FAA GNSS Programs & GPS Evolutionary Architecture Study (GEAS) Status

Presented to: **Stanford PNT Symposium**

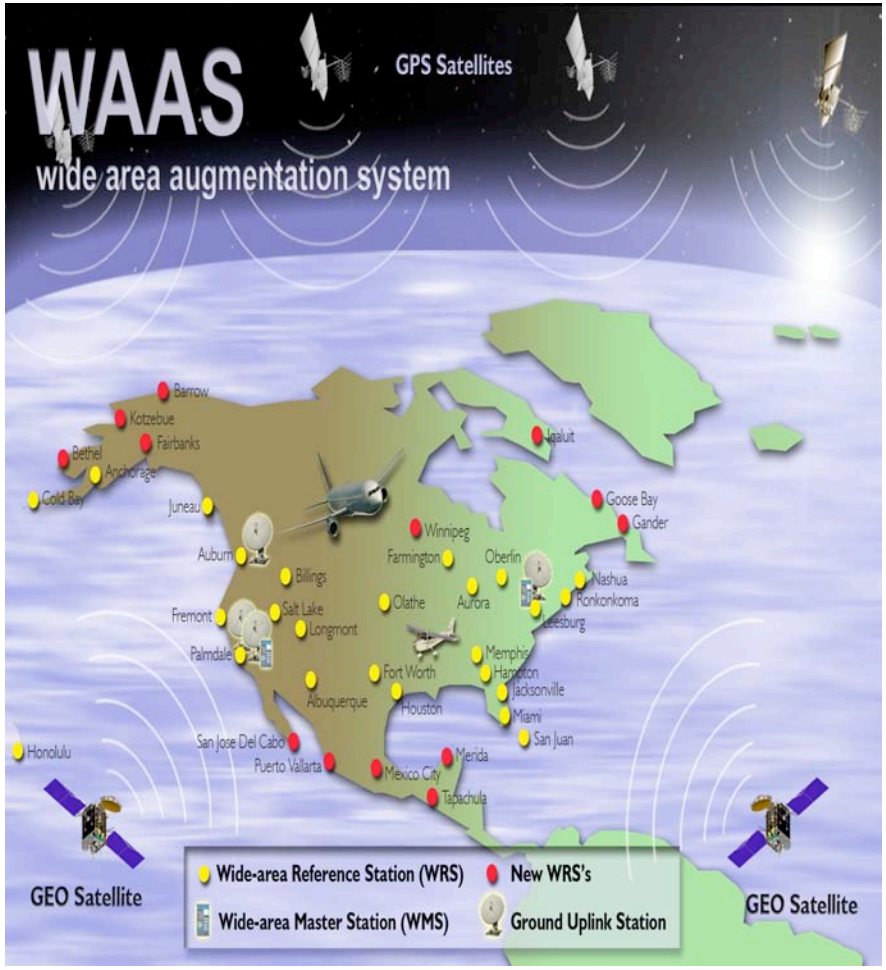
By: **Leo Eldredge, FAA**

Date: **November 6th, 2007**

Agenda

- **Wide Area Augmentation System (WAAS) Status**
- **Local Area Augmentation System (LAAS) Status**
- **GNSS Evolutionary Architecture Study (GEAS) Status**

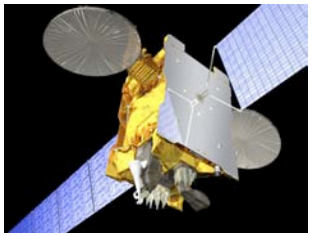
WAAS Architecture



38 Reference Stations

3 Master Stations

4 Ground Earth Stations



2 Geostationary Satellite Links

2 Operational Control Centers

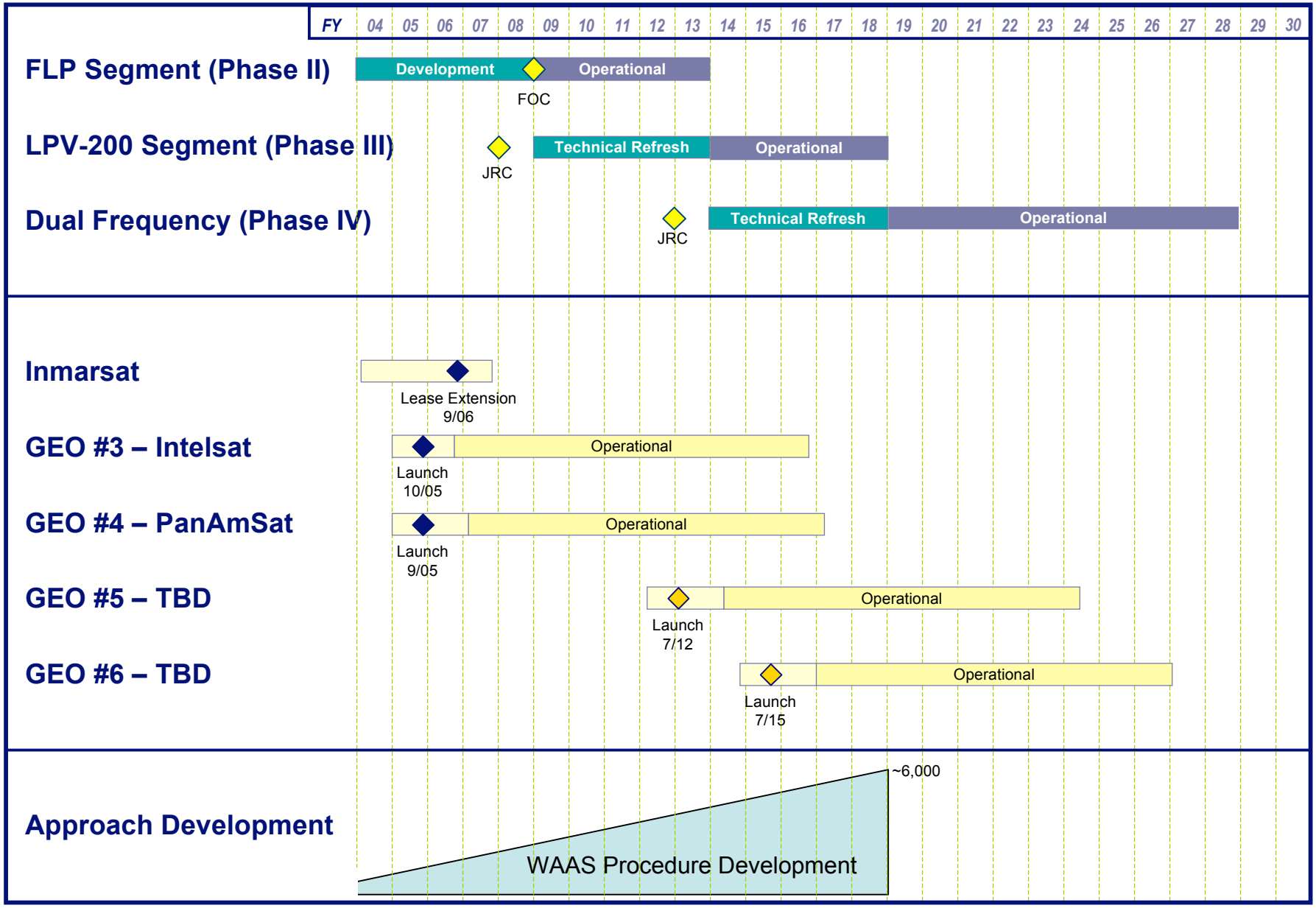
WAAS LPV Performance

	GPS Standard	GPS Actual	WAAS LPV-200 Standard	WAAS LPV-200 Actual
Horizontal 95%	36 m	2.74 m	16 m	1.08 m
Vertical 95%	77 m	*3.89 m	4 m	1.26 m

**** Use of GPS vertical not authorized for aviation without augmentation (SBAS or GBAS)***

WAAS Performance evaluated based on a total of 1,761 million samples (or 20,389 user days)

WAAS Enterprise Schedule

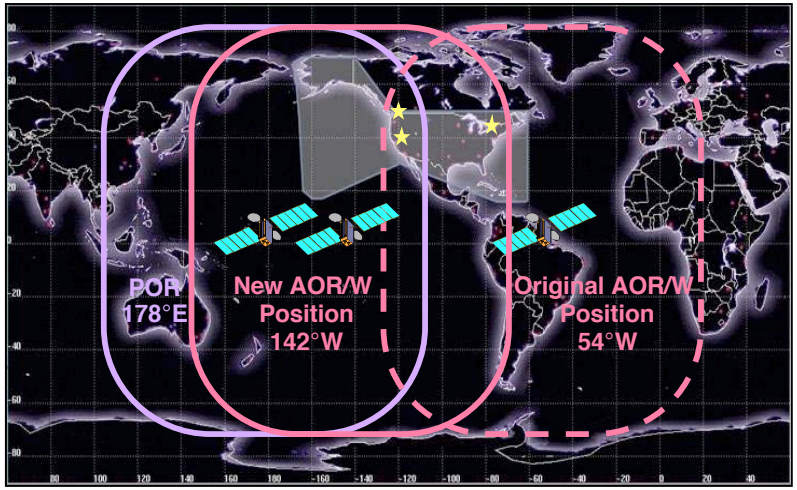


WAAS Phase II Status

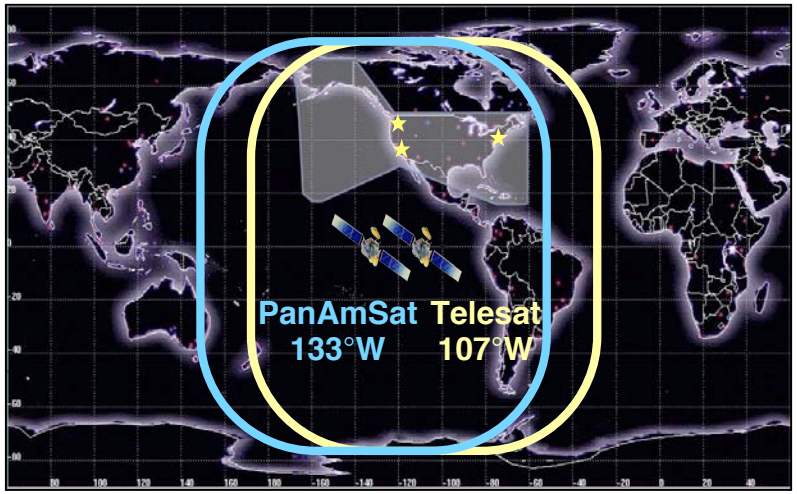
- **Expand LPV Service to all of CONUS and Significant Portions of Alaska, Canada, Mexico**
  - Install 13 Additional WAAS Reference Stations (WRS)
    - 4 Alaska – *Complete*
    - 4 Canada – *Complete*
    - 5 Mexico - *Complete*
  - Software Modifications - *Underway*
- **Provide Redundant GEO Coverage**
  - Replace Both GEO Satellites - *Complete*
- **Improve Service Reliability**
  - Add Third WAAS Master Stations (WMS) - *Complete*
  - Software Improvements To Broadcast Corrections - *Underway*
- **Approve LPV Service Down to 200 Feet**
  - Complete Safety Analysis to Approve WAAS Users For ILS Equivalent Service - ***Complete***

GEO Satellite Improvements

- **Phase I – IOC**
  - Inmarsat Satellites
    - AOR-W – 54W
    - POR – 178E
  - AOR-W Moved to 142W
  - Leases Expired July 2007

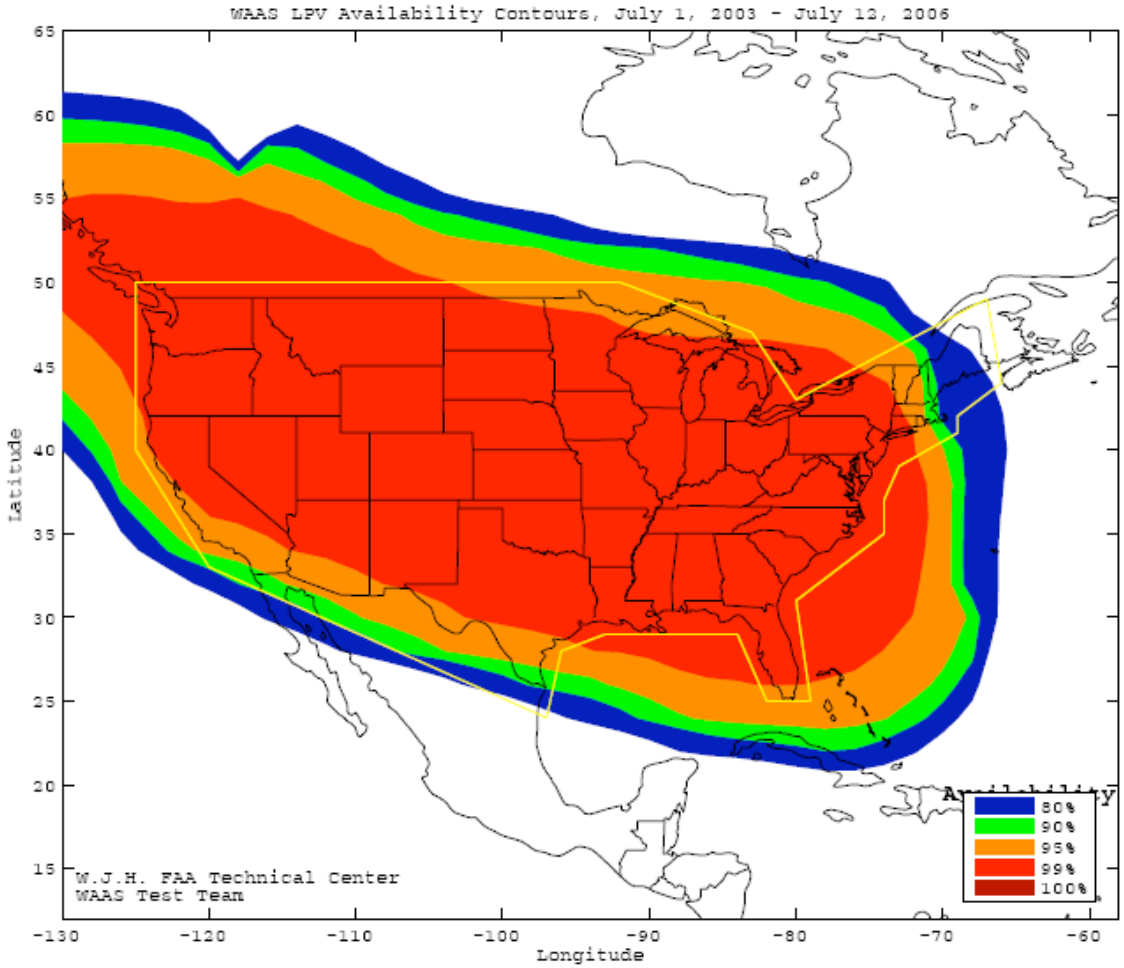


- **Phase II**
  - New GEOs
    - Panamsat (Galaxy XV) – 133W
    - Telesat Canada (Anik F1R) – 107W
  - Operational July 2007



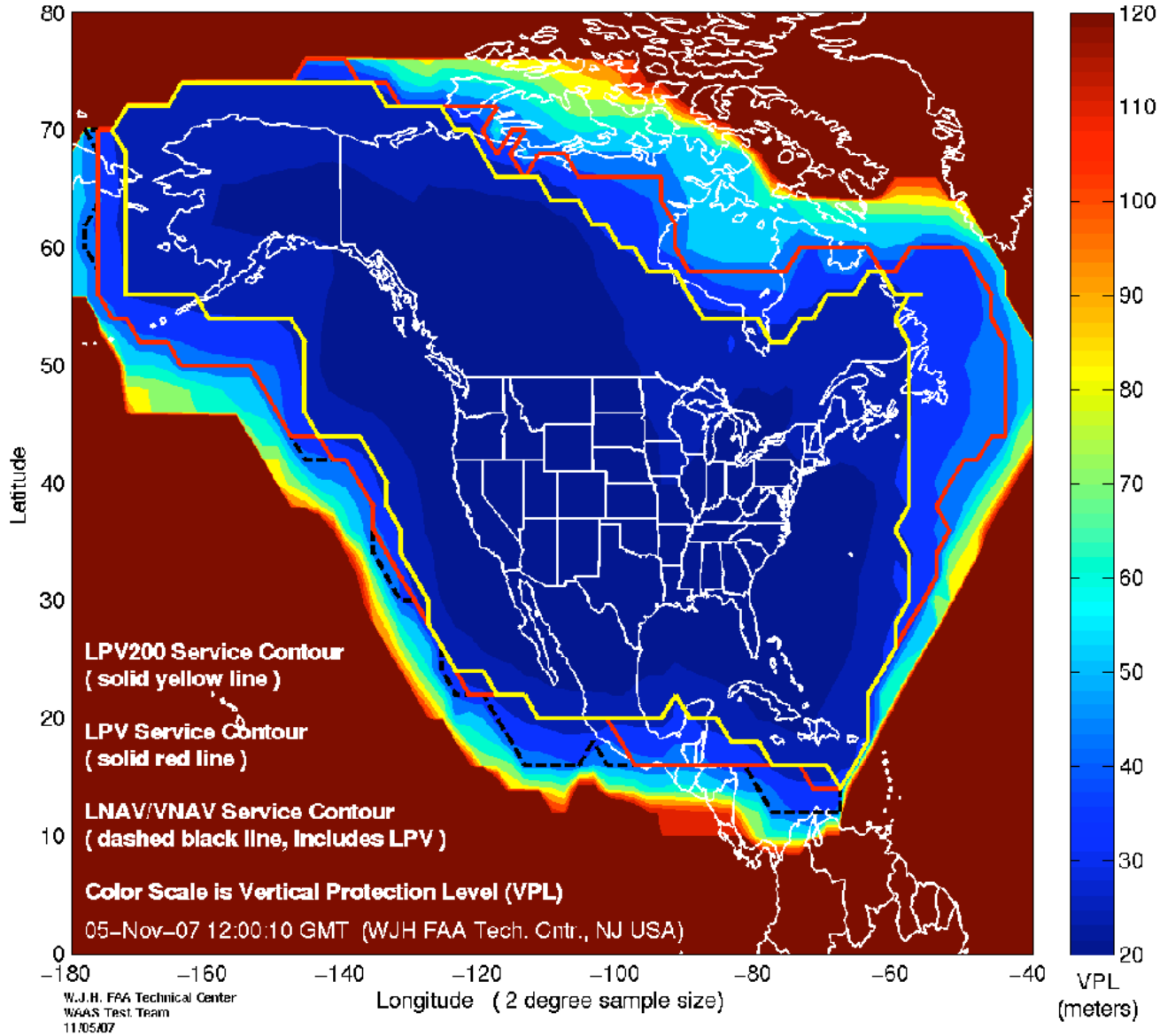
WAAS LPV Coverage

- IOC 2003 -



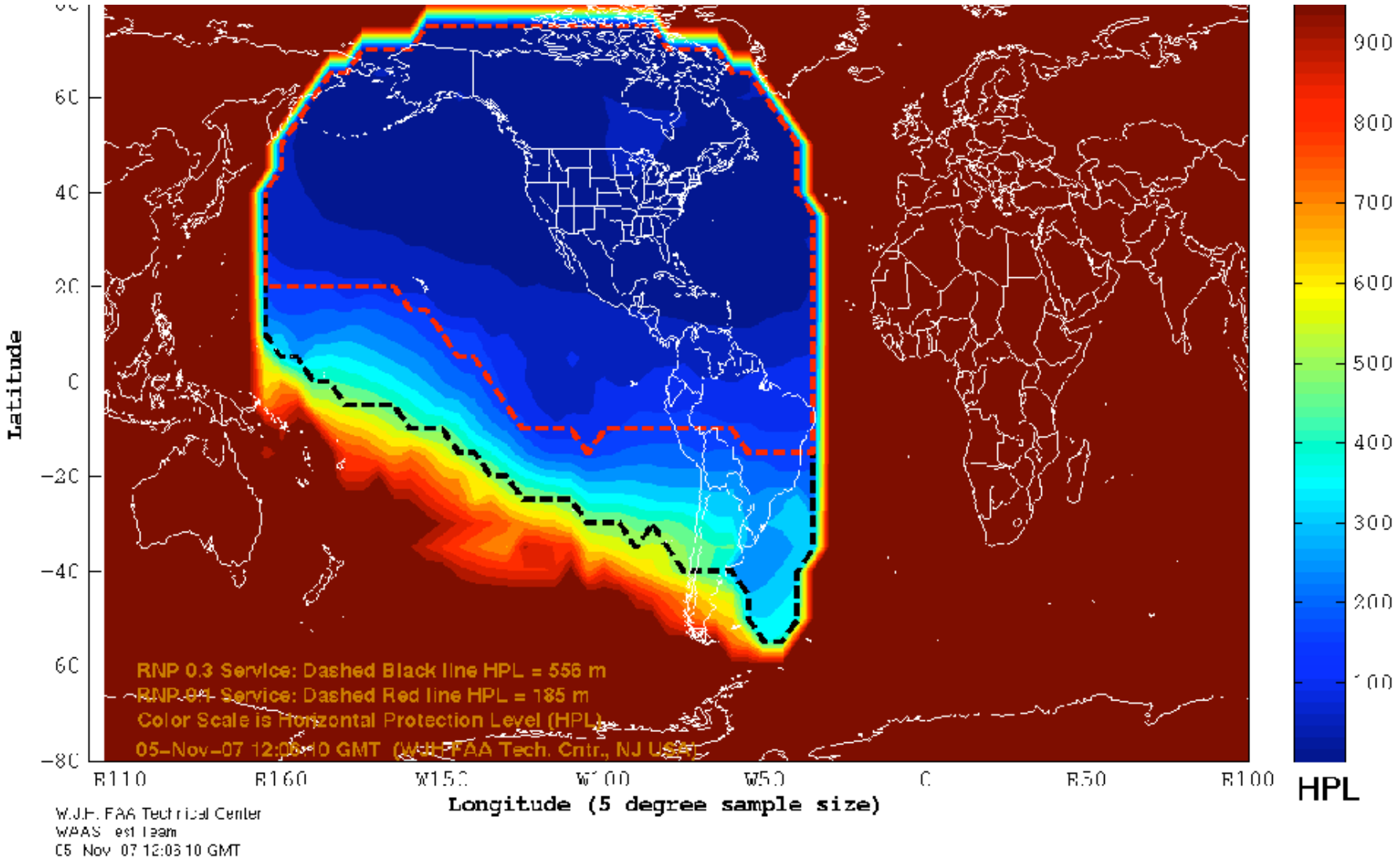
WAAS LPV Coverage

- Current 2007 -



WAAS RNP Coverage

- Current 2007 -



WAAS Program – Phase III

(2009-2013)

Full LPV-200 Performance

- **Continue To Improve Service For LPV-200**
- **Support Transition Of WAAS Maintenance And Development Capabilities To The FAA**
- **Planned WAAS Algorithm Updates For Phase III**
  - Acquisition Of Additional GEO Satellite
  - Continued GIVE Algorithm Tuning to Maximize Availability During the Approaching Solar Maximum
- **Conduct Planning and Engineering Analysis to Prepare for Dual Frequency Operations**
  - GPS Evolutionary Architecture Study (GEAS)

WAAS Program – Phase IV

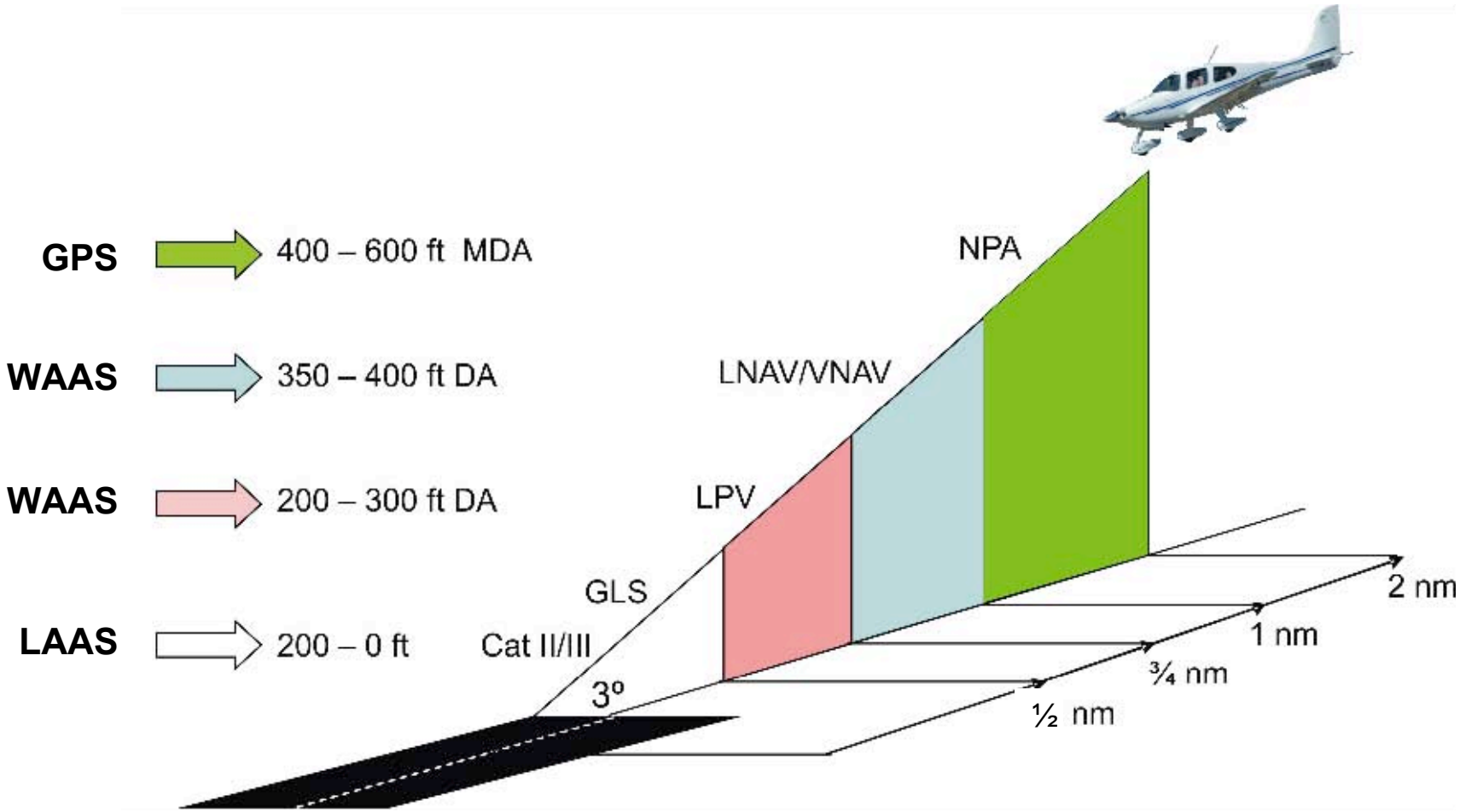
(2014-2028)

- **Dual Frequency Operations**
  - Maintain a robust, reliable, and sustainable LPV-200 capability
  - Support Single frequency WAAS users through end of Phase IV (2028)
  - Implement WAAS Changes Needed for Dual Frequency (L1/L5) GPS Operations

WAAS Avionics Status

- **Approximately 40% Of Est. 140,000 GA Aircraft Are Equipped With Garmin Receivers**
  - Total WAAS Equipped Users ~20,000
- **Rockwell-Collins: FAA Flight Inspection Challenger Aircraft Approval – August 2007**
- **Canadian Marconi: Contract To Integrate WAAS Sensor Into FAA Global 5000 Aircraft To Complete In 2008**
- **Universal Avionics: Developing WAAS Enabled Capability In Dual Thread UNS-1 Flight Management System**
  - Approval Completed in October in 2007
  - Retro-Fit of FAA Citations Expected in 2008

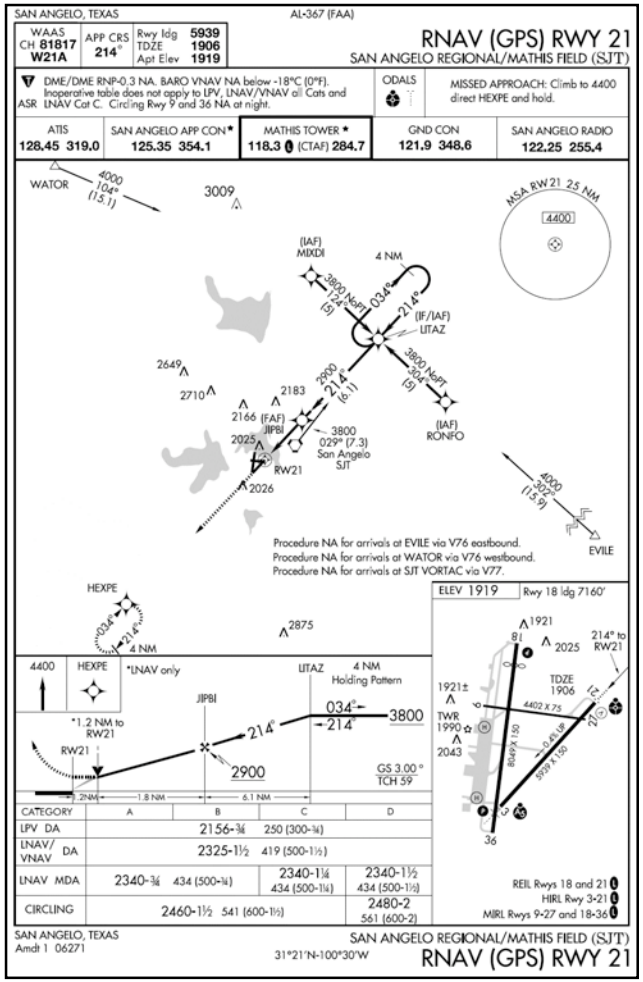
Instrument Approach Services



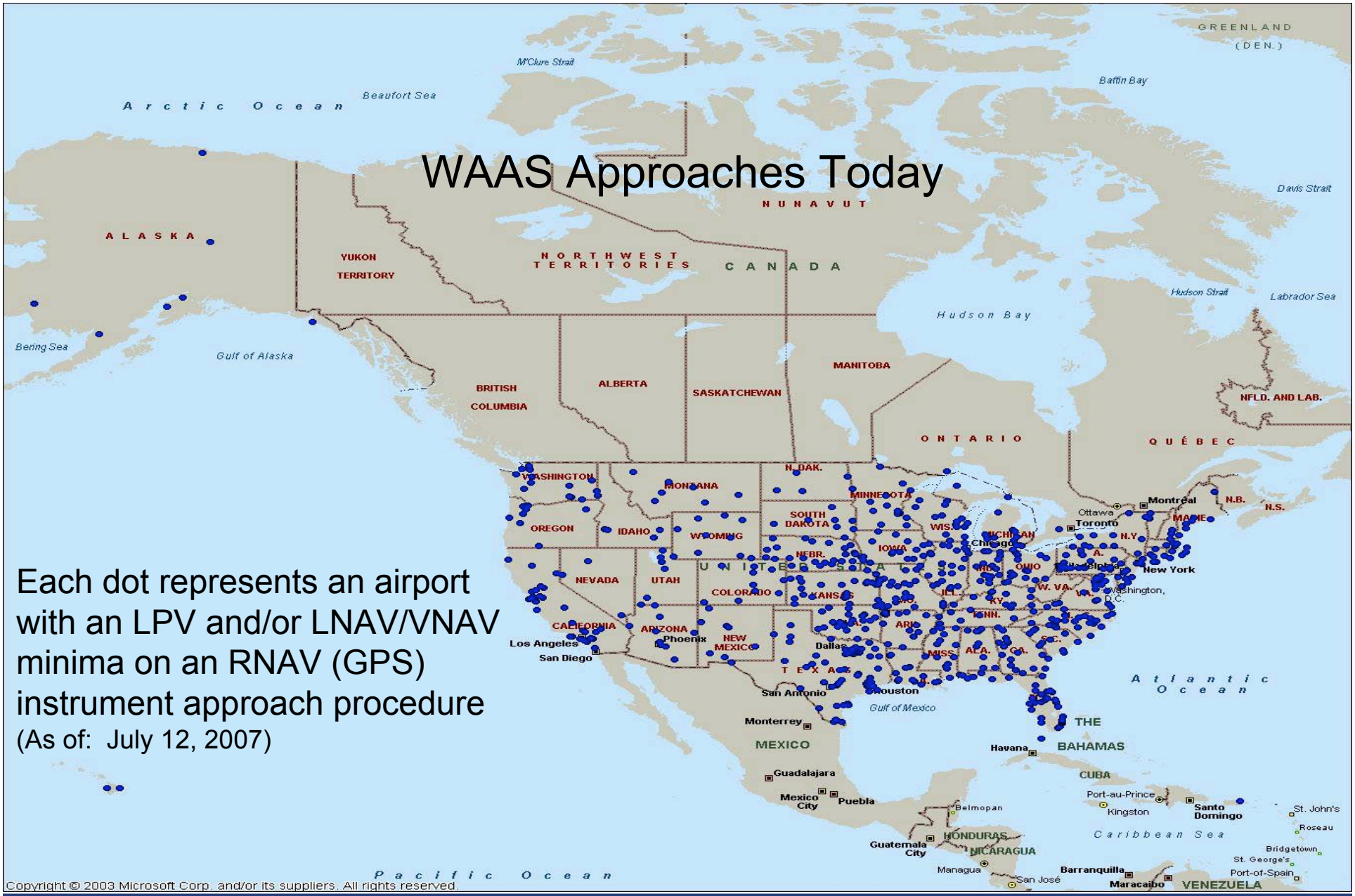
GPS/WAAS Approach Procedures

LPVs	**925**
LNAV/VNAVs	**1121**
LNAVs	**4225**

LP procedure criteria under development for use at runways where obstacles prevent a vertically guided approach

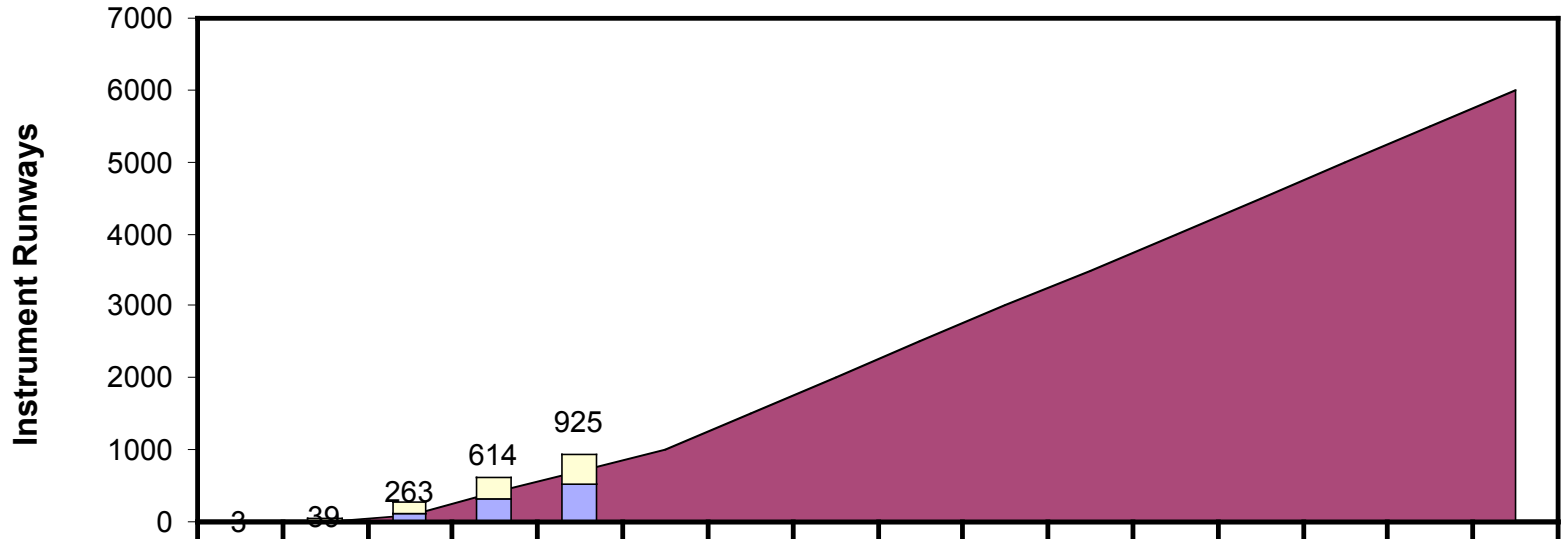


WAAS Approaches Today



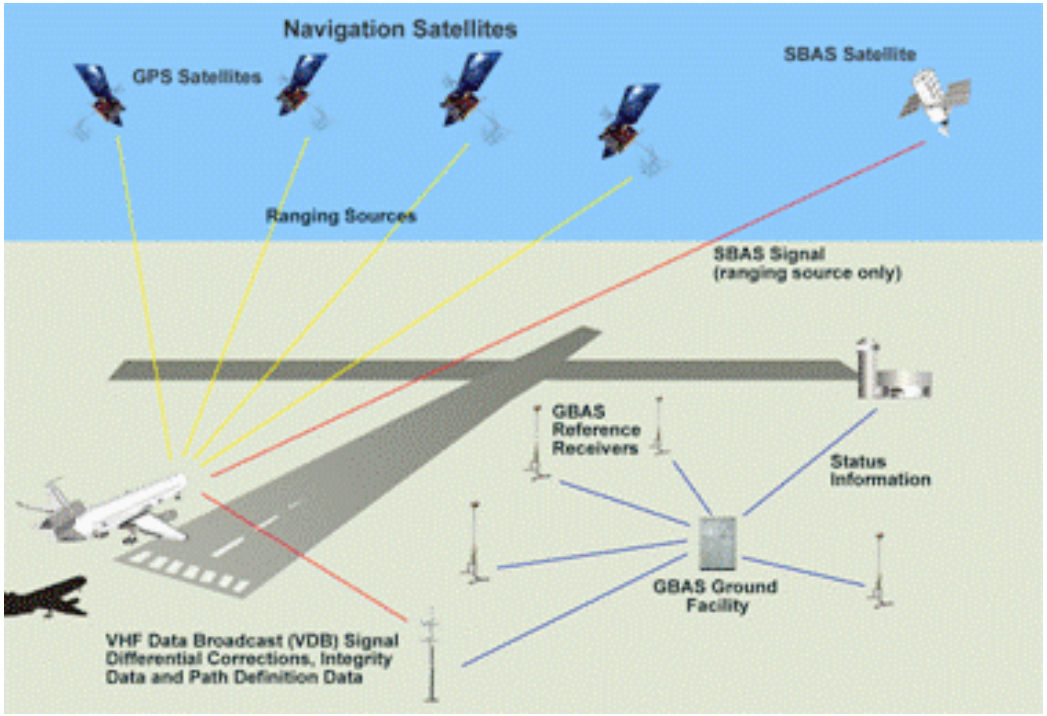
Each dot represents an airport with an LPV and/or LNAV/VNAV minima on an RNAV (GPS) instrument approach procedure
(As of: July 12, 2007)

Procedure Production Goals



	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
FLIGHT PLAN CUM GOAL	0	0	100	400	700	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
NON-ILS RWY ENDS	1	10	106	328	516											
ILS RWY ENDS	2	29	157	286	409											
Total	3	39	263	614	925											

Local Area Augmentation System (LAAS)



- **Precision Approach For Category I, II & III**
- **Multiple Runway Coverage At An Airport**
- **Terminal Area Procedures for Arrival and Departure**

LAAS Status

- **Integrity Analysis and Prototype Development**
  - FAA GBAS prototype work under Honeywell Contract
  - Hazardous Misleading Information (HMI) Analysis underway to validate GBAS architecture/design
- **GBAS CAT I Approval Process**
  - System Design Approval for Honeywell architecture (SLS 4000) Planned to Complete by 2008
- **GBAS Avionics**
  - GBAS/LAAS Standards (MASPS / MOPS / TSO / SARPS) completed
  - Boeing 737-800 series GBAS equipped
  - Airbus A320, A380 certification planned for 2007
- **CAT-III Research & Development Activities**
  - Continuing Work to Develop Requirements Compatible with Aircraft Operations and Approval Process
- **International GBAS Cooperation**
  - International GBAS Working Group
  - FAA Memorandum of Cooperation established with Australia, Brazil, Spain, Germany

GNSS Evolutionary Architecture Study (GEAS)

Presented to: Stanford PNT Symposium

By: Leo Eldredge, FAA GNSS Group

Date: October 30, 2007

GEAS Purpose

- **Chartered By The FAA To Investigate Long Range Planning Considerations For WAAS**
  - Recognized That Meeting Aviation Integrity Requirements Is One Of The Most Challenging Aspects
  - Facilitate Common Understanding Through Technical Interchange Between DoD and FAA
- **Strategic Planning For:**
  - GPS Modernization
  - User Equipment Standards Development
  - WAAS Dual Frequency Upgrade

GEAS Objectives

To Evaluate GNSS-Based Architectures To Provide Robust LPV-200 Service Worldwide Circa 2025-30

Corollary Objectives:

- Assess Capability Of Modernized GPS To Simplify Fault Detection And Provide An Alternate Broadcast Channel
- Technical Feasibility Of World Wide Autoland
- Interaction With National PNT Architecture Effort
  - Coordinated By The DoD National Space Security Office (NSSO) And DoT Research & Innovative Technology Administration (RITA)

GEAS Panel

Deane Bunce (Co-Chair)	FAA ATO-W
Leo Eldredge	FAA ATO-W
Deborah Lawrence	FAA ATO-W
Calvin Miles	FAA ATO-W
Kevin Bridges	FAA AVS
Hamza Abduselam	FAA AVS
Tom McHugh	FAA ATO-P
Bill Wanner	FAA ATO-P
David Schoonenberg	NSSO
Mike David	NSSO
Karen Van Dyke	RITA/Volpe
Navin Mathur	GPS TAC
Geoff Harris	G-Wing/Aerospace
Karl Shallberg	GREI
Boris Pervan	IIT
John Dobyne	G-WIng/ARINC
Karl Kovach	G-Wing/Aerospace
Willie Bertiger	JPL
Young Lee	MITRE
JP Fernow	MITRE
Frank Van Grass	Ohio University
Juan Blanch	Stanford University
Per Enge (Co-Chair)	Stanford University
Todd Walter	Stanford University
Pat Reddan	Zeta Associates

GEAS Architecture Options

- **A Large Challenge In Providing Global Coverage is Meeting The 6 Second Time-to-alarm (TTA)**
- **The GEAS Is Currently Investigating Three Architectures That Address This Problem**
  - GPS Integrity Channel (GIC)
  - Relative RAIM (RRAIM)
  - Absolute RAIM (ARAIM)

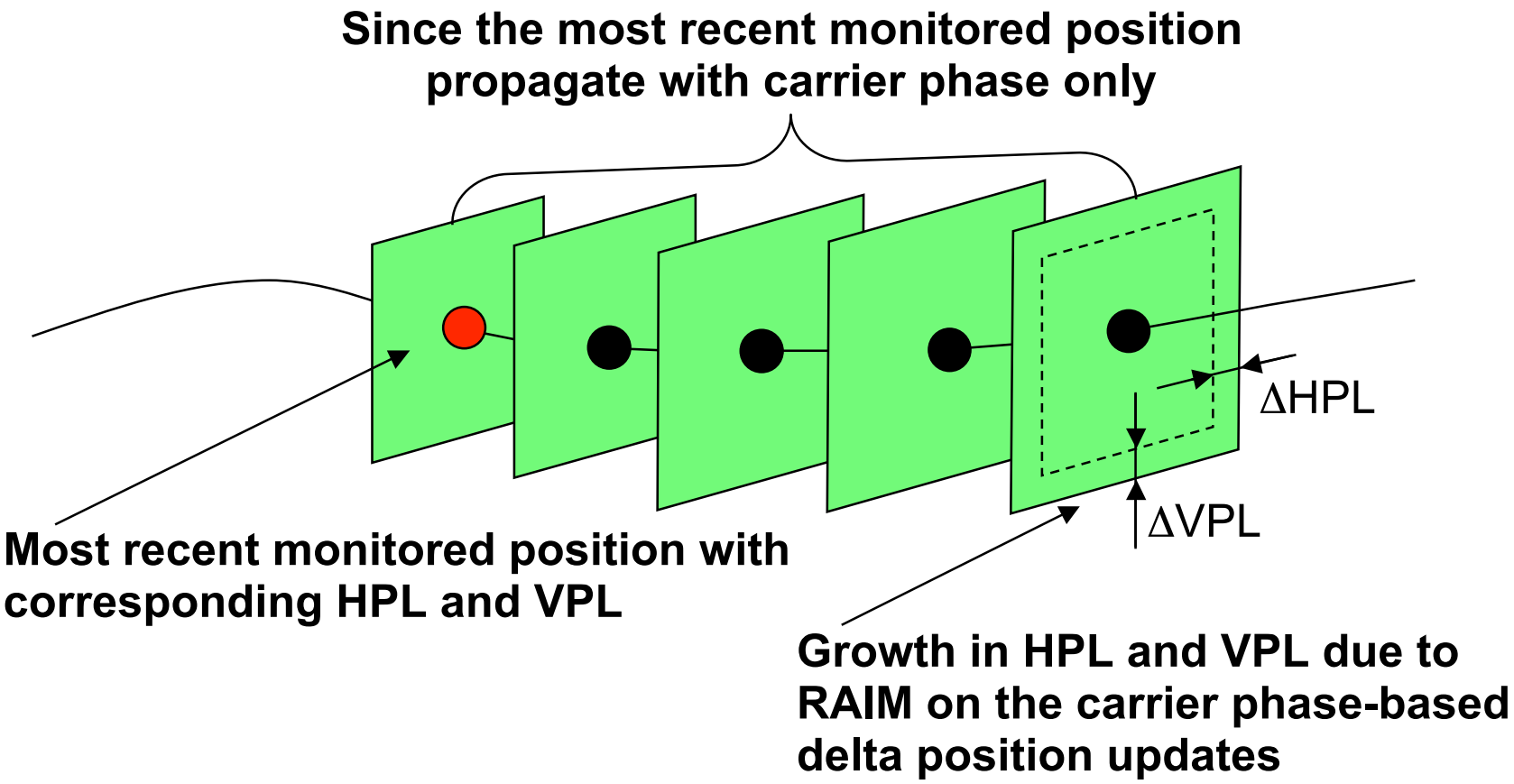
GNSS Integrity Channel (GIC)

- **Avionics**
  - No RAIM/FDE Required – WAAS Scenario
  - Dual Frequency (L1/L5) – Ionosphere Delay Estimation
- **Worldwide Monitor Network**
  - Monitors External to the User Detect All SV Faults
  - Requires Monitoring Network Capable of Continuous Monitoring of All GPS Satellites From At Least Two Locations
  - Latency to Support Time to Alarm of 6 Seconds or Less
- **Broadcast at High Data Rate**
  - Data Rate Comparable to Current WAAS Broadcast of 250 bps

Relative RAIM: *Range Rate Residuals*

- **Avionics**
  - RRAIM Algorithms Check Residuals Between Carrier Phase Measurements and Estimated Change in Position
  - Integrity/Correction Messages Provide Starting Point
  - Dual Frequency (L1/L5) – Ionosphere Delay Estimation
- **Worldwide Monitor Network**
  - Provide Slow Integrity/Correction Messages
  - Time to alarm of 60 to 600 seconds
- **Broadcast at Slow Data Rate**
  - May Be Suitable For GPS Messages or eLoran

Relative RAIM Concept

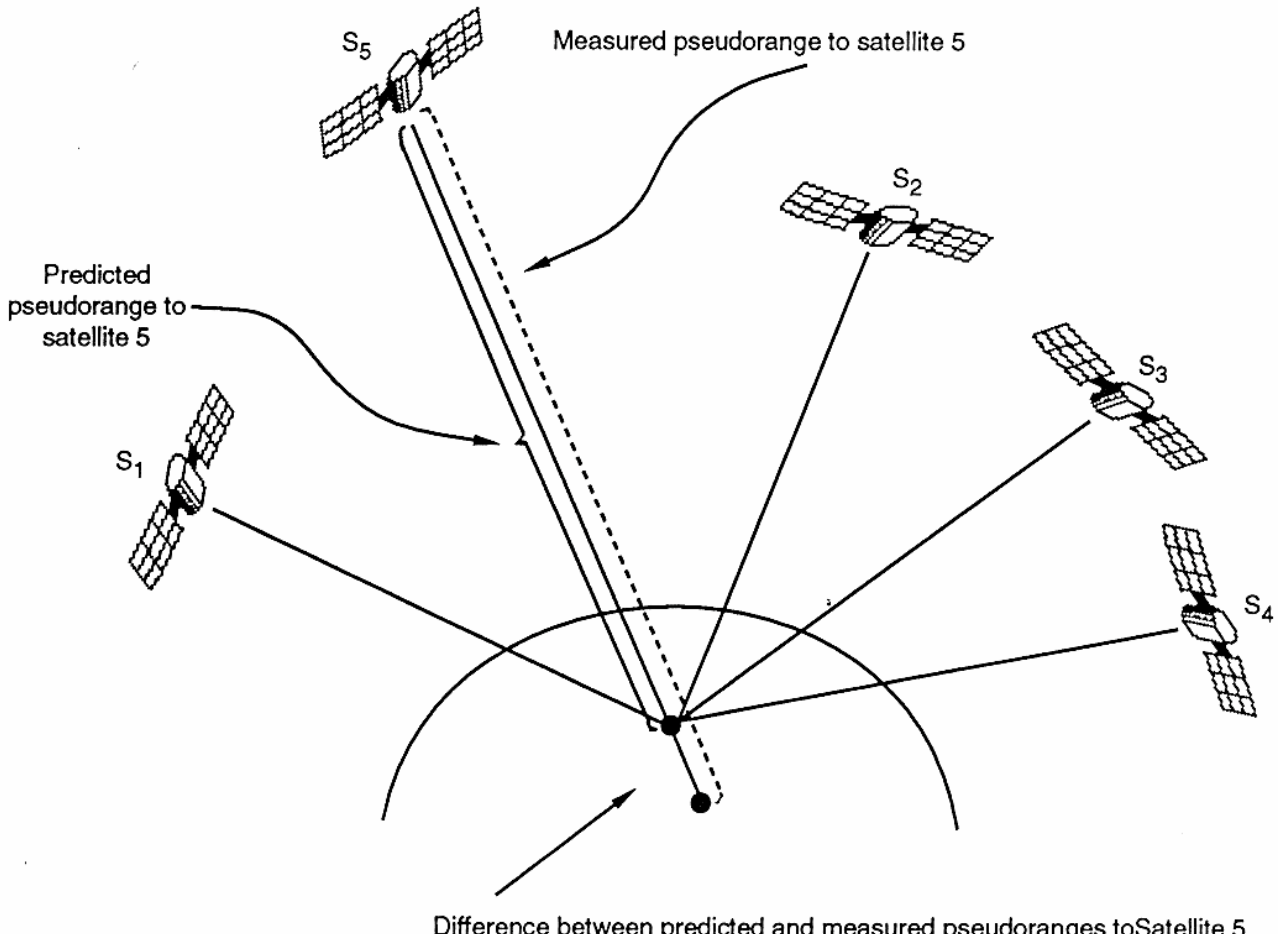


From Prof. van Graas, Ohio University

Absolute RAIM: *Range Residuals*

- **Avionics**
  - Relies on Receiver Autonomous Integrity Monitoring as the Primary Integrity Solution
  - Dual Frequency (L1/L5) – Ionosphere Delay Estimation
- **Worldwide Monitor Network**
  - Update error variance and mean for each SV
  - Time to alarm of 10 minutes or more
- **Broadcast at Low Data Rate**
  - Reliability Estimates (Prior Probability) for Each SV
    - Used by the Avionics ARAIM Algorithms
  - Potential to Broadcast Via GPS Message
  - VHF Networks or eLoran

Absolute RAIM Concept



GIC Preliminary Results

	Satellite Constellation					
URA / UDRE from monitor network (m)	**24 minus worst case 1 SV**	**24**	**27 minus worst case 1 SV**	**27**	**30 minus worst case 1 SV**	**30**
1.0/6.6	17.25%	52.90%	38.00%	83.12%	76.55%	97.45%
0.7/4.6	62.17%	92.09%	71.65%	**99.30%**	95.63%	**99.83%**
0.35/2.3	87.84%	**100%**	**100%**	**100%**	**100%**	**100%**
	LPV-200 Coverage Estimates at 99.5% Availability for +/- 70 Degrees Latitude					

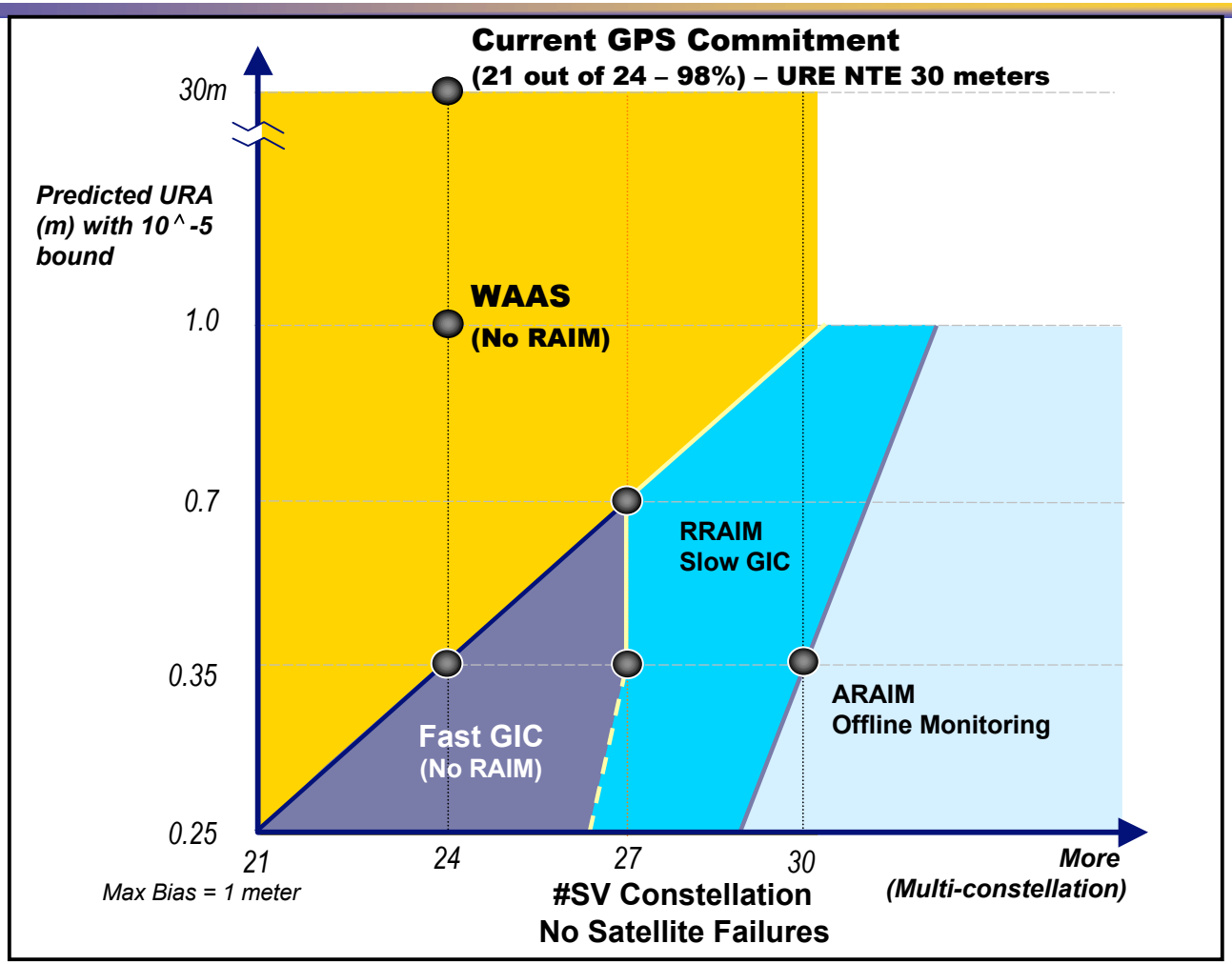
RRAIM Preliminary Results

	Satellite constellation					
URA & UDRE from monitor network (m)	**24 minus worst case 1 SV**	**24**	**27 minus worst case 1 SV**	**27**	**30 minus worst case 1 SV**	**30**
1.0 & 6.6	27.8%	70.41%	46.15%	86.55%	82.53%	97.88%
0.7 & 4.6	75.7%	98.55%	86.32%	**100%**	98.49%	**100%**
0.35 & 2.3	76.9%	98.55%	87.31%	**100%**	98.49%	**100%**
	LPV-200 Coverage Estimates at 99.5% Availability for +/- 70 Degrees Latitude					

ARAIM Preliminary Results

	Satellite constellation					
URA from monitor network (m)	**24 minus worst case 1 SV**	**24**	**27 minus worst case 1 SV**	**27**	**30 minus worst case 1 SV**	**30**
1.0	2.1%	20.2%	12.5%	73.2%	70.5%	98.3%
0.7	3.4%	24.8%	19.3%	84.4%	79.2%	99.2%
0.35	5.6%	36.9%	25.6%	91.8%	87.0%	**99.8%**
	LPV-200 Coverage Estimates at 99.5% Availability for +/- 70 Degrees Latitude					

GEAS Initial Results



Summary

- **GEAS Panel Investigating Three Potential Architectures**
  - GIC
  - RRAIM
  - ARAIM
- **Results Indicate Satellite Constellation Size and Quality Are Most Significant Contributors**
  - Reasonable Availability Can Be Expected From All Three Options With A 30 SV Constellation And URA Of Less Than 0.7 Meters of Less
- **Initial Findings Will Be Documented In A Report By December 2007**

Questions