Asia-Pacific Economic Cooperation

APEC TPT-WG44

44th Transportation Working Group Meeting

April 25-28, 2017
Chinese Taipei

Subject: U.S. GNSS and Augmentations

Presenter's Name: Ken Alexander

Economy: United States

Overview: U.S. GNSS and Activities Update

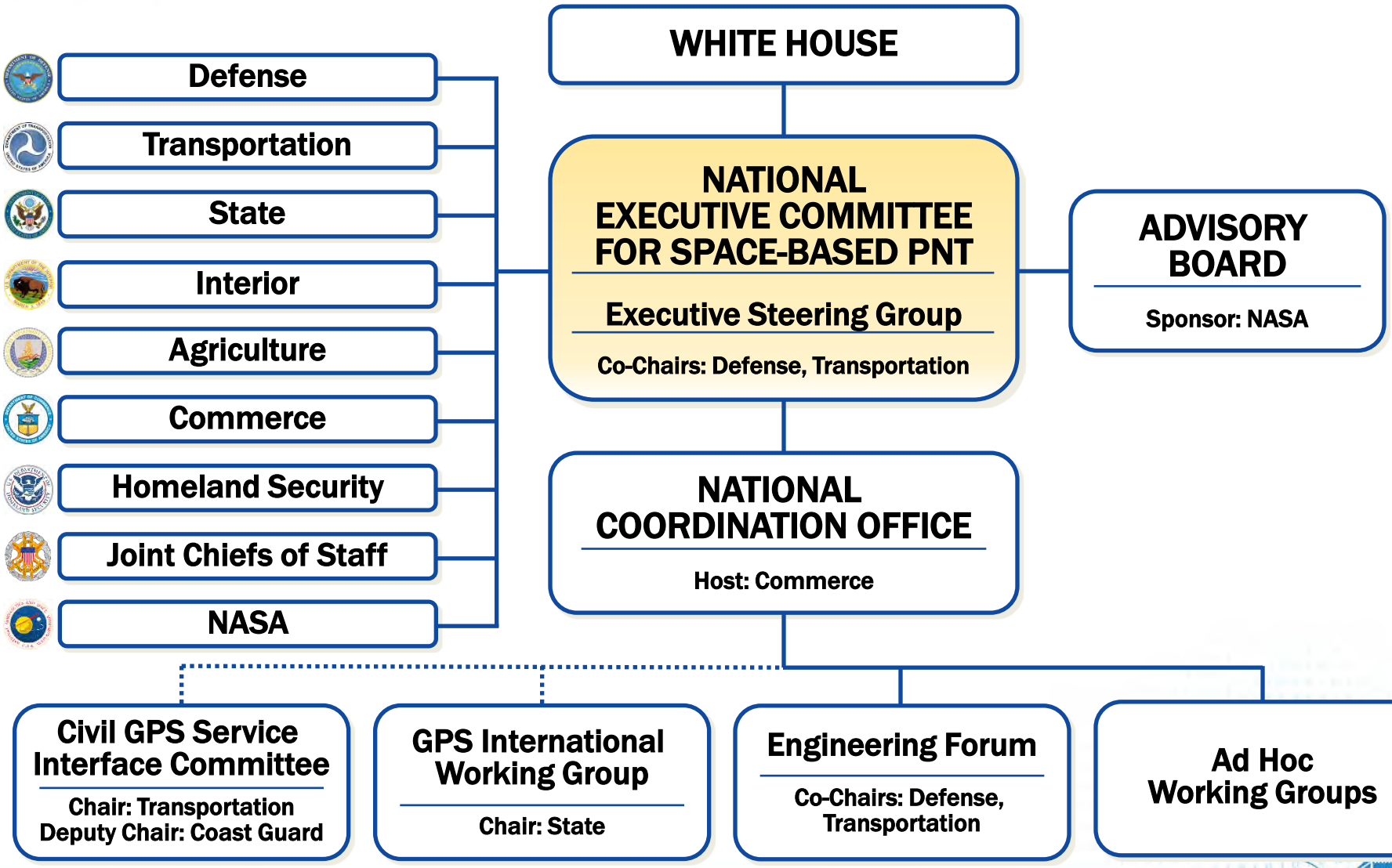
- GPS Policy, Sustainment and Modernization
- Wide Area Augmentation System (WAAS) Satellite Based Augmentation System (SBAS)
- Advanced Receiver Autonomous Integrity Monitoring (ARAIM) and Dual-Frequency / Multi-Constellation (DF/MC) Receivers
- Ground Based Augmentation System (GBAS)
- Nationwide Differential GPS (NDGPS)

U.S. Policy Promotes Civilian GPS Use

- Continuous, worldwide, free of direct user fees
- Encourage compatibility and interoperability with other economies GNSS services and promotes transparency in civil service provisioning
- Operate and maintain GPS constellation to satisfy civil and economy security needs
  - Other economies PNT services may be used to augment and strengthen the resiliency of GPS
- Invest in domestic capabilities and support international activities to: detect, mitigate and increase resiliency to harmful interference

Space-Based PNT Policy Guidance: Maintain leadership in the service, provision, and use of GNSS

Space-Based PNT Organization



PNT Executive Committee (EXCOM) Strategic Focus Areas include:

- GPS Sustainment and Modernization
- International Cooperation
- Spectrum Management
- Critical Infrastructure
- PNT Resilience
- Complementary PNT
- Outreach and Education

U.S. Federal Communications Commission (FCC) Part 25 Rules

- FCC Part 25 rules require licensing or waiver of non-Federal* receive-only Earth stations (receivers) operating with non-U.S. licensed satellites
- U.S. National Telecommunications and Information Administration (NTIA) established criteria for recommending a waiver of the FCC rules
- Other economies waiver requests are initiated through consultation with U.S. Department of State

FCC has not approved licensing, or waiver, of its Part 25 rule for any other economy, or other entity, for multi-GNSS receiver use in the U.S.

** FCC Part 25 rule does not apply to U.S. Federal Government Use of Multi-GNSS receivers*

FCC Part 25 Rule Evaluation Criteria and EU Waiver Request

- **Considerations (criteria):**
  1. Grant of a waiver is in public interest
  2. System complies with United Nations Space Debris Mitigation guidelines
  3. Grant of waiver is consistent with U.S. international trade and other treaty obligations
  4. Waiver request is limited to receive-only RNSS (which includes positioning) and standard time and frequency satellite services
  5. Operation of RNSS signals offered by foreign RNSS system found compatible with U.S. government systems operating in specified RNSS frequency bands
- **European Union (EU) submitted waiver request in 2013**
  - NTIA submitted request to FCC and recommended approval
  - FCC issued public notice inviting interested parties to comment
  - Comment period closed; Response period closed 23 Mar 2017

GPS Overview

Civil Cooperation

- 1+ Billion civil & commercia users worldwide
- Search and Rescue
- Civil Signals
  - L1 C/A (Original Signal)
  - L2C (2nd Civil Signal)
  - L5 (Aviation Safety of Life
  - L1C (International)

Department of Defense

- Services (Army, Navy, AF, USMC)
- Agencies (NGA & DISA)
- U.S. Naval Observatory
- PNT EXCOMS
- GPS Partnership Council

Spectrum

- World Radio Conference
- International Telecommunication Union
- Bilateral Agreements
- Adjacent Band Interference

37 Satellites / 31 Set Healthy

Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age	Oldest
GPS IIR	12	15.1	19.6
GPS IIR-M	7	9.5	11.4
GPS IIF	12	3.1	6.7
Constellation	31	9.2	19.6

AS OF: 3 MAR 17

Maintenance/Security

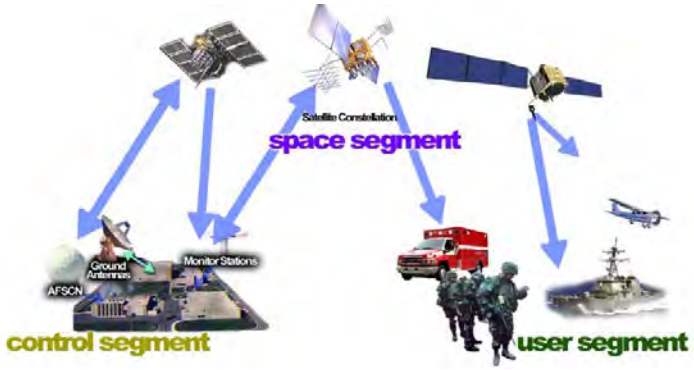
- All Level I and Level II
  - Worldwide Infrastructure
  - NATO Repair Facility
- Develop & Publish ICDs 2x per Year
  - ICWG: Worldwide Involvement
- Update GPS.gov Webpage
- Distribute PRNs for the World
  - 120 for U.S. and 90 for GNSS

Department of Transportation

- Federal Aviation Administration

Department of Homeland Security

- U.S. Coast Guard



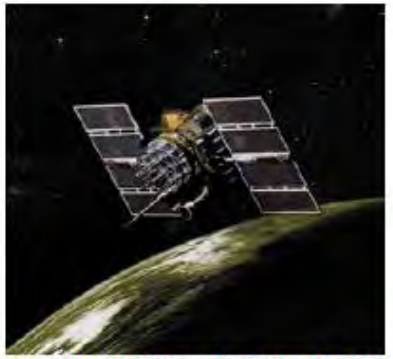
International Cooperation

- Europe - Galileo
- China - Beidou
- Russia - GLONASS
- Japan - QZSS
- India - IRNSS

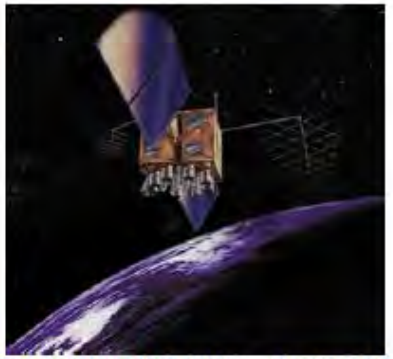
Constellation Snapshot

Four Generations of Operational Satellites

- **Block IIA - 5 Residual**
  - 7.5 year design life
  - Launched 1990 to 1997
- **Block IIR - 12 Operational**
  - 7.5 year design life (oldest satellite is 19 years old)
  - Launched 1997 to 2004
- **Block IIR-M - 7 Operational, 1 Residual**
  - 7.5 year design life
  - Launched 2005 to 2009
  - Added 2nd civil navigation signal (L2C)
- **Block IIF - 12 Operational**
  - 12 year design life
  - Launched 2010 to 2016
  - Added 3rd civil navigation signal (L5)



Block IIA Satellite – Designed & Built by Rockwell International



Block IIR/IIR-M Satellite – Designed & Built by Lockheed Martin

Block IIF Satellite – Designed & Built by Boeing

*** Current as of 3 March 17**

GPS SIS Performance Scoreboard

GPS SIGNAL IN SPACE (SIS) PERFORMANCE (CM)

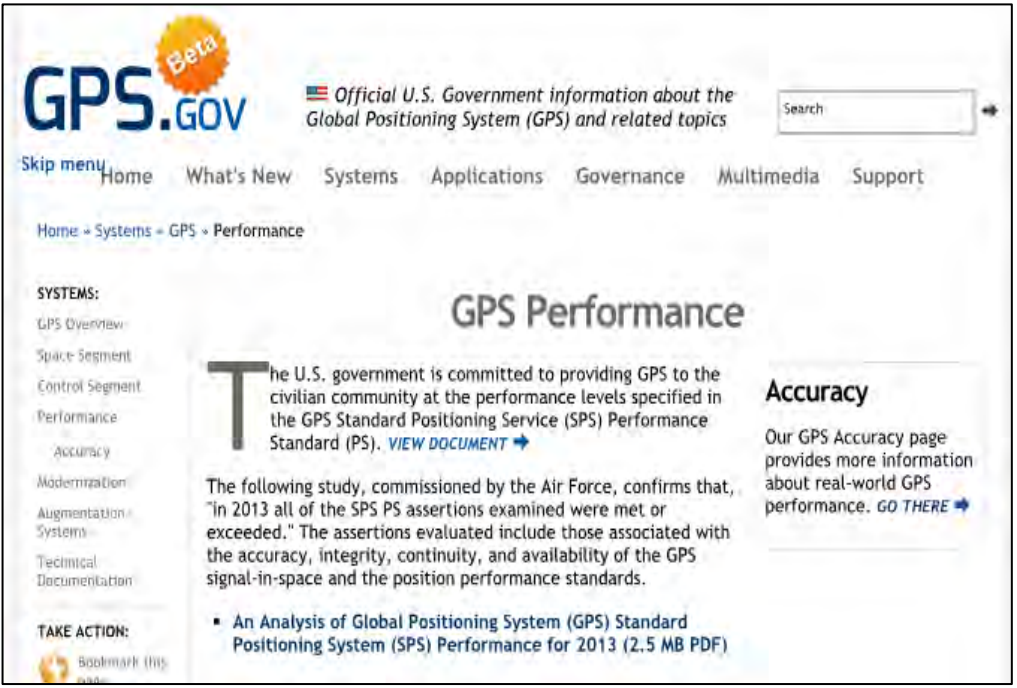
	BEST WEEK *		BEST DAY *		WORST DAY *	
	ENDING	SIS	ENDING	SIS	ENDING	SIS
ROLLING YEAR	29 NOV 16	44.1	26 JAN 17	35.0	27 OCT 16	67.3

BEST WEEK EVER 29 NOV 16 44.1

*ROLLING YEAR

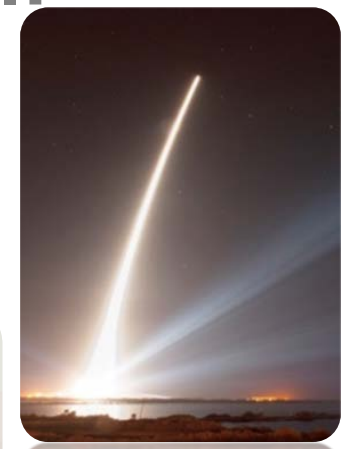
GPS Performance Report Card

- 2013 report now available on gps.gov
  http://www.gps.gov/systems/gps/performance/
- Report measures GPS performance against GPS SPS Performance Standard
- GPS Performance Standard Update anticipated in 2017



DOCUMENT SECTION	PERFORMANCE METRIC	2013 STATUS
3.4.1 SIS URE Accuracy	≤ 7.8 m 95% Global average URE during normal operations over all AODs	✔✚
	≤ 6.0 m 95% Global average URE during normal operations at zero AOD	✔✚
	≤ 12.8 m 95% Global average URE during normal operations at any AOD	✔✚
	≤ 30 m 99.94% Global average URE during normal operations	✔✚
	≤ 30 m 99.79% Worst case single point average URE during normal operations	✔✚
3.5.1 SIS Instantaneous URE Integrity	≤ 1×10^{-5} Probability over any hour of exceeding the NTE tolerance without a timely alert	✔✚
3.6.1 SIS Continuity - Unscheduled Failure Interruptions	≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from the slot due to unscheduled interruption	✔✚
3.7.1 SIS Per-Slot Availability	≥ 0.957 Probability that (a.) a slot in the baseline 24-slot will be occupied by a satellite broadcasting a healthy SPS SIS, or (b.) a slot in the expanded conguration will be occupied by a pair of satellites each broadcasting a healthy SIS	✔✚
3.7.2 SIS Constellation Availability	≥ 0:98 Probability that at least 21 slots out of the 24 slots will be occupied by a satellite (or pair of satellites for expanded slots) broadcasting a healthy SIS	✔✚
	≥ 0.99999 Probability that at least 20 slots out of the 24 slots will be occupied by a satellite (or pair of satellites for expanded slots) broadcasting a healthy SIS	✔✚
3.7.3 Operational Satellite Counts	≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	✔✚
3.8.1 PDOP Availability	≥ 98% Global PDOP of 6 or less	✔✚
	≥ 88% Worst site PDOP of 6 or less	✔✚
3.8.2 Position Service Availability	≥ 99% Horizontal, average location	✔✚
	≥ 99% Vertical, average location	
	≥ 90% Horizontal, worst-case location	
	≥ 90% Vertical, worst-case location	
3.8.3 Position Accuracy	≤ 9 m 95% Horizontal, global average	✔✚
	≤ 15 m 95% Vertical, global average	
	≤ 17 m 95% Horizontal, worst site	
	≤ 37 m 95% Vertical, worst site	

GPS IIF

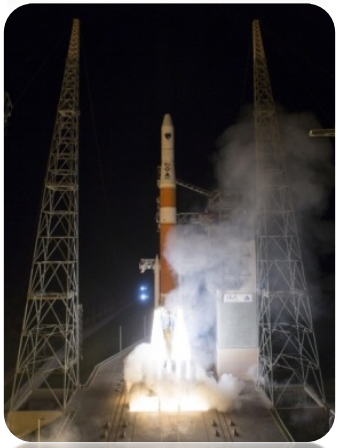


20 Feb 14: IIF-5

16 May 14: IIF-6

1 Aug 14: IIF-7

29 Oct 14: IIF-8



25 Mar 15: IIF-9

15 Jul 15: IIF-10

31 Oct 15: IIF-11

5 Feb 16: IIF-12

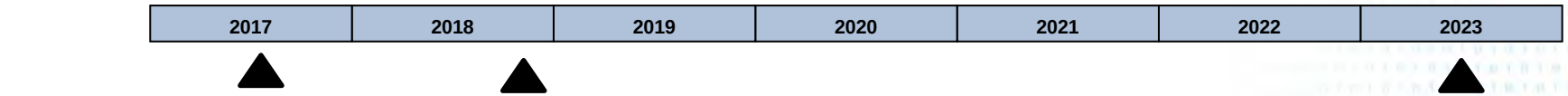
8 Launches in 24 Months – Most aggressive GPS launch schedule since 1993

GPS III

- GPS III is newest block of GPS satellites
  - 4 civil signals: L1 C/A, L1C, L2C, L5
    - First satellites to broadcast common L1C signal
  - 4 military signals: L1/L2 P(Y), L1/L2M
- General characteristics
  - Orbit: Six orbit planes at 55 degree inclination
  - Altitude: 10,898 nautical miles
  - Design life: 15 years, 12 years mean mission duration
  - Launch weight: 8,115 lb.
  - On-Orbit weight: 4,764 lb.
  - Size: 97 in wide, 70 in deep, 134 in high
- Current Status
  - SV01 placed into storage 27 Feb 17
  - SV02/03 in assembly & integration
  - SV04-08 in box level assembly

GPS III SV 11+

- Build on legacy of GPS IIF and GPS III programs
  - Drive down costs, maintain production readiness to achieve 2023 need date
- Plan to compete GPS III Follow-on Production
  - Promote competition and reduce risk for production GPS space vehicles
- Two-phase approach
  - Phase 1: Production Readiness Feasibility Assessment
    - Gain insight into contractor SV & navigation payload production maturity/risk
    - The Boeing Company, Lockheed Martin Space Systems Company, and Northrop Grumman Aerospace Systems awarded contracts on 9 May 2016
  - Phase 2: Production Competition
    - Full and open competition for up to 22 GPS III SVs



Now on the Air: Modernized Civil Signals

- U.S. initiated continuous CNAV message broadcast (L2C & L5) on 28 Apr 2014; began with 2x-a-week uploads and moved to daily (nominal) uploads in Dec 2014
  - Position accuracy not guaranteed during pre-operational deployment
  - L2C message currently set “healthy”
  - L5 message set “unhealthy” until sufficient monitoring capability established
- User-Range Error (URE) CNAV Performance Post
  - Daily uploads are consistent with or slightly exceed LNAV performance

Modernization Timeline

- **2014:** Civil Navigation (CNAV) message available for test
- **2016**: 19 L2C satellites, 12 L5 satellites available
- **2017:** 1st GPS III satellite successfully completed all planned test and integration activities
- **2018 - 2021:** GPS III initial launch campaign
- **2021:** Approximate date for initial L1C signal transmission
- 2021: Approximate date for 24 L2C capable satellites
- **2024:** Approximate date for 24 L5 capable satellites

GPS Summary

- U.S. supports free access to civilian GNSS signals and all necessary public domain documentation
- GPS is a critical component of global infrastructure
  - Compatible with other satellite navigation systems and interoperable at the user level
  - Guided at an economy level as multi-use asset
  - Acquired and operated by U.S. Air Force on behalf of USG
- U.S. policy promotes open competition and market growth for commercial GPS and its augmentations
- Modernization milestones: Multiple launches and new Civil Navigation messages broadcast

GPS: Continuous improvement, predictable, dependable positioning performance

Wide Area Augmentation System (WAAS)

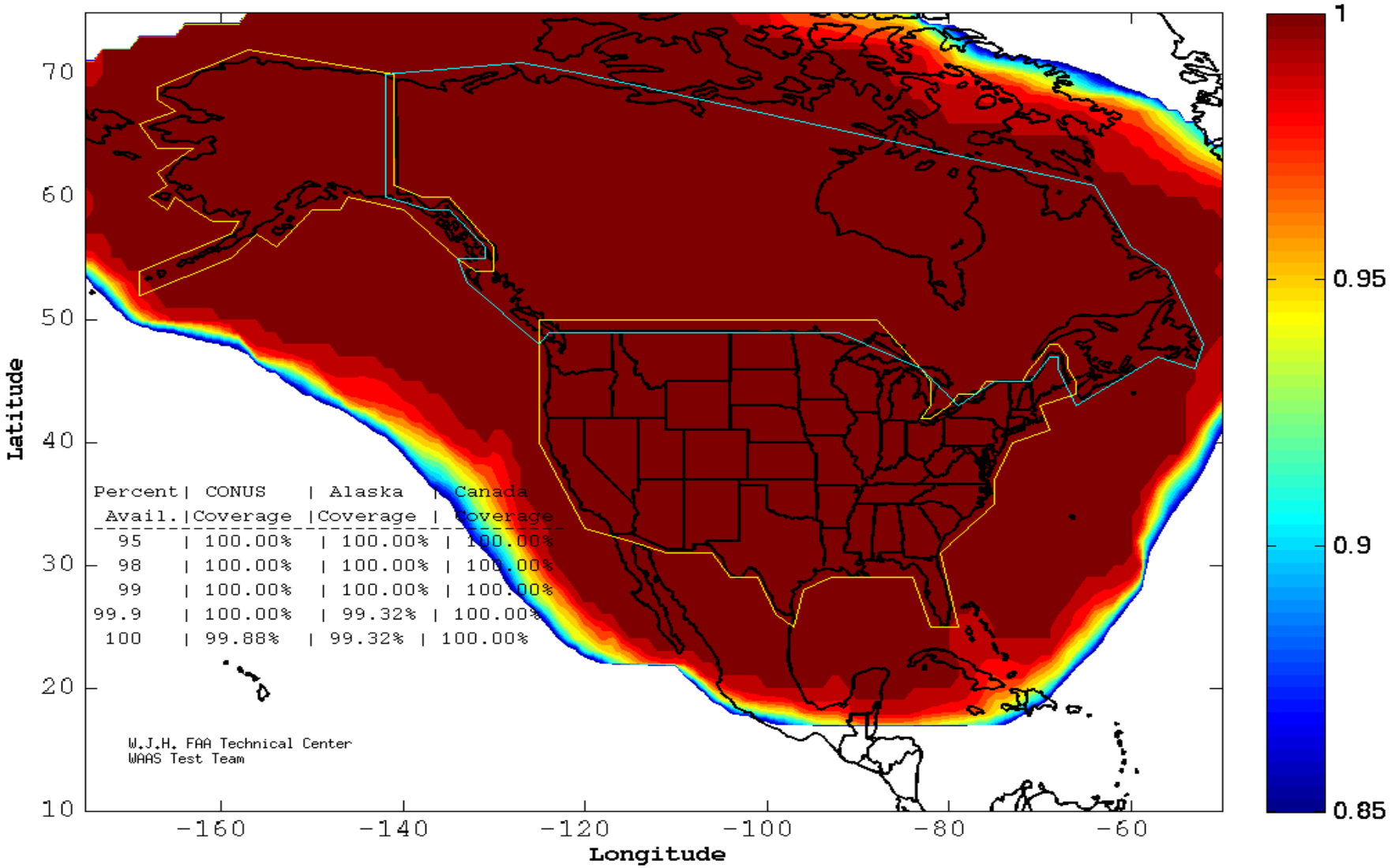
- Coverage
- Schedule
- Current GEO System
- Dual Frequency Operations
- Space and Ground Operations
- Procedures
- Avionics Development

Current WAAS Components

WAAS Program Strategy

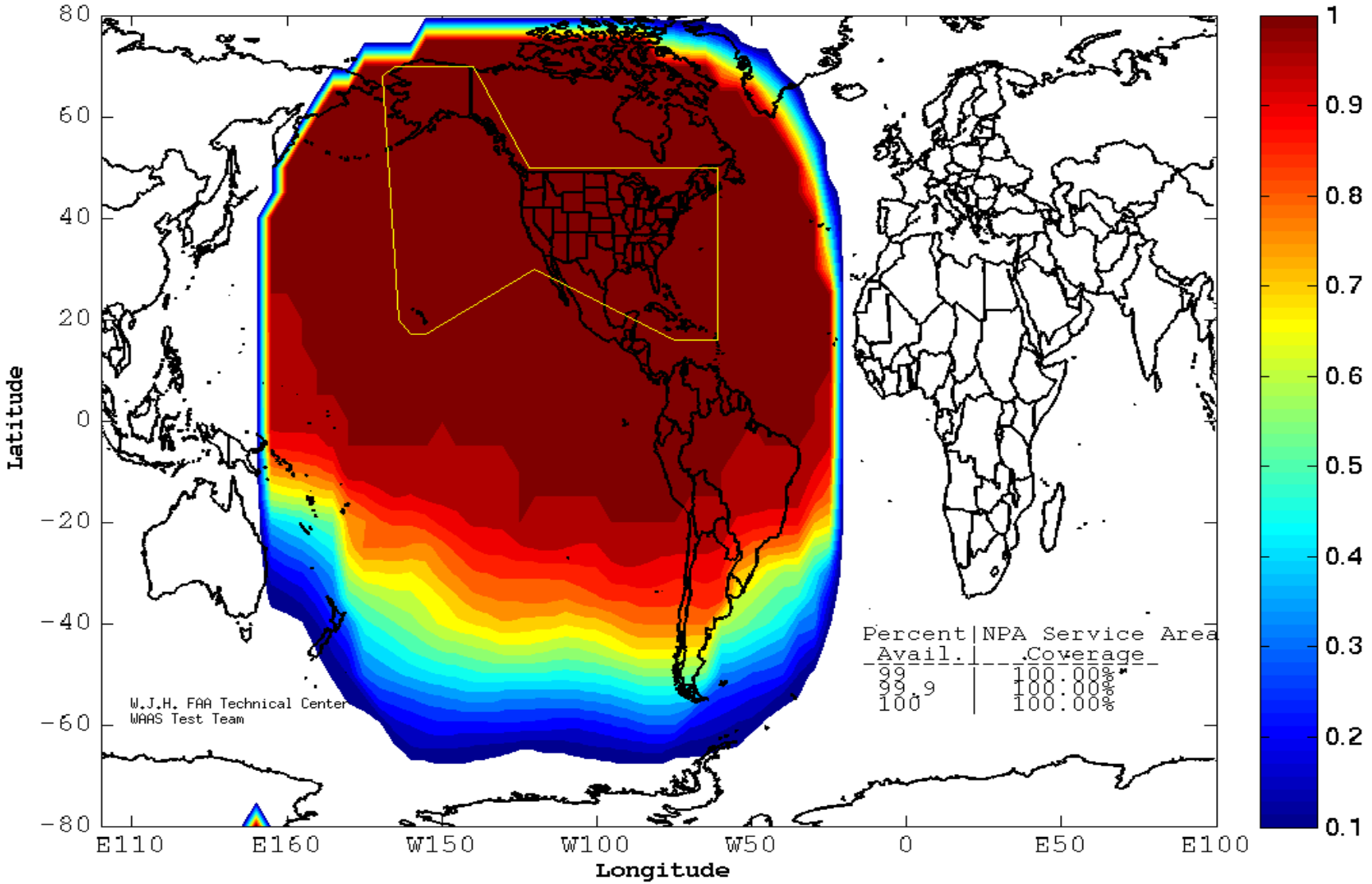
- Integrate 5th and 6th GEOs
- Establish procurement strategy for 7th GEO
- Continue 2nd civil signal L5 implementation
- Develop Dual-Frequency Avionics Standards (MOPS)
- Evaluate Dual-Frequency, Multi-Constellation Avionics
- Evaluate Advanced Receiver Autonomous Integrity Monitoring (ARAIM)
- Continue technical refresh activities

WAAS Localizer Performance Vertical (LPV) Availability April 3, 2017



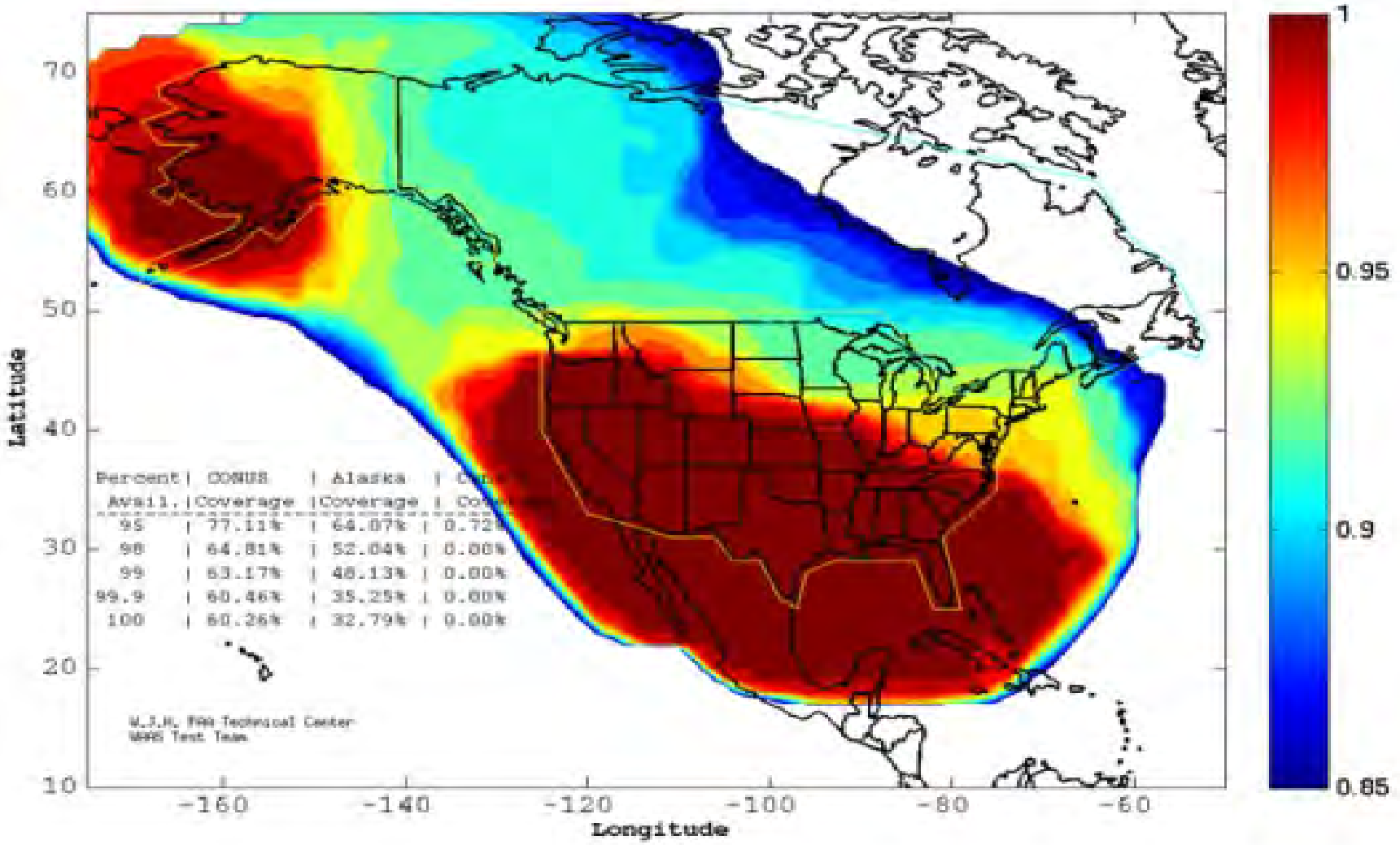
WAAS RNP 0.3 Availability

April 3, 2017

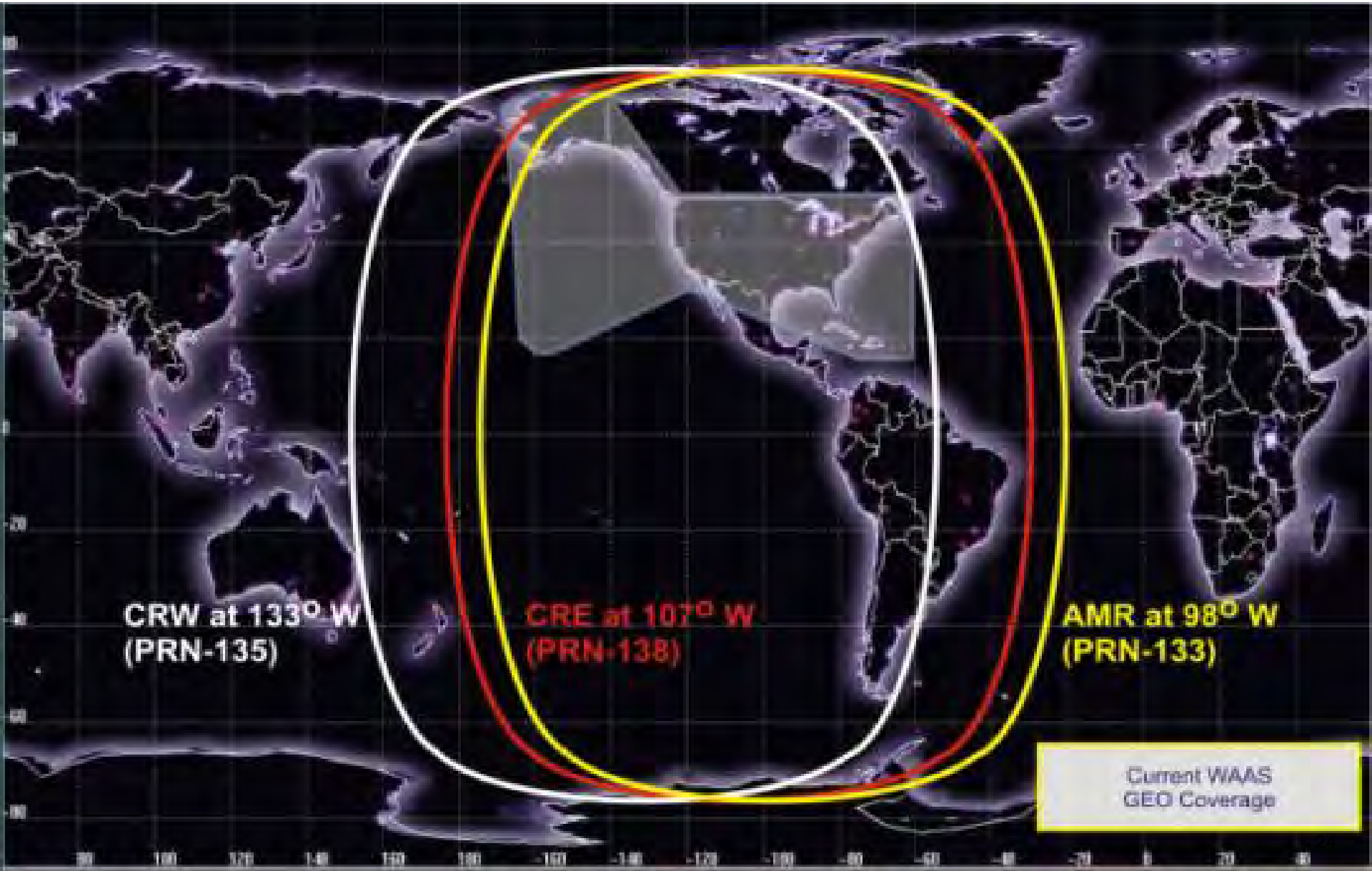


WAAS LPV Coverage

6 March 2016 Ionospheric Event



Current WAAS GEOs



GEO Sustainment (GEOs 5/6/7)

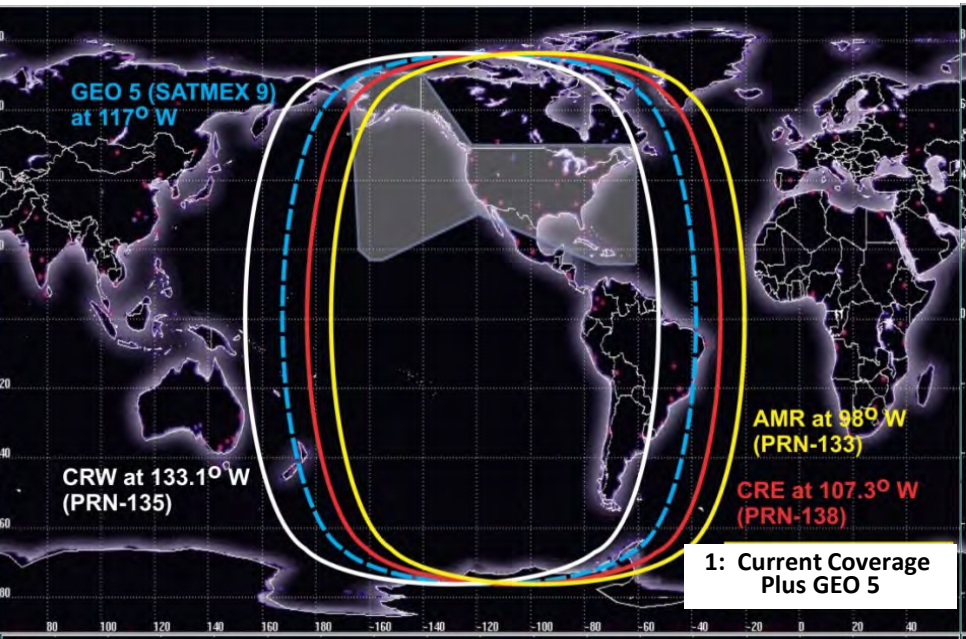
- Replace legacy GEO's upon lease expiration
- GEO 5 Satellite Acquisition
  - EUTELSAT 117 West B (ex SatMex 9)
  - Provides full coverage of CONUS & Alaska
  - Satellite launched June 2016
  - Signal-in-Space testing since Dec 2016
  - Expected operational in 2018
- GEO 6 Satellite Acquisition
  - GUS site build out in progress
  - Host satellite is SES-15
  - Planned for 129 West
  - Provides full coverage or CONUS & Alaska
  - Scheduled launch 2nd Qtr. CY2017
  - Signal testing expected in early CY2018
  - Expected operational in 2019
- GEO 7 Satellite acquisition
  - Targeting 2018 contract award

Eutelsat 117WB

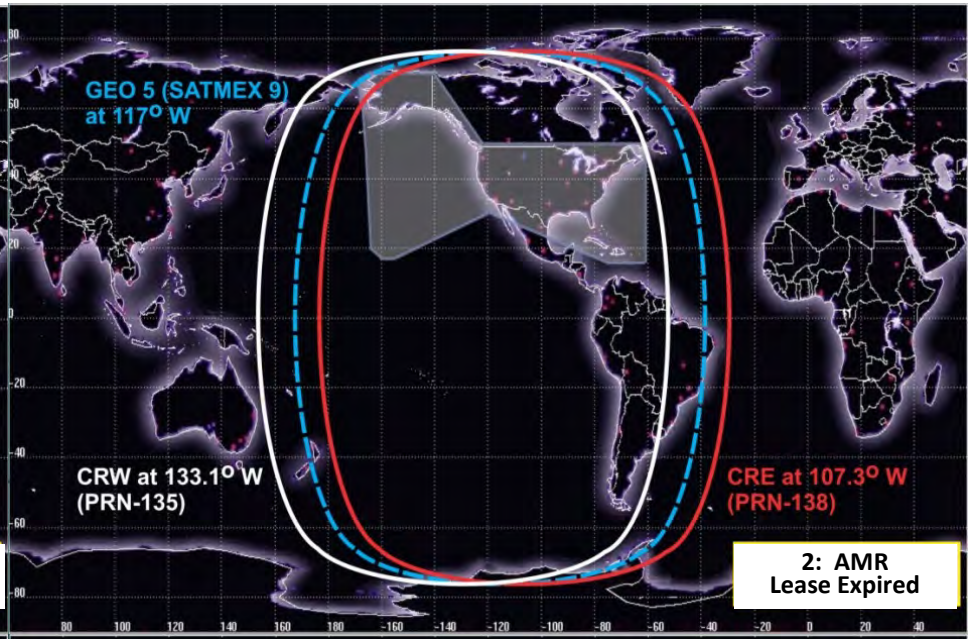
Asia-Pacific Economic Cooperation

WAAS GEO Activities

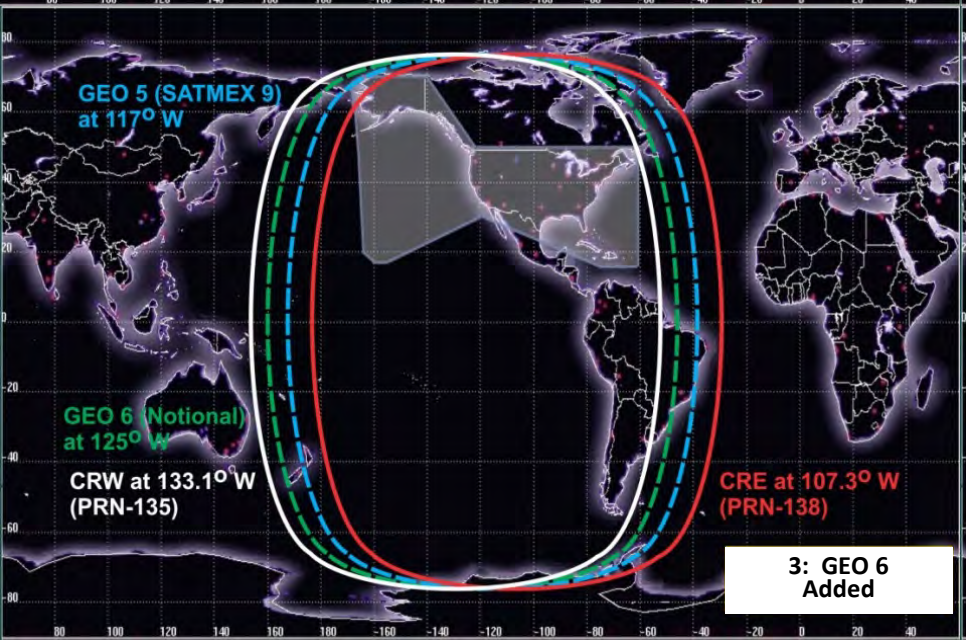
APEC TPT-WG44



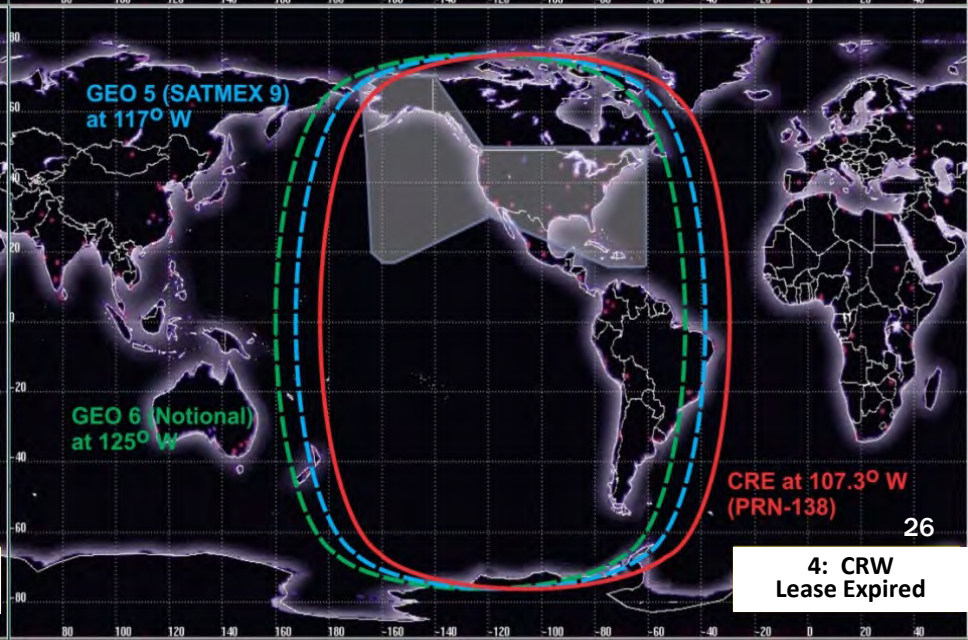
1: Current Coverage Plus GEO 5



2: AMR Lease Expired



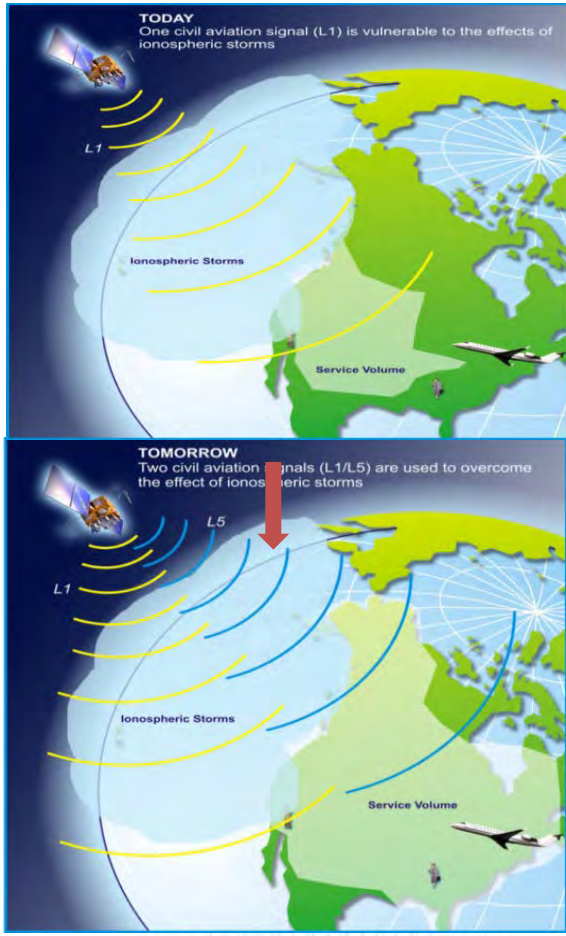
3: GEO 6 Added



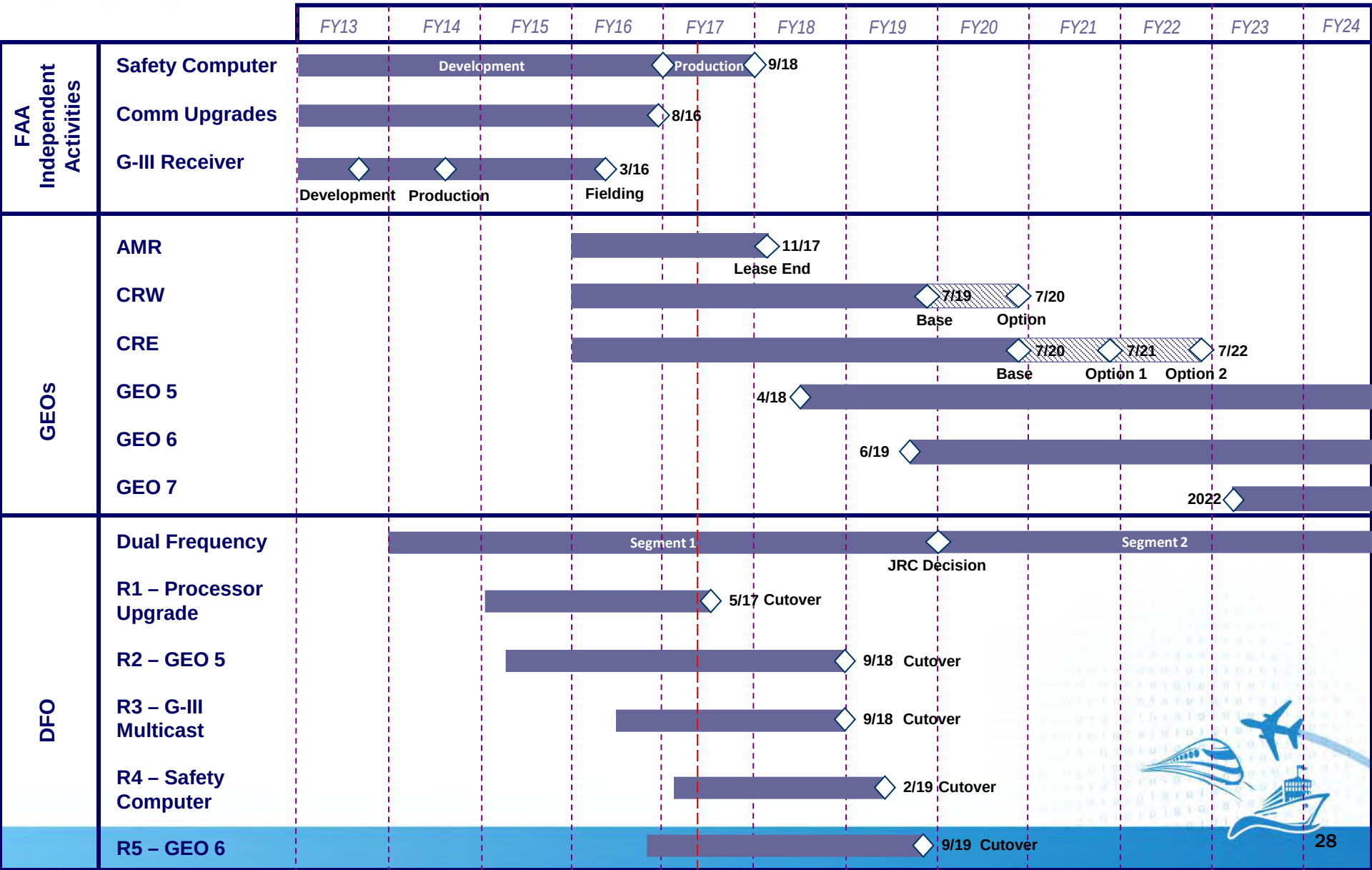
4: CRW Lease Expired

WAAS Phase IV Dual Frequency Operations Status

- GPS L1 Plus L5 provides high availability of SBAS vertical service during ionospheric disturbances
- Release 1 – Processor Upgrades
  - System integration and test complete
  - Over 31 sites completed cutover, remaining sites to complete by summer 2017
- Release 2 – GEO-5 Integration
  - Integration and testing throughout 2017
  - Scheduled operational mid CY 2018



WAAS Schedule



WAAS Phase IV Dual Frequency Operations Status (continued)

- Release 3 – G-III Multicast Update
  - Software development underway with build provided by April 2017
  - Implements updated G-III Multicast structure to incorporate GPS L5 signal into operational system; scheduled for cutover 2018
- Release 4 – Corrections & Verifications (C&V) Safety Computer (SC) Update
  - New SC production contract awarded September 2016
  - C&V design scheduled for 2nd quarter CY17
  - C&V scheduled for validation testing and cutover in CY18
- Release 5 – SC GUS Processor (GPT) and GEO 6 Integration
  - GUS installation April 2017
  - Commence GEO signal testing mid 2018
  - Complete cutover mid 2019

WAAS Phase IV Investigations

- Dual-Frequency Multi-constellation Capability (DFMC)
- International Focus on leveraging other compatible constellations
  - International Civil Aviation Organization (ICAO) Navigation Systems Panel (NSP) work plan supports SBAS standards for use of other Global Navigation Satellite Systems (GNSS)
  - SBAS Interoperability Working Group (IWG) has proposed
    - Preliminary DFMC requirements and
    - SBAS interface control standard
  - ICAO NSP, RTCA and EUROCAE developing draft standards
  - FAA supporting DFMC SBAS standards development

http://www.gps.gov/policy/cooperation/#europe

WAAS Phase IV Investigations (2 of 3) Advanced RAIM (ARAIM)

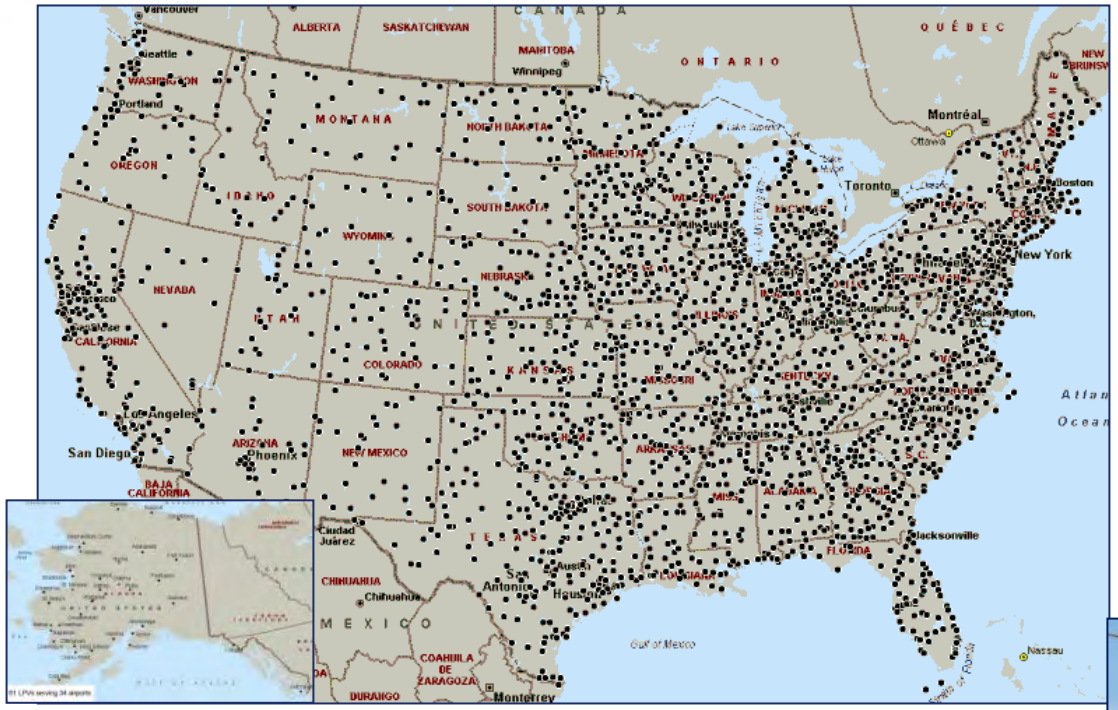
- Avionics-centric approach to dual-frequency multi-constellation
- U.S./EU WG-C published Milestone 3 report describing overall concept and assessing its feasibility; Report available at: http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8690
  - Supports ICAO, RTCA/EUROCAE standards development New work develops standards and supporting validation materials
- FAA focus on development of initial requirements for horizontal navigation (H-ARAIM)
  - Developing airborne prototypes for flight testing
  - Document ground offline monitoring and begin prototyping as needed
  - Preliminary H-ARAIM safety case (include V-ARAIM time permitting)
  - Preliminary ICAO/RTCA requirements
  - Propose and validate new GPS/Galileo commitments
- GPS planning new message types (MT 38/39) with provision for ARAIM Integrity Support Message (ISM)

http://www.gps.gov/policy/cooperation/#europe

WAAS Phase IV Investigations (3 of 3) G-III Receiver Galileo Prototype

- Next generation WAAS receiver (G-III) fielded at all reference stations since June 2016
- Prototype effort initiated to add Galileo processing to G-III receiver platform via software update
- G-III/Galileo prototype intended for DFMC research and Galileo signal monitoring
- Galileo prototype G-III software currently undergoing testing with an expected formal delivery in mid 2017
  - Will allow for tracking of 14 GPS, 4 SBAS and 12 Galileo satellites across all U.S. and EU GNSS bands

WAAS Procedures and Users



Approach Procedures

- 4,405 WAAS Procedures published (as of Mar 2017)
  - 3,781 Localizer Precision Vertical (LPV) procedures
    - Serving 1,841 airports

Users

- Over 95,000 WAAS/SBAS equipped aircraft
- All aircraft classes served in all phases of flight
- WAAS/SBAS is enabling technology for FAA NextGen
  - Automatic Dependent Surveillance Broadcast (ADS-B)
  - Performance Based Navigation (PBN)

FAA Ground Based Augmentation System (GBAS) Activities

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U.S. GBAS Cat I Update

- Non-Federally owned and operated system
- Vendor and airport authority determine implementations
  - Currently Newark, NJ & Houston, TX
- Thousands of approaches
- Block II upgrade improves iono perf.
- U.S. Airlines procuring GBAS aircraft
  - United Airlines
  - Delta Airlines
  - American Airlines and
  - Southwest Airlines
- International Airlines:
  - British Airways
  - Lufthansa
  - Emirates
  - Cathay Pacific

CAT III / GAST D Validation Activities

- GAST-D standards support approach and landing operations to CAT III minima by augmenting single-frequency GPS (L1)
- FAA validation activities included commercial prototypes
  - Jan 2013: Avionics prototyping contract completed
  - May 2015: Ground System prototyping completed
  - Ionospheric Gradient Mitigation work complete
- Dec 2016: GAST-D Standards and Recommended Practices validated and approved by ICAO Navigation Systems Panel (NSP/3)
  - VDB compatibility with ILS and VHF Com equipment work continues (largely independent of GAST D)

CAT III / GAST D Validation Activities (continued)

- RTCA Avionics Minimum Operational Performance Standard (MOPS)
  - Compliment ICAO Annex 10 standards
  - Completed Mar 2017; Awaiting Plenary and Program Management Committee approval (pending May 2017)
- Honeywell SLS-5000 GAST-D
  - ICAO GAST-D compliant configuration (CAT-III)
  - System architecture updates similar to those prototyped and tested at the FAA's William J Hughes Technical Center
  - Current Design Approval target date: pending

37

GBAS International Cooperation

- International GBAS Working Group (IGWG)
  - Organized by FAA and EUROCONTROL to foster communication and collaboration among states implementing GBAS
  - Next Meeting: 18-21 April in Atlanta, Georgia USA
- FAA International Memorandums of Understanding
  - EUROCONTROL
  - Germany
  - Spain
  - Australia
  - Brazil: FAA assisting in ionospheric threat model development for lower latitudes; GBAS Bilateral Agreement signed March 2017

RTCA SC-159 Deliverables (1 of 2)

Product	Description	Due Date	Change
DO-253D	Updated GBAS MOPS.	March 2017	was 3/16
DO-246E	Updated GBAS ICD.	March 2017	was 3/16
GPS/GLONASS L1-only MOPS	New MOPS for GPS/GLONASS (FDMA + antenna) L1-only airborne equipment.**	May 2017	was 3/16
DO-229E	Updated GPS/SBAS MOPS (to increase the number of SBAS Pseudorandom Noise [PRN] codes from 19 to 39) Graceful degradation to RAIM	Complete December 2016	-
GNSS-Aided Inertial Systems MOPS	New MOPS for GNSS-aided inertial navigation systems.	October 2017	
DO-235C	Updated L1 interference environment report.	December 2017*	
DO-292A	Updated L5 interference environment report.	December 2017*	
GNSS L1/L5 Antenna MOPS	New GNSS dual-frequency (1575/1176 MHz) antenna MOPS for airborne equipment	December 2017*	

RTCA SC-159 Deliverables (2 of 2)

GNSS(SBAS) L1/L5 MOPS	**Initial MOPS for Verification and Validation** **Validated GPS/SBAS MOPS for dual-frequency equipment including, if possible, at least one additional core constellations.****	**2019-2020*** **2021-2022***	
GNSS(GBAS) L1/L5 MOPS	**Initial MOPS for Verification and Validation** **Validated GPS/GBAS MOPS for dual-frequency equipment and including, if possible, at least one additional core constellations.****	**2020-2021*** **2022-2023***	

* These dates are based upon the current schedule for deployment of L5-capable GPS satellites.

** The level of detail of requirements for additional core constellations dependent upon multiple prerequisites as discussed in Specific Guidance Section below. Additionally, in the case of GNSS (SBAS or GBAS) L1/L5 MOPS, constellation providers are advised to provide final necessary technical information at least two year priors to completion of Initial MOPS for Verification and Validation in order to have their constellations included in the MOPS.

Specific Guidance

Para 5. New MOPS should address, to the extent practicable, the threats of intentional interference and spoofing.

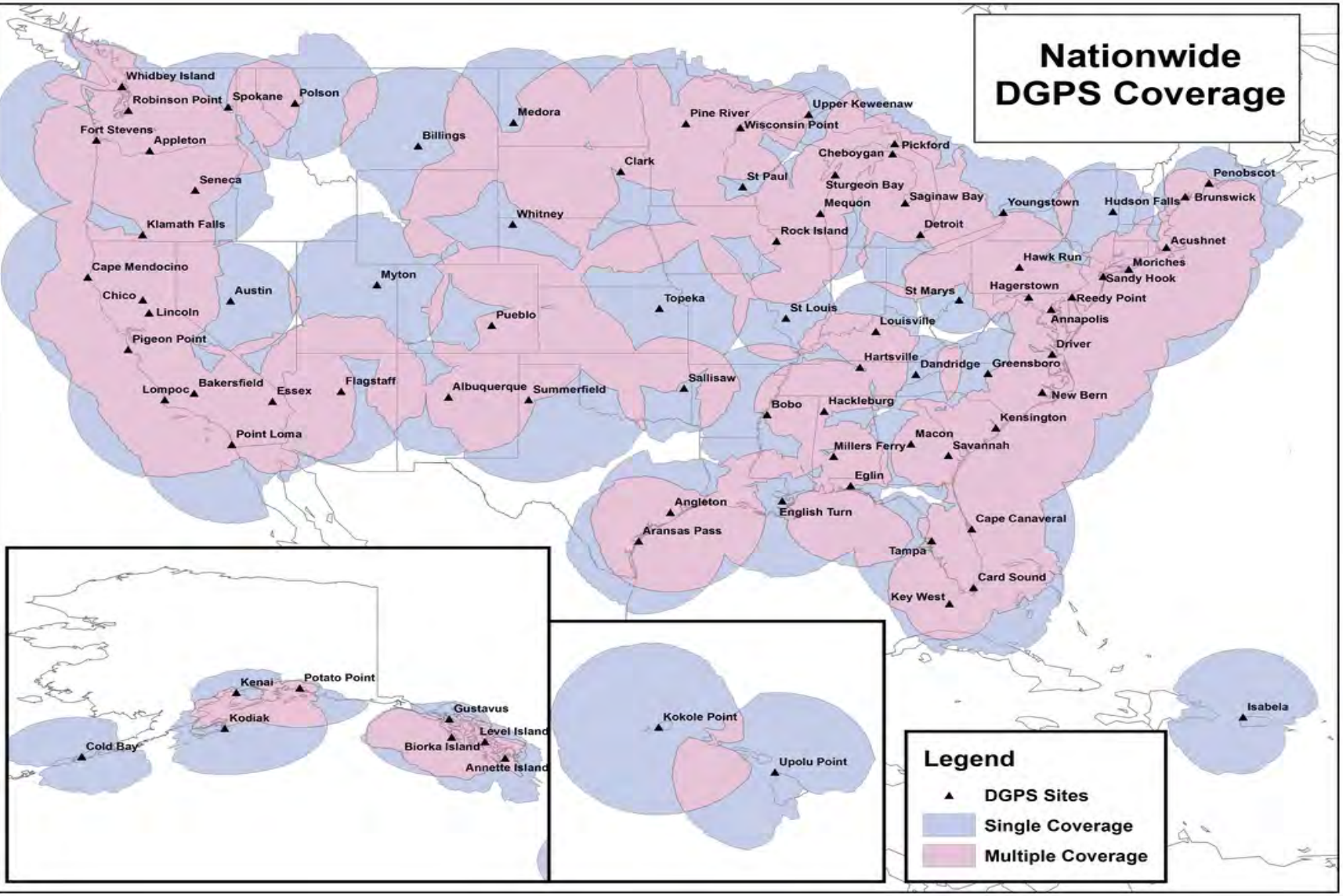
Para 6. New MOPS should address, to the extent practicable, the possibility of higher levels of adjacent-band interference in the future operational environment.

Economywide Differential GPS Update

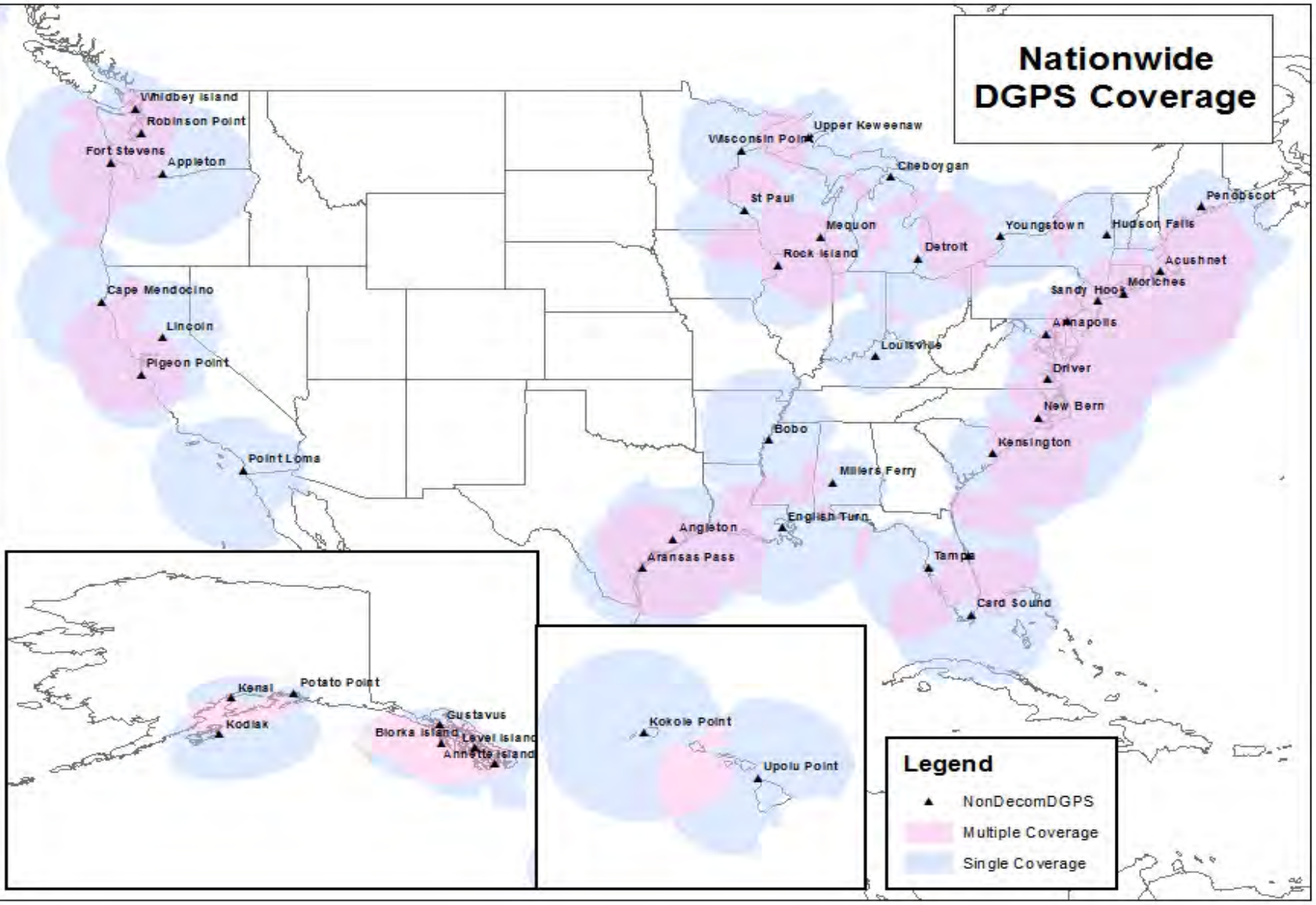
Economywide Differential GPS Update

- NDGPS coverage reduced from 83 sites to 46 sites on August 4, 2016; 44 sites currently retained
  - Eliminated inland coverage
  - Maintained majority of maritime coverage and shifted to single maritime coverage in most areas
- Signal was terminated 30 days after *Federal Register* Notice was released
- Equipment removal initiated and will fully decommission DOT DGPS sites during FY16-FY18 period
- Continuing to evaluate future DGPS need as other GPS augmentation systems mature
- Assessing potential CPNT use of DGPS infrastructure
- Evaluating future reductions and alternatives

Previous NDGPS Coverage with 83 Sites



Current NDGPS Coverage with 44 Sites



GPS Information, Presentations, etc.

GPS BULLETIN

Information for Policymakers from the National Coordination Office for Space-Based Positioning, Navigation, and Timing (PNT)

May 3, 2016

Space Bill Addresses PNT

On April 14, Rep. Jim Bridenstine (R-OK) introduced the American Space Renaissance Act.

Section 103 of the bill is titled "Positioning, Navigation, and Timing." According to the Congressman, the provision "Expresses a sense of Congress on the importance of positioning, navigation, and timing (PNT) for national security and economic prosperity. Requires the Secretary of Defense to provide a strategy to ensure DOD PNT leverages the best available signals from alternative PNT systems. The strategy will address issues associated with monitoring and verifying accuracy, integrity, availability, security, and reliability of foreign PNT signals."

Section 104 cites the National Executive Committee for Space-Based PNT as a model for establishing a new National Executive Committee on Weather.

Learn more at GPS.gov

DHS Demonstrates Precision Timing Technology at NYSE

On April 20, DHS announced the successful demonstration of Enhanced LORAN (eLoran), a precision timing technology, for financial transactions at the New York Stock Exchange (NYSE). Recognizing the challenges of space-based signals and the importance of having multiple timing sources, eLoran is one technology being considered to provide a complementary timing solution to existing GPS technology.

Precise and synchronized timing of financial transactions is critical to markets worldwide and is mandated by regulation in the European Union and is increasingly required in the United States. Today, precision timing capabilities are provided primarily by GPS. However, GPS's space-based signals are low-power and susceptible to possible disruptions. GPS signals are also difficult to receive indoors and in urban canyons.

The live demonstration at the NYSE was hosted by Juniper Networks, Harris Corporation, and UrsaNav, under a cooperative agreement with DHS. Over 60 industry and government representatives attended, including senior officials from DHS, DOT, DOD, Treasury, and DOE. The ensuing discussion highlighted the over-reliance upon GPS for precise timing, the threat of a loss of civil GPS services, possible impacts to the U.S. critical infrastructure and the economy, and a common interest in developing resilient timing solutions for our nation's critical infrastructure.

View press release at DHS.gov

Federal GPS site: www.gps.gov

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