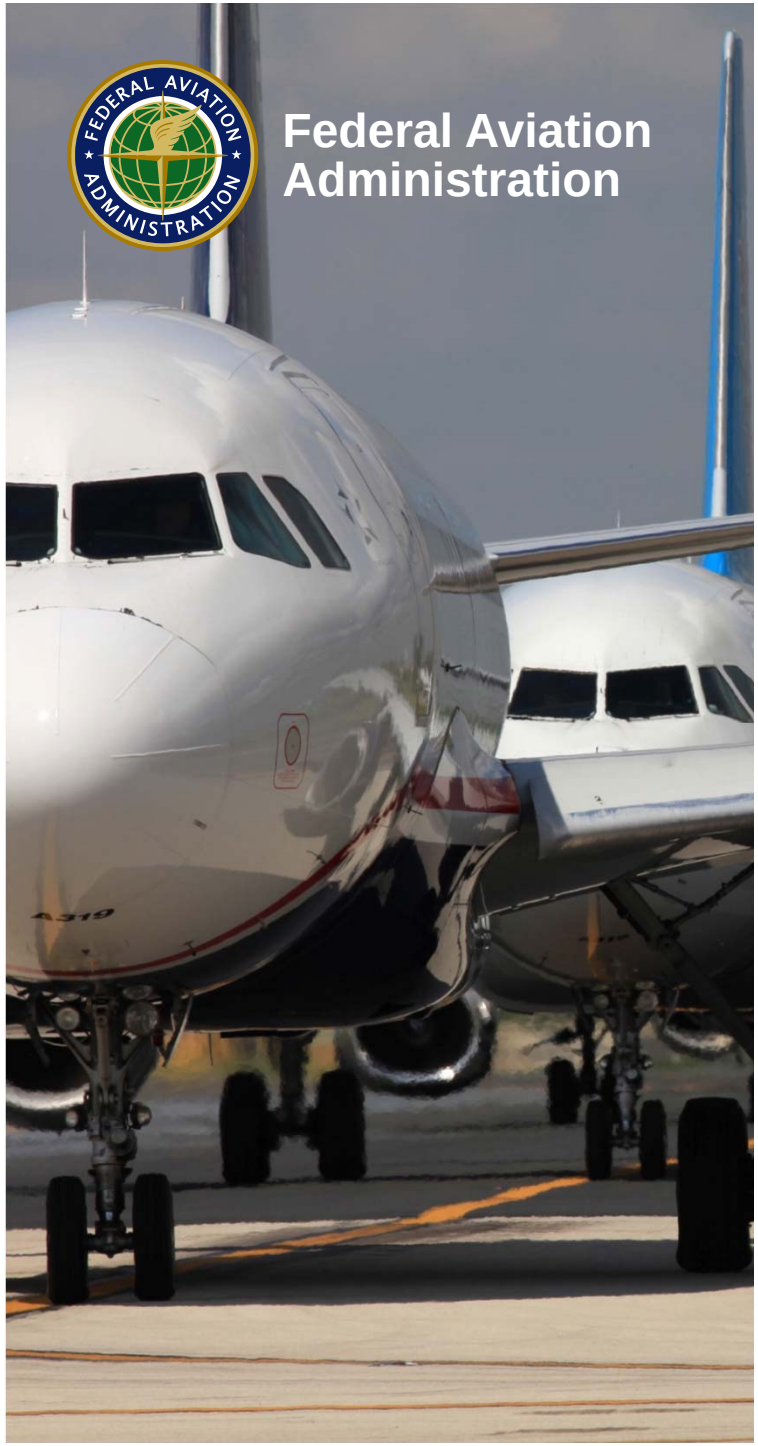
Wide Area Augmentation System (WAAS) Update



By: Carlos Rodriguez (AJM -321)

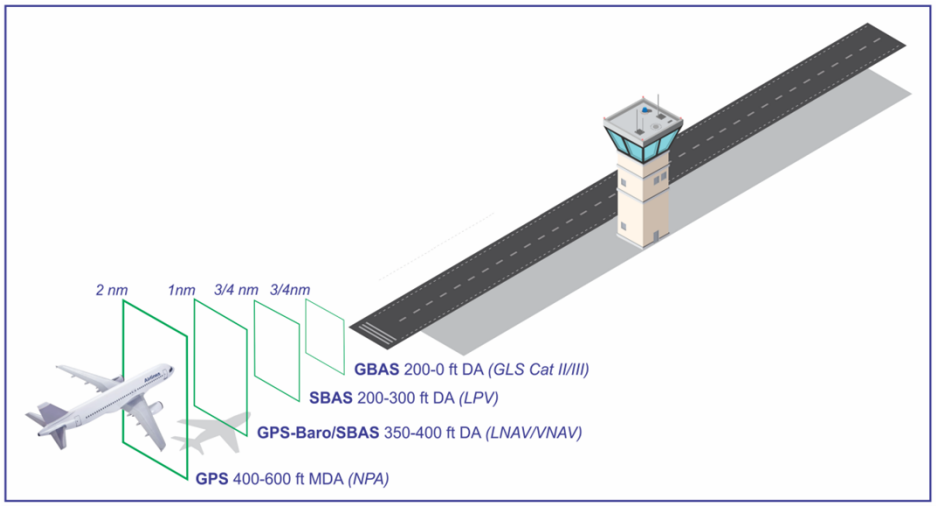
FAA Satellite Navigation Program Manager

Date: August 16, 2016

Agenda

- Overview
- Ground and Space Segments
- Performance and Future Upgrades
- Operational Implementation
- International Coordination
- GPS

Satellite Based Navigation



GPS

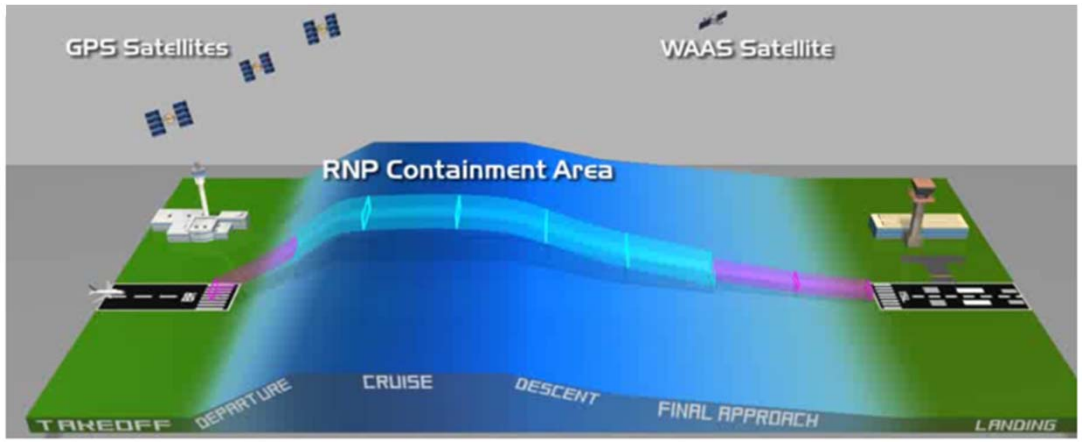
- **Approved for Aviation use in 1993**
- **Established as global leader and gold standard for satellite navigation**
- **Extensive modernization efforts underway that will make available additional civil signals including L5**
  - International leader in a growing community of future Global Navigation Satellite System (GNSS)
  - Efforts directly support next phase of development for WAAS program

WAAS

- **Commissioned for service in 2003**
- **Sets standard for Global Satellite Based Augmentation System (SBAS) development (Japan, Europe, India and now Russia)**
- **Augments the GPS L1 signal providing improved accuracy and integrity**
- **WAAS modernization efforts tied directly to GPS modernization**
  - US WAAS plans to modernize using new GPS L5 signal

Overview

- **WAAS provides precise navigation and landing guidance covering the entire National Airspace System (NAS)**
- **Combination of ground-based and space-based assets**

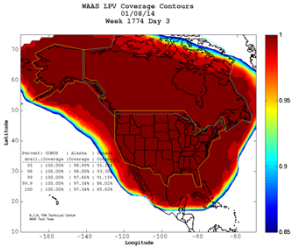


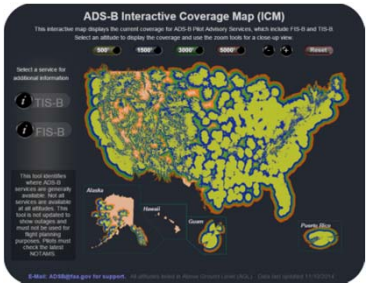
- **Augments the Global Positioning System (GPS) Standard Positioning Service (SPS)**
- **Enables Operators to fly Required Navigation Performance (RNP) 0.1**
- **Provides both safety and capacity improvements in the NAS and has been operational since 2003**

Current WAAS Components

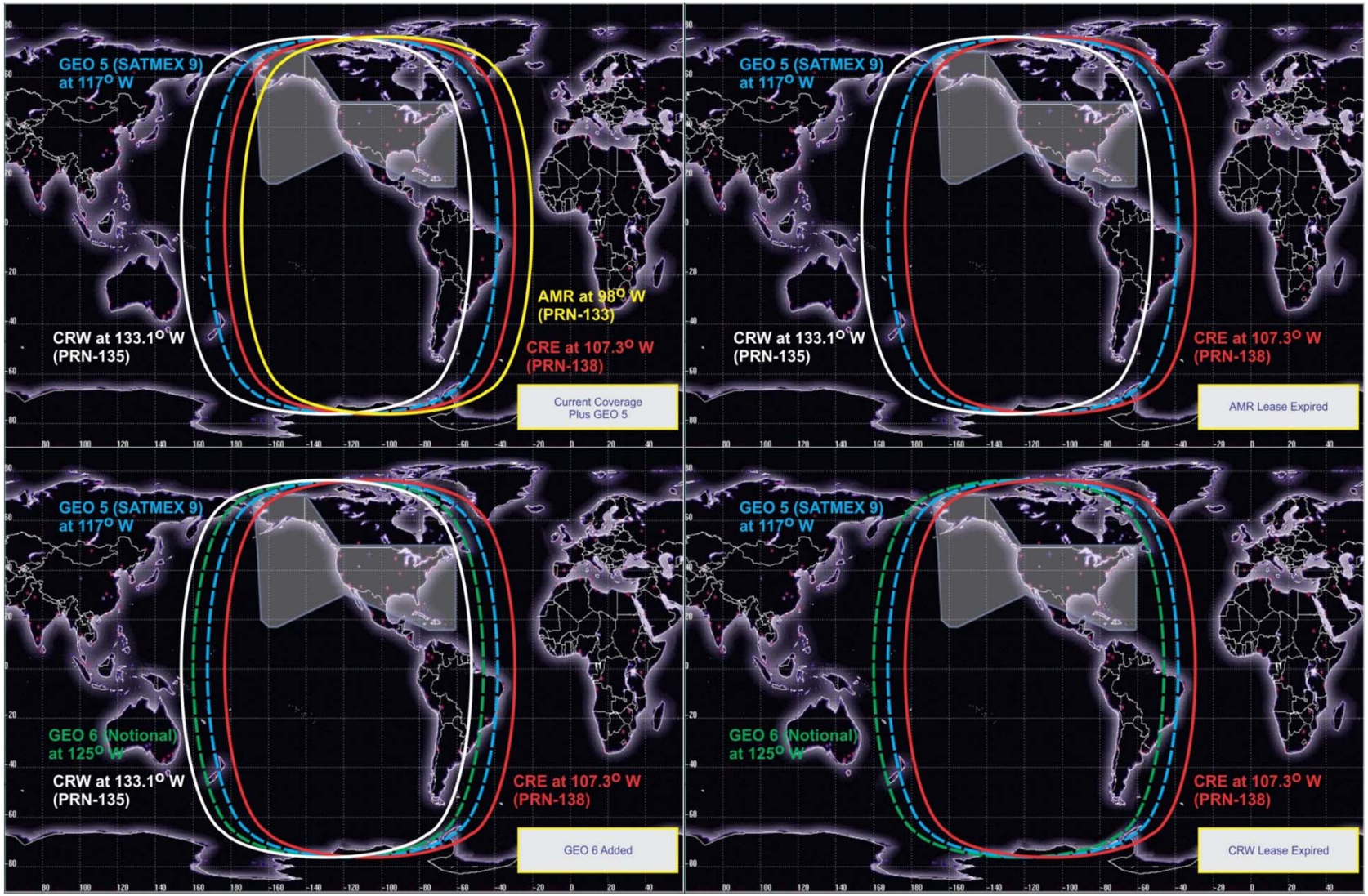
Benefits of WAAS

- **Augments GPS**
  - Real-time GPS Corrections and Integrity Information
    - Greater Position Accuracy
    - High Confidence in Computed Position
- **Enhances navigation in all phases of flight**
  - Enroute, Arrival, and Departure:
    - Provides 100% Availability Of GNSS For Even The Most Critical RNP or RNAV Operations
    - Provides Coverage At All Altitudes Up to 100,000 Feet
    - Provides Navigation Services To Areas Not Served by Any Navigation Aid before WAAS Existed
  - Approach:
    - Enhances Safety By Providing Vertical Guidance To Every Runway End In the Coverage Area
    - No Ground Hardware Required At Airport
    - Allows IFR Operations To All Qualified Airports
    - Supports Closely Spaced Parallel Operations (CSPO)
- **Enabling technology for NextGen programs**
  - Automatic Dependent Surveillance Broadcast (ADS-B)
  - Performance Based Navigation (PBN)
    - Ex. Area Navigation (RNAV), Required Navigation Performance (RNP), and Point in Space (PinS) procedures
- **Future reductions of ground-based navigation aids**
  - ILS rationalization decision closely tied to the implementation and sustainment of WAAS
  - 2011 Federal Register Notice (FRN) identified all future Category I approaches to be supported by LPV





WAAS GEO Activities

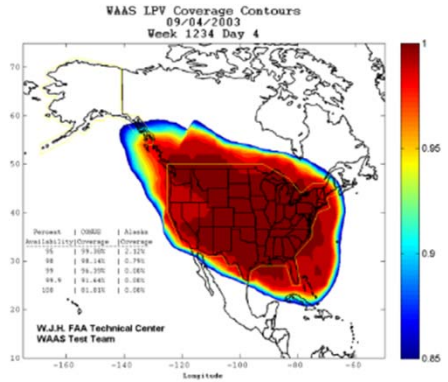


GEO Sustainment (GEOs 5/6/7)

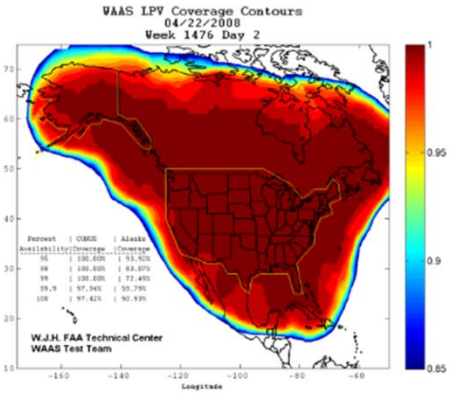
- **GEO 5/6 Satellite Acquisition**
  - GEO 5
    - Successful launch June 2016
      - Initial launch date affected by Space X Falcon 9 launch failure June 2015
    - Signal in Space Testing in to begin early CY2017
    - Expected operational in 2018
  - GEO 6
    - Critical Design Review (CDR) completed February 2016
    - Expected Operational in 2019
- **GEO 7 Satellite acquisition**
  - Targeting 2019 for a contract award

GEO 5 (Eutelsat 117WB)

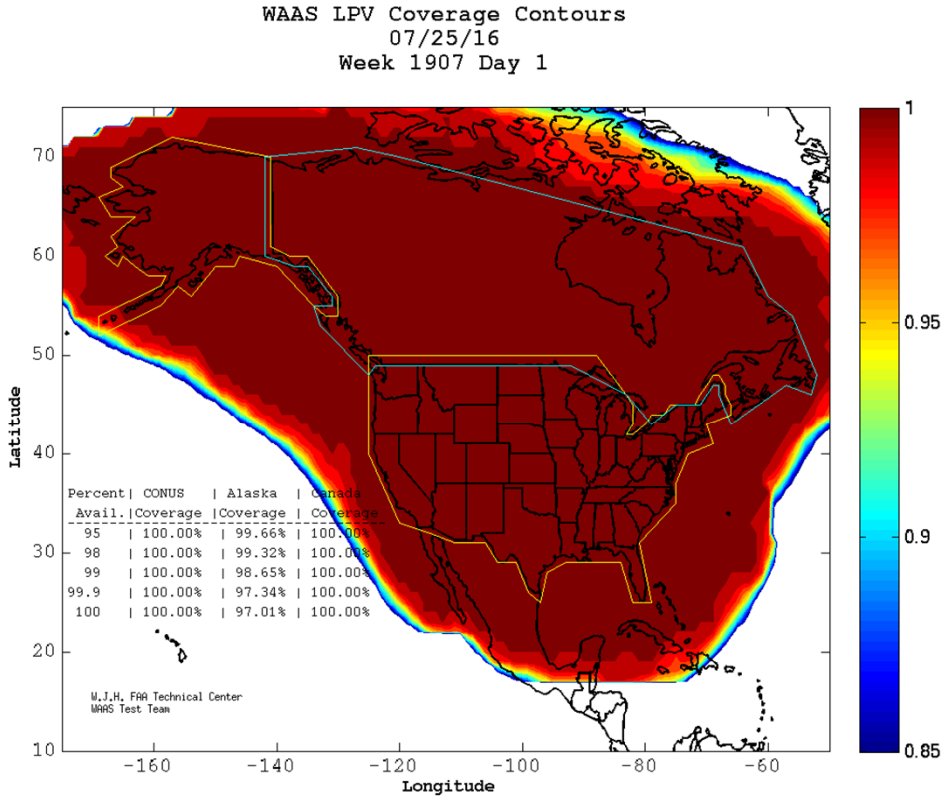
LPV/LPV-200 Service Coverage



2003 IOC – LPV Coverage in lower 48 states only



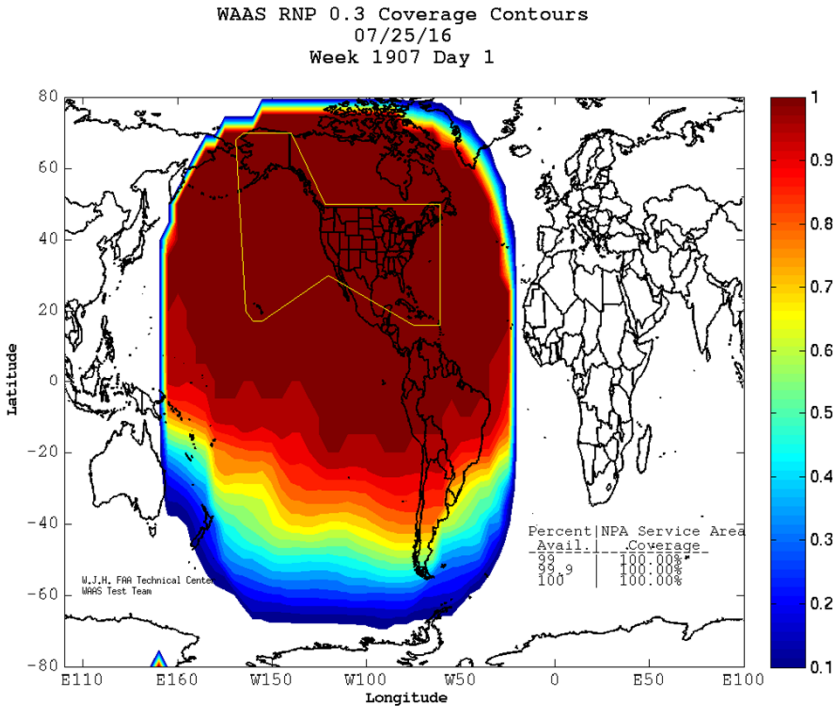
2008 Coverage - LPV 200 Coverage in CONUS (2 Satellites)

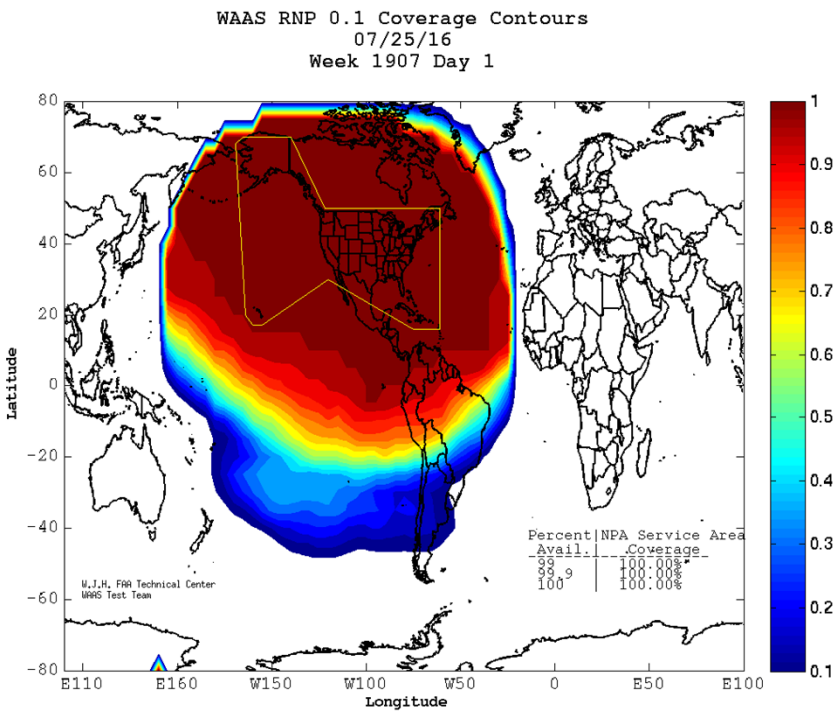


2012 Coverage - Full LPV 200 Coverage in CONUS (3 Satellites)

LPV (Localizer Performance with Vertical guidance) - Vertically-guided landing approaches as low as 200 feet

WAAS RNP 0.3 and RNP 0.1 Coverage

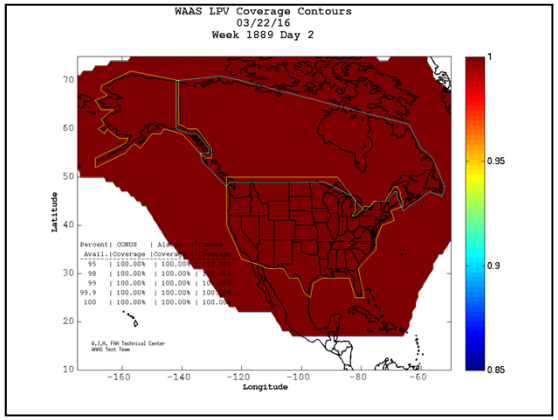




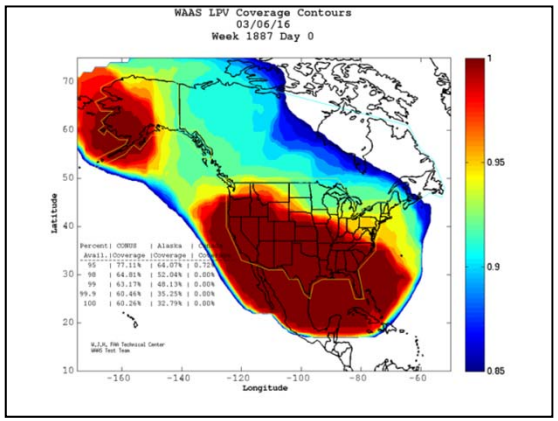
Actions to ensure high availability of WAAS

- **Current WAAS provides high availability service to aviation users in North America**
- **There are times when WAAS vertical service availability is reduced in North America, typically during ionosphereic disturbances**
  - Disturbances affect WAAS by reducing availability while preserving integrity
- **To continue high availability of WAAS vertical service during ionospheric disturbances, FAA is:**
  - Preparing WAAS to take advantage of dual frequency service that will be provided by GPS
- **To prepare for dual frequency service the FAA is:**
  - Upgrading WAAS reference station GPS/WAAS receivers
  - Upgrading the internal WAAS message data structure to include dual frequency data
  - Addressing obsolescence of WAAS assets by replacing aging hardware
  - Planning for future enhancements to WAAS algorithms through prototyping

Current WAAS LPV Coverage



WAAS LPV Coverage March 6, 2016 Iono event



WAAS Development Phases

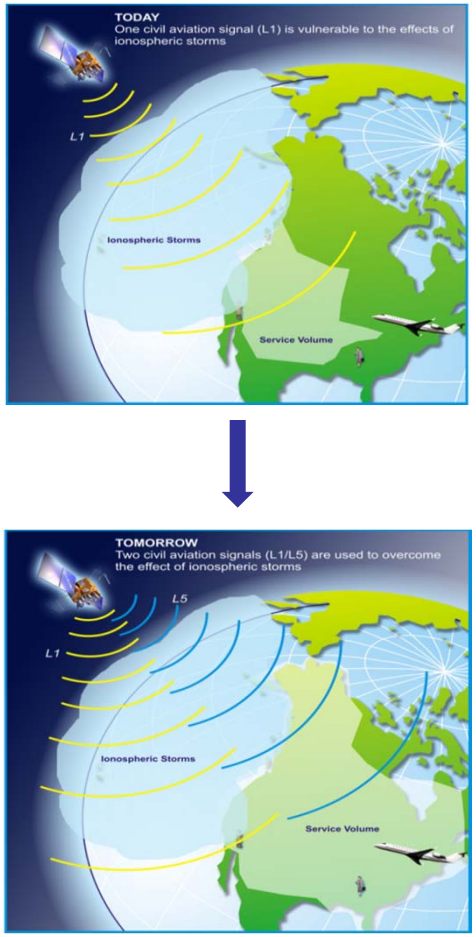
- **Phase I: IOC (July 2003) Completed**
  - Provided LNAV/VNAV/Limited LPV Capability
- **Phase II: Full LPV (FLP) (2003 – 2008) Completed**
  - Improved LPV availability in CONUS and Alaska
  - Expanded WAAS coverage to Mexico and Canada
  - Provided improved approach minimums (LPV-200)
- **Phase III: Full LPV-200 Performance (2009 – 2014) Completed**
  - Improve performance during moderate ionospheric activity
  - Preparation for GPS L5 transition
  - Expanded LPV-200 availability
- **Phase IV: Dual Frequency (L1,L5) Operations (2014 – 2044)**
  - Sustain WAAS GEOs
  - Technology refresh to address equipment obsolescence
  - Infrastructure modifications to support future L1/L5 user capability
  - Transition from use of L2 P(Y) to L5 in WAAS and provide dual-frequency service
    - Planning to transition within 2 years of GPS L5-signal Full Operational Capability (FOC)

Why Dual Frequency Operations?

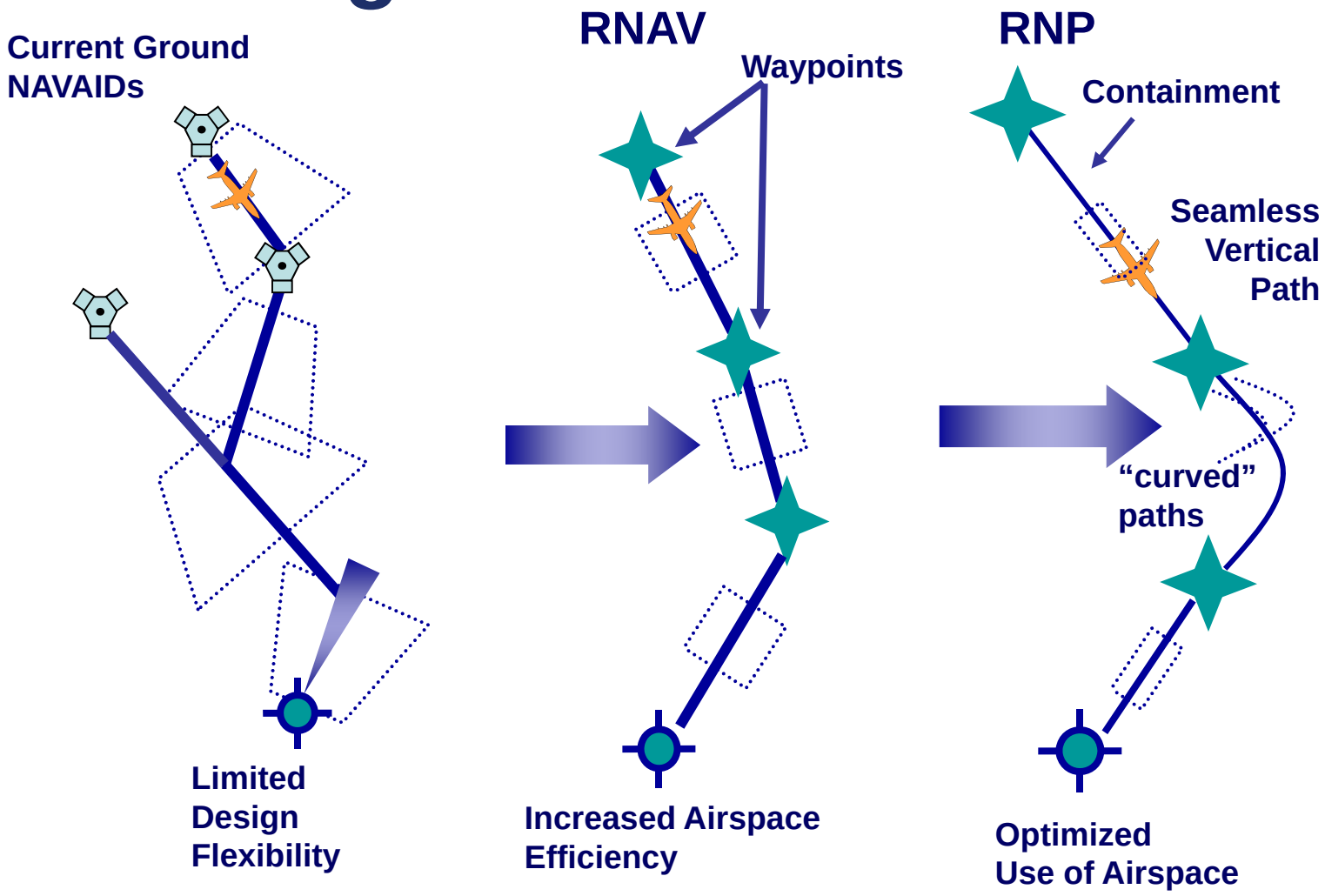
- **DoD planned 'Sunset' of L2 P(Y) semi-codeless will require transition to use of GPS L5 signal**
  - Current expected transition date: 2026
  - Requires GPS L5 to reach full operational capability
- **Current Single Frequency WAAS impacted by ionospheric disturbances**
  - Future Dual-frequency avionics will support high availability of LPV operations even under extreme ionospheric conditions

WAAS Phase IV - Dual Frequency Operations (2014-2044)

- **Final Investment Decision for Phase IV Segment 1 (2014-2019) Dual Frequency Operations (DFO) approved**
  - Segment 1 (2014-2019) - Develop infrastructure improvements to support L5 & Tech Refresh
  - Segment 2 (2019+) - Implementation of L1/L5 (dual frequency) user capability
- **GEO sustainment will occur during both segments**
- **Future considerations**
  - Dual-Frequency Multi-constellation Capability
    - International Focus is on taking advantage of other GPS like constellations
  - User Equipment Standards for Dual-Frequency Operations
    - FAA working with Interoperability Working Group (IWG) on definition document that provides the basis for interface design and MOPS development for L1/L5 and multi-constellation
  - Advanced RAIM (ARAIM)
    - Avionics-centric approach to dual-frequency multi-constellation



Moving Towards Performance-based Navigation



Key PBN Commitments by Timeframe

- **Approach/Terminal**
  - Continue to deploy RNAV (GPS) approaches with vertical guidance
  - Update criteria and policies for increased access
  - Replace conventional procedures with PBN
- **Enroute**
  - Replace Jet routes with PBN-based structure and point-to-point navigation
  - DME/DME redundancy in Class A
- **Oceanic**
  - Expand User Preferred Routes
  - Explore reduced RNP-based separation standards

Near-Term (2016-2020) *Increase Utilization*	Mid-Term (2021-2025) *Streamlining Service Delivery*	Far-Term (2026-2030) *A Streamlined NAS*
Approach/Terminal ❑ Implement RNAV (GPS) with LPV and LNAV/VNAV approaches at qualifying runways meeting current TERPS criteria ❑ Criteria to increase the number runways qualifying for vertically-guided approaches ❑ Expand use of Established on RNP (EoR) at first site ❑ Expand use of Equivalent Lateral Spacing Operations (ELSO) at first two sites ❑ Criteria for low visibility access with LPV ❑ Use of PBN approaches with visual separation standards ❑ Expand development of PBN special helicopter approaches to hospitals ❑ Policy for Enhanced Flight Vision Systems (EFVS) operation to touchdown ❑ Policy for Synthetic Vision Guidance System (SVGS) to qualifying approaches ❑ Demonstrate A-RNP at first site ❑ Initiate expanded DME/DME coverage for Navigation Service Group 1 and 2 airports ❑ Continue replacing conventional approaches, SIDs, and STARs with PBN procedures **Enroute** ❑ Class A airspace is covered by DME/DME (IRU not required) redundancy ❑ Shorten development and implementation time for new ATS routes by removing rulemaking requirement ❑ Initial transition to improved point-to-point navigation solution **Oceanic** ❑ Expand User Preferred Routes (UPR) for navigation between North America and Asia. ❑ Implement reduced separation climb/descend requirements for RNP-4 capable aircraft ❑ Transition from Minimum Navigation Performance Specification (MNPS) to PBN in the ICAO North Atlantic (NAT) Region ❑ Analyze further reduced RNP-based separation standards	**Approach/Terminal** ❑ Implement Vertically-guided RNAV (GPS) approaches at runways meeting new TERPS criteria ❑ Expand use of RNAV (GPS) approaches (with LPV and LNAV/VNAV) with RF ❑ Expand use of EoR at sites supported by cost-benefit analysis ❑ Expand use of ELSO at sites supported by cost-benefit analysis ❑ Leverage A-RNP at key sites ❑ DME/DME coverage expanded for Navigation Service Group 1 and 2 airports based on site-specific evaluations ❑ Continue replacing conventional approaches, SIDs, and STARs with PBN procedures **Enroute** ❑ NRS grid, Jet routes, and most Victor Airways replaced by PBN routes where structure is needed and PBN-based point-to-point elsewhere **Oceanic** ❑ Leverage reduced separation standards to further expand UPRs **NAS Operations** ❑ Key airports transitioned to time/speed-based management	**Approach/Terminal** ❑ Vertically-guided RNAV (GPS) approaches at qualifying airports with an IAP ❑ A-RNP procedures at sites supported by cost-benefit analysis ❑ Complete the transition to PBN procedures **Oceanic** ❑ Transition to dynamic UPRs where supported by operator capability **NAS Operations** ❑ NAS transitioned to time/speed-based management

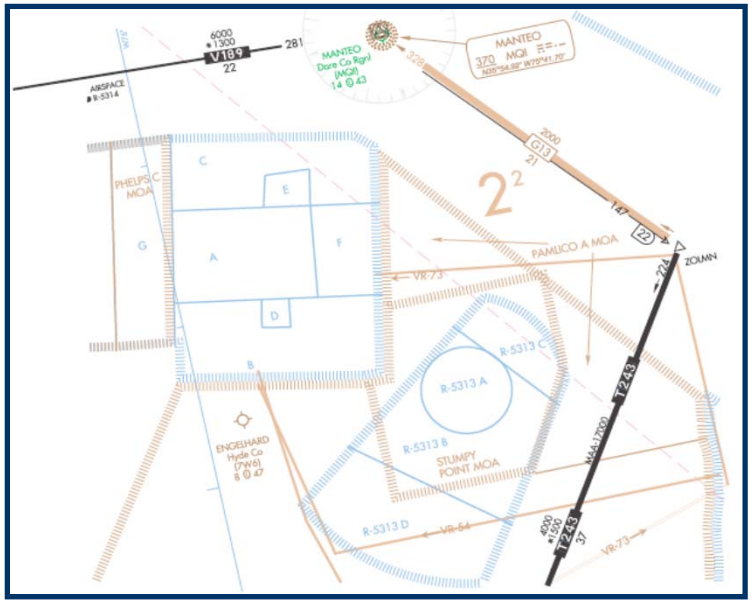
WAAS Enables Performance Based Navigation

		Performance Based Navigation (≥ 99.0% Availability)		Surveillance[1] (≥ 99.9% Availability)		
		Accuracy (95%)	Containment (10^{-7}/hr)	Separation	NACp (95%)	NIC (10^{-7})
En Route	RNAV 10	10 nm	20 nm	5 nm	FAA: 8 (92.6m)	FAA: 7 (0.2 nm)
	RNAV 5	5 nm	10 nm			
	RNP 4	4 nm	8 nm			
	RNP 2	2 nm	4 nm			
Terminal (NPA)	RNAV 1 (2)	1 (2) nm	2 (4) nm	3 nm	FAA: 8 (92.6m)	FAA: 7 (0.2 nm)
	RNP APCH / LNAV	0.3 nm	0.6 nm			
	RNP APCH / LP	16 m	40 m			
Approach (APV)	LNAV/VNAV	0.3 nm	0.6 nm	2.5 nm DPA	TBD	FAA: 7 (0.2 nm)
	RNP AR	0.1 nm	0.1 nm [2]			
	LPV	16m/4m	40m/50m [2]			
	LPV-200	16m/4m	40m/35m [2]			
Precision Approach	**CAT-I**	**16m/4m**	**40m/10-35m [2]**	**2.0 nm IPA**	**TBD**	**FAA: 7 (0.2 nm)**
	Autoland[3]	**16m/4m**	**40m/10-12m [2]**			

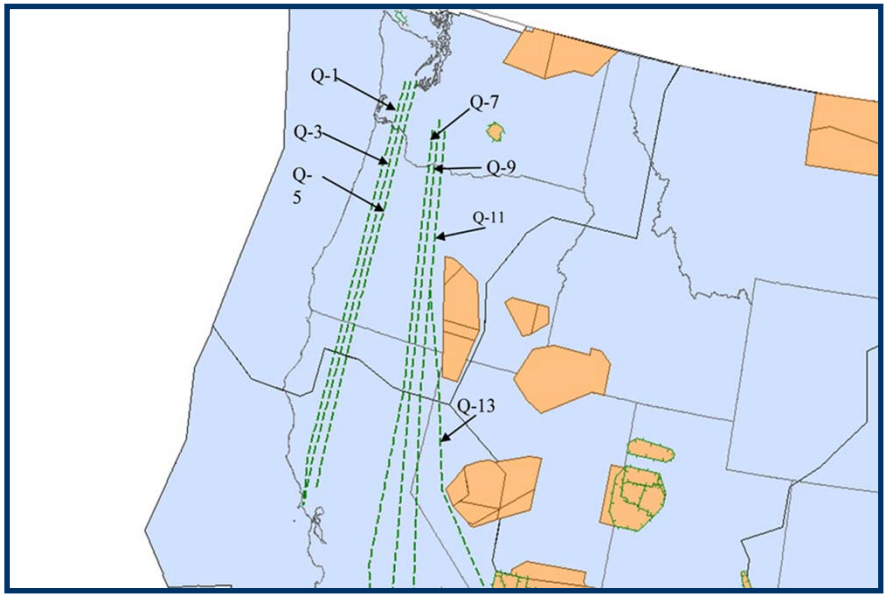
1 – The surveillance requirements reflect the source of the requirements. The current table only includes the FAA requirements.
2 – Containment is 1-2x10^{-7} per approach
3 – The feasibility of autoland with SBAS is under investigation. Requirements and criteria have not been validated. An additional safety assessment will be required to show suitability of VALs above 10.0 m. Weather minima may vary depending on system performance

WAAS and the En Route Environment

- **WAAS supports the new airway routes**
- **“T” routes for airways below 18,000 feet**
- **“Q” routes for airways above Flight Level**



T-Route



Q-Routes

GPS/WAAS & ADS-B

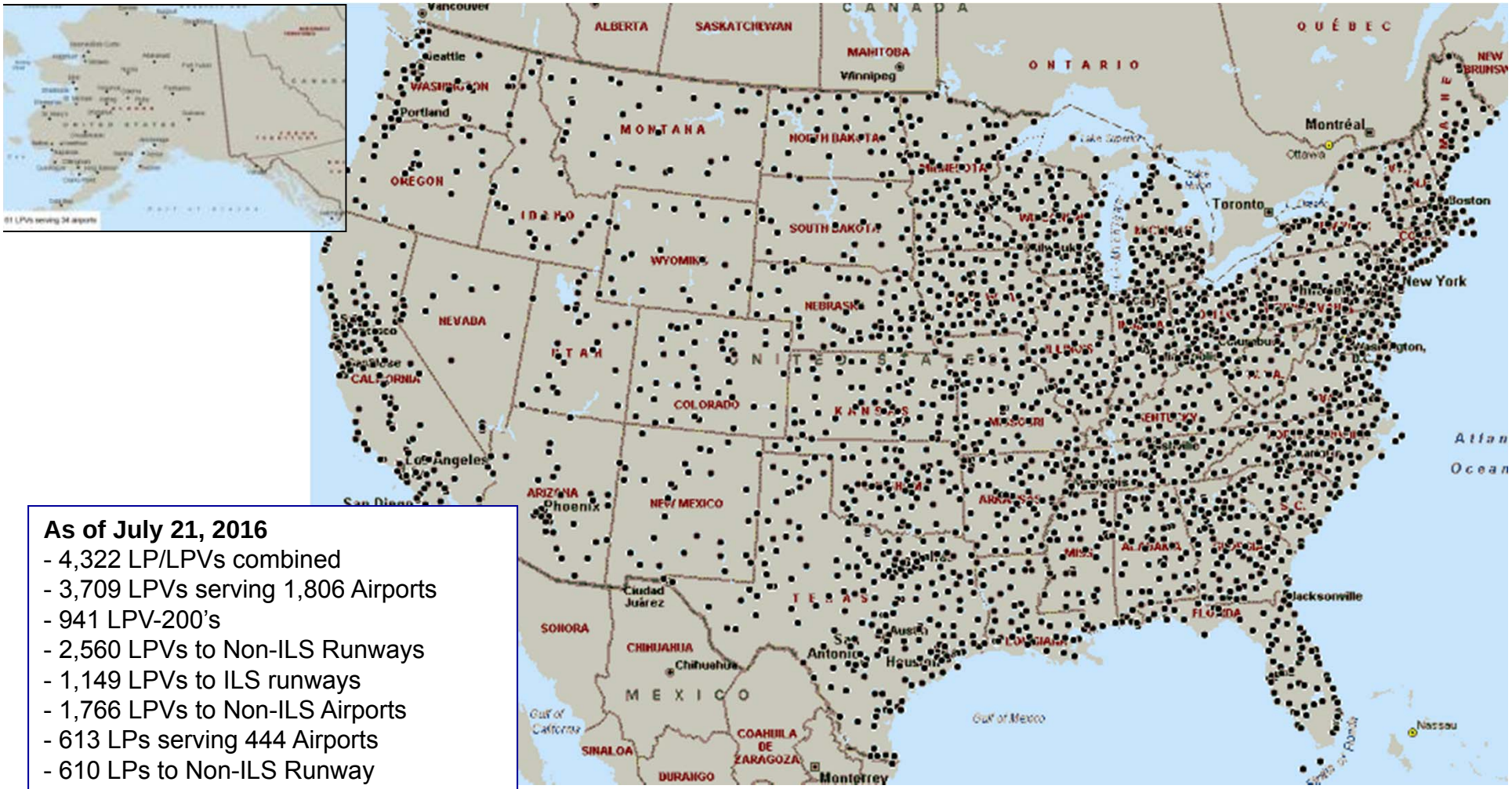
Relationship between GPS/WAAS & ADS-B:

- GPS is the only known practical means of achieving ADS-B navigation accuracy from a cost effectiveness standpoint
- ADS-B navigation accuracy requirements essentially necessitates application of GPS or WAAS to meet the ADS-B criteria
- WAAS required to meet most stringent ADS-B performance criteria

Operational implications:

- Class A airspace (above FL180) aircraft are required to equip with avionics certified to TSO-C166b. Applies to Transport Category aircraft.

Airports with WAAS LPV-200/LPV/LP Instrument Approaches



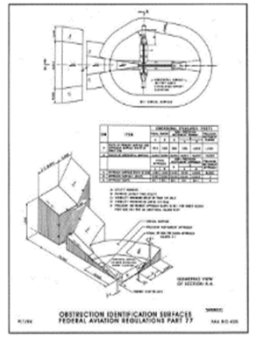
As of July 21, 2016
- 4,322 LP/LPVs combined
- 3,709 LPVs serving 1,806 Airports
- 941 LPV-200's
- 2,560 LPVs to Non-ILS Runways
- 1,149 LPVs to ILS runways
- 1,766 LPVs to Non-ILS Airports
- 613 LPs serving 444 Airports
- 610 LPs to Non-ILS Runway
- 3 LPs to ILS Runways

WAAS Avionics Equipage Status

- **Over 91,000 WAAS equipped aircraft in the NAS**
  - WAAS receivers provided by companies such as:
    - Garmin, Universal, Rockwell Collins, Honeywell, Avidyne, Innovative Solutions & Support (IS&S), Thales and Genesys Aerosystem (Chelton)
- **Since 2006, aircraft equipage rates has increased each year**
- **All classes of aircraft are served in all phases of flight**
- **Enabling technology for NextGen programs**
  - Automatic Dependent Surveillance Broadcast (ADS-B)
  - Performance Based Navigation (PBN)

NAS Implementation Activities

- **Procedure Design/Procedure Development**
  - Description of route or a terminal procedure
  - Charts are used by the pilots
- **Flight Inspection**
  - Provides airborne flight inspection of electronic signals-in-space for navigational aids in the National Airspace System
  - Flight procedures are evaluated for accuracy, aeronautical data, human factors fly-ability, and obstacle clearance
- **Government/Industry Partnerships**
  - Support Emergency Medical Helicopters
    - Establish Federal–State Agency partnership with the Maryland State Police Aviation Command (MSPAC) to prototype a low-level helicopter IFR infrastructure to support the FAA ATO top five list for safety hazards
  - Garmin Hand Flown RF Turn
    - Agreement established to collect hand flown RF Turn FTE data to support FAA approval
    - Garmin received FAA approval for STC Amendment March 2016
  - Other Transaction Agreements (OTAs) - Avionics Integration, Data Collection etc.
    - Provides aircraft operators with opportunity to implement and operate NextGen technologies without substantial investments



Equipage Increase tied to NAS Implementation Activities

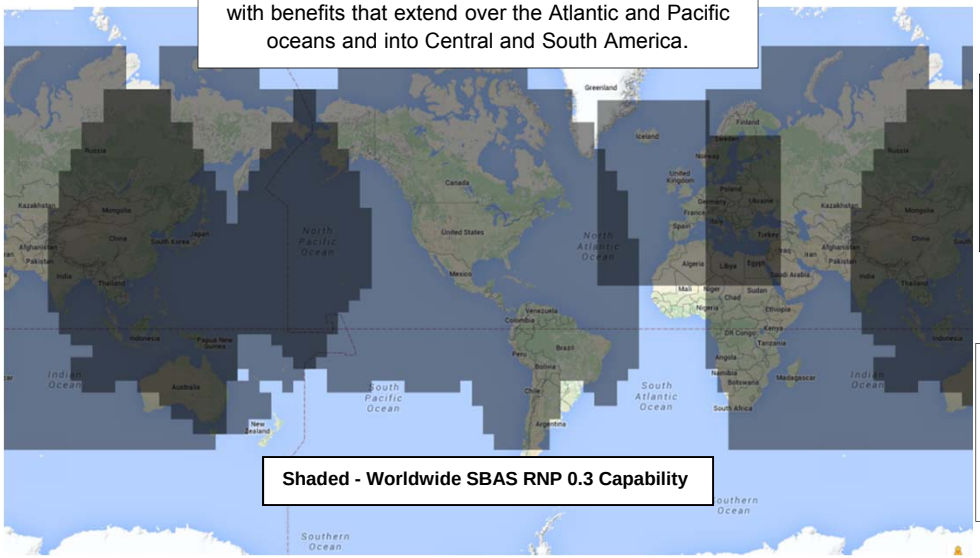
- **General Aviation**
  - Avid users, Part 23 and Part 25 aircraft
  - 88,000+ users
- **Regional Airlines and Cargo Carriers**
  - Accelerating equipage due to competitive advantages gained
  - Ex., Horizon Air, Cape Air, Northern Air Cargo, FedEx
- **Helicopters**
  - Unique benefits for helicopters incentivizing equipage
  - Ex., Low-level helicopter infrastructure, point in space (PinS) approach procedures
- **Major Air Carriers**
  - Delta and Southwest evaluating implementation of WAAS/LPV

International SBAS Capability

- **WAAS is the U.S. version of a global network Satellite Based Augmentation System (SBAS)**
- **The U.S. is the originator of the SBAS design from which MSAS and GAGAN architectures are based**
- **The FAA plays an integral part in the SBAS Interoperability Working Group (IWG) so that WAAS equipped aircraft can fly seamlessly around the world using SBAS**
- **WAAS future development is being coordinated internationally to ensure continued interoperability with the other operational SBAS systems as well as up an coming SBAS systems such as the Chinese Satellite Navigation Augmentation System (SNAS)**

Wide Area Augmentation System (WAAS)
Commissioned in July 2003. Serves North America with benefits that extend over the Atlantic and Pacific oceans and into Central and South America.

***In Development* -**
System of Differential Correction and Monitoring (SDCM) Will augment GPS and GLONASS to provide horizontal and vertical guidance. Will serve Russia and the surrounding area.



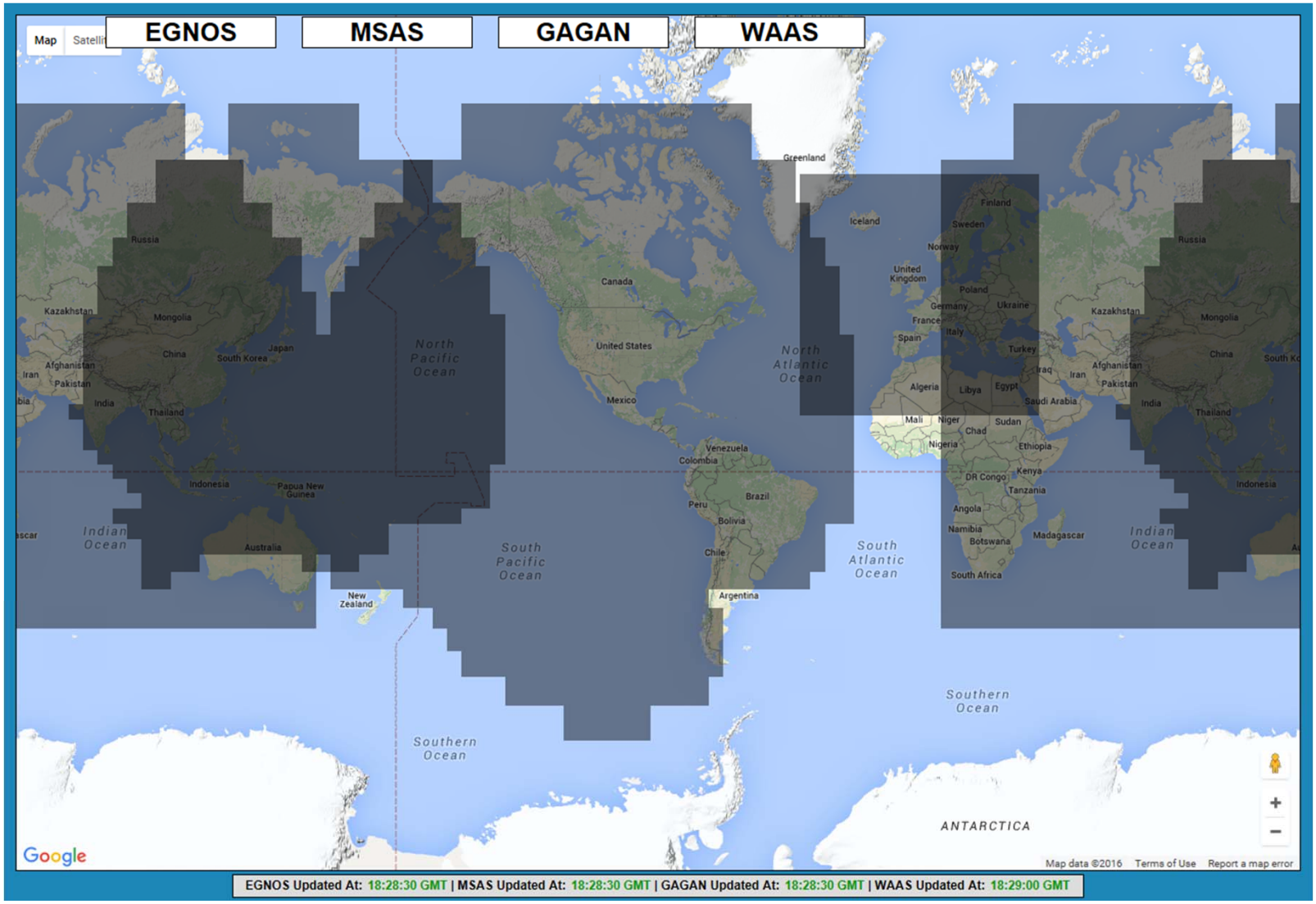
Shaded - Worldwide SBAS RNP 0.3 Capability

European Geostationary Navigation Overlay Service (EGNOS)
Certified for aviation (comparable service as WAAS) in March 2011. Serves Europe and northern portion of Africa.

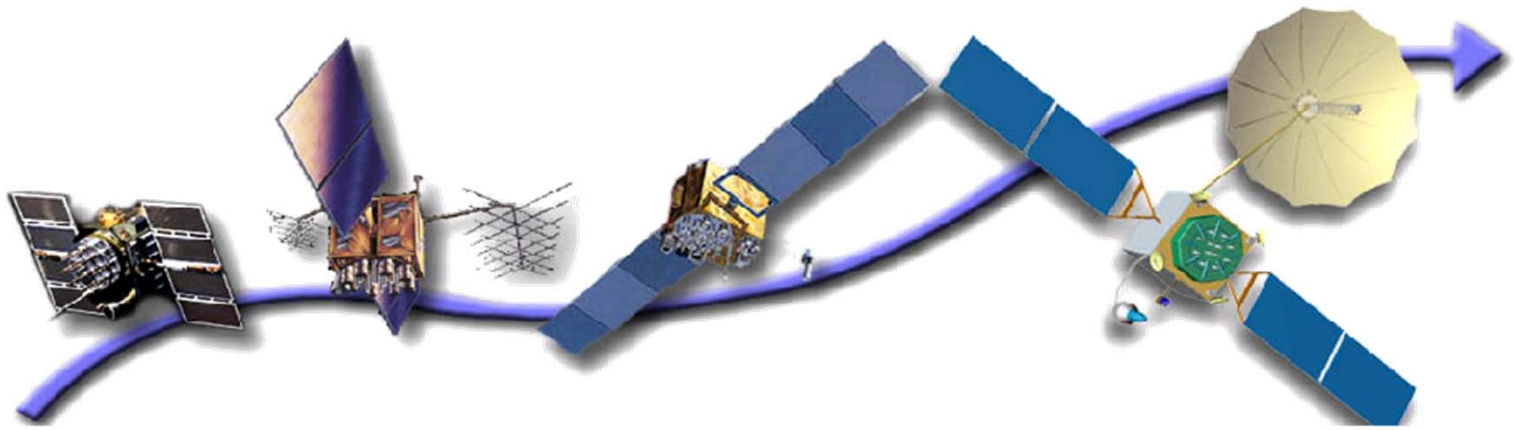
Multi-functional Transport Satellite (MTSAT) Satellite Augmentation System (MSAS)
Commissioned in 2007. Provides LNAV Service. Serves Japan and surrounding area.

GPS Aided Geostationary Earth Orbit (GEO) Augmented Navigation (GAGAN)
Will serve India and the surrounding area. Certified for aviation use in December 2013.

Current Global SBAS RNP 0.3 Coverage



GPS Modernization Program



Increasing System Capabilities w ***Increasing Defense / Civil Benefit***

Block IIA/IIR

Basic GPS

- Standard Service
  - **Single frequency (L1)**
  - Coarse acquisition (C/A) code navigation
- Precise Service
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Block IIR-M, IIF

IIR-M: IIA/IIR capabilities plus

- **2nd civil signal (L2C)**
- M-Code (L1M & L2M)

IIF: IIR-M capability plus

- **3rd civil signal (L5)**
- Increased robustness
- Aviation Safety

Block III

- **Backward compatibility**
- **4th civil signal (L1C)**
- Increased accuracy
- Assured availability
- Navigation surety
- Controlled integrity
- Increased security
- System survivability

GPS III

- **GPS III is the newest block of GPS satellites**
  - 4 civil signals: L1 C/A, L1C, L2C, L5
  - 4 military signals: L1/L2 P(Y), L1/L2M
- **Provides**
  - Backward Compatibility
  - Availability of Position Accuracy
  - Advanced Military functions

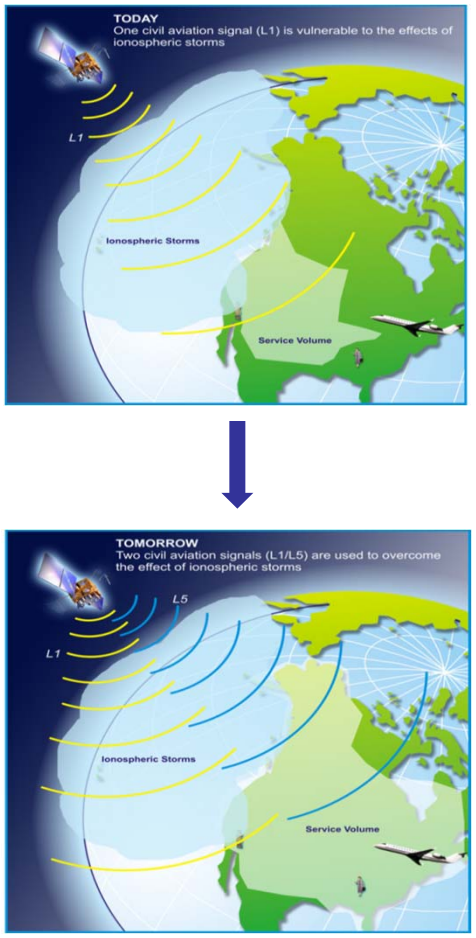
OCX

- **New generation GPS satellites (GPS IIR-M, IIF & III) and the Next Generation GPS Operational Control System (OCX) will provide new capabilities to both signal structure and satellite command and control**

Questions

WAAS Phase IV Dual Frequency Operations Status

- **Release 1 – Processor Upgrades**
  - Design Review completed March 2015
  - Software updates completed June 2016
  - System integration and test in CY16
  - Cutover scheduled to be complete fall of 2017
- **Release 2 – GEO-5 Integration**
  - Updated SGS design completed August 2015
  - GUS site installation activities completed April 2016
  - Set GEO-5 operational 4th quarter CY17



WAAS Phase IV Dual Frequency Operations Status (cont.)

- **Release 3 – GIII Multicast Update**
  - Implementation of updated GIII Multicast October 2017
  - Scheduled for cutover 2nd quarter CY18
- **Release 4 – Corrections & Verifications (C&V) Safety Computer (SC) Update**
  - Initial 28 SC's to be delivered by August 2016
  - C&V design scheduled for 3rd quarter CY17
  - C&V scheduled for validation testing and cutover in CY18
- **Release 5 – SC GUS Processor (GPT) and GEO 6 Integration**
  - SES tests planned for November 2016
  - Payload delivery 4th quarter CY2017
  - Satellite launch 2nd quarter CY2018
  - Commence GEO signal testing in 4th quarter CY18
  - Complete cutover late 2019