APEC
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U.S. GPS/GNSS Augmentations and GNSS Special Topics

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U.S. National Coordination Office for Space-Based PNT

APEC TPT-WG41
TRANSPORTATION WORKING GROUP MEETING 41
26-29 MAY 2015

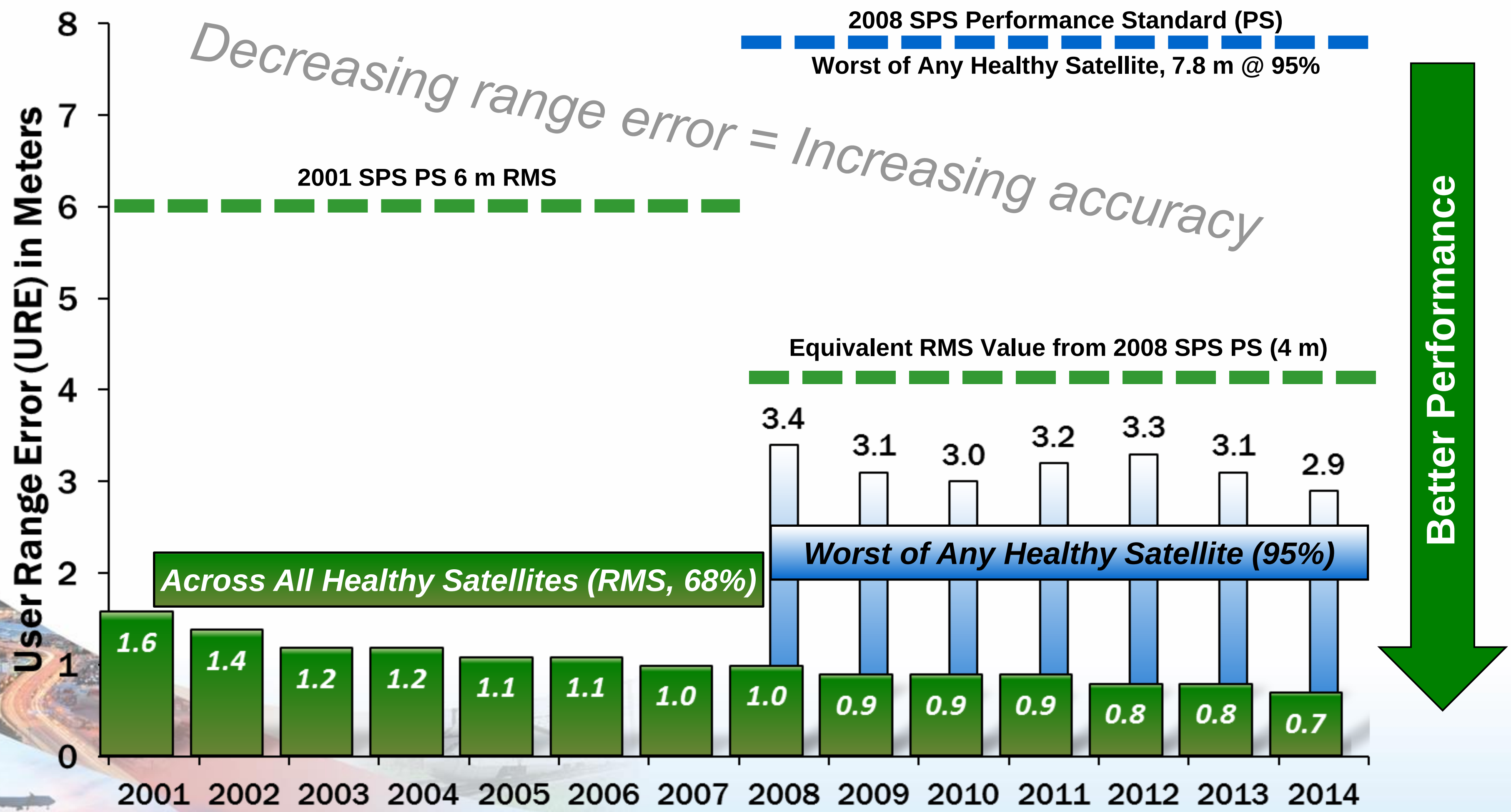
Topics

- U.S. GPS Modernization
- NEXTGEN Navigation System Strategy
- Wide Area Augmentation System (WAAS)
- Advanced RAIM
- Ground Based Augmentation System Update (GBAS)
- Alternative Positioning, Navigation and Timing (APNT)
- National Differential Global Positioning System (NDGPS)
- Complementary PNT

GPS Constellation Status

- Robust operational constellation
  - 31 Operational Satellites (Baseline: 24+3)
  - 3 GPS IIA – L1 C/A, L1 P(Y), L2 P(Y) signals
  - 12 GPS IIR – same signals as IIA
  - 7 GPS IIR-M – adds L2C, L1M, L2M signals
  - 9 GPS IIF – adds L5 signal
- 8 additional satellites in residual/test status
- Modified Battery Charge Control has extended GPS IIR and IIR-M life by 1-2 years per SV
- Global GPS civil service performance commitment met continuously since Dec 1993 (IOC)
  - Best performance 43.8 cm User Range Error (URE) 1 Jan 15; best weekly average 52.7 cm URE 23 Nov 14
  - Performance improving as new satellites replace older satellites

Standard Positioning Service (SPS) Signal-in-Space Performance

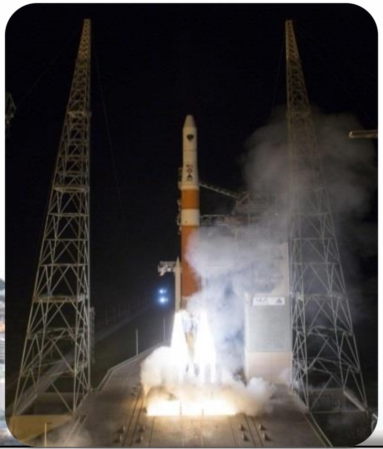


System accuracy better than published standard

GPS IIF Status

- 4 successful GPS IIF launches in 2014
- SV-9 launched 25 Mar 2015
- 9 total GPS IIFs on-orbit
- 3 more GPS IIFs in the pipeline
  - 2 more GPS IIF launches planned in 2015
  - SVs 10, 11, and 12 in storage

25 Mar: IIF-9



20 Feb: IIF-5

16 May: IIF-6

1 Aug: IIF-7

29 Oct: IIF-8

2014—Most GPS launches in a single year since 1993

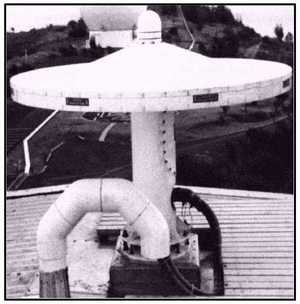
GPS III Status

- 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
  - Three improved Rubidium atomic clocks
- SV07/08 contract awarded 31 Mar 2014
- SV09/10 planned for purchase under current Lockheed contract
- Navigation payload space environment testing at Lockheed Martin's Colorado facility Sep 14
- GPS III Non-flight Satellite Test bed reduced risk for integration, test and launch processing
- GPS III SV01 available for launch in CY 2017

Lockheed-Martin (Waterton, CO) – Prime

Ground Segment Status

- Current system Operational Control Segment (OCS)
  - Flying GPS constellation on Architecture Evolution Plan (AEP) and Launch & early orbit, Anomaly, and Disposal Operations (LADO) software systems
  - Cyber security enhancements in progress


Monitor Station

- Next Generation Operational Control System (OCX)
  - Modernized command & control system with M-Code, modern civil signal monitoring, info assurance infrastructure and improved PNT performance: Raytheon (Aurora) Prime
  - Successfully completed four GPS III launch exercises
  - OCX Block 0 supports launch & checkout for GPS III; currently in integration & test; delivery expected Jan 2016
  - OCX Block 1 supports transition from OCS in 2019
  - Civil Signal Performance Monitoring capability scheduled for OCX Block 2 in 2020


Ground Antenna

Modernized Civil Signals

- United States initiated continuous CNAV message broadcast (L2C & L5) on 28 Apr 14; beginning with twice-a-week uploads and daily (nominal) uploads since 31 Dec 2014
  - Position accuracy not guaranteed during pre-operational deployment
  - L2C message currently set “healthy”
  - L5 message set “unhealthy” until sufficient monitoring capability established and initial operational capability established
- User-Range Error (URE) CNAV performance
  - Daily uploads consistent with or exceed LNAV performance
  - Inter-signal correction enable single point positioning competitive with dual-frequency P(Y) code receivers
- 24 Satellites broadcasting L5 signal estimated in 2024

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PBN Roadmap (2006) – What's accomplished?

Near Term (2006-2010)	Mid Term (2011-2015)	Far Term (2016-2025)
En Route RNAV Q routes ❑ RNP-2 routes T routes and lower MEAs Requirements to incorporate aircraft navigation capabilities into en route automation **Oceanic** ❑ RNP-10 and 50/50 NM lat/long Pacific RNP-10 and 60 NM lat in WATRS ❑ Expand 30 NM longitudinal/ 30 NM lateral separation (30/30) in the Pacific ❑ Explore RNP-4 in NAT **Terminal** RNAV SIDs/STARs at OEP airports RNP-1 SIDs/STARs where beneficial Automation requirements for merging RNAV arrivals Concepts for RNAV and RNP with 3D, constant descent arrivals (CDA), and time of arrival control **Approach** At least 25 RNP SAAAR per year 300 RNAV (GPS) per year Standards for closely spaced and converging runway operations based on RNP	**En Route** ❑ RNP-2 routes T routes and lower MEAs Enhanced automation incorporating aircraft navigation capabilities ❑ At end of mid term, mandate RNP-2 at and above FL290, and mandate RNAV at and above FL180 **Oceanic** Limited RNP-4 and 30 NM lat in WATRS Increase use of operator-preferred routes and dynamic re-routes **Terminal** RNAV SIDs/STARs at many of the top 100 airports RNP-1 or lower SIDs/STARs where beneficial Airspace redesign and procedures for RNAV and RNP with 3D, CDA, and time of arrival control ❑ At the end of mid term, mandate RNAV for arriving/departing at OEP Airports **Approach** At least 50 RNP per year 300 RNAV (GPS) per year Closely spaced parallel and converging runway operations based on RNP Satellite-based low visibility landing and takeoff procedures (GLS)	**Performance-Based NAS Operations** RNP Airspace at and above FL290 Separation assurance through combination of ground and airborne capabilities Strategic and tactical flow management through system-wide integrated ground and airborne information system System flexibility and responsiveness through flexible routing and distributed decision-making ❑ Optimized operations through integrated flight planning, automation and surface management capabilities ❑ Mandate RNAV everywhere in CONUS ❑ Mandate RNP in busy en route and terminal airspace

Operationally available

In progress

VOR MON Program

- VOR MON program supports the NAS transition from the current VOR airways to more efficient Performance Based Navigation (PBN) consistent with NextGen goals and the NAS Efficient Streamlined Services Initiative (NESS)
- VOR MON Program will discontinue VORs enabling pilots to:
  - Revert from PBN to conventional navigation in the event of a GPS outage
  - Tune and identify a VOR within 77 miles at a minimum altitude of 5,000 feet above ground level;
  - Navigate using VOR procedures clear of a GPS outage area;
  - Navigate using VOR procedures to a MON airport within 100 miles to fly an ILS or VOR instrument approach without distance measuring equipment (DME);
  - Navigate along VOR Airways especially in mountainous terrain where surveillance services are not available; and
  - Navigate to an area where radar surveillance services are provided
- Approximately 30% (308) of VORs are potential candidates for discontinuance
  - Actual discontinuance will be accomplished using established policies

VOR MON Program Status

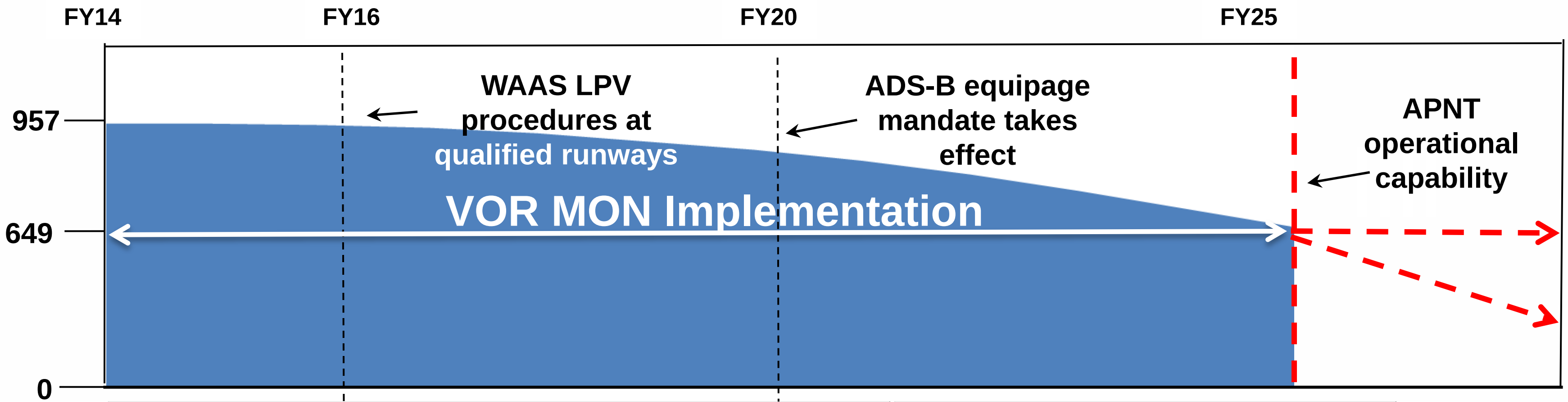
Accomplishments

- Concept of Operations – Jan 2014
- Investment Analysis Readiness Decision (IARD) – Mar 2014
- Program Charter Signed – Apr 2014
- DoD/DHS Retention Coordination Received – Jan 2015
- RTCA Tactical Operation Committee (TOC) Recommendations Received – Feb 2015
- Standard Service Volume (SSV) Flight Testing Started– Mar 2015

Next Steps

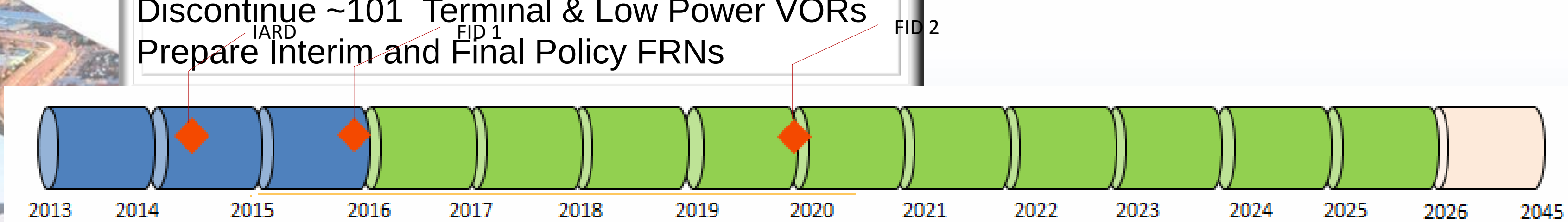
- Final Investment Decision artifacts – Developing detailed plans, cost and remaining artifacts to meet the Sep 2015 date
- Publish Interim Federal Register Notice with Phase 1 target discontinuance list

VOR MON Notional Strategy and Timeline



Phase 1
Complete FID
Support National Route Structure Plan (NRSP)
IFP Remove, Replace, Amend
ILS amendments
RNAV IAP development
Discontinue ~101 Terminal & Low Power VORs
Prepare Interim and Final Policy FRNs

Phase 2
Update FID and SRM artifacts
Continue IFP work
Discontinue ~207 VORs



VOR MON Program Timeline

NextGen DME

- Purpose
  - Determine a distribution of DME sites to yield RNAV 1 coverage with no critical sites:
    - Using many existing DMEs and some new locations
    - Serving airliners with IRU
    - Offering en route and terminal coverage for major airports
- RNAV 1 coverage with no critical sites
  - DME range errors compliant with AC90-100A
  - No solution depends on any one DME
- Allows outage gaps consistent with DME/DME/IRU inertial coasting limits of FAA's RNAV-pro
  - Minimum ground speed of 200 kts
  - Maximum coasting time of 10 minutes
  - Maximum coasting gap = (200 kts * 10 min) = 33⅓ nmi

NextGen DME Enroute Plan

- 8 New Sites
- 72 FOM 2 upgrades
  - May require upgrades from L-Class to H-Class
    - If so, frequency changes may be required
- 30 DME sites identified as critical
  - These sites require redundancy and backup power (or equivalent measures) to support 99.9% RNAV service availability requirement
  - Some of these are also identified as requiring FOM upgrades

NextGen DME Terminal and Enroute Plan

- Building on four years of DME/DME modeling for NextGen DME
  - Service for 64 major airports and en route
  - Retain around 400 existing sites
    - About ⅔ of these require the service volume to be increased
  - Relocate around 200 new sites
    - Some DMEs at discontinued sites may be moved to these new sites
  - Decreases the total number of sites by about ⅓

NextGen DME Assumptions

1. Service improvements intended to accommodate DME/DME (no inertial) RNAV
2. Pending the issuance of an AC for enroute RNP, RNP and RNAV are assumed to be equivalent in terms of coverage areas
3. AC 90-100A is currently the sole applicable document for defining operational DME/DME RNAV coverage as a function of the infrastructure
4. The maximum allowable coverage gap is 4 NM in any dimension
5. Infrastructure investments to enhance offshore service are beyond the scope of this effort
6. New DME facilities will be capable of providing service compatible with ARINC 424 FOM 2 (maximum range of 130 NM)
7. DME "Y" channels are available for new facilities, if required for frequency management purposes
8. FAA policy and procedures will accommodate "standalone" DME facilities
9. FAA is responsible for final business case decisions on infrastructure investments
10. Future phases of this effort will encompass
    - Loading/capacity analyses, service/infrastructure improvements for the far term (2025), potential infrastructure reductions, and detailed implementation plans including site surveys

Summary

- FAA is transitioning to Performance Based Navigation (PBN)
- However, resiliency is essential to safety, efficiency, capacity
- Sufficient legacy NAVAIDS will be retained to support the National Airspace System (NAS) in the event of GPS interference
  - VOR MON Program plans to discontinue approximately 30% of VORs in the NAS by 2025
  - NextGen DME programs to provide RNAV 1 coverage with no critical sites
  - ILS Rationalization Decision planned in FY16 to determine if the FAA can achieve cost savings while retaining airport access and safety benefits
  - National Procedures Assessment Initiative plans to remove 730+ NDB/VOR unused or underutilized procedures

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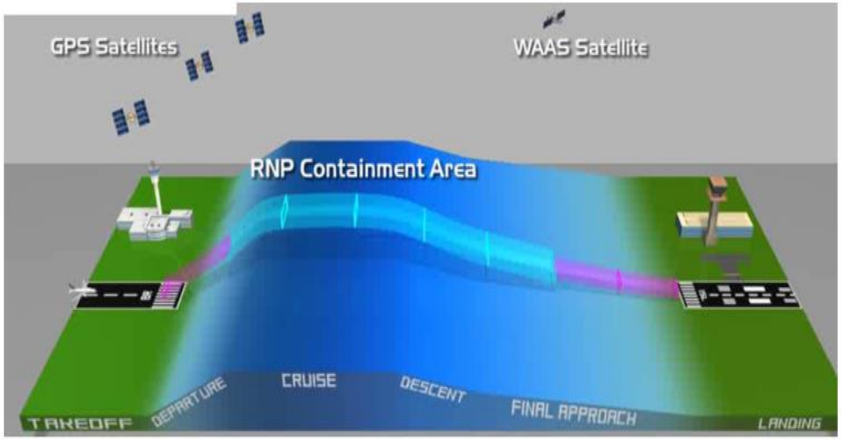
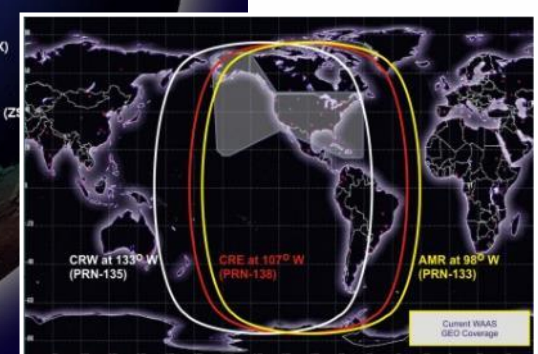
WAAS Program Overview

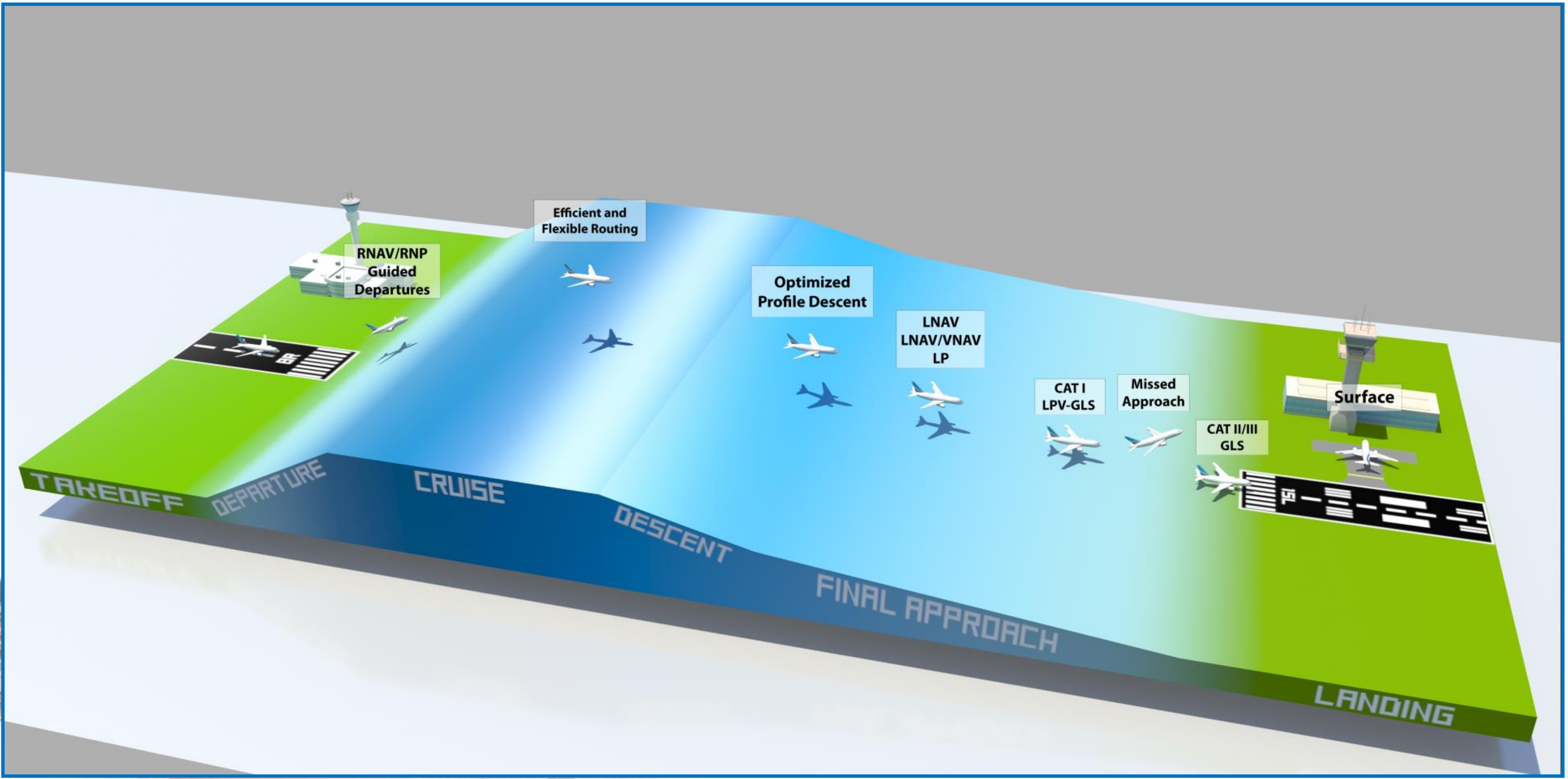


- WAAS provides precise navigation and approach guidance covering entire National Air Space (NAS)
- Combination of ground-based and space-based assets
- Augments the Global Positioning System (GPS) Standard Positioning Service (SPS)
- Provides both safety and capacity improvements in the NAS and has been operational since 2003
- Can reduce FAA operations costs by enabling removal of a portion of the legacy ground-based navigation infrastructure

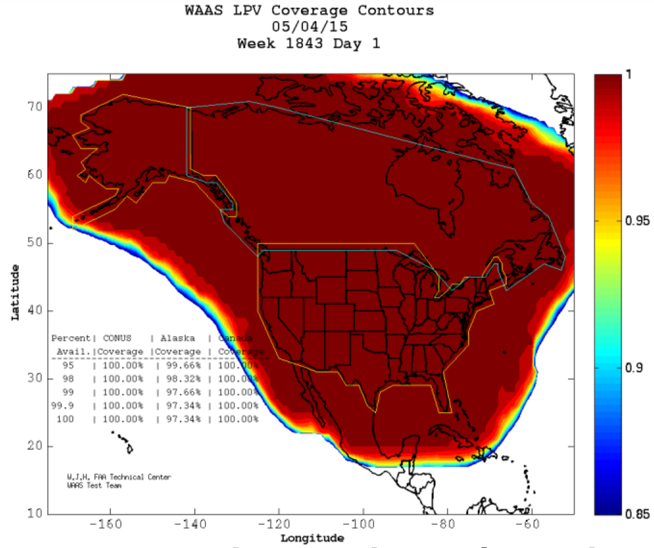
WAAS Infrastructure



WAAS Supported Operations

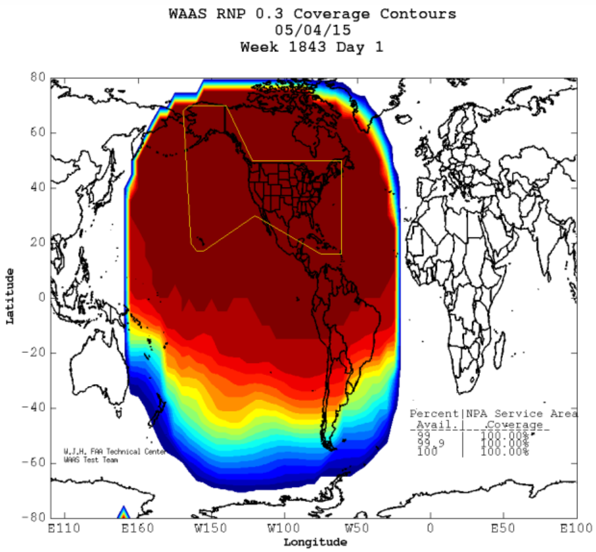


WAAS LPV/ RNP 0.3/ RNP 0.1 Coverage

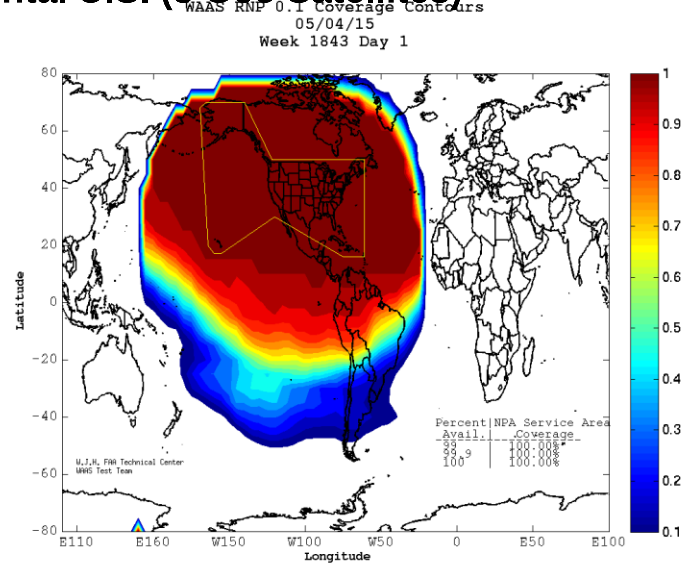


Full LPV 200 Coverage in Continental U.S. (3 Geo Satellites)

RNP 0.3



RNP 0.1



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
- Phase III: Full LPV-200 Performance (2009 – 2014) **- Completed**
  - Improve performance during moderate ionospheric activity
  - Preparation for GPS L5 transition
- 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 and provide dual-frequency service
    - Planning transition to L5 within 2 years of GPS L5-signal Full Operational Capability (FOC)

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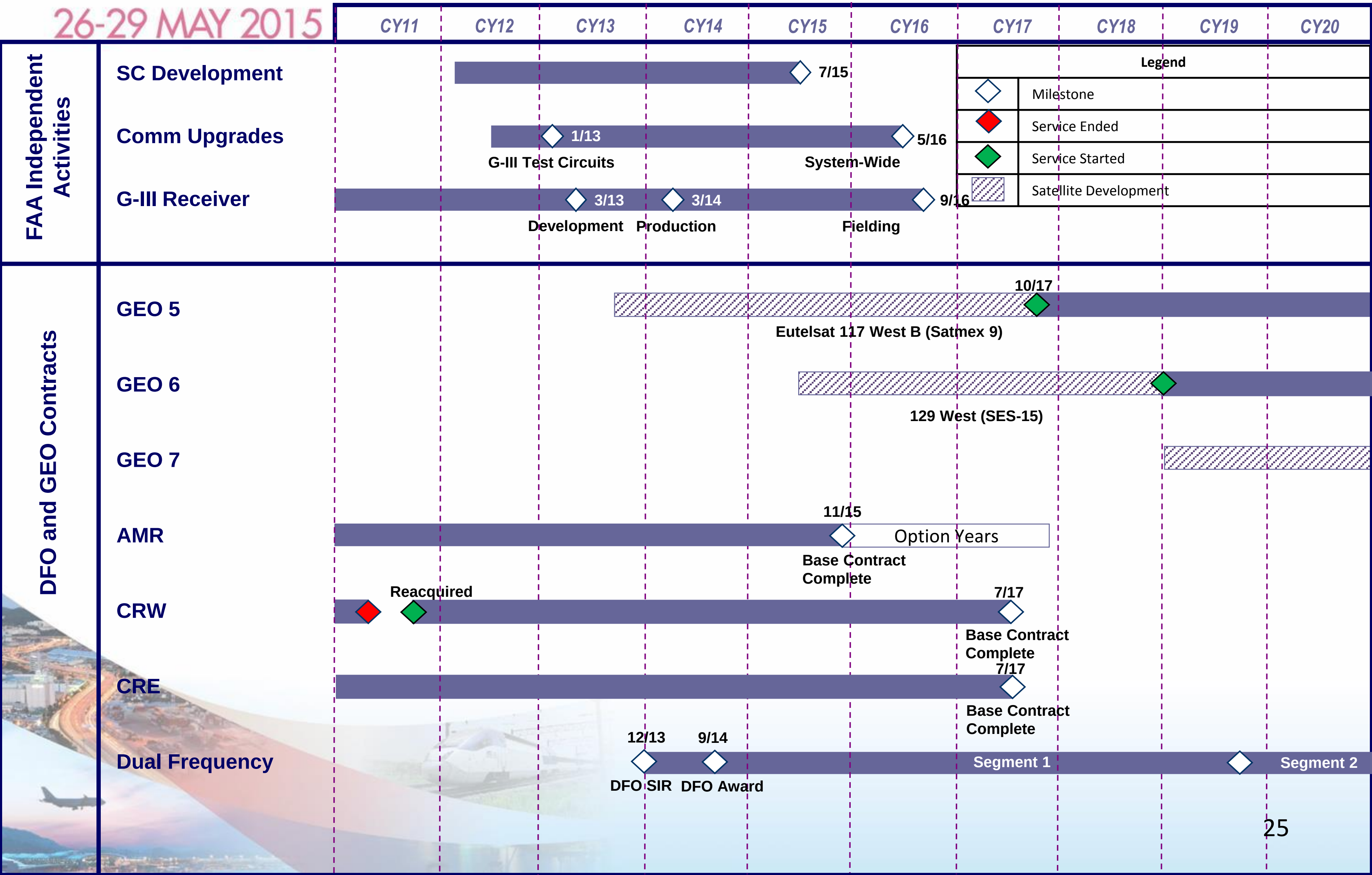
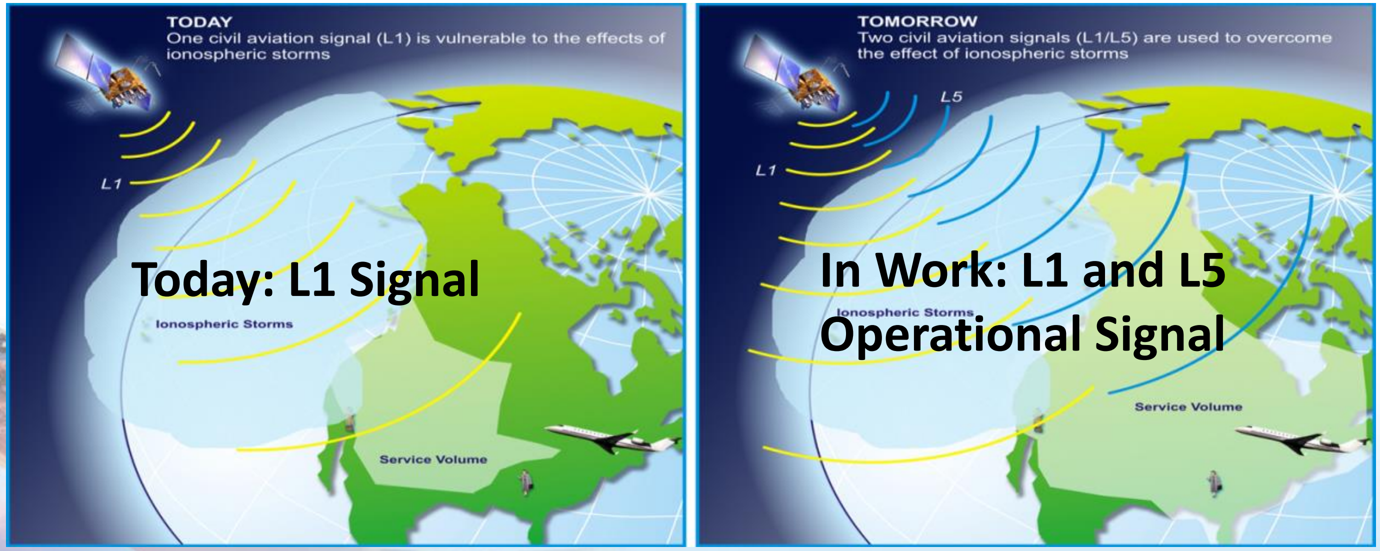
WAAS Schedule



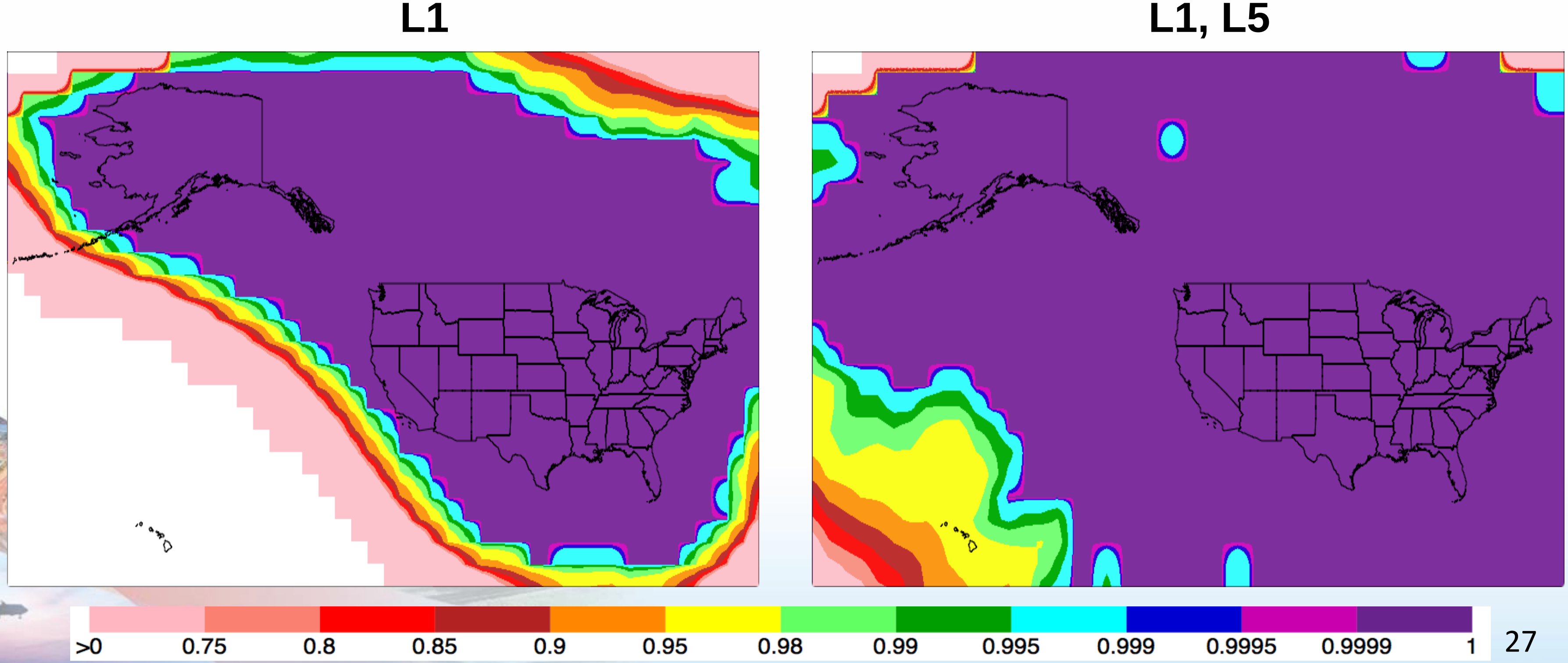
Dual Frequency Operations

- Sunset of L2 P(Y) semi-codeless “commitment” compels WAAS to use another signal to maintain current service
  - USG Federal Register Notice identified ‘sunset’ in December 2020
  - L2C/L5 readiness dates slipping (updates in Federal Radio-navigation Plan)
- In May 2014 WAAS Final Investment Decision for Phase IV Segment 1 Dual Frequency Operations (DFO) was approved
  - Segment 1 - Develop infrastructure to support L5 & Tech Refresh



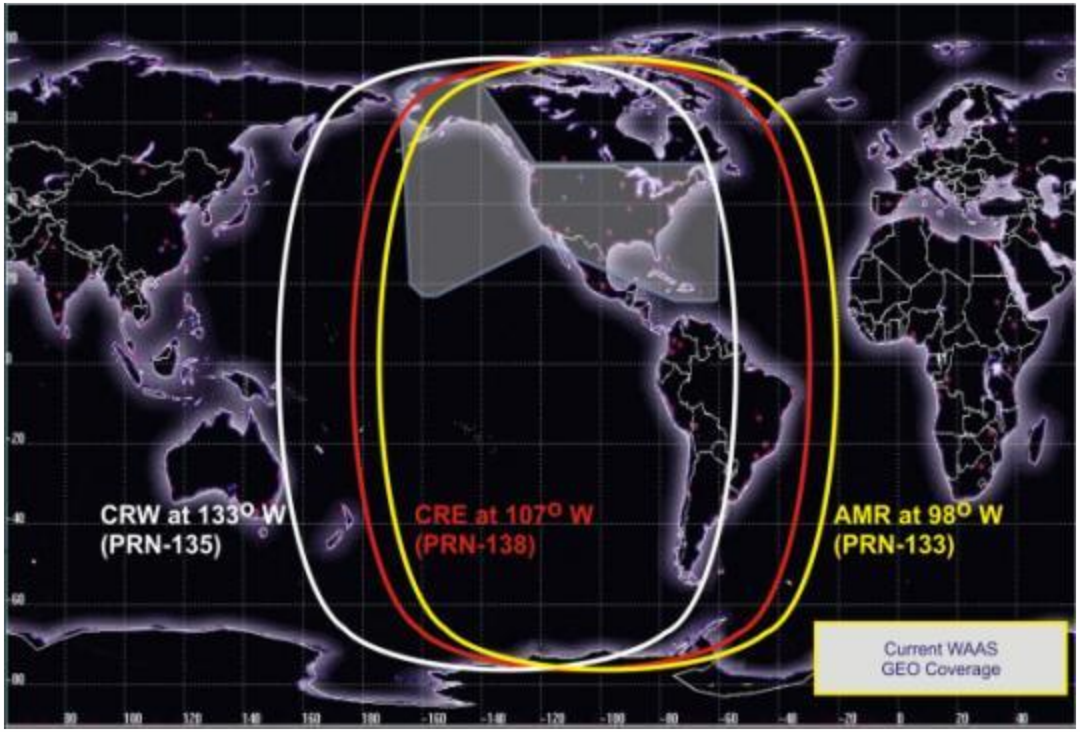
Dual Frequency Operational Benefits

- Dual freq L1/L5 service improves availability and continuity
- Provides LPV 200 services to Hawaii
- Eliminates edge of coverage issues



WAAS GEO Activities

- Current WAAS GEOs
  - Intelsat Galaxy XV (CRW)
  - Anik F1R (CRE)
  - Inmarsat I4F3 (AMR)*
- GEO Sustainment
  - GEO 5/6 GEO service leases awarded in 2012
    - GEO 5 in progress, expected addition in 2017
    - GEO 6 authorization to proceed awarded Mar 15
  - GEO 7 ops expected in 2019



*AMR ranging only supports horizontal navigation

GEO 5

- Payload status
  - Started satellite payload and GUS site design in 2013
    - EUTELSAT 117 West B (former SatMex 9) satellite
    - 117W orbital slot provides full coverage of CONUS and Alaska
  - Achieved Preliminary and Critical Design review milestones
  - Payload being integrated onto the satellite, launch in late 2015
- GUS status
  - Refurbish old POR site in Santa Paula
  - Built new site in Southbury
  - Equipment installation in early 2016

WAAS Enables PBN

		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

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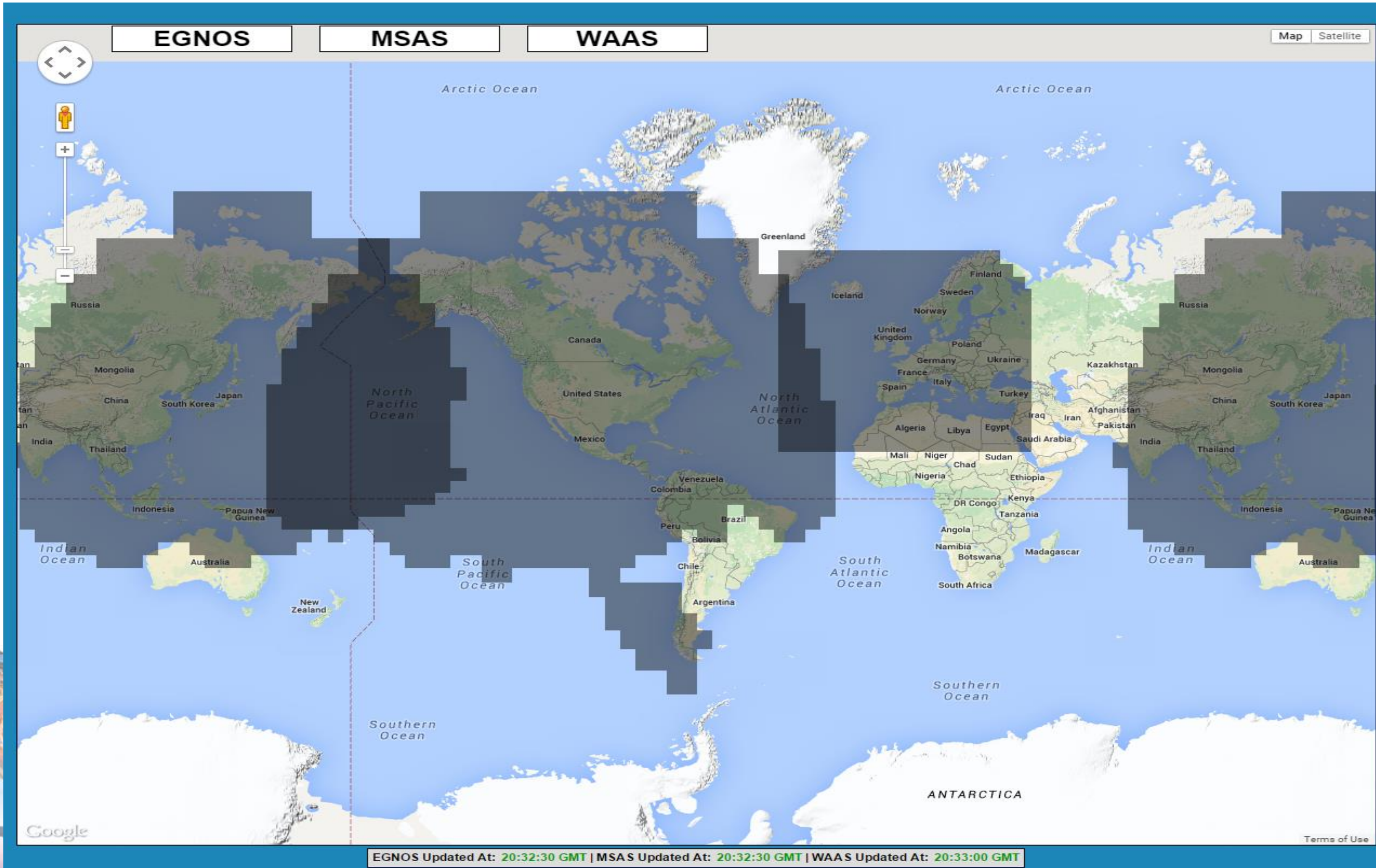
Current SBAS RNP 0.3 Coverage



WAAS Phase IV Investigations

- Dual-Frequency Multi-constellation Capability
  - International Focus is on taking advantage of other GPS like constellations
    - International Civil Aviation Organization (ICAO) Navigation Systems Panel (NSP) has developed a work plan supporting development of future standards for use of other Global Navigation Satellite Systems (GNSS)
    - ICAO working on CONOPS addressing all DFMC applications (e.g. SBAS, GBAS)
  - 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
  - ARAIM subgroup developing concept definition
    - Coordinate standards development with ICAO, RTCA and EUROCAE
    - Request for public feedback on Milestone 2 report analysis and conclusions
    - Evaluate feedback and finalize Milestone 2 report and incorporate into Milestone 3 report expected in winter 2015/16

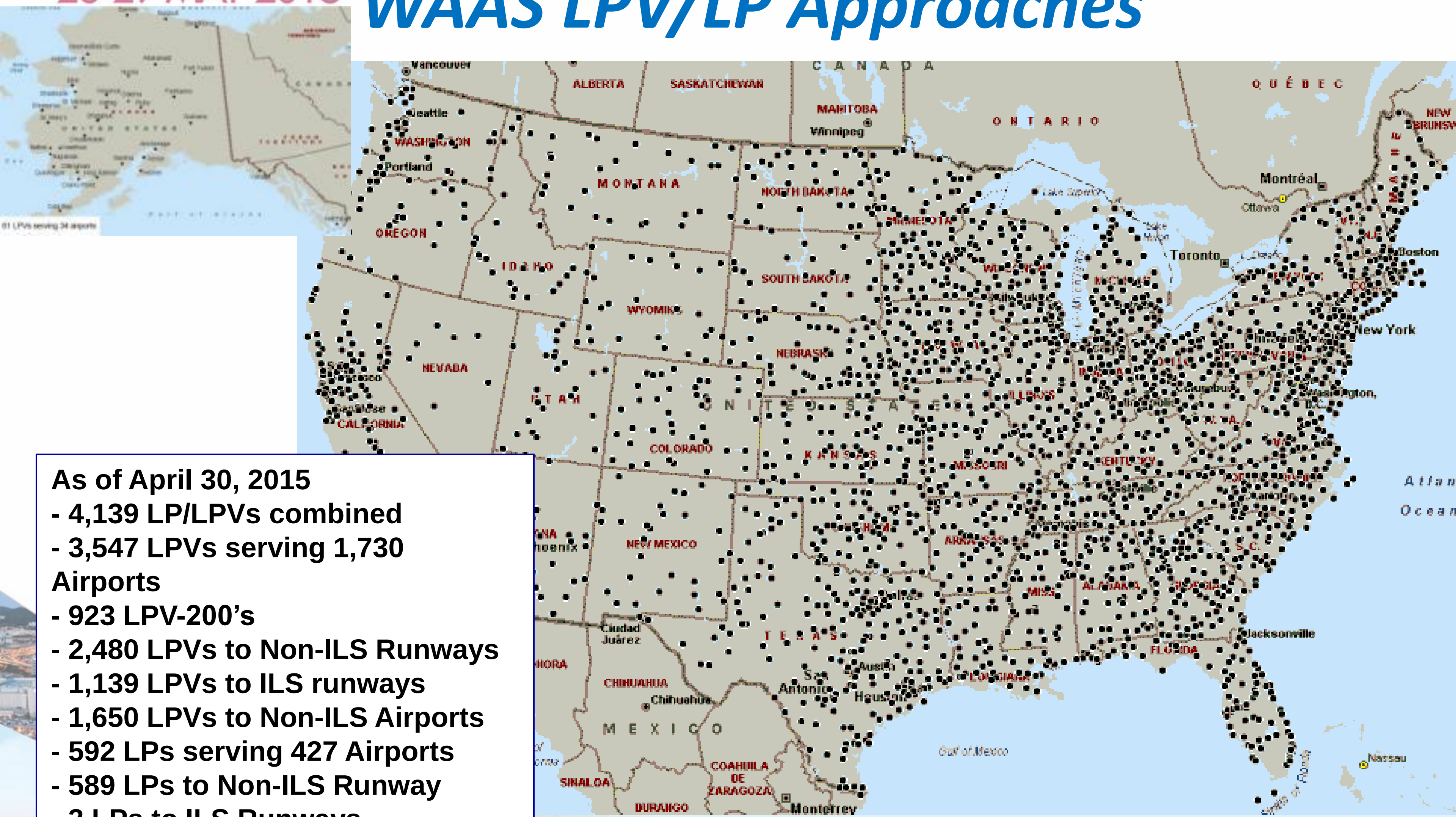
http://www.gps.gov/policy/cooperation/#europe

WAAS Users

- Approximately 82,000 WAAS equipped aircraft in the NAS
  - Providers include: Garmin, Universal, Rockwell Collins, Honeywell, Avidyne, Innovative Solutions & Support (IS&S), Thales and Genesys Aerosystem (Chelton)
- Aircraft equipage rate increasing each year
- Smaller airports and communities they serve are within reach, even in low weather
- 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) Ex. - Area Navigation (RNAV), Required Navigation Performance (RNP), and Point in Space (PinS) procedures




WAAS LPV/LP Approaches



As of April 30, 2015
- 4,139 LP/LPVs combined
- 3,547 LPVs serving 1,730 Airports
- 923 LPV-200's
- 2,480 LPVs to Non-ILS Runways
- 1,139 LPVs to ILS runways
- 1,650 LPVs to Non-ILS Airports
- 592 LPs serving 427 Airports
- 589 LPs to Non-ILS Runway
- 3 LPs to ILS Runways

WAAS Outreach Initiatives

- Point-in-Space (PinS) Project for WAAS-equipped fixed wing aircraft in Alaska
  - Supports FAA's "Increase Alaska Safety" mandate by demonstrating feasibility of WAAS-equipped fixed wing aircraft Point-in-Space (PinS) approaches originating from "T" route waypoints in Alaska
- FAA/DoD Lakota (UH-72) Helicopter WAAS/LPV Project
  - Encourages increased use of WAAS/LPV by U.S. Army as well as other military services
    - Helicopter Point-in-Space (PinS) procedures for various missions
    - FAA/DoD equipage of Lakota helicopter with GPS/WAAS and ADS-B

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ARAIM Technical Subgroup (TSG)

- Formed under Working Group C (WG-C) defined by the 2004 U.S.-EU Agreement on GPS-Galileo Cooperation
  - Purpose of WG-C is to promote cooperation on the design and development of the next generation of civil satellite-based navigation and timing systems
- ARAIM TSG objective is to investigate candidate concepts for provision of future integrity services
- Performance goals include:
  - Enroute and terminal area flight
  - Lateral and vertical guidance during approach operations down to 200’
    - Analysis performed using LPV-200 criteria
- Three phases with work captured in three phase reports

ARAIM Implementations

- Provides vertical, as well as horizontal, aircraft guidance
- Avionics can compare ranging measurements to different satellites to ensure they are consistent
- The satellites must perform within a certain range of expectations to meet aviation integrity requirements
- Individual aviation authorities may independently monitor satellite performance and could provide an Integrity Support Message (ISM)
- Alternatively, authorities can accept "trusted" ISM from other sources including GNSS provider State
- Given an assumed set of fault modes, responsibility for mitigating each fault can be assigned to aircraft, ground, space segment, or some combination
- Each ARAIM architecture requires an allocation strategy so that each segment can be assessed relative to its goal

KEY ARAIM ARCHITECTURAL PROPERTIES

- Key architectural properties:
  - Bounding methodology (ranging quality, GNSS failures)
  - Communication and computation latency
  - Broadcast methodology
  - Integrity Support Message (ISM) contents
  - Handling of constellation faults
  - Reference network
- Properties are strongly interconnected, so a choice in one area may strongly influence choices in others

RAIM and Advanced RAIM Comparison

	RAIM	ARAIM
Operations	Down to RNP 0.1	LPV 200
Hazard category	Major	Hazardous
Signals	L1CA	L1CA/E1-L5/E5a
Threat model	Single fault only	Multiple faults
Nominal error model	Gaussian Uses bound broadcast by GPS	Gaussian + nominal/max bias validated by independent ground monitoring
Constellations	GPS	Multi-constellation

Interim Conclusion

- To be effective, ARAIM requires increased trust in core constellations and/or the supporting ground infrastructure
- Implementation architecture must provide additional trust through a bounding methodology
- Key architecture selection tradeoff decisions:
  - Threats mitigated by ground, versus threats mitigated by satellites, and/or avionics algorithm
  - Level of confidence required to validate constellation performance and how quickly a response to identified issues is needed (i.e. Time to ISM Alert (TIA) latency)?

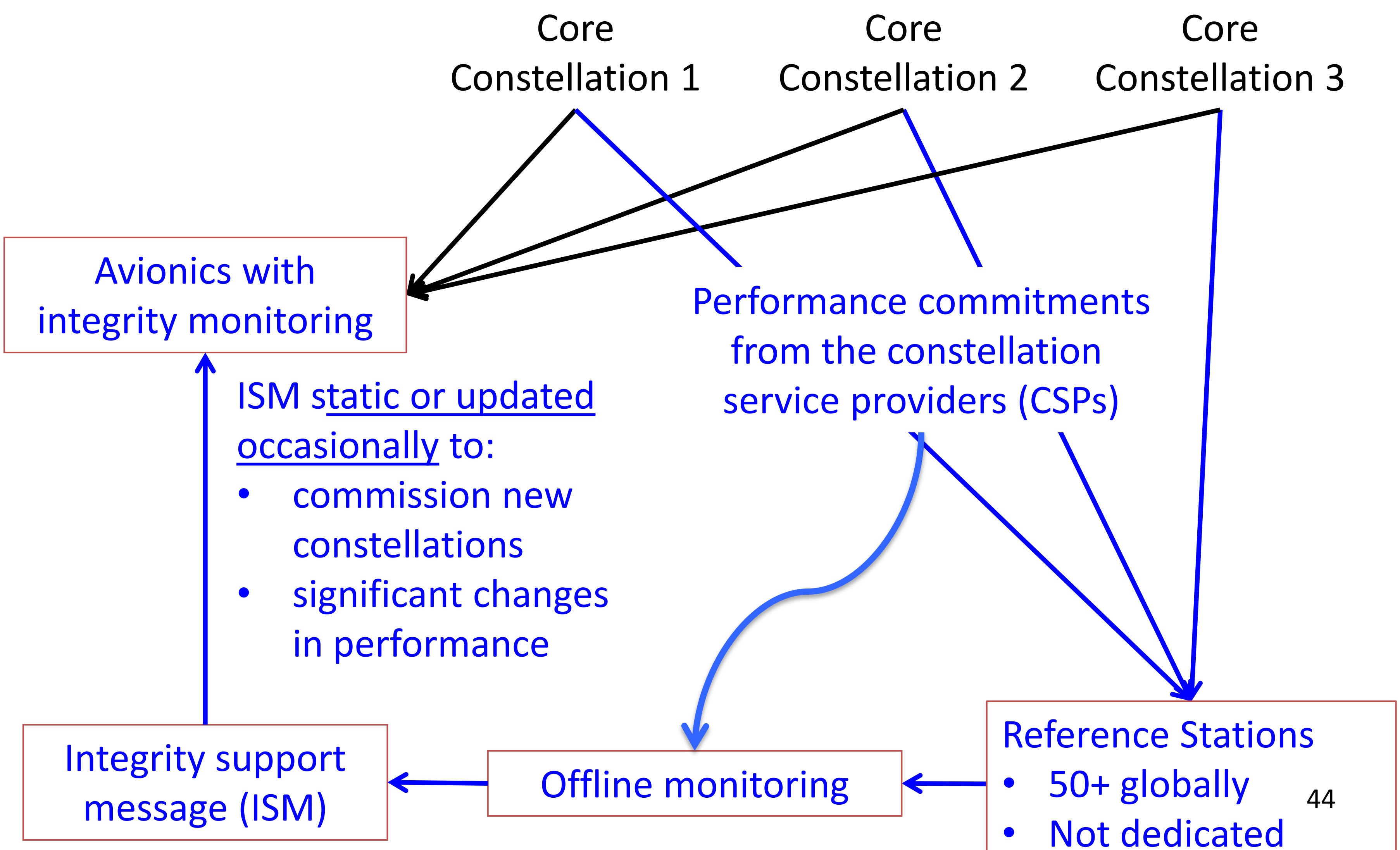
Architecture Comparison

	Offline	Online
Reference network	Global (50+ stations), Non-dedicated (e.g. IGS, NASA's GDGPS)	Global (15-20 stations), Dedicated, Guaranteed Latency (2-3 RX/station)
Source of clock and ephemeris	Uses navigation messages from core constellations	Independent ephemeris overlay
ISM generation	Offline analysis and validation of post processed data	Online monitoring (automatic)
ISM latency	Days to Weeks	Hours
Broadcast channel options	Aeronautical Database, ATC Datalink, VDB, core constellation spare bits	ATC Datalink, VDB, Alternate PNT, GEO, core constellation spare bits

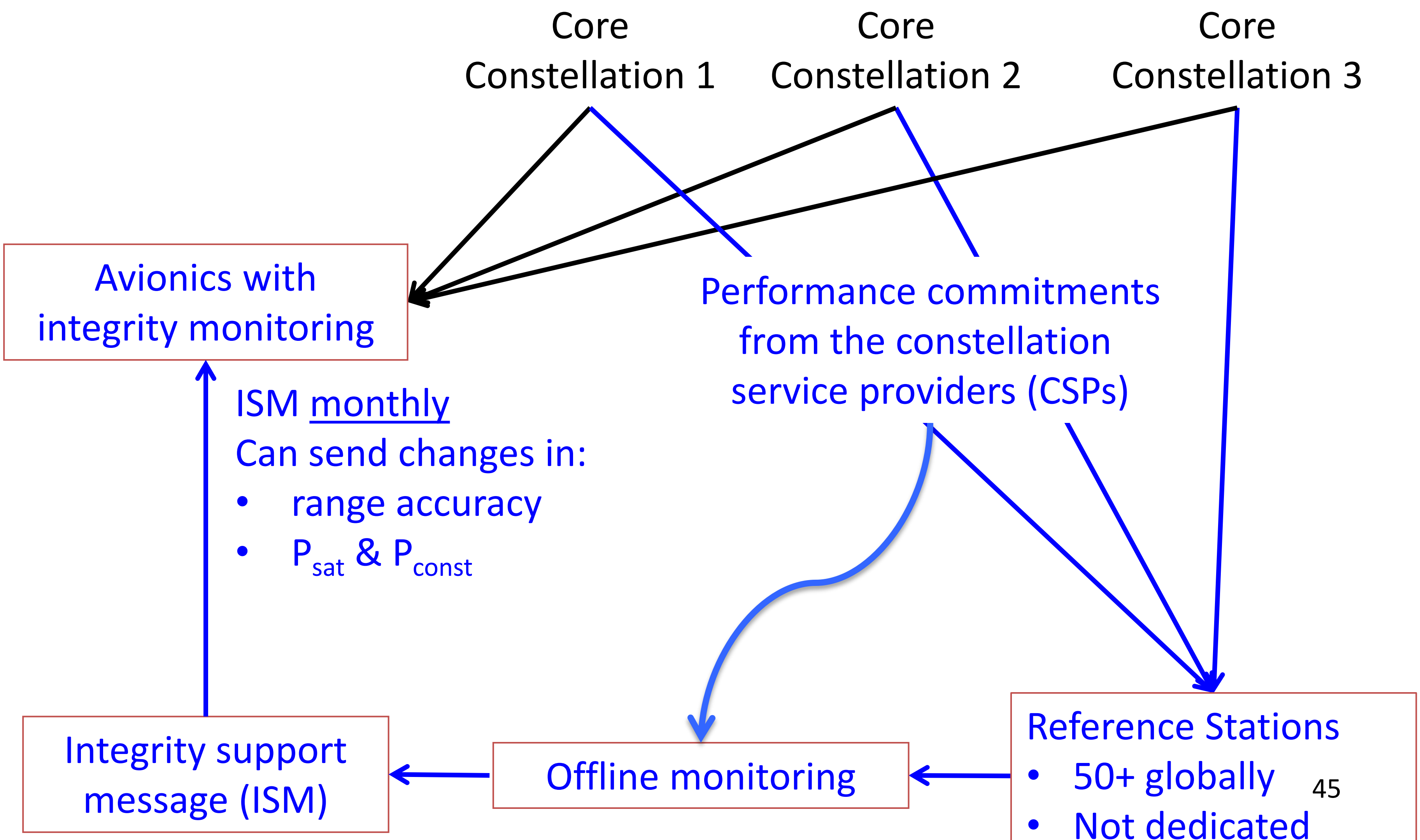
ARAIM SG Work Plan

- Milestone (MS) 1 and 2 complete:
  http://www.gps.gov/policy/cooperation/europe/2013/working-group-c/
  http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_id=6454
- Milestone 3 will address the following:
  - Roadmap for implementation
  - Vertical ARAIM (V-ARAIM) and SBAS relationship
  - Obtain stakeholder feedback on MS IIB report using questionnaire
  - Identify priority technical issues to be worked post-MS III
- Current MS 3 status
  - Questions been sent to RTCA, ICAO and EUROCAE
    - Additional solicitation of GPSD and FAA stakeholders needed
      - ARAIM SG ability to address challenges and risks associated with ARAIM that could feed into future GPS or WAAS/EGNOS investments or acquisition decisions
  - Draft report section preparations prior to Jun 2015 WG-C meeting

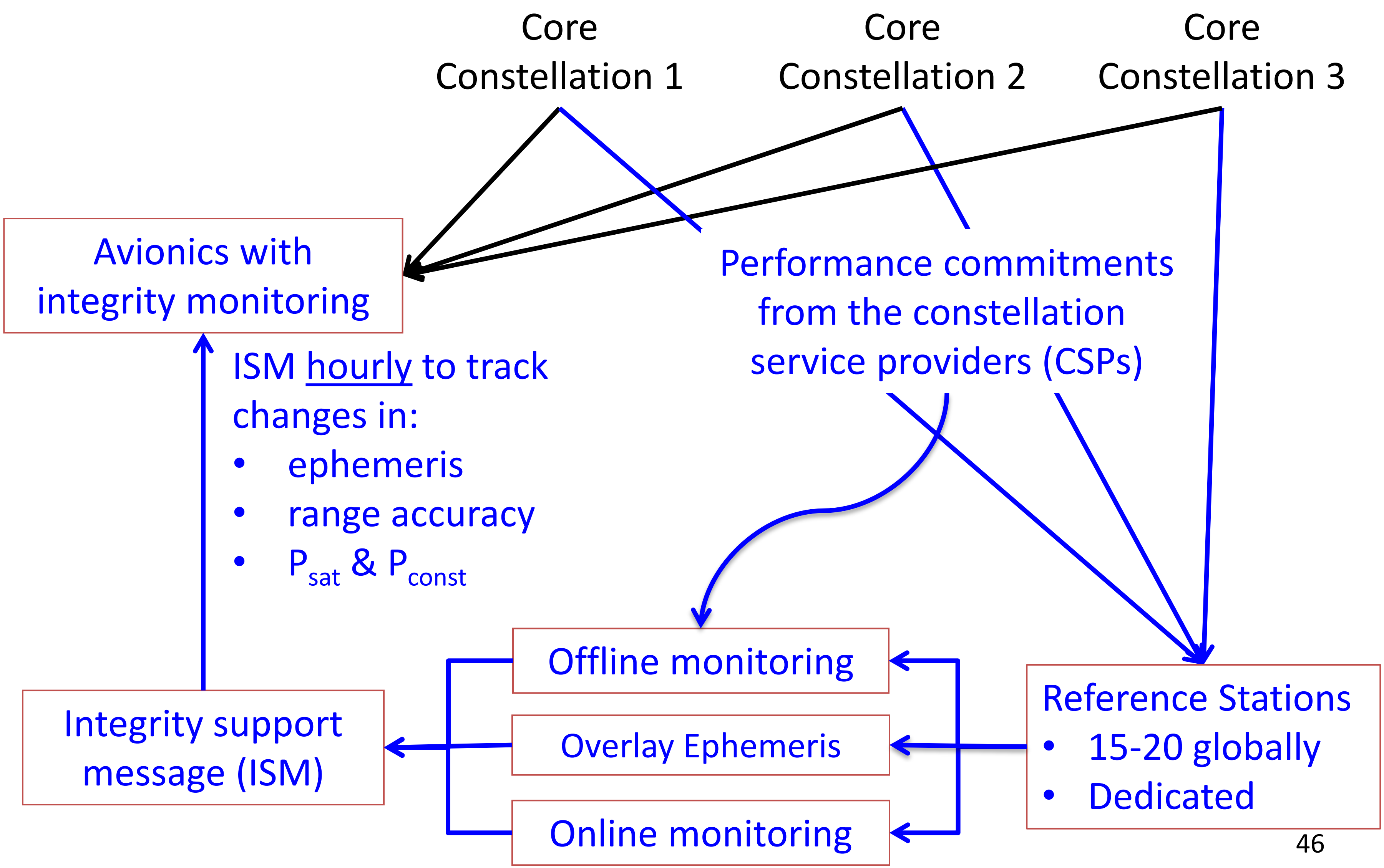
Horizontal-Only ARAIM



Offline Architecture



Online Architecture



Horizontal ARAIM Performance

L1 and L5 Constellation/P_{const}	GPS 10^{-8} Gal 10^{-8}	GPS 10^{-8} Gal 10^{-4}	GPS 10^{-4} Gal 10^{-4}	Single (10^{-8}) Constellation
Depleted (GPS 23 - Gal 23)	RNP 0.1	RNP 0.1	RNP 0.1	RNP 0.3
Baseline (GPS 24 - Gal 24)	RNP 0.1	RNP 0.1	RNP 0.1	RNP 0.1
Optimistic (GPS 27- Gal 27)	RNP 0.1	RNP 0.1	RNP 0.1	RNP 0.1

L5 Only Constellation/P_{const}	GPS 10^{-8} Gal 10^{-8}	GPS 10^{-8} Gal 10^{-4}	GPS 10^{-4} Gal 10^{-4}	Single (10^{-8}) Constellation
Depleted (GPS 23 - Gal 23)	RNP 0.1	RNP 0.3	RNP 0.3	RNP 2
Baseline (GPS 24 - Gal 24)	RNP 0.1	RNP 0.3	RNP 0.3	Low RNP 0.3
Optimistic (GPS 27- Gal 27)	RNP 0.1	RNP 0.3	RNP 0.3	RNP 0.3

Table E-1. Estimated global level of horizontal service for user range accuracy = 2.5 m. The top table is for dual frequency GNSS, and the bottom table is for a reversionary mode based on L5 only.

Color coding is based upon RNP 0.1 objective using the following level of service criterion: 90% coverage of 99.5% availability between -70 and 70 degrees latitude; Text indicates level of service achieved.

Vertical ARAIM Performance

Off-line

ARAIM residuals test used to do constellation check. $P_{sat} = 10^{-5}$, $P_{const} = 10^{-4}$					
Constellation/URA	.5 m	.75 m	1 m	1.5 m	2 m
Depleted (GPS 23 – GAL 23)	LPV-250	LPV-250			
Baseline (GPS 24 – GAL 24)	LPV-200	LPV-200	LPV-200	LPV-250	
Optimistic (GPS 27 – GAL 27)	LPV-200	LPV-200	LPV-200	LPV-250	LPV-250

On-line

ARAIM residuals test not used to do constellation check. $P_{sat} = 10^{-5}$, $P_{const} = 10^{-8}$					
Constellation/URA	.5 m	.75 m	1 m	1.5 m	2 m
Depleted (GPS 23 – GAL 23)	LPV-200	LPV-200	LPV-200	LPV-250	LPV-250
Baseline (GPS 24 – GAL 24)	LPV-200	LPV-200	LPV-200	LPV-200	LPV-250
Optimistic (GPS 27 – GAL 27)	LPV-200	LPV-200	LPV-200	LPV-200	LPV-250

Table E-2: Vertical Service Available from ARAIM as a Function of Constellation Strength and User Range Accuracy (URA). The top half of the table describes the performance of ARAIM when the residuals test contained in the avionics must also be used to check for constellation-wide faults. The bottom half of the table assumes that other means are used to check for constellation-wide faults.

Color coding is based upon LPV-200 objective using the following level of service criterion: 90% coverage of 99.5% availability between -70 and 70 degrees latitude; Text indicates level of service achieved.

Topics

- U.S. GPS Modernization
- NEXTGEN Navigation System Strategy
- Wide Area Augmentation System (WAAS)
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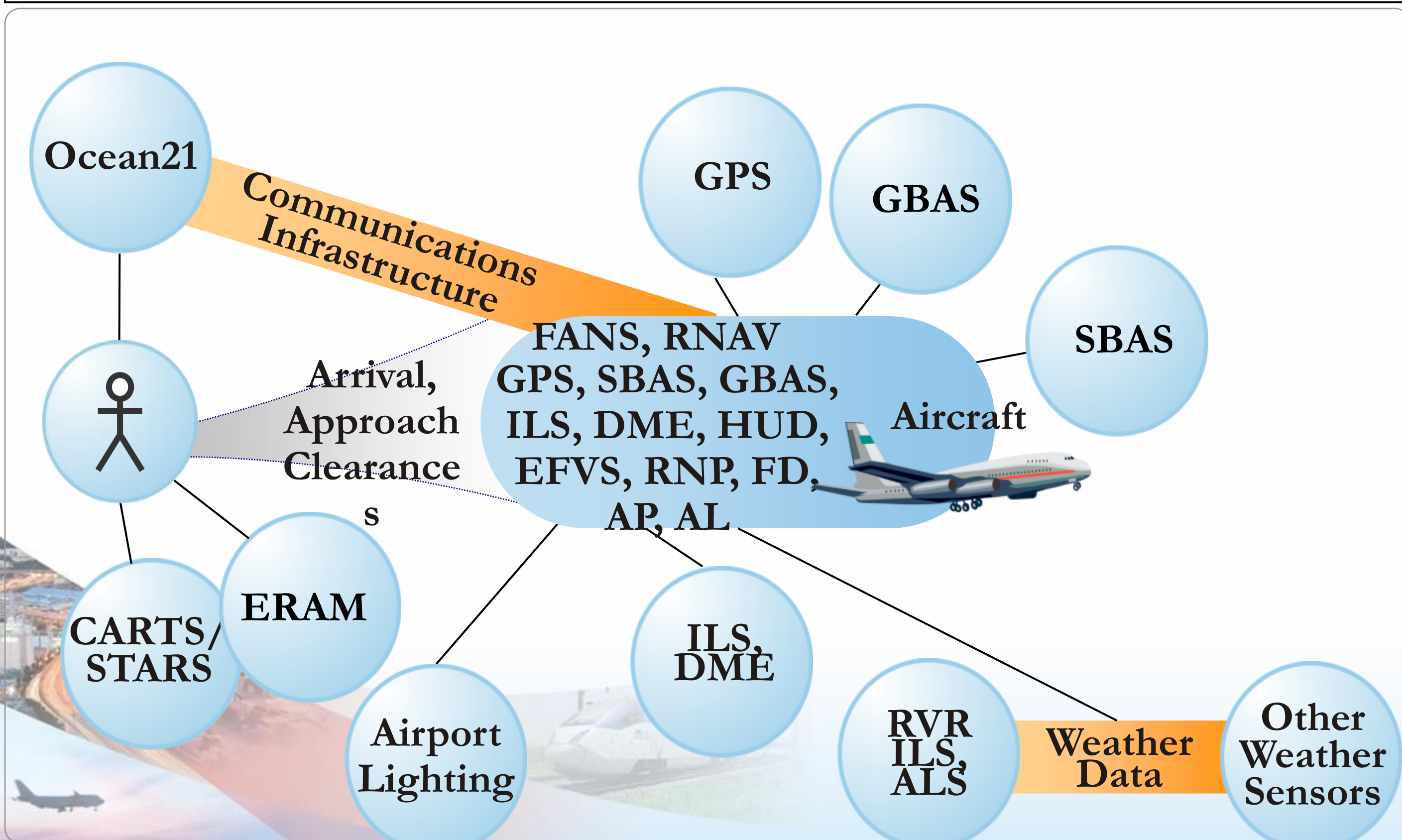
- Complementary PNT

FAA Program Activities

The Improved Approaches and Low-Visibility Operations (IALowVis) initiative supports optimizing and improving low-visibility approach operations through more effective procedure design and implementation, ATC training, user equipage, and installation/certification of ground infrastructure as necessary.



Capabilities
Expanded Low-Visibility Ops Using Lower Runway Visual Range Minima
Optimized Profile Descents (OPDs) Using RNAV STARs
Tailored Arrivals
GBAS Category I Non-Federal System Approval
Enhanced Flight Vision Systems (EFVS) Visual Segment to 100 Feet
EFVS to Touchdown
GBAS Category II/III Non-Federal System Approval

CAT I (GAST C) Activity

- Honeywell granted System Design Approval (SDA) of ground facility in 2009; subsequently updated in 2012
  - Operational at Newark (EWR) in September 2012
  - Operational at Houston (IAH) in April 2013
- FAA Ground-Based Performance Monitoring and Service Prediction Capability for installed Honeywell SLS-4000
  - Tool supports issuing NOTAMS when service is not expected to be available
  - Receives VDB and uses local GPS receiver; interfaces to NANUs
    - EWR (Newark, NJ; MOU with Port Authority of New York and New Jersey (PANYNJ)
    - IAH (Houston, TX; MOU with Houston Airport Systems (HAS))
    - MWH (Moses Lake, WA; MOU with Boeing)

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CAT I (GAST C) Activity

- Honeywell SLS-4000 GAST-C Block II refines current ground facility; System Design Approval expected in June 2015
  - Intended to enhance system availability in CONUS
  - Updates facilitate use in low-latitudes (e.g., equatorial regions)
    - FAA design approval will constrain tailoring parameters consistent with the CONUS ionosphere threat model
    - Approval authorities (i.e., low latitude states) must approve the design, regional threat models, etc. for their regions of interest.
  - FAA Block II SDA approval is expected in the 3rd Quarter 2015 time frame
- Working with RTCA and ICAO to consider potential "extended service volume" for GLS to include the IAF on long approaches

U.S. Operations Update

- Airport Operations (Status: April 2015)
  - Total 1631 approaches / Average 80/month
  - Newark, NJ, 720 Operations (737/787)
  - Houston, TX, 911 Operations (737/787/A380/B747-8)
- U.S. Airlines
  - United Airlines Equipage
    - B737 – 112 aircraft / B787 – 16 aircraft
  - Delta Airlines
    - B737 – 34 Aircraft / Total order of 112
    - Planning to equip also Airbus fleet (A350, A321)
- Boeing/Airbus GLS customers

B737	67 customers / 900 aircraft 3660 provisioned
B747-8 GLS standard	10 customers / 84 aircraft
B787 GLS standard	29 customers / 235 aircraft

A320	12 customers
A380	9 customers
A330/340	4 customers
A350	7 customers

November 2014 - Over 1,000 GBAS landings by United Airlines

December 2014 - Delta at Houston

February 2015 Delta at Newark

International Airline Operations in U.S.

- Newark (since Sept 2014)
  - British Airways - B787 (179 GLS approaches)
- Houston (since Dec 2014)
  - Emirates - A380 (26 GLS approaches)
  - Lufthansa - A380 (12 GLS approaches)
  - Cathay Pacific - B747-8 (26 GLS approaches)

International Cooperation

- International GBAS Working Group
  - Organized by FAA and EUROCONTROL to foster communication and collaboration among states implementing GBAS
  - **Next Meeting 1 to 4 June at FAA William J. Hughes Technical Center**
- International MoUs
  - Australia
  - Brazil

    -- Aiding development of Ionospheric Threat Model for lower latitudes
  - Eurocontrol
  - Germany
  - Spain

FAA GBAS System Design Approvals (SDA)

- SDA Goal
  - Assess the safety and performance requirements associated with non-Federal GBAS designs (basis is ICAO SARPS)
  - Assess the overall viability of the design with respect to its use in the NAS (Siting, installation, maintenance, etc..)
- SDA supports NextGen goals associated with establishing a means for GAST-D service in the future
  - Planned non-Federal design approval in mid 2018
  - Schedule driven by vendor investment and priorities as well as a dependency on FAA SDA support
- FAA supporting two SDA requests
  - Honeywell SLS-4000 GAST C (CAT I) Block II
  - Honeywell SLS-5000 GAST-D (CAT III)

CAT III (GAST D) Activities

- Validation of ICAO SARPS for baseline set of GBAS Approach Service Type D (GAST-D) Requirements
  - GAST-D to support approach and landing operations using CAT III minima by augmentation of single-frequency GPS (L1)
  - Validation included work producing commercial prototypes (Avionics/Ground system)
    - Avionics System Prototyping Contract Complete January 2013
    - Ground System Prototyping Contract Complete May 2015
- RTCA Minimum Operational Performance Standards (MOPS)
  - Finalizing avionics requirements that compliment ICAO Annex 10 standards
- Honeywell SLS-5000 GAST-D
  - ICAO GAST-D compliant configuration (CAT-III)

Current Design Approval Target: mid 2018

GAST-D Validation - Schedule

- Background
  - After several years of working on high-level requirements and considering various concepts for how GBAS should be extended, the CSG began drafting a SARPs change proposal in 2007
  - Baseline Development Standard (BDS) established in 2010
  - Since then, robust prototyping programs were conducted in U.S., Europe and Japan
  - Independent ground subsystem prototypes were built by at least four companies with involvement by several States and EUROCONTROL
  - Flight testing with four different airborne prototypes was conducted successfully by three entities (two are major airframe manufacturers)
    - Interoperability flight testing conducted
- ICAO NSP/1 – April 2015
  - Baselined SARPS amendment accepted pending closure of two items
  - Key items remaining open:
    - VDB compatibility with ILS and VHF Com equipment
    - Ionospheric Gradient Mitigation
- Final NSP Closure of Validation – expected December 2015

Programmatic Challenges

- GBAS currently fielded in U.S. as a Non-Federal system
- Implementation schedule currently driven by vendor and airports
- Increased airports & airline interest; increasing aircraft equipage
- Increased GBAS installations by international Air Navigation Service Providers (ANSPs)
- FAA requires funding to continue supporting GBAS as a Non-Fed
- Eurocontrol SESAR work plans for multi-frequency and multi-constellation CAT III GBAS research; RTCA MOPS in 2019?
  - Current FAA GBAS program not defined beyond single-frequency GBAS CAT III (GAST-D) SDA in 2018
- FAA initiated benefits study in Feb 2015
  - Results could lead to a change in U.S. GBAS implementation strategy

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FAA APNT Background

- Investigating alternatives for higher-precision RNAV back-up services for GPS-based PNT
- GPS PNT enables:
  - Performance-based navigation (PBN) and Automatic Dependent Surveillance Broadcast (ADS-B) services
  - Trajectory-Based Operations (TBO), area navigation (RNAV), Required Navigation Performance (RNP) and other NextGen improvements

FAA APNT Benefits

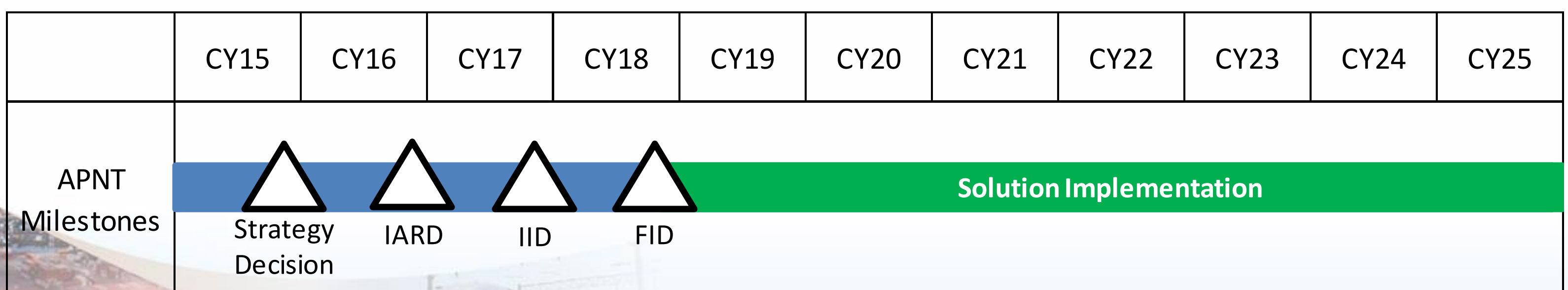
- Provides a RNAV backup to GPS in the event of a GPS interference event or outage
- Leverages existing infrastructure
- Safe recovery of aircraft (landing)
- No significant Increase in pilot/controller workload
- Strategic modifications of flight trajectories
- Continued dispatch using to/from operations
- Supports transition to Performance Based Navigation

Operational Requirements Definition Plan

- Step 1: Define minimum operational service levels objectives based upon scenario approach by event type
  - Example: Assess impacts to efficiency and capacity for an intentional interference event in Terminal environment
- Step 2: Coordinate results to obtain FAA stakeholder concurrence
- Step 3: Develop operational requirements
  - Conduct functional analysis
  - Derive/validate operational requirements
  - Update APNT preliminary requirements document
- Step 4: Update APNT documents: shortfall analysis, Concept of Operations, Functional Analysis
  - Update APNT preliminary requirements document

APNT Timeline

- Approved acquisition decision dates per Enterprise Architecture Roadmap, Version 9.0, Jan 2015
  - APNT Strategy Decision (<u>new milestone</u>) in Dec 2015
  - Investment Analysis Readiness Decision (IARD) orig. Dec 2015, amended to Dec. 2016
  - Initial Investment Decision (IID) orig. Dec. 2016, amended to Dec 2017
  - Final Investment Decision (FID) orig. Dec. 2017, amended to Dec 2018



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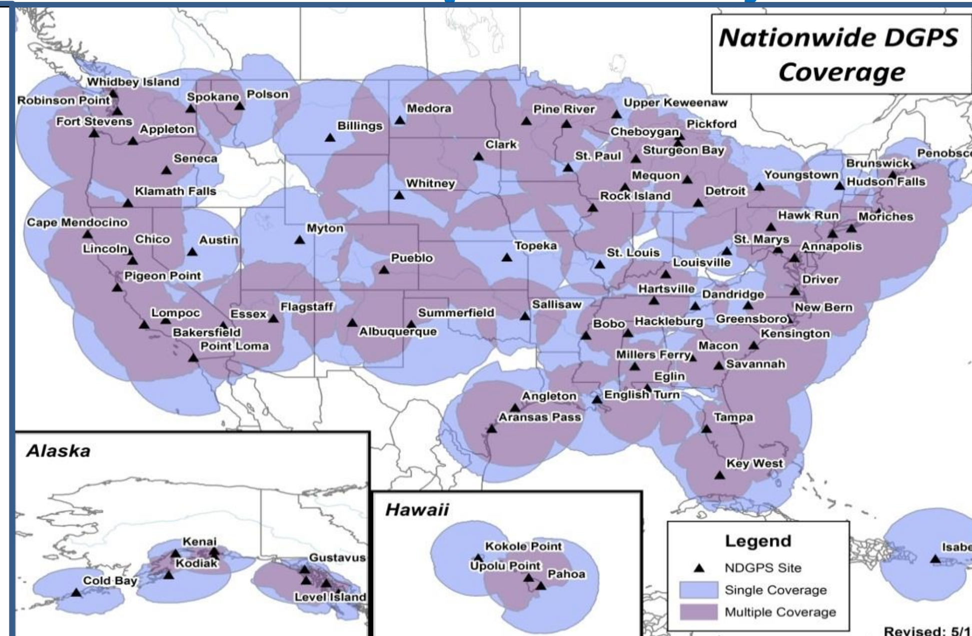
Nationwide Differential GPS (NDGPS)

System Description

85 Nationwide Remote Broadcast Sites throughout United States and territories

- 92% nationwide signal coverage
- Better than 10 meter accuracy
- 10 second integrity alarm to the user
- Satisfies Harbor/Harbor Approach requirements
- 99.7% availability requirement
- Sites equipped with out-of-tolerance user alerting



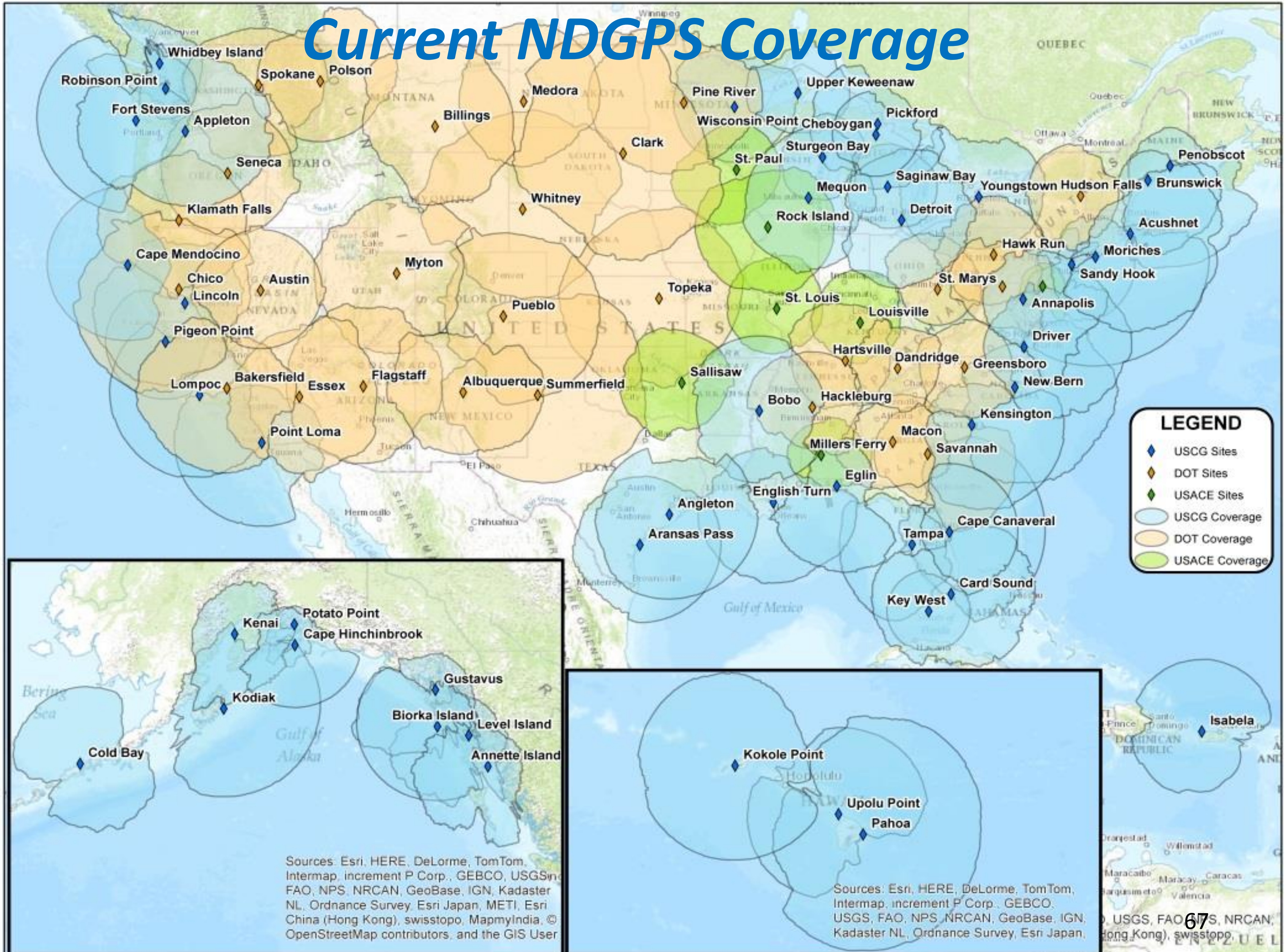
Operations

- Redundant equipment at sites
- Redundant controls stations at NAVCEN

Stakeholders

- U.S. Army Corps of Engineers (USACE)
- Department of Transportation (DOT)
- U. S. Coast Guard
- National Oceanic & Atmospheric Admin.

Current NDGPS Coverage



Future of NDGPS Assessment

- Contributing Factors:
  - Discontinuation of Selective Availability minimized benefit
  - Lack of USCG requirements
    - No international or domestic carriage requirement
    - GPS authorized as Federal Aid to positioning (ATON)
    - Navigation Standards Manual allows use of WAAS/SBAS
  - Continued GPS/SBAS modernization and performance gains
  - Reduced availability of consumer grade DGPS receivers
  - FRA has no NDGPS requirement for Positive Train Control
  - Agriculture sector does not use NDGPS

2013 Federal Register Notice

- Joint DHS/USCG and DOT/RITA Federal Register Notice (FRN) request for public comments [78 FR 22554; April 16, 2013]
  - Targeted Outreach to User Community
  - Direct Questions:
    (1) Do you use NDGPS in its current form for positioning, navigation, and timing?
    (2) What would be the impact if the NDGPS were to be discontinued?
    (3) Are there alternatives that could be used to meet your PNT requirements?
    (4) Are there alternative uses for the existing NDGPS infrastructure?
  - Responses were few
- General assessment based on comments in docket
  - Few users of the NDGPS VHF broadcast
    - Majority of limited use is in the maritime sector
      - Primarily by pilots for precision shiphandling
  - Reference station data is used by various entities

Next Steps

- Issue new Federal Register Notice describing proposed path forward in late spring/early summer 2015

- Prepare FY'17 budget request based on decision

Topics

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Complementary PNT

- U.S. Space-Based PNT Executive Committee looked at the need for a complement to GPS
  - Assessment driven by many factors: from policy to technology
  - U.S. needs during potential GPS outage from natural or man-made events
- The new 2014 Federal Radionavigation Plan signed by the Secretaries of Defense, Transportation, and Homeland Security served as a basis for initially assessing requirements http://www.navcen.uscg.gov/pdf/FederalRadionavigationPlan2014.pdf
- Current Activity: Identify and assess alternatives
  - Assessed a broad mix of terrestrial RF and autonomous PNT technologies
- Decision timeline: No earlier than summer 2015
  - Supports FY17 investment decisions
- *Federal Register* Notice published 23 March 2015 for public stakeholder engagement

Public Comment/Stakeholder Outreach

- DOT drafted a *Federal Register* Notice in conjunction with CPNT Team seeking:
    1. Brief description of PNT application(s)
    2. PNT performance required for a complementary PNT capability
    3. Availability and coverage area required for a CPNT capability
    4. Willingness to equip with an eLoran receiver
    5. Current/planned availability of e-Loran user equipment
    6. Other non-eLoran PNT technologies or operational procedures currently available or planned
- Widely circulated to stakeholder communities
- Comments posted on www.regulations.gov when received
- Comments due by May 22, 2015 (60-Day Comment Period)

Synopsis of Comments Provided At End of Comment Period

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Cooperative Research and Development Agreement (CRADA) – May 2015

- Department of Homeland Security's Science and Technology Directorate (DHS S&T), Federal Resilient Systems Laboratory and the U.S. Coast Guard have entered into a CRDA with Exelis, Inc. and UrsaNav with a 3 year Period of Performance
- Objective: testing and demonstration of eLoran capabilities at former Loran-C sites to evaluate eLoran as a potential complementary system to GPS
  - Research, evaluate, and document eLoran technology as a candidate for providing position, navigation, and timing (PNT) information.
  - Capabilities and potential utilization methods of eLoran will be explored in depth, to identify all strengths, capacities, and potential vulnerabilities of the technology

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ICG-10 - November 1-6, 2015

- U.S. will host in Boulder, Colorado
  - 45 km from Denver
- Venue: University Corporation for Atmospheric Research (UCAR)
  - Consortium of more than 100 member colleges and universities focused on atmospheric research and Earth system sciences
  - UCAR manages the National Center for Atmospheric Research (NCAR) on behalf of the National Science Foundation
- Tour Sites confirmed
  - National Oceanic and Atmospheric Administration, National Space Weather Prediction Center
  - UNAVCO: University-governed consortium, which facilitates geoscience research and education using geodesy
  - National Institute of Standards and Technology, Time and Frequency Laboratory

UCAR Center Green Facility

Conclusion

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

GPS: Continuous improvement, and predictable, dependable performance

Thank You !

Brief located at: http://www.gps.gov/multimedia/presentations/2015/

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