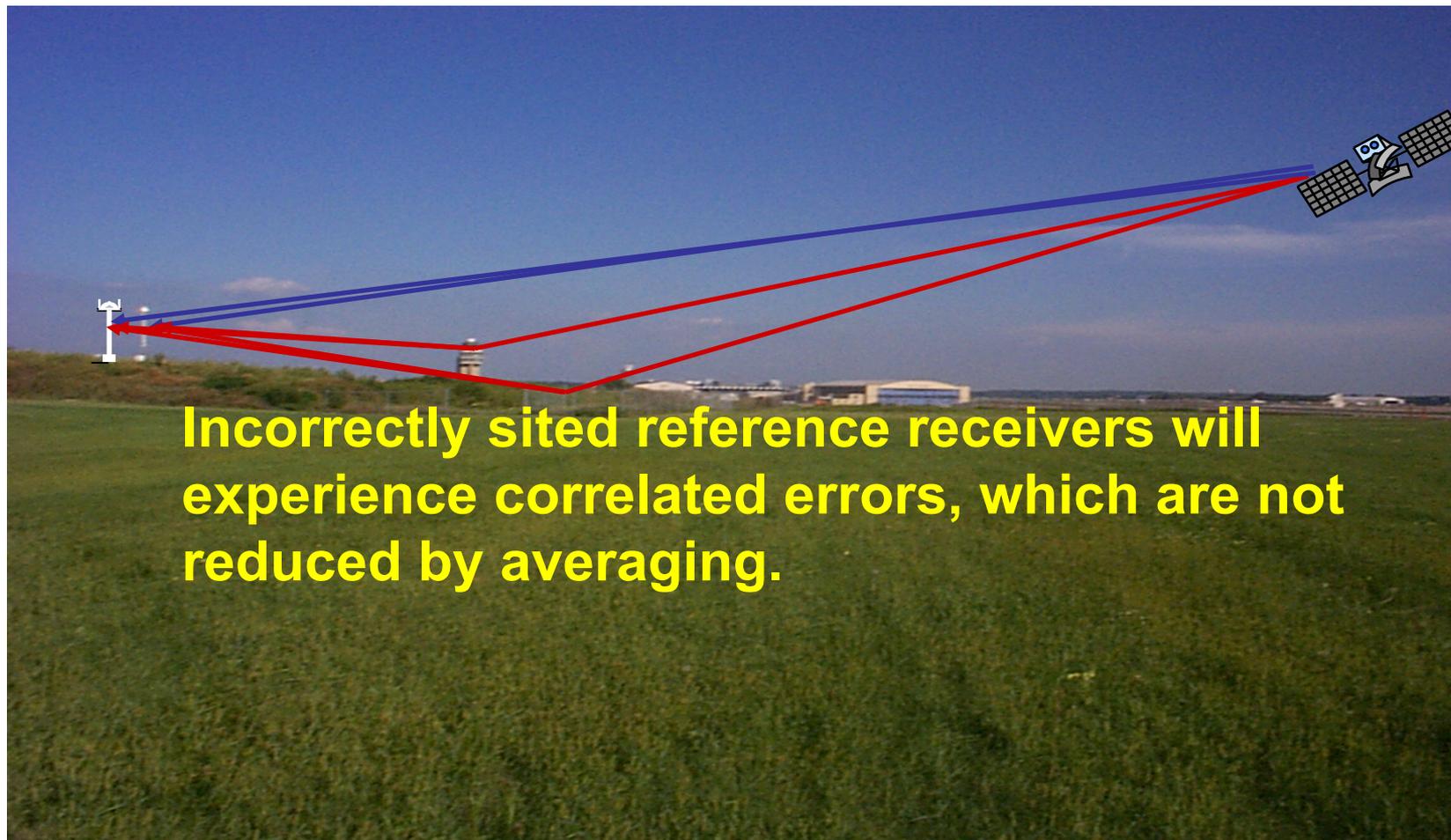
KRA 4: Non-Zero Mean Errors

- **LAAS integrity parameters represent pseudorange correction errors as zero-mean Gaussian distributions**
- **Error sources that may cause non-zero mean errors must be calibrated or proven insignificant**
 - Common-mode ground reflection mitigated by siting
- **Multipath limiting antenna (MLA) technology is used to mitigate ground multipath**
 - MLA code and carrier phase center biases have proven difficult to calibrate

KRA 4: Non-Zero Mean Errors: Single Reflection Ground Multipath



KRA 4: Non-Zero Mean Errors: Potential Correlation of Ground Multipath

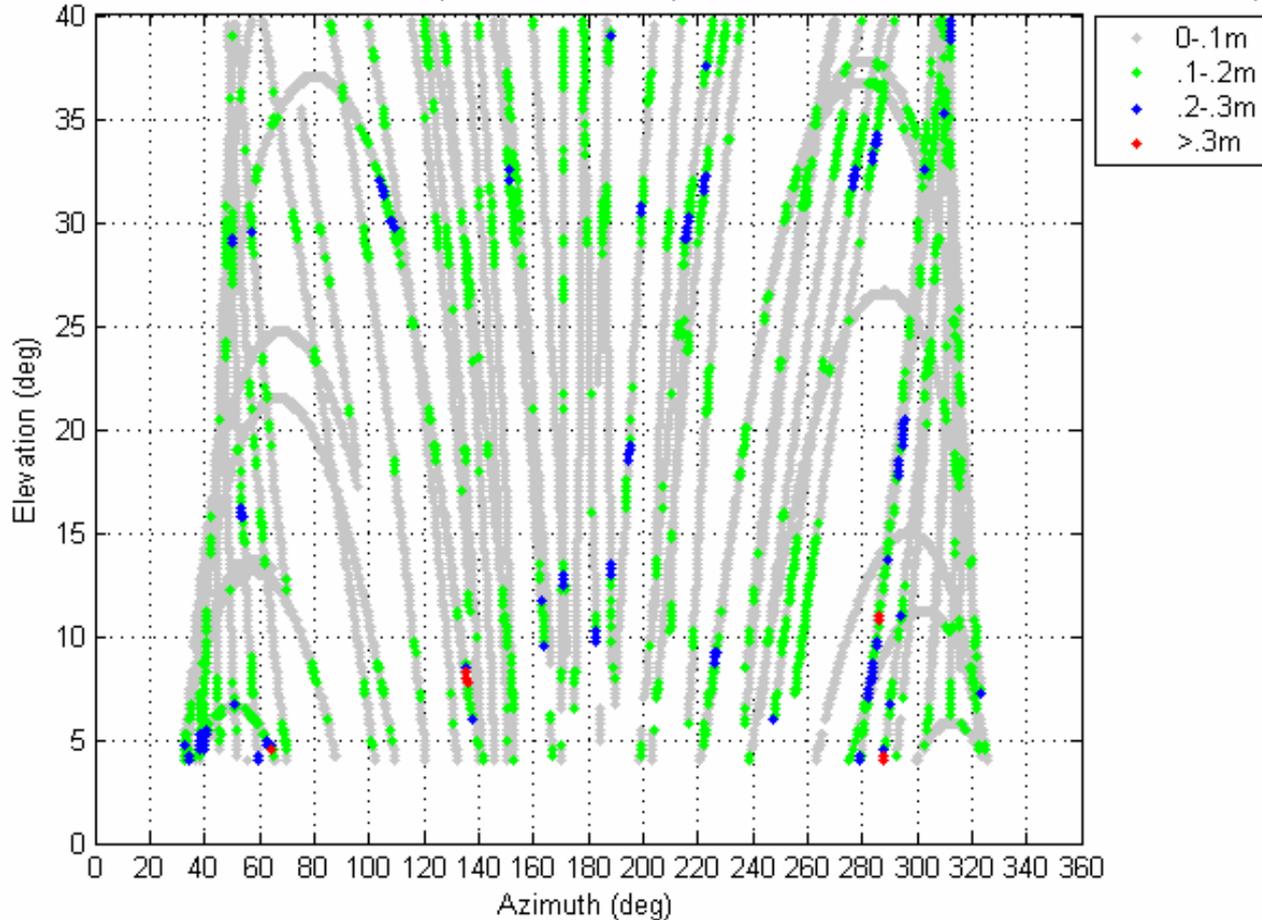




KRA 4: Non-Zero Mean Errors

Az/EI Characterization

MULTIPATH CHARACTERIZATION PLOT (032601 -LTP It1,dipole-millennium Elevations:4-40; Azimuths:0-360)



**Sky Plot view of
LTP observed
Errors
Single Reference
02/26/01**

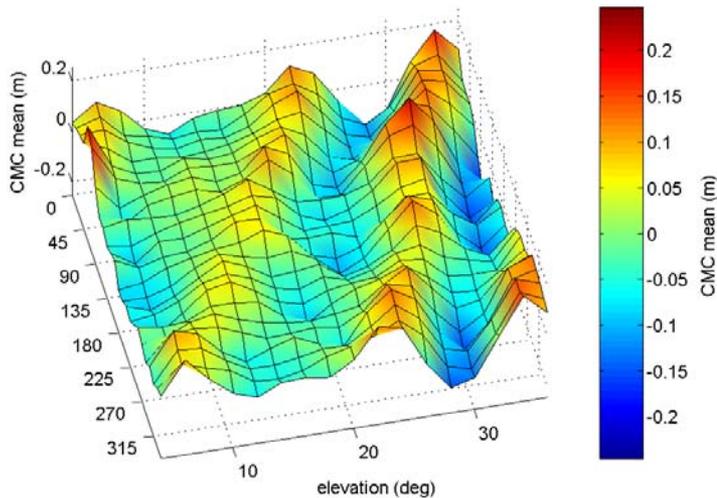
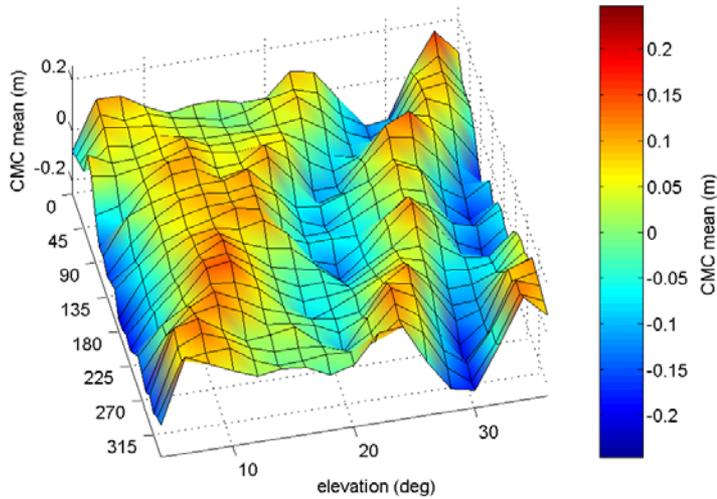
**Typical
Variation of
observed errors**

PRNlist: 1 2 3 4 5 6 7 8 9 10 11 13 14 17 18 20 21 23 24 25 26 27 28 29 30 31

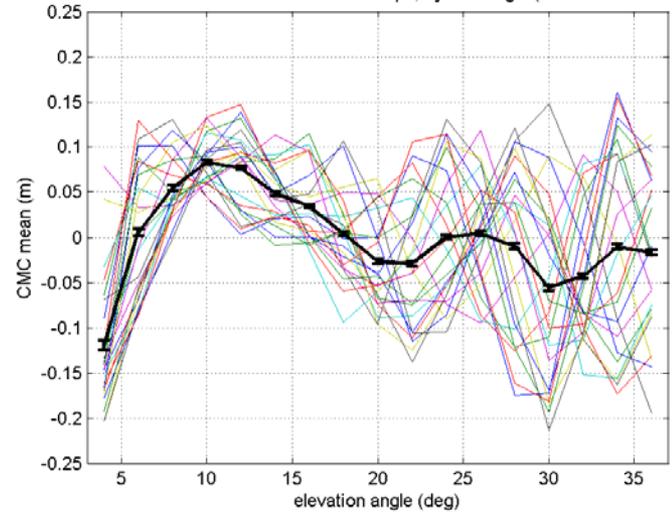
28-Oct-2003 09:44:05

025/049 on LT-3

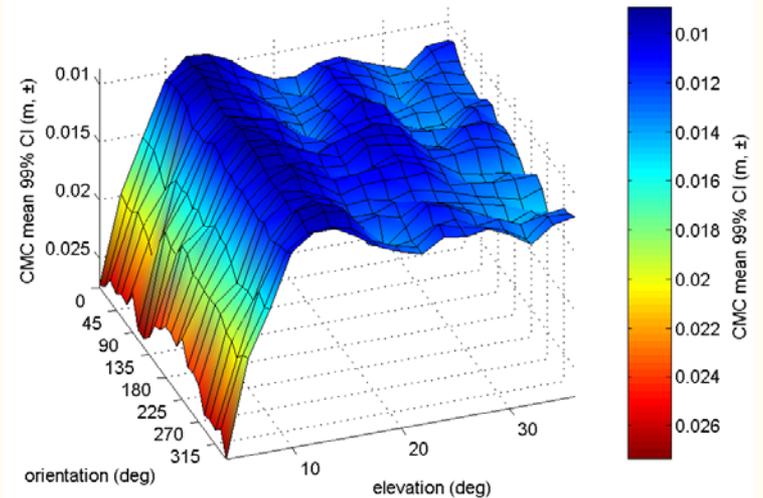
CMC mean by MLA orientation and elevation angle 05FEB04-05FEB07



CMC mean for MLA orientation at 15° steps, by elev angle (bold: overall mean)



CMC mean 99% CI by MLA orientation and elev angle 05FEB04-05FEB07



KRA 4: Non-Zero Mean Errors

New Strategy

- **The manufacturer and LIP were unable to verify source of observed azimuth variation**
 - Must identify all sources of long-term or bias-like errors. Show that they can be calibrated or mitigated by design or siting.
 - Any residual must be covered bounded by σ_{pr_gnd}
- **Determine calibration parameters for current the MLA**
 - Detailed antenna model verified by observed data
- **FAA led the development of a second MLA design**
 - Right-hand circular single port design
 - Antenna phase center variation was a primary design consideration

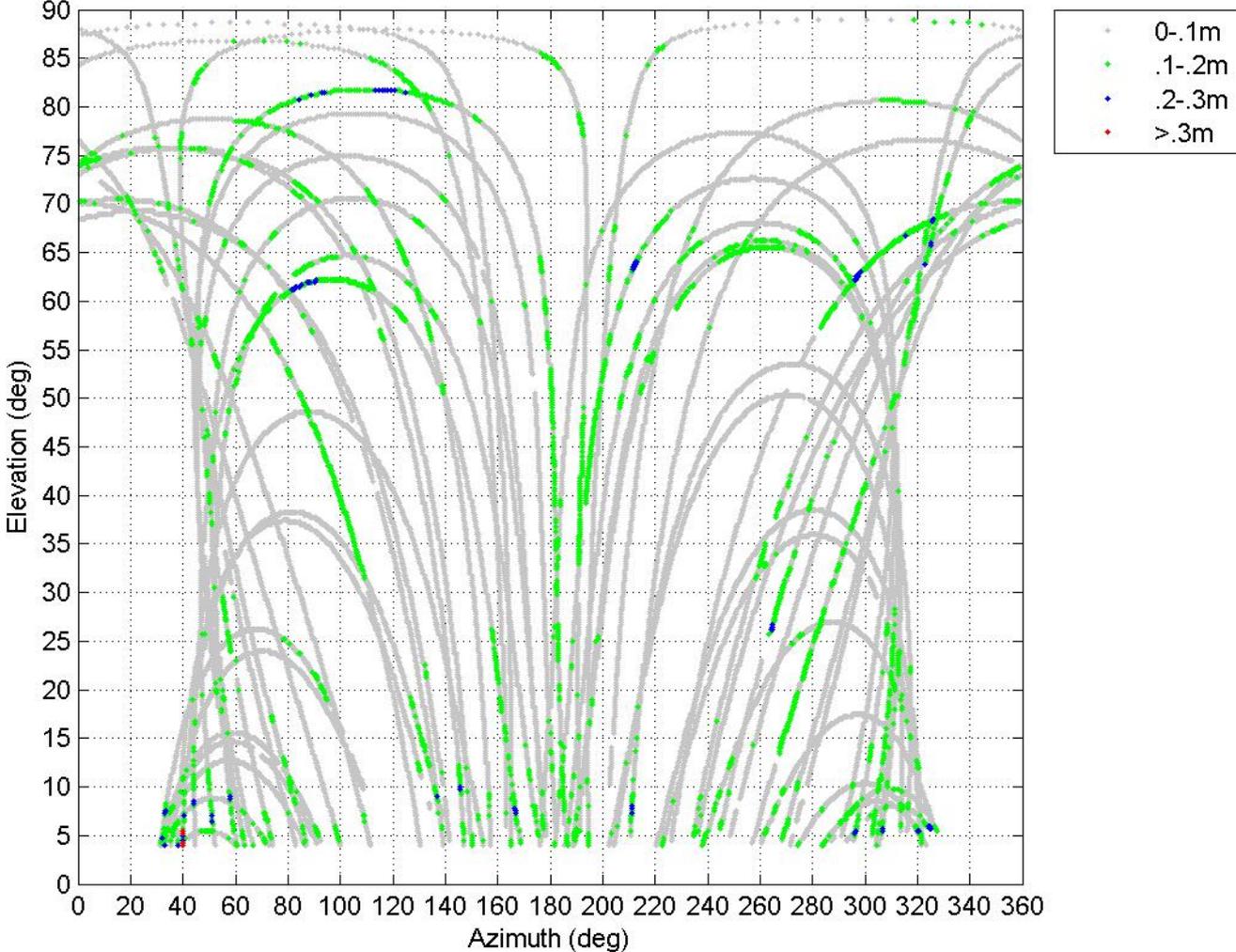
KRA 4: BAE Antenna Results

- **BAE prototype antenna delivered on 12/15/2006**
- **L1/L2/L5 single port design MLA**
- **Right-hand circular element design**
 - Potential siting advantages
- **Results of field testing with the LTP look very good**

BAE Systems Model ARL-1900 Array Antenna – Photos of Power Divider and Array Antenna



ERROR CHARACTERIZATION PLOT (010706 -LTP It2,BAE-millennium Elevations:4-90; Azimuths:0-360)



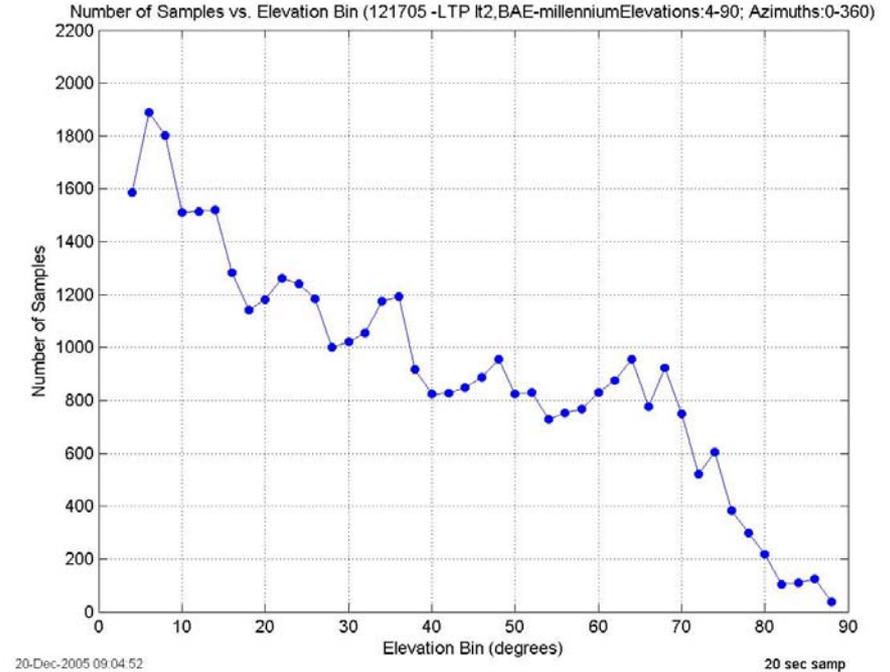
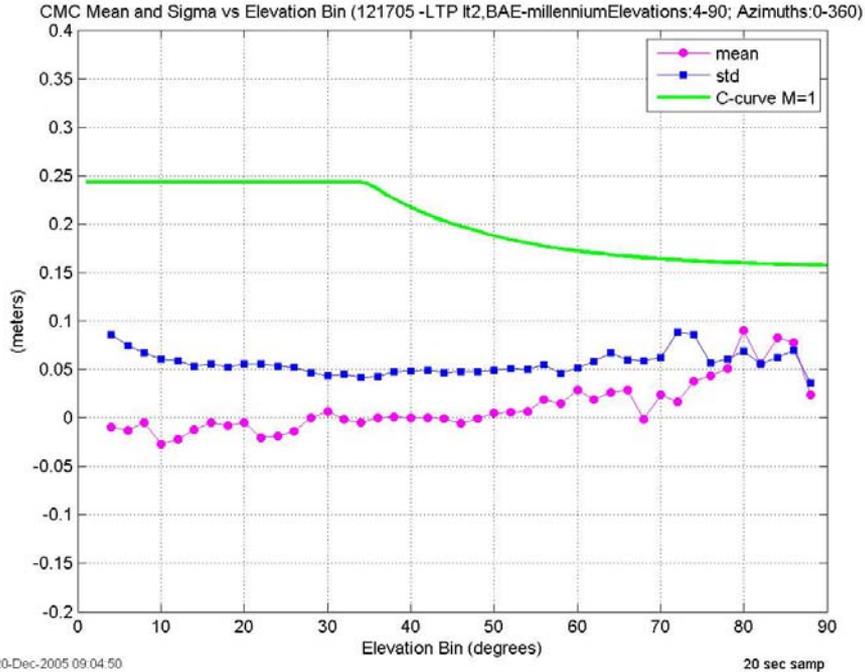
PRNlist 1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 18 19 20 21 22 23 24 26 27 28 29 30

10-Jan-2006 14:15:36



KRA 4: BAE Antenna Results

C-Curve Performance



KRA 6: Sigma Monitor

- **Protection level bounding requires that the broadcast σ_{pr_gnd} represent the current pseudorange correction noise and error statistics**
- **Monitoring must be capable of maintaining and confirming the prior probability of 10^{-5} of latent Reference Receiver faults**

KRA 6: Sigma Monitor Requirements

- **FAA Non-Fed Specification**
 - FAA-E-3017 September 29, 2009
- **3.2.1.2.8.7.3 Condition for Valid Sigma Pseudorange Ground**

The LGF shall detect conditions relating to the broadcast Sigma Pseudorange Ground that result in noncompliance with the results in Sections 3.1.2.1 and 3.1.2.2. When the increase in system risk associated with degraded performance is minimal (is no greater than one order of magnitude), but exceeds design tolerances, the LGF shall initiate a service alert. The threshold shall be adjustable, with a default value set to achieve a nominal false alert rate of 1×10^{-6} per 15-second interval.

KRA 6: Sigma Monitor Requirements

- **3.2.1.2.8.7.3 Condition for Valid Sigma Pseudorange Ground (Continued)**

When the increase in system risk is not minimal, the LGF shall exclude the offending RR or generate an alarm, as appropriate, and the alarm threshold shall be adjustable. A service alert shall be issued when a RR is excluded except when a single RR remains, at which time an alarm shall be issued. Self-recovery shall not be applied in either case. Automatic restart shall not be attempted when an alarm condition exists when system risk is not minimal. The rate of false RR exclusion or alarm shall be less than 1×10^{-7} per 15-second interval.

Sigma Monitor Test Object



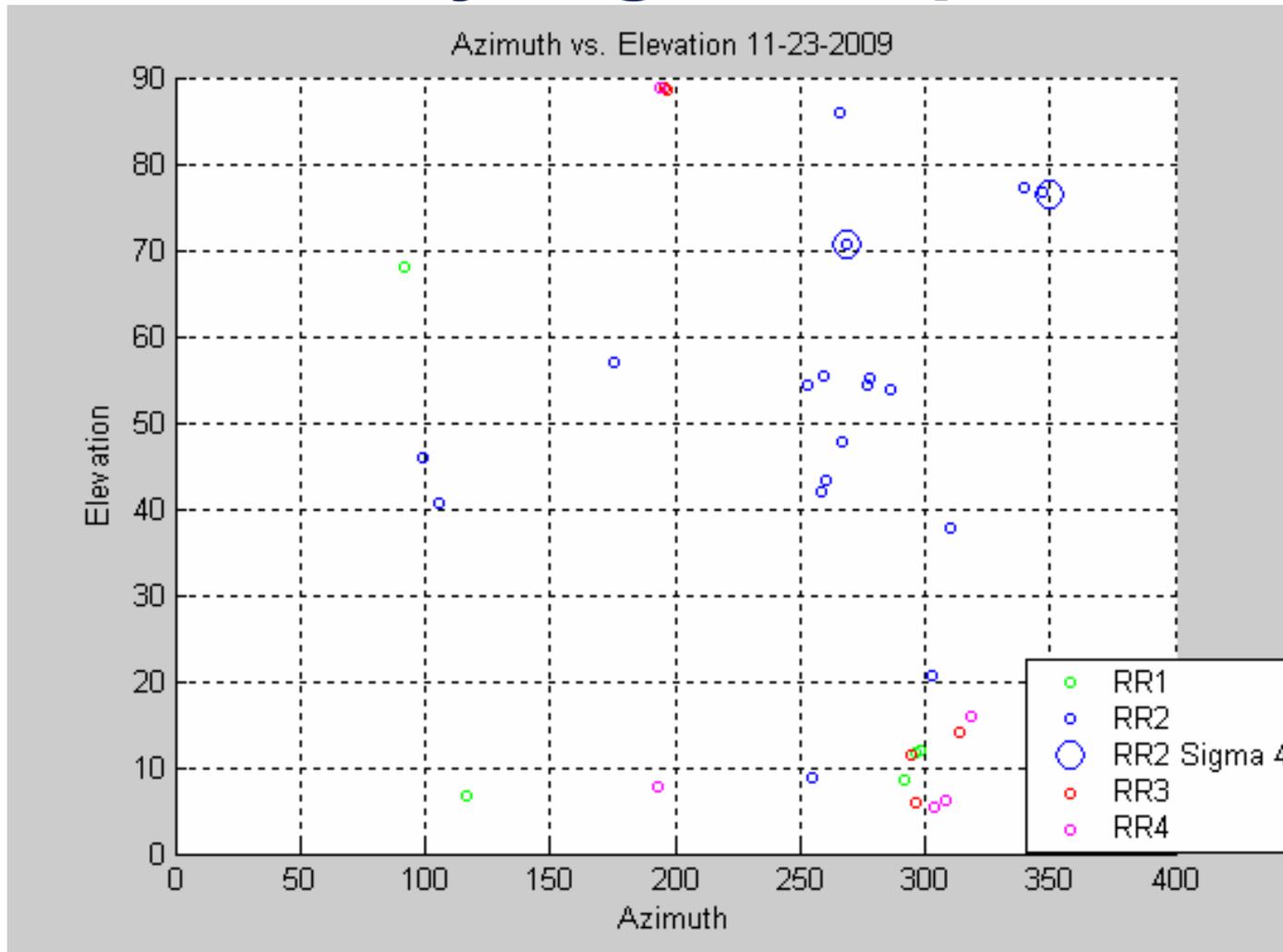
Typical Objects



Less Typical...



Expected Daily Sigma Report



KRA 6: Sigma Monitor Challenges

- **The sigma monitor is a statistical monitor**
 - The system must collect enough data to accurately characterize the noise, and changes to the noise
 - Trade off areas include sample independence, AZ/EL binning, and required confidence
- **Some expected number of events should occur if the monitors thresholds are designed correctly**
- **Activities near the GPS antennas may increase activity**

KRA 7: Sigma Ionosphere

- **Significant work area for approval**
 - Ionosphere activity is variable depending on location
- **Ionospheric model and mitigation will be covered in detail in a later briefing**
- **Parameters and requirements for KRA 7 are covered in this briefing**

KRA 7: Integrity Parameters

RTCA LAAS CAT I ICD $\sigma_{\text{vert_iono_gradient}}$

2.4.4.2 Message Type 2 Parameters

$\sigma_{\text{vert_iono_gradient}}$: is the standard deviation of a normal distribution associated with the residual ionospheric uncertainty due to spatial decorrelation such that the uncertainty in the differential ionosphere delay correction is:

$$\sigma_{\text{iono}} = F_{PP} \times \sigma_{\text{vert_iono_gradient}} \times (x_{\text{air}} + 2 \times \tau \times v_{\text{air}})$$

where:

F_{PP} = the vertical-to-slant obliquity factor for the given satellite and

$$\left[1 + F_{PP} \left(\frac{R_e \cos \theta}{R_e + h_I} \right)^2 \right]^{-\frac{1}{2}}$$

R_e = radius of the earth = 6378.1363 km

h_I = ionospheric shell height = 350 km

θ = the elevation angle of satellite

$\sigma_{\text{vert_iono_gradient}}$ = parameter provided by the ground subsystem in Message Type 2

x_{air} = slant range distance in meters between the current aircraft location and the reference point

τ = 100 seconds, the time constant of the smoothing filter

v_{air} = the horizontal speed of the aircraft in meters/sec

KRA 7: Integrity Parameters

$\sigma_{\text{vert_iono_gradient}}$ FAA Specification

3.2.1.3.5 Sigma Ionosphere

The Sigma Vertical Ionosphere Gradient Field shall denote the value stored in LGF NVM.

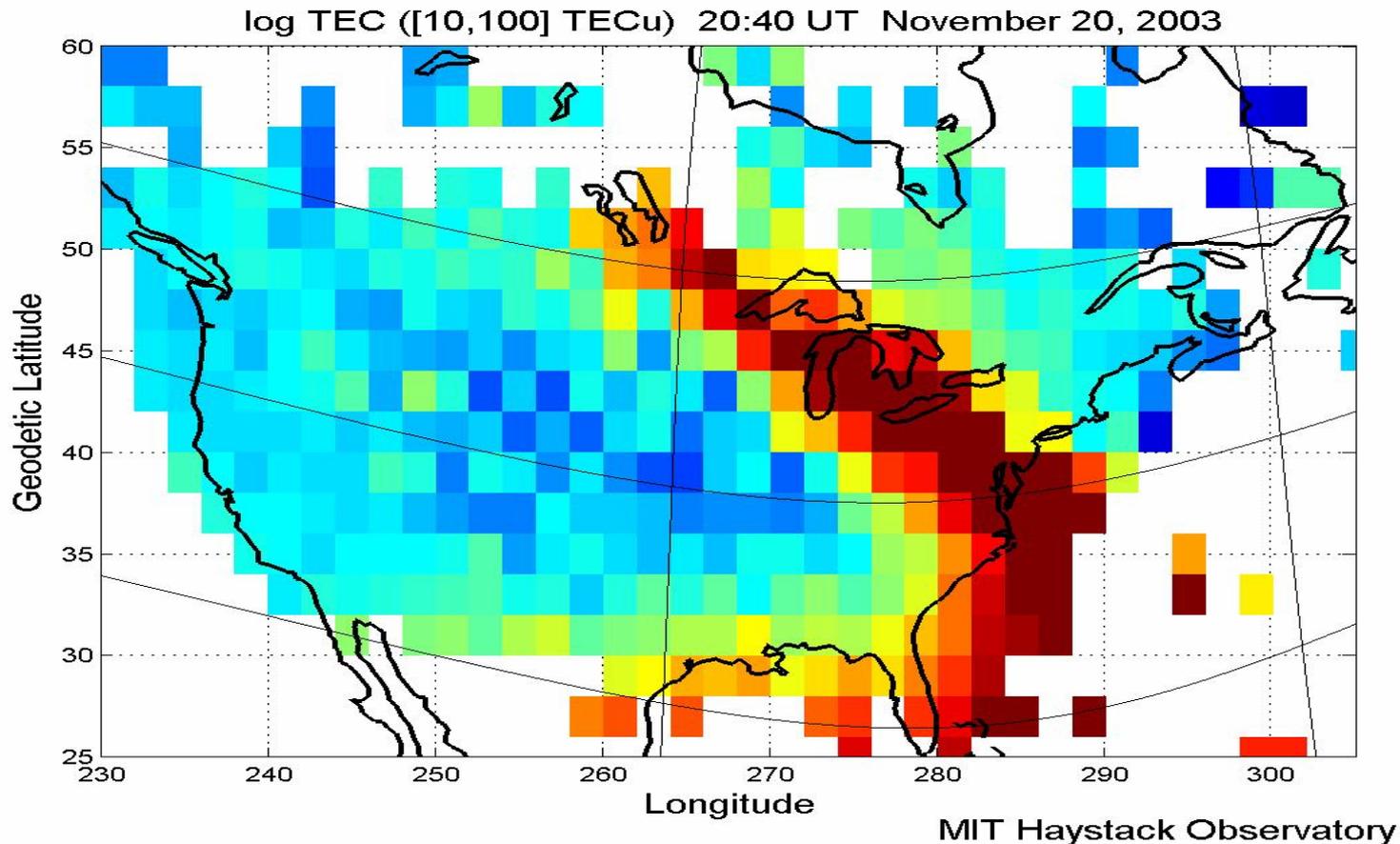
3.2.1.3.5.1 Condition for Valid Sigma Ionosphere

The LGF shall detect Ionospheric conditions that result in noncompliance with the requirements in Sections 3.1.2.1 and 3.1.2.2. When the increase in system risk associated with increased ionosphere gradients exceeds design tolerances, the LGF shall exclude the offending ranging source(s) and generate alerts as appropriate. When ionospheric disturbances cannot be isolated to specific ranging sources, and system risk is not minimal (increases by more than one order of magnitude) as a result, the LGF shall generate an alarm. Self-recovery shall be accomplished after ranging source exclusions or alarms are generated once the integrity requirements in Sections 3.1.2.1 and 3.1.2.2 are again met. The probability of a false alarm shall be less than 5×10^{-8} per 15-second interval.

Note: The sigma ionosphere vertical gradient term must be valid for all users within D_{max} from the LGF reference point, as identified in Section 3.1.2.

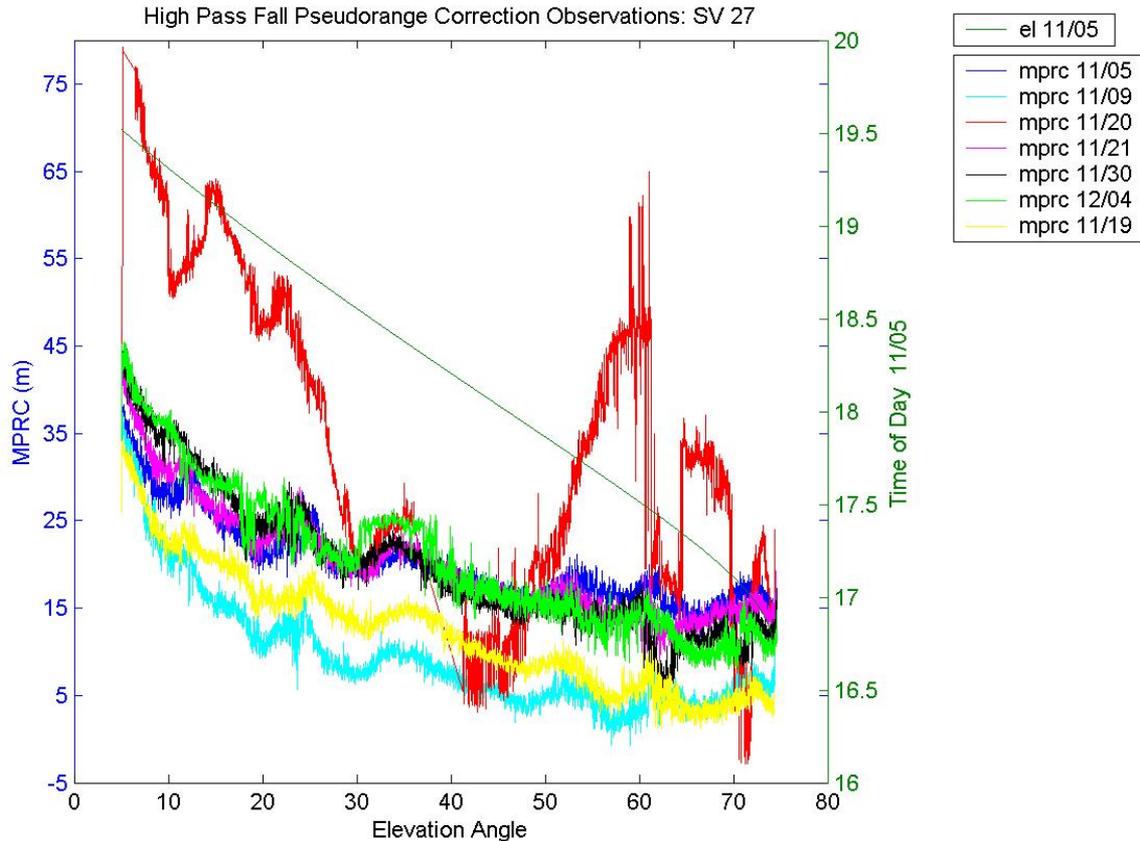
KRA 7: CONUS Ionospheric Anomaly

November 20, 2003



KRA 7: Ionospheric Anomaly 11/20/2003

LTP Pseudorange Correction



KRA 7: Sigma Ionosphere

- **Determine nominal values for** $\sigma_{\text{vert_iono_gradient}}$
- **Validate bounding performance**
 - Simulation
- **Develop the threat model for Anomalous Ionospheric events**
 - Determine what parts of the threat space can be detected or mitigated by existing ground monitors
 - Determine the maximum error that a user may experience during an ionospheric event
 - Develop mitigation methods to provide integrity during ionospheric events



KRA 7: Ionospheric Storm Integrity

- **Ionospheric storm activity unobservable to a GBAS station can not be mitigated by detection**
- **The GBAS airborne user can be impacted by a storm before the ground facility can see it, and integrity could be compromised**
 - These cases must be shown to be sufficiently rare, or mitigated
- **A solution for the CAT I system was determined**
 - The results are based on ionospheric storm threat model created from data collected within CONUS and assumptions about how a user will be threatened
 - Other implementers must evaluate their ionospheric environment to ensure that the CONUS threat model contains potential threats in their regions of interest

KRA 8: Sigma Troposphere

- **Development of a methodology for setting troposphere-specific site parameters**
- **Verify that the tropospheric errors can be bounded by the protection level equations and the defined broadcast parameters**

3.2.1.3.6 Refractivity Index

The Refractivity Index Field shall denote the refractivity index stored in LGF NVM.

3.2.1.3.7 Scale Height

The Scale Height Field shall denote the scale height stored in LGF NVM.

3.2.1.3.8 Refractivity Uncertainty

The Refractivity Uncertainty Field shall denote the refractivity uncertainty stored in LGF NVM.

KRA 8: Sigma Troposphere

- **Design and Approval Items**

- Determine nominal and maximum observed variation of temperature and humidity at selected locations
 - Use the model to simulate maximum expected LAAS errors
- Determine values for tropospheric parameters which provide integrity for all users
 - Verify with data collection and simulation
- Gather additional verification data from available public sources

LAAS Tropo Equations

Tropospheric Correction (TC)

$$TC = N_R h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(\theta)}} \left(1 - e^{-\Delta h / h_0} \right)$$

Tropospheric Residual Uncertainty (σ_{tropo})

$$\sigma_{tropo} = \sigma_N h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(\theta)}} \left(1 - e^{-\Delta h / h_0} \right)$$

- LAAS TC reduces to zero as Δh approaches zero
- Model only accounts for vertical tropo gradients (Δh)

Determining The LAAS Tropo Vertical “Threat” Values

- Documentation
 - RTCA DO-253A + A.J. Van Dierendonck papers
 - A method for determining the broadcast LAAS Tropo Parameters was developed
 - Skidmore, T. and F. van Graas, “An Investigation of Tropospheric Errors on Differential GNSS Accuracy and Integrity,” ION GNSS 2004, Long Beach, California, September 21-24, 2004
- (N_R, h_0) are a function of the following:
 - Temperature, Pressure, and Relative Humidity
 - Aircraft and Ground Station Altitudes
- (σ_N) is the 1-sigma error residual of N_R
- Values determined by actual weather data
 - Ex. Ohio U. Scalia Laboratory for Atmospheric Analysis

Computing The Scale Heights (h_0)

$$h_{0dry} = \frac{42700 - h_s}{2}$$

$$h_{0wet} = \frac{13000 - h_s}{2}$$

$$h_0 = \frac{N_{Rwet} h_{0dry}}{N_{Rdry} h_{0wet} + N_{Rwet} h_{0dry}}$$

- h_s is the surface height (meters) above Sea Level
- N_R is the total refractivity index
- N_{Rdry} is the refractivity index of the dry component
- N_{Rwet} is the refractivity index of the wet component



Computing Refractivity Indices

$$N_R = N_{R\text{dry}} + N_{R\text{wet}}$$

$$N_R \approx \frac{77.6P_s}{T_s} + 2.2777 \times 10^4 \frac{(RH_s)}{T_s^2} 10^{\left(\frac{7.4475(T_s - 273)}{T_s - 38.3} \right)}$$

- Which is now related to surface measurements
 - $(T_s, P_s, RH_s) = (T_o, P_o, RH_o)$

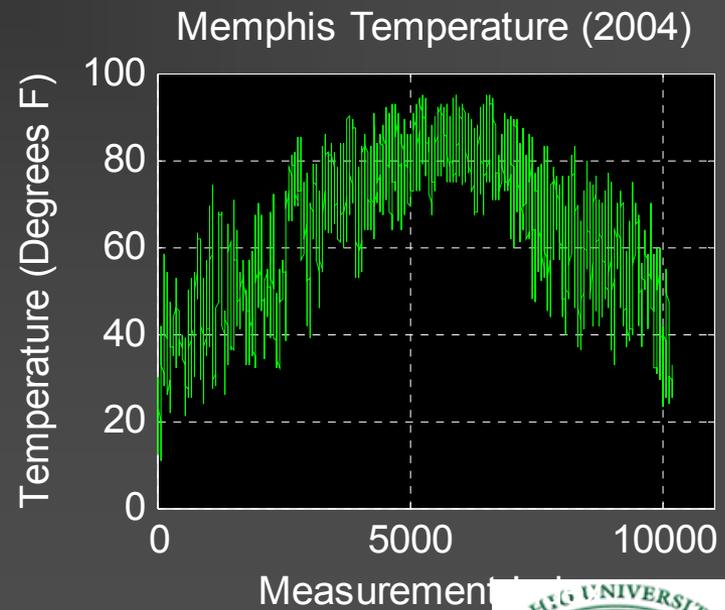
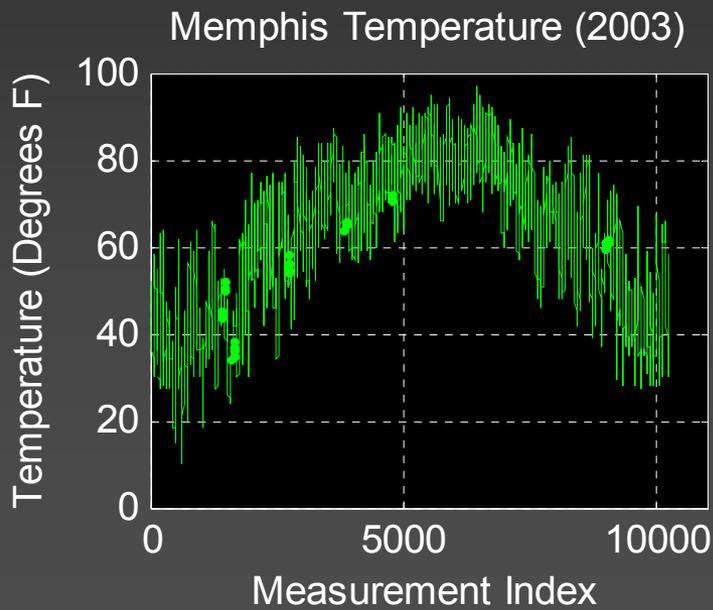
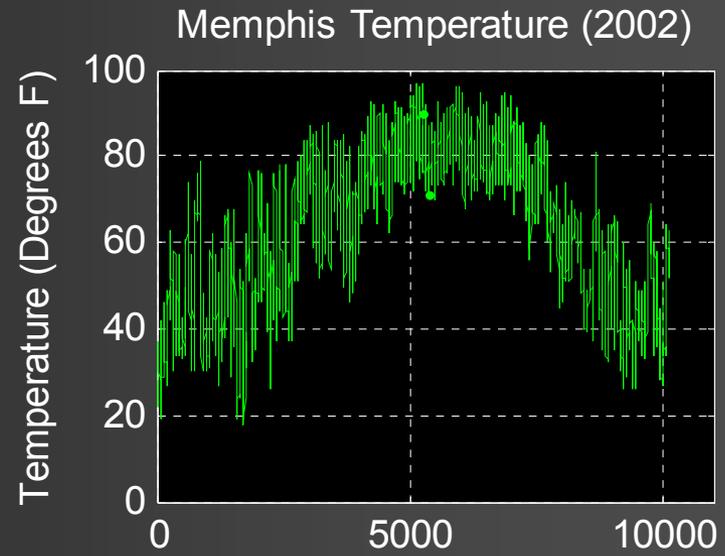
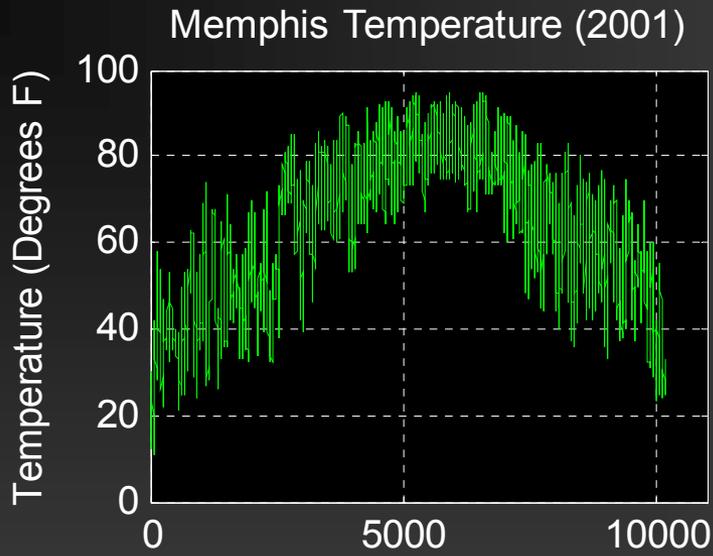


Memphis, Tennessee

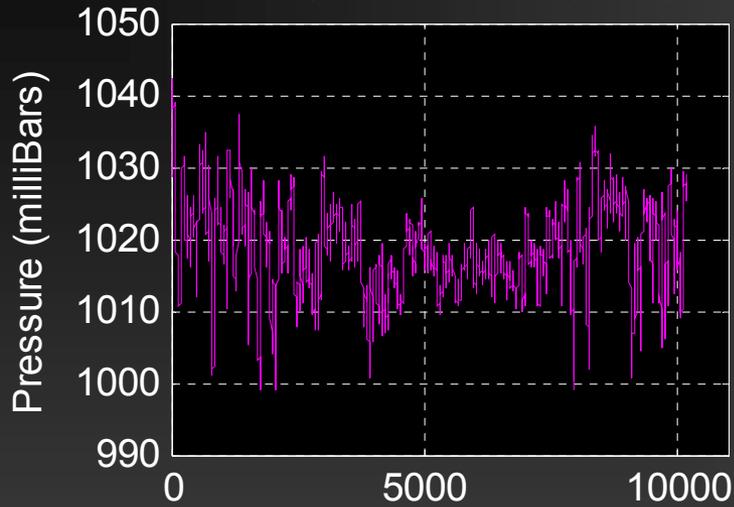
Weather Data

- Source: National Climatic Data Center
 - NCDC Web Page
 - <http://www.ncdc.noaa.gov/oa/ncdc.html>
 - Integrated Surface Hourly Data
 - Assume that all data is valid
 - Not edited for bad measurements and/or outliers
 - Use Temperature, Dew Point, and Pressure
 - Relative Humidity computed from Temperature and Dew Point by standard formula(s)

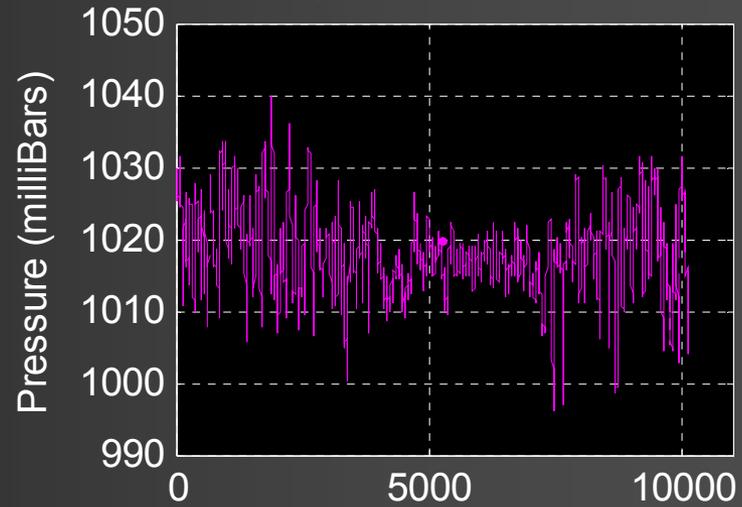




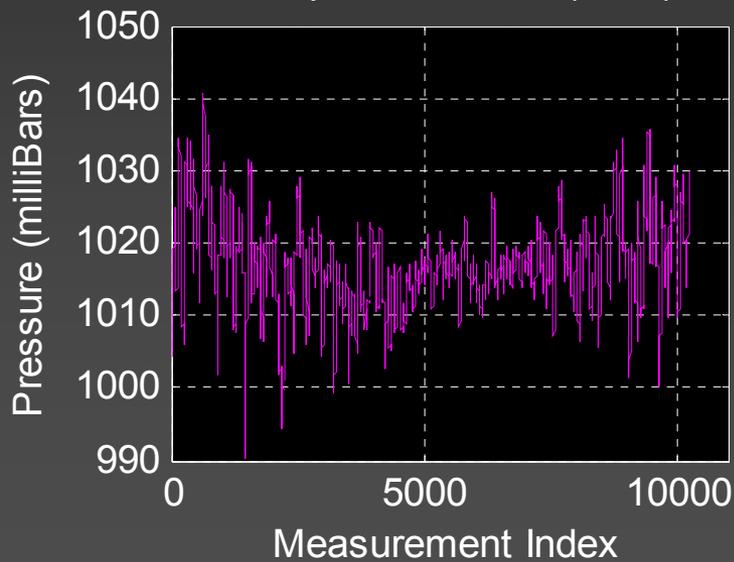
Memphis Pressure (2001)



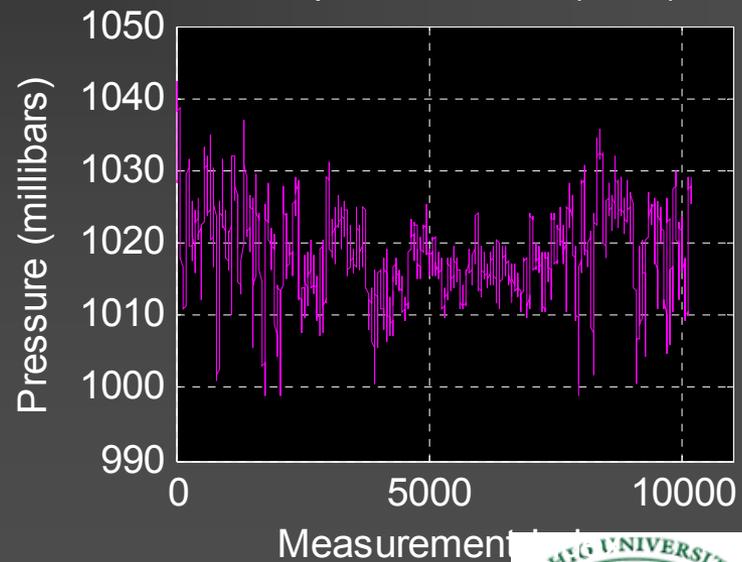
Memphis Pressure (2002)

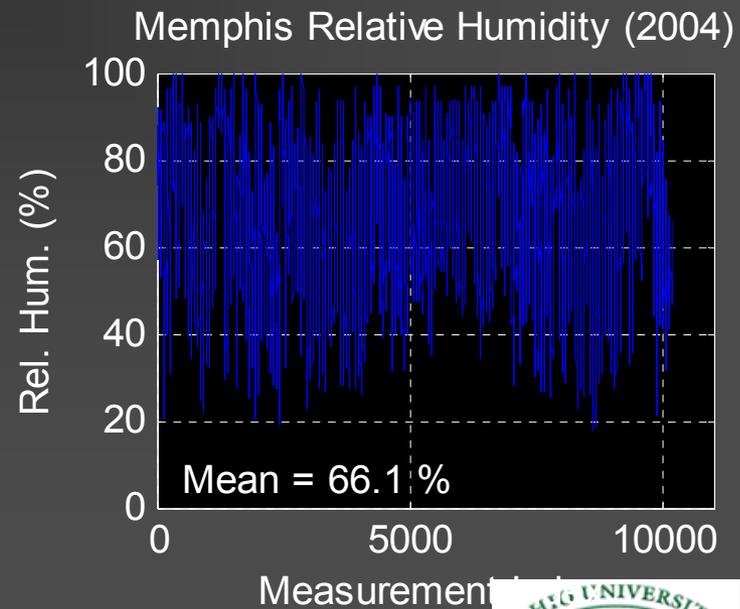
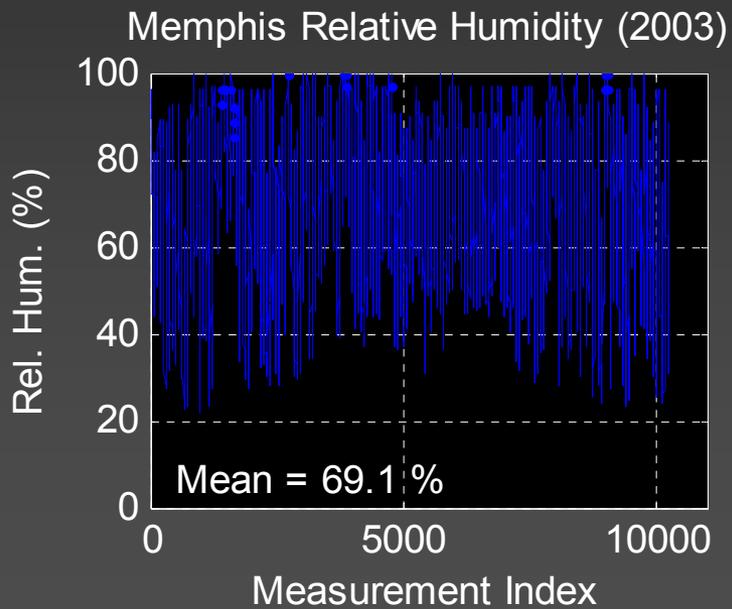
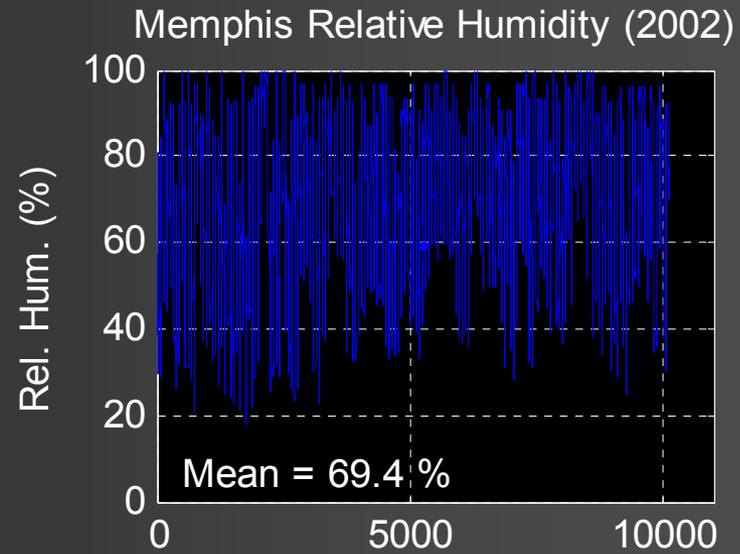
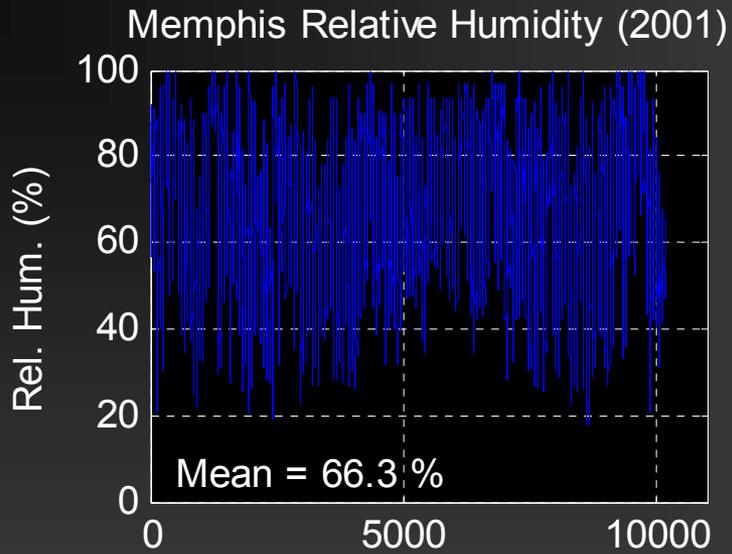


Memphis Pressure (2003)

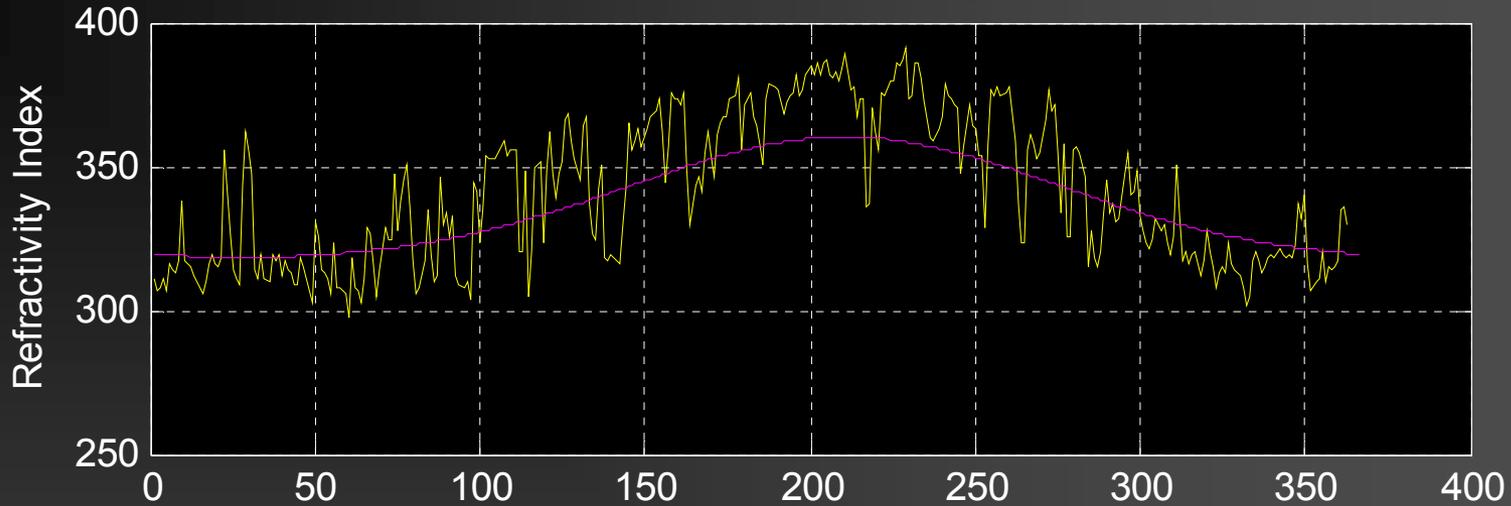


Memphis Pressure (2004)

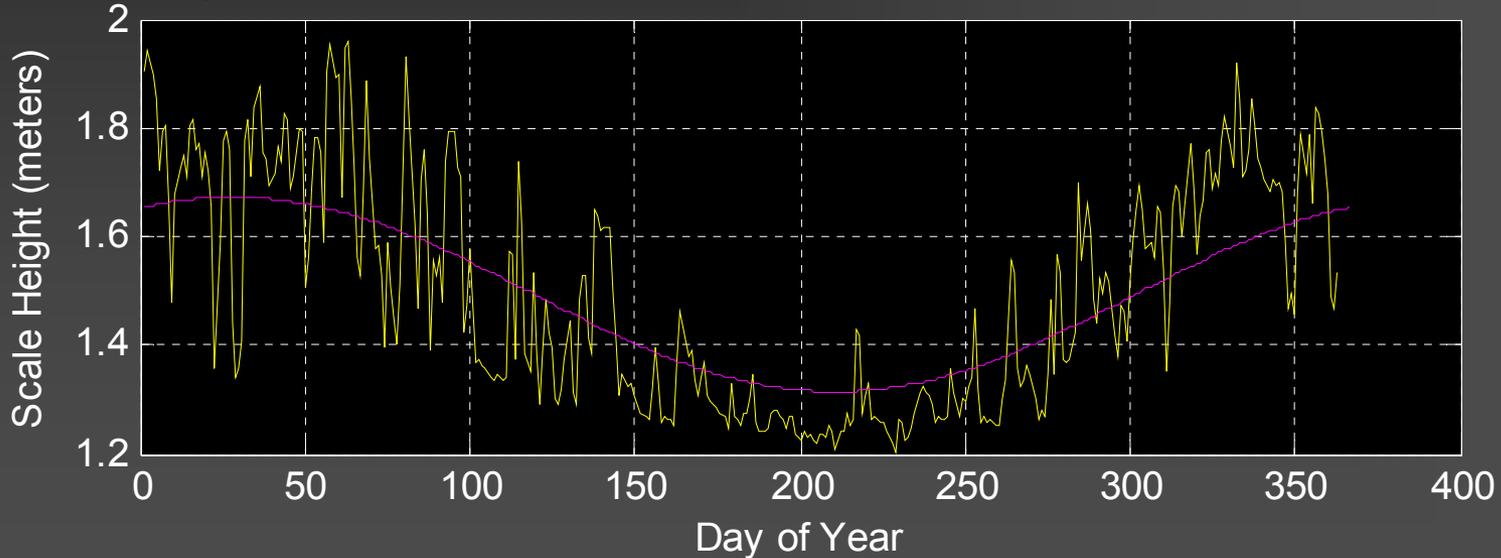




Computed and WAAS Predicted Refractivity Index: Memphis (2002)



$\times 10^4$ Computed and WAAS Predicted Scale Height: Memphis (2002)



WAAS Predicted values based on Relative Humidity yearly average

KRA 8: Design Recommendation

- **TC and σ_{tropo} (vertical) are fairly insensitive to seasonal variations in Refractivity Index and Scale Height**
 - Worst Case (based on Refractivity Index)
 - 5 degree Elevation Satellite
 - 6 cm at a Refractivity Index Delta Extreme of 100
- **Recommendation**
 - Use single Year of Weather Data to compute Refractivity Index, RI Uncertainty, & Scale Height
 - Set these as constant values in LAAS
 - Values fit in ICD data fields

KRAs 9 and 10:

Ephemeris Errors: Types B, A1, and A2

- **KRA 9: Type B ephemeris failure defined as an anomalous broadcast ephemeris not proceeded by a SV maneuver**
- **KRA 10: Type A1 ephemeris failure defined as an anomalous broadcast ephemeris proceeded by a scheduled SV maneuver**
- **Challenge is detecting SV position errors with relatively short LAAS baselines**
 - On-airport installations

KRAs 9 and 10: Integrity Parameters

Ephemeris Decorrelation Parameter

3.2.1.2.7 Ephemeris Decorrelation Parameter (P)

The Ephemeris Decorrelation Parameter field shall characterize the impact of residual ephemeris errors due to spatial decorrelation for the ranging source, associated with the first ranging source measurement block, in the Type 1 message. For every valid GPS ranging source, the LGF shall broadcast a P -value to represent the impact of undetected ephemeris errors on user range error. The maximum value for P shall be 1.5×10^{-4} m/m. The LGF shall exclude any ranging source for which the P -value cannot be validated. The broadcast ephemeris P -value for a given satellite shall account for the condition where the broadcast reference point (Section 3.2.1.3.9) does not match the reference receiver centroid location. When a healthy SBAS ranging source is within the reception mask, the impact of SBAS ephemeris monitoring shall be reflected in the P -values for all ranging sources included in the SBAS messages broadcast by this ranging source (except those indicated as “Do Not Use”, which must be excluded per Section 3.2.1.2.8.3.1(h)). When a healthy SBAS ranging source is not available within the reception mask, the P -values shall be based on GPS SPS signals.

KRAs 9 and 10: LAAS Integrity Protection Level Equations VPL_E

- **LAAS integrity for SV position errors comes from the estimate of the ephemeris error and its projection into the position solution**
 - Ephemeris error source is the GPS navigation data transmitted from the SV, or from a maneuver.
 - The uplink parameters are the p-values
 - These are measures of the uncertainty remaining after an ephemeris test has been performed
 - Almanac/Ephemeris tests provide little proof
 - Yesterday's and Today's (YE-TE) tests provide good confidence
 - WAAS broadcast ephemeris errors greatly reduce required p-value
- **A protection level for each satellite is calculated**

VPL_E Equation

LGF-User Distance

$$VPL_{e_j} = |S_{3,j}| \cdot |x| \cdot \frac{MDE_e}{R_j} + K_{md_e} \sqrt{\sum_{k=1}^N S_{3,k}^2 \sigma_k^2}$$

From weighted p-inverse of user geometry matrix

SV index

Missed-detection multiplier

Differential ranging error variance

LGF broadcasts “P-value” for each approved GPS satellite.

- The lower the MDE, the larger the LGF-User distance can be without availability impact.

KRAs 9 and 10 Ephemeris Monitoring

- **Ephemeris A2 failures were considered sufficiently improbable to disregard for CAT I GBAS**
 - An A2 failure is an un-announced movement of a satellite
- **On April 10, 2007, PRN 18 was repositioned by the GPS space segment without indicating bad health status**
 - The movement was properly announced by a NANU
- **Complete details were published in the GPS PAN report, Aug 2007**
 - www.nstb.gps.tc.faa.gov

Notice Advisory to NAVSTAR Users (NANU)

NOTICE ADVISORY TO NAVSTAR USERS (NANU) 2007053

SUBJ: SVN54 (PRN18) FORECAST OUTAGE JDAY 100/1330 - JDAY 101/0130

1. NANU TYPE: FCSTDV
NANU NUMBER: 2007053
NANU DTG: 061804Z APR 2007
REFERENCE NANU: N/A
REF NANU DTG: N/A
SVN: 54
PRN: 18
START JDAY: 100
START TIME ZULU: 1330
START CALENDAR DATE: 10 APR 2007
STOP JDAY: 101
STOP TIME ZULU: 0130
STOP CALENDAR DATE: 11 APR 2007
2. CONDITION: GPS SATELLITE SVN54 (PRN18) WILL BE UNUSABLE ON JDAY 100 (10 APR 2007) BEGINNING 1330 ZULU UNTIL JDAY 101 (11 APR 2007) ENDING 0130 ZULU.
3. POC: CIVILIAN - NAVCEN AT 703-313-5900, [HTTP://WWW.NAVCEN.USCG.GOV](http://www.navcen.uscg.gov)
MILITARY - GPS OPERATIONS CENTER at [HTTP://GPS.AFSPC.AF.MIL/GPSOC](http://gps.afspc.af.mil/gpsoc),
DSN 560-2541,
COMM 719-567-2541, [\[log in to unmask\]](#),
[HTTP://gps.afspc.af.mil/gps](http://gps.afspc.af.mil/gps)
MILITARY ALTERNATE - JOINT SPACE OPERATIONS CENTER, DSN 276-9994,
COMM 805-606-9994, [\[log in to unmask\]](#)

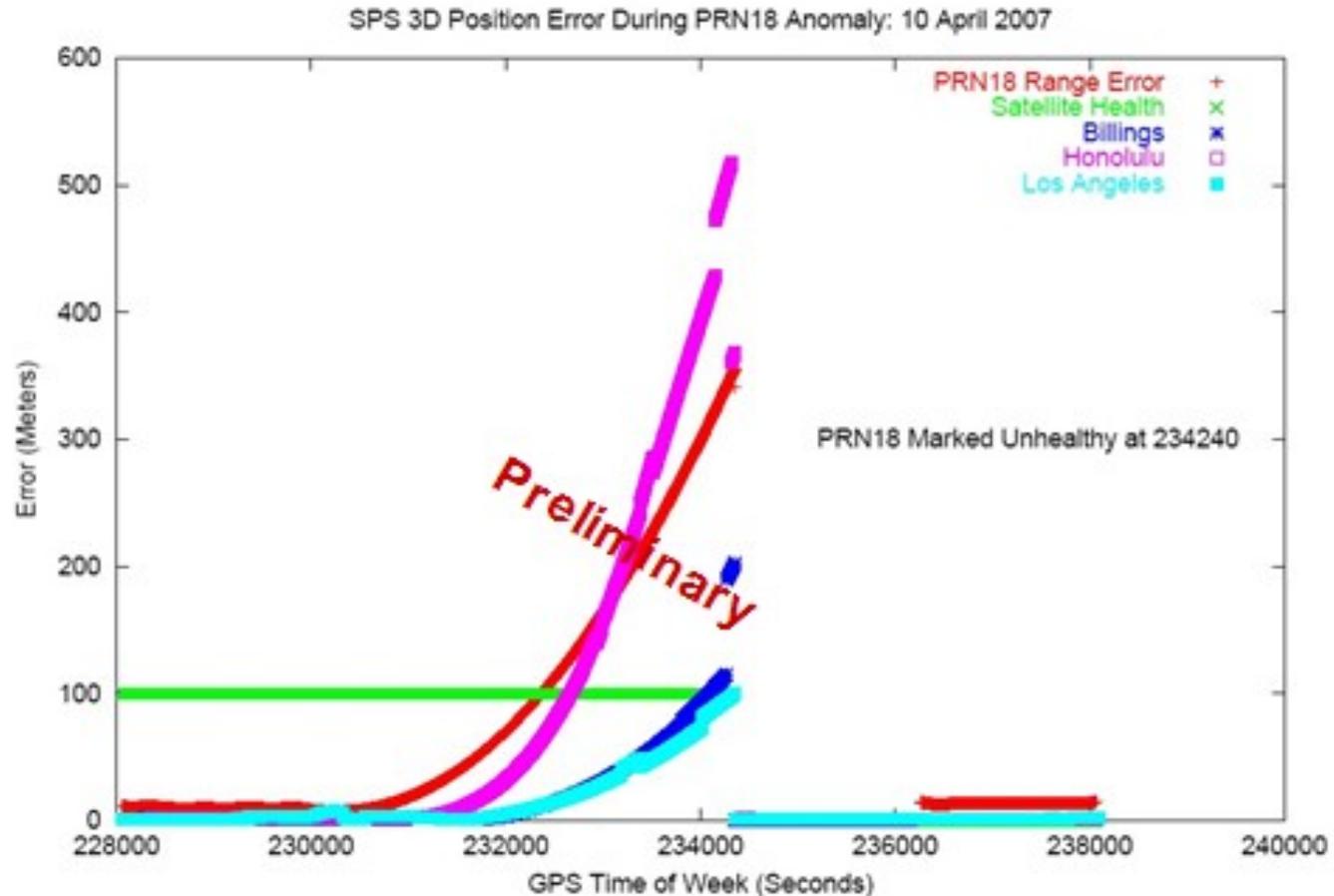
NOTICE ADVISORY TO NAVSTAR USERS (NANU) 2007057

SUBJ: SVN54 (PRN18) FORECAST OUTAGE SUMMARY JDAY 100/1704 - JDAY 100/2124

1. NANU TYPE: FCSTSUMM
NANU NUMBER: 2007057
NANU DTG: 102139Z APR 2007
REFERENCE NANU: 2007053
REF NANU DTG: 061804Z APR 2007
SVN: 54
PRN: 18
START JDAY: 100
START TIME ZULU: 1704
START CALENDAR DATE: 10 APR 2007
STOP JDAY: 100
STOP TIME ZULU: 2124
STOP CALENDAR DATE: 10 APR 2007
2. CONDITION: GPS SATELLITE SVN54 (PRN18) WAS UNUSABLE ON JDAY 100 (10 APR 2007) BEGINNING 1704 ZULU UNTIL JDAY 100 (10 APR 2007) ENDING 2124 ZULU.
3. POC: CIVILIAN - NAVCEN AT 703-313-5900, [HTTP://WWW.NAVCEN.USCG.GOV](http://www.navcen.uscg.gov)
MILITARY - GPS OPERATIONS CENTER at [HTTP://GPS.AFSPC.AF.MIL/GPSOC](http://gps.afspc.af.mil/gpsoc),
DSN 560-2541,
COMM 719-567-2541, [\[log in to unmask\]](#),
[HTTP://gps.afspc.af.mil/gps](http://gps.afspc.af.mil/gps)
MILITARY ALTERNATE - JOINT SPACE OPERATIONS CENTER, DSN 276-9994,
COMM 805-606-9994, [\[log in to unmask\]](#)

Observed GPS SPS Errors

April 10, 2007



KRAs 9 and 10:

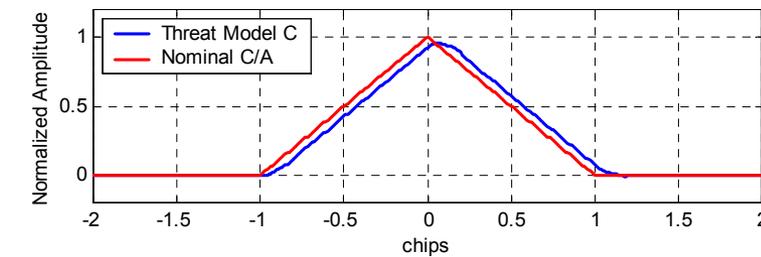
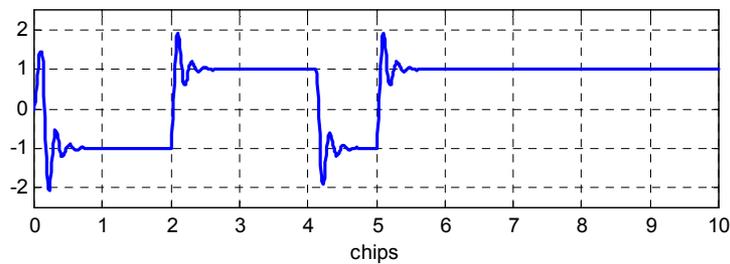
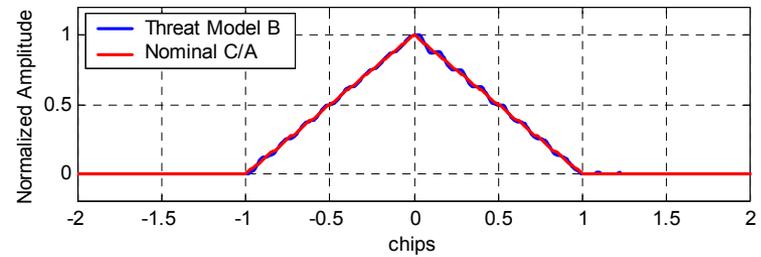
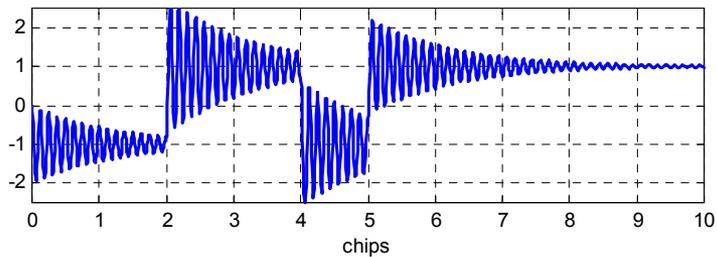
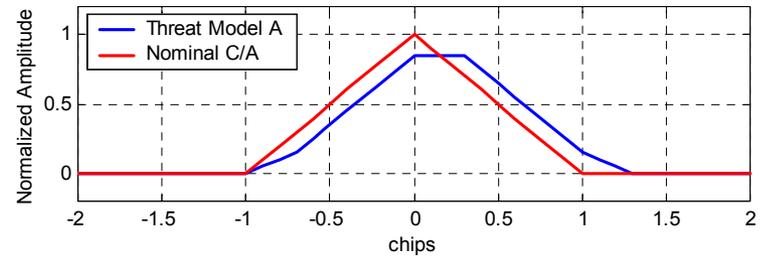
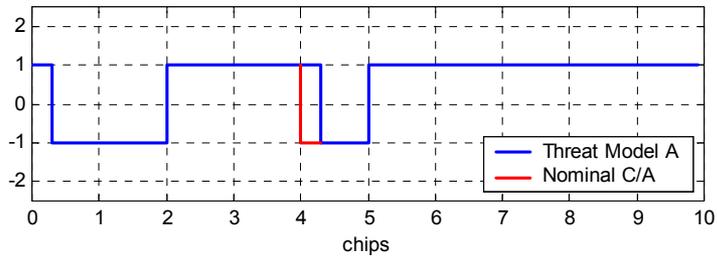
Ephemeris Monitoring Mitigation

- **Several new tests were added to the design that can be used to detect satellite displacement errors**
 - The tests address the observed case without relying on monitoring NANUs
 - Also addresses problematic corner cases of the ephemeris B and A1 mitigations that were uncovered in the HMI analysis
 - Final simulations were performed to show that all data failures following a maneuver were detected
 - Including maneuvers out of view of the GBAS

KRA 11: Signal Deformation Monitor

- **Signal deformation was shown to cause non-differentially correctable errors when user and reference GPS reception techniques differed**
- **Although there is a well-developed, internationally coordinated threat model, several implementation issues remained**
 - Proof of acceptable false alarm and missed detection performance
 - Characterize the performance in the presence of multipath
 - Develop the IF filter model to incorporate variation over the range of expected nominal receiver production
 - Demonstration and analysis to prove that all transient modes are protected within the existing threat space
 - Demonstrate the implementation can be adequately tested

KRA 11: Signal Deformation Monitor

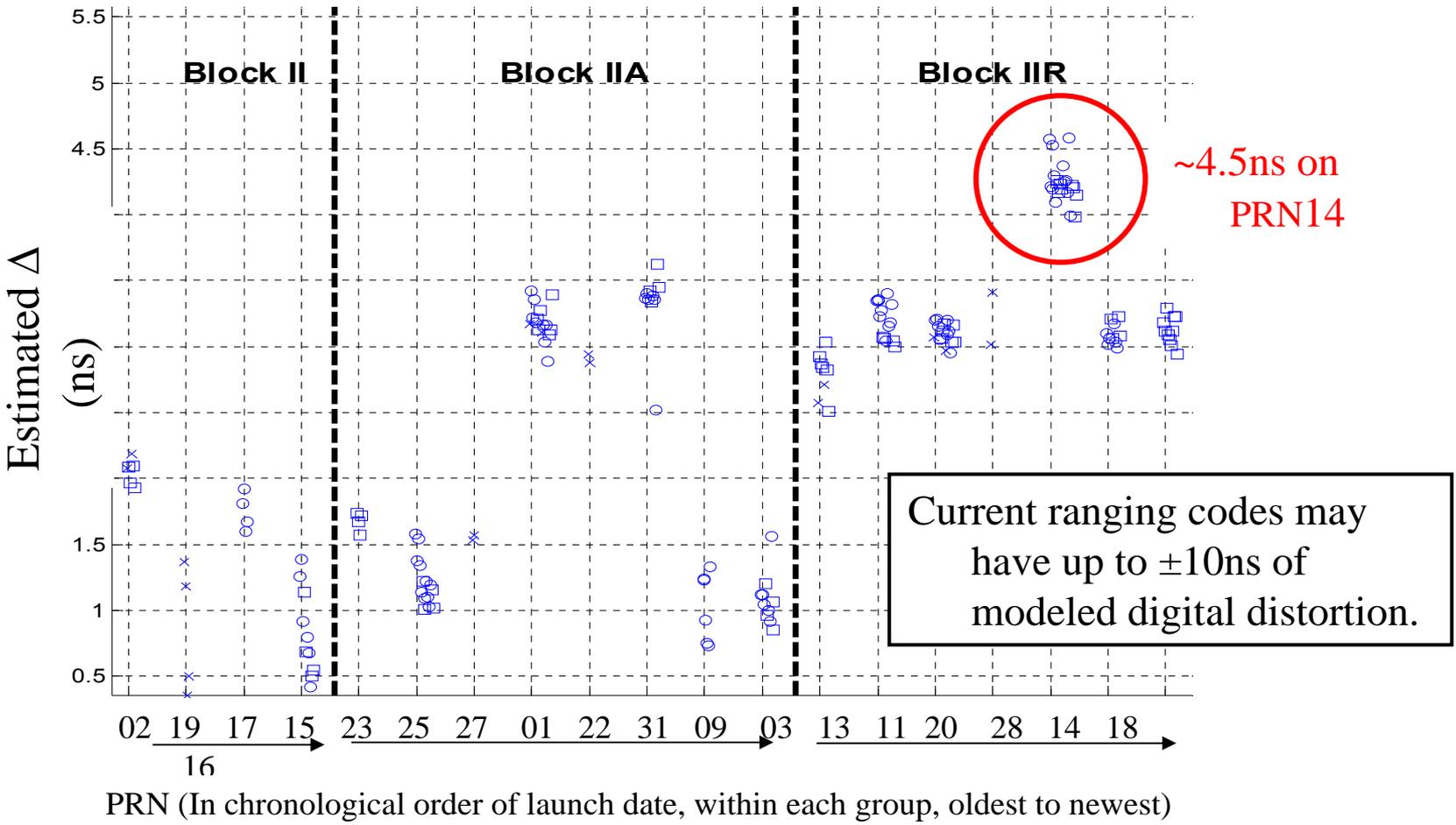


KRA 11: Signal Deformation Monitoring Natural Biases

- **Satellite signals can be distorted by failures such that differential corrections will have errors for some set of users**
- **Natural (nominal, non-faulted) deformations exist**
 - The airborne user design space is limited, any difference between the ground receiver and the user receiver implementation will cause errors that must be bounded
 - Natural bias errors must be bounded by σ_{pr_gnd}

Nominal Signal Deformation (Digital Only) - Data

Estimates of C/A code Δ Sorted by SV Block Type (II, IIA, IIR)



Courtesy: A. Mitelman



KRA 11: SDM Natural Bias Mitigation

- **Satellites introduced into the constellation must be evaluated against the natural bias level protected by σ_{pr_gnd}**
 - Relationship between SDM test statistic biases and user errors is being more precisely simulated
- **Satellites with excessive natural bias must be additionally inflated or excluded**
 - An additional test was added to the design to monitor the natural bias levels and perform this exclusion
- **Details of a bias-monitoring test statistic and implementation are design-specific**

KRA 12: Low Power

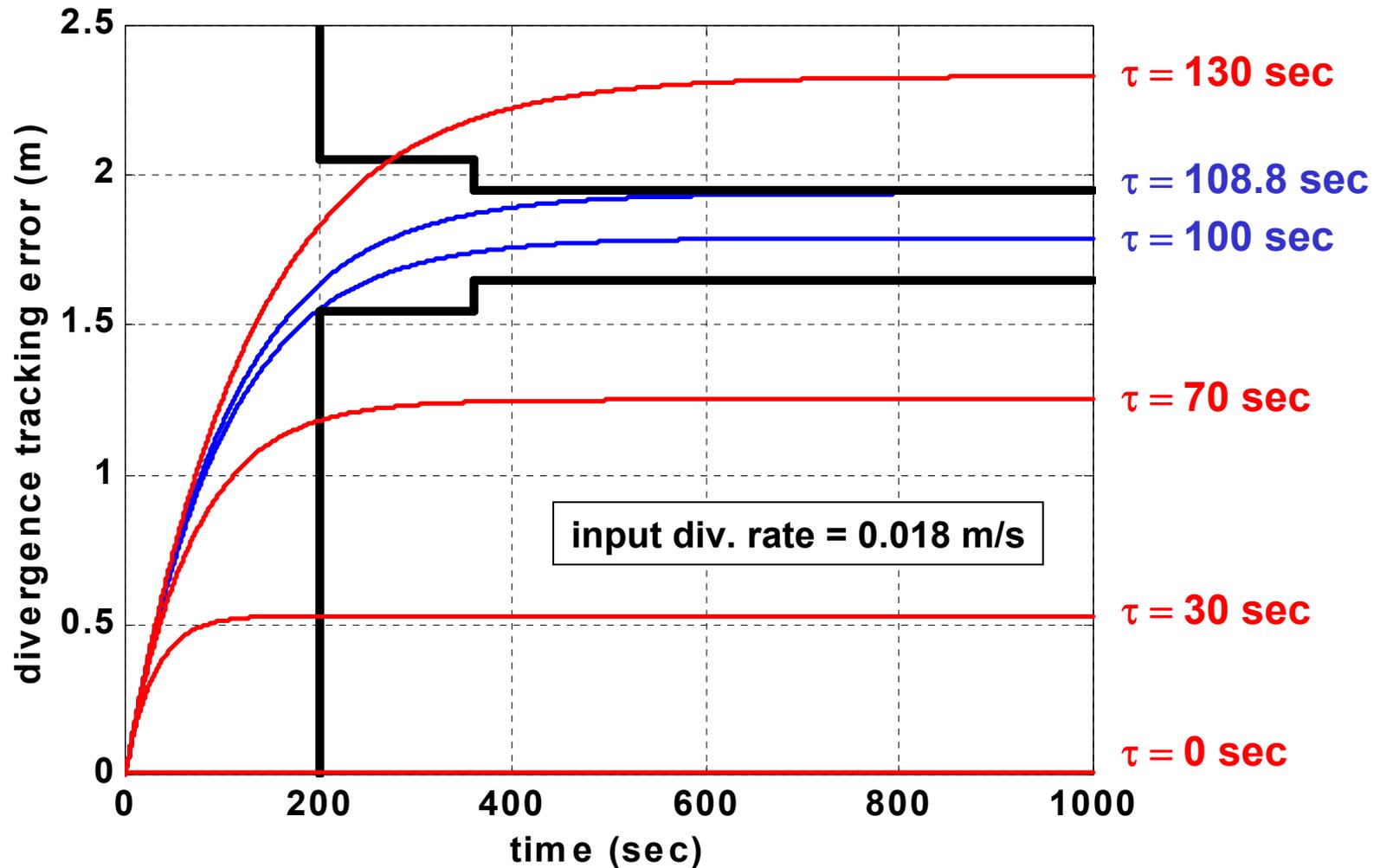
- **The LGF must detect if the broadcast power of any ranging source is transmitting less than the specified minimum power**
 - While it may be able possible to adequately track this signal, it is an indication the SV has other failures
 - Impact on other monitors must be determined
 - Low SV power is difficult to distinguish from other potential threats
 - RFI
 - Signal fading due to multipath
- **LGF monitors for cross-correlation errors that may result from large relative power differences only**

KRA 13: Code/Carrier Divergence

- **The LGF must detect if the code and carrier signals broadcast signal from the ranging source are incoherent**
 - While the ground pseudorange smoothing filter is specified, the airborne is not
 - Filter and timing differences will produce non correctable errors in the presence of divergence
 - Nominal divergence is specified and must be bounded in σ_{pr_gnd}

Example 1st Order Filter Responses

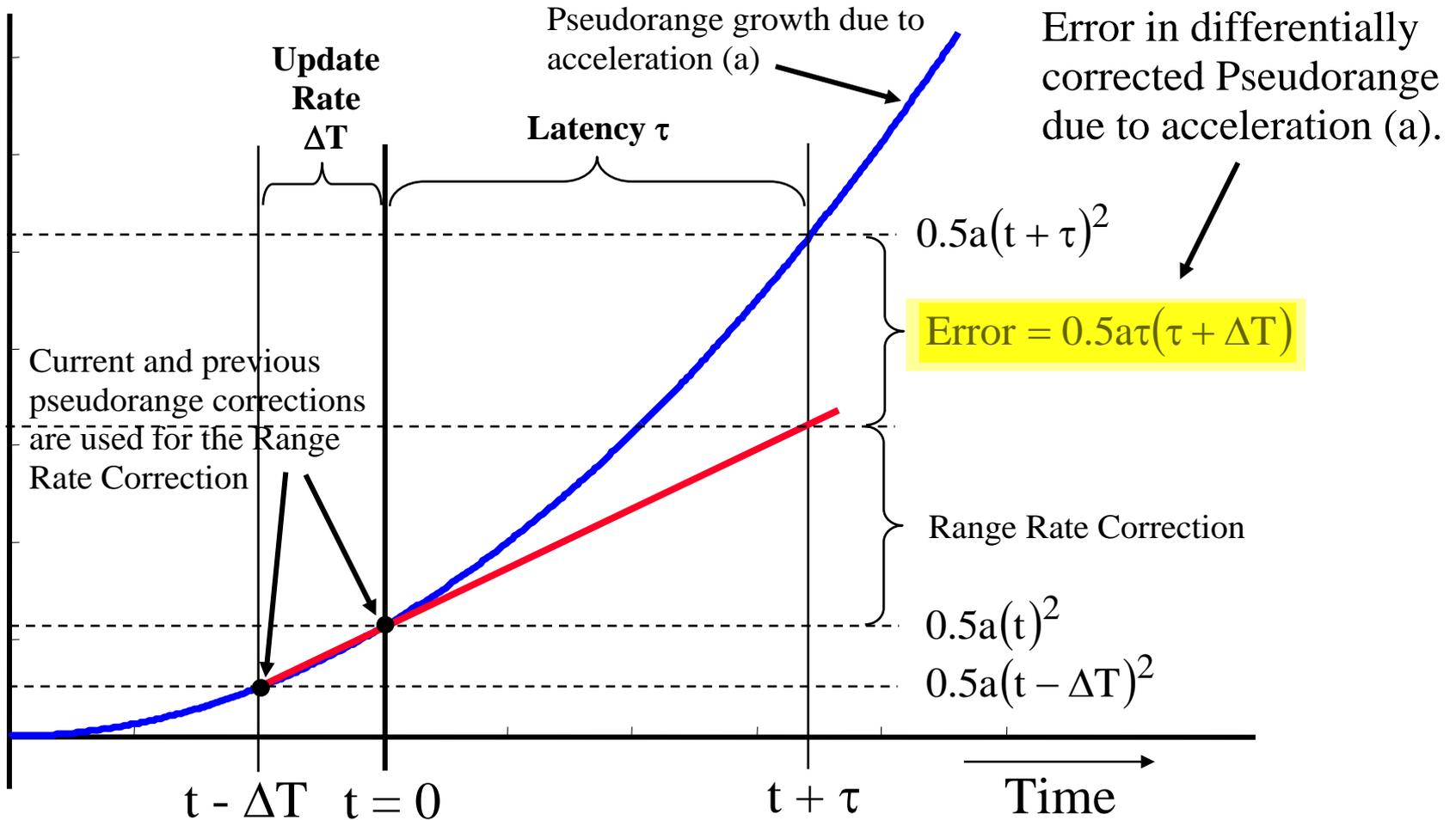
1st Order Time Invariant (TI) Filter Response



KRA 14: Excessive Acceleration

- **The LGF must detect if the acceleration calculated from the range measurements from each SV is less than the maximum expected**
 - Selective Availability (SA) maximum specified rate
 - Appropriate non-SA rate if appropriate
- Excessive acceleration is difficult to distinguish from other potential threats
 - Scintillation
 - Ionospheric activity

Derived Requirements – Pseudorange Error



KRA 15: Executive Monitor

- **The executive monitor must be capable of distinguishing between reference receiver failures and ranging source failures**
 - The execution and priority of the fault monitors must be determined such that erroneous data is not passed into additional monitor streams

Summary

- **LAAS uses a number of protection level equations that include statistical and instantaneous measures of system performance**
 - The LAAS Ground Facility is required to monitor the validity of the statistical parameters it broadcasts
- **The integrity proof must examine the details of the integrity parameters used in these protection levels and the combined coverage of the multiple protection levels**
- **The complete details of the integrity proof are provided in the SLS-4000 HMI Document**
 - Separate presentation