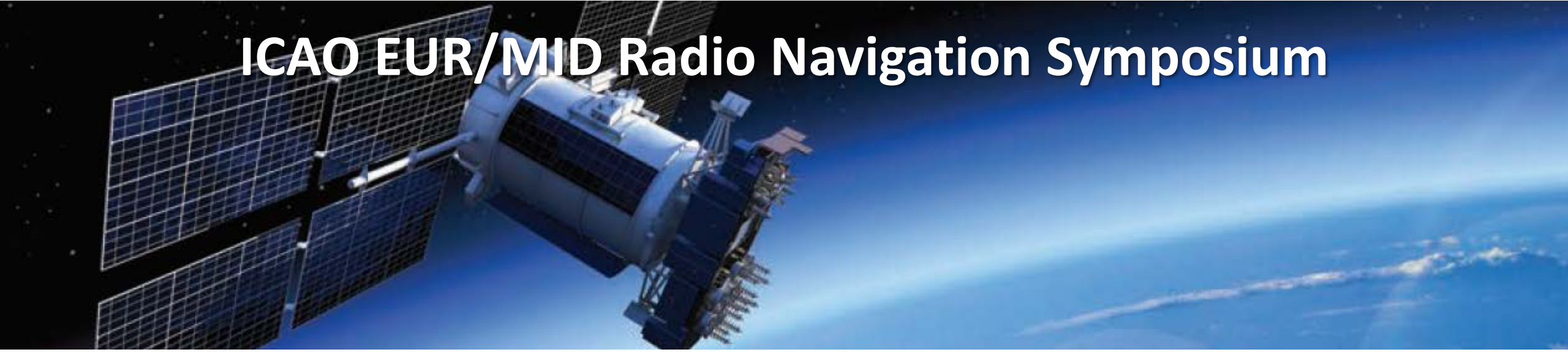


ICAO EUR/MID Radio Navigation Symposium

Session 4: Update on GNSS Constellations
U.S. Global Positioning System Update

Ken Alexander
FAA Chief Scientific and Technical Advisor for Satellite Navigation Systems
Co-Chair U.S. National PNT Engineering Forum

Antalya, Turkiye
(6-8 February 2024)

GPS Overview

Civil Cooperation

3+ Billion civil & commercial users worldwide

Search & Rescue capability

Civil Signals

- L1 C/A (Original Signal)
- L2C (2nd Civil Signal)
- L5 (Aviation Safety of Life Signal)
- L1C (Int'l Interoperability Signal)

Spectrum

World Radio Conference

International Telecommunication Union

Bilateral Agreements

Adjacent Band Interference Challenges

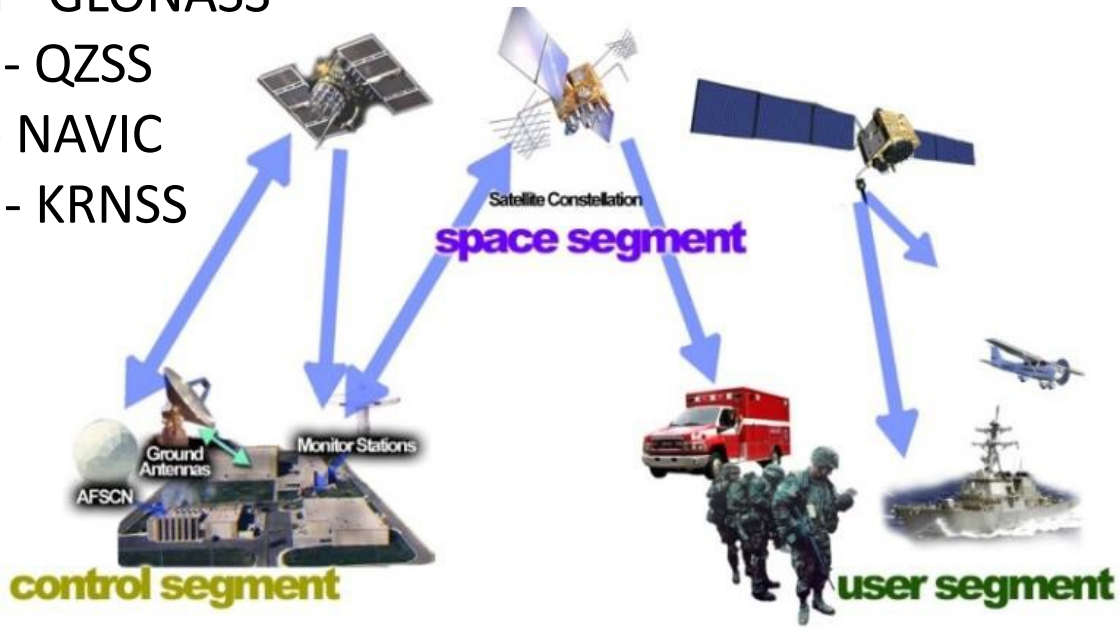
International Cooperation

57 Authorized Allied Users

- 25+ Years of Cooperation

GNSS

- Europe - Galileo
- China - Beidou
- Russia - GLONASS
- Japan - QZSS
- India - NAVIC
- Korea - KRNSS



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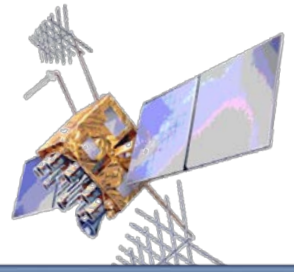
GPS Modernization

SPACE SEGMENT (SATELLITES)

Legacy (GPS IIA/IIR)

GPS IIR-M

- 2nd Civil Signal (L2C)



GPS IIF

- 3rd Civil Signal (L5)
- Longer Life
- Better Clocks

GPS III (SV01-10)

- Accuracy & Power
- Increased Anti-Jam Power
- Inherent Signal Integrity
- 4th Civil Signal (L1C)
- Longer Life
- Improved Clocks

GPS IIIF (SV11-32)

- Unified S-Band Telemetry, Tracking, & Commanding
- Search & Rescue (SAR) Payload
- Laser Retroreflector Array
- Redesigned NDS Payload
- Regional Military Protect (RMP)

CONTROL SEGMENT (GROUND)

Legacy (OCS)

- Mainframe System
- Command & Control
- Signal Monitoring

Architecture Evolution Plan (AEP)

- Distributed Architecture
- Increased Signal Monitoring Coverage
- Improved Security and Accuracy
- Launch And Disposal Operations

OCX Block 0

- GPS III Launch & Checkout
- GPS III Contingency Ops (COps)
- GPS III Mission on AEP

M-Code Early Use (MCEU)

- Update OCS to operationalize Co M-Code on AEP

OCX Blocks 1 & 2

- Fly GPS IIR/-M, GPS IIF, GPS III
- Modernize Cyber Architecture
- Operationalize Civil Signals (L1C, L2C, L5)
- Full M-Code

OCX Block 3F

- GPS IIIF Command & Control
- New capabilities

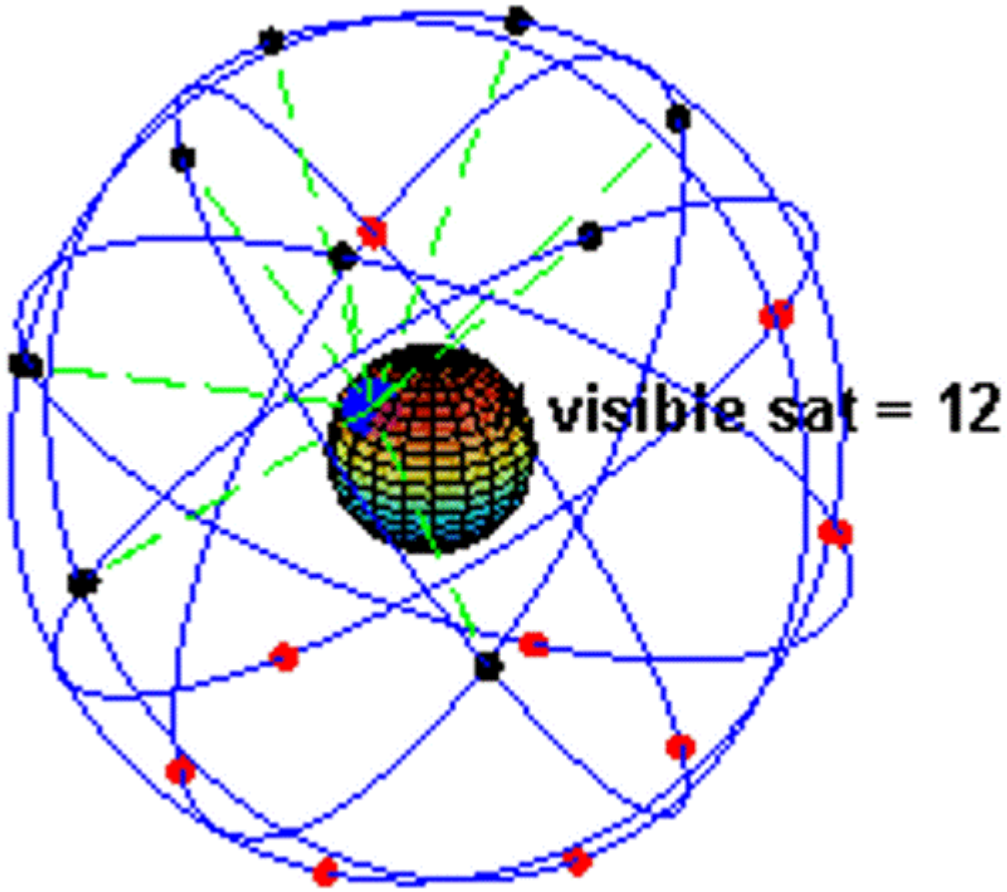
GPS Signal in Space Performance

From 01 Jan 2023 to 12 Oct 2023

Satellite Block	Quantity	Average Age (yrs)	Oldest (yrs)
GPS IIR	7	21.7	26.1
GPS IIR-M	7	16.1	17.9
GPS IIF	11	9.6	13.3
GPS III	6	2.9	4.7

Average URE*	Best Day URE	Worst Day URE
48.4 cm	34.1 cm (23 Jun 23)	163.7 cm (25 Jan 23)

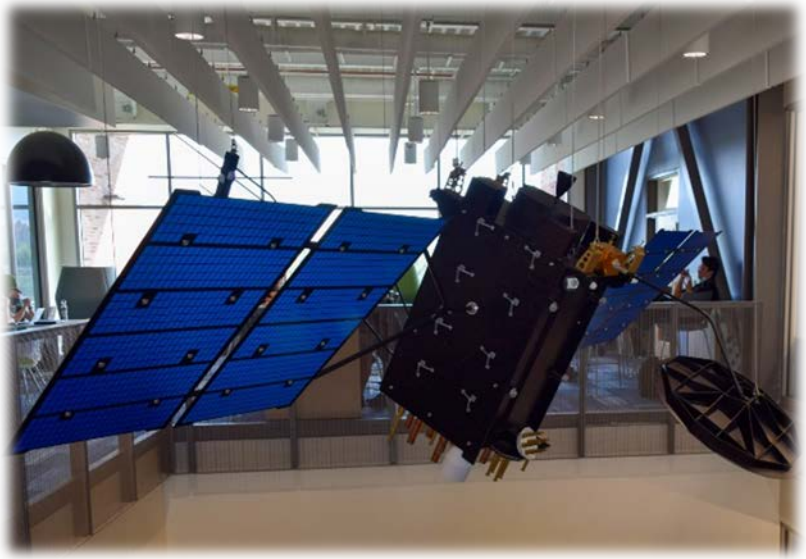
* All User Range Errors (UREs) are 95% Root Mean Squared values



- **6 Additional satellites in test/residual configuration**
- GPS Operates in 6 Planes at an altitude of 20,200 km

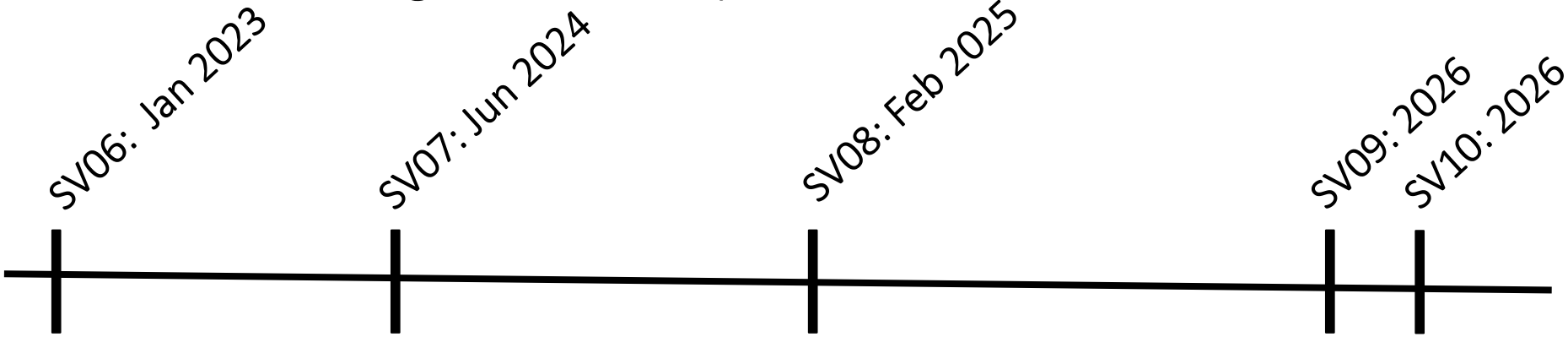
GPS IIIF Program

- Continues GPS III modernization efforts, provides backward compatibility & includes:
  - Regional Military Protection (RMP) for boosted M-code signal
  - M-code power increased by 8x in localized areas to give resiliency in disadvantaged areas
  - Re-designed Nuclear Detection suite
  - Canadian-built search and rescue (SAR) payload
    - Up to 85% faster detection and locating of distress signals
  - Laser Retro reflector Array (LRA)
- Status: Purchased SVs 11 thru 20
  - GPS III Non-Flight Satellite Testbed complete 2Q FY24
  - GPS IIIF SV11 available for launch planned for 2026

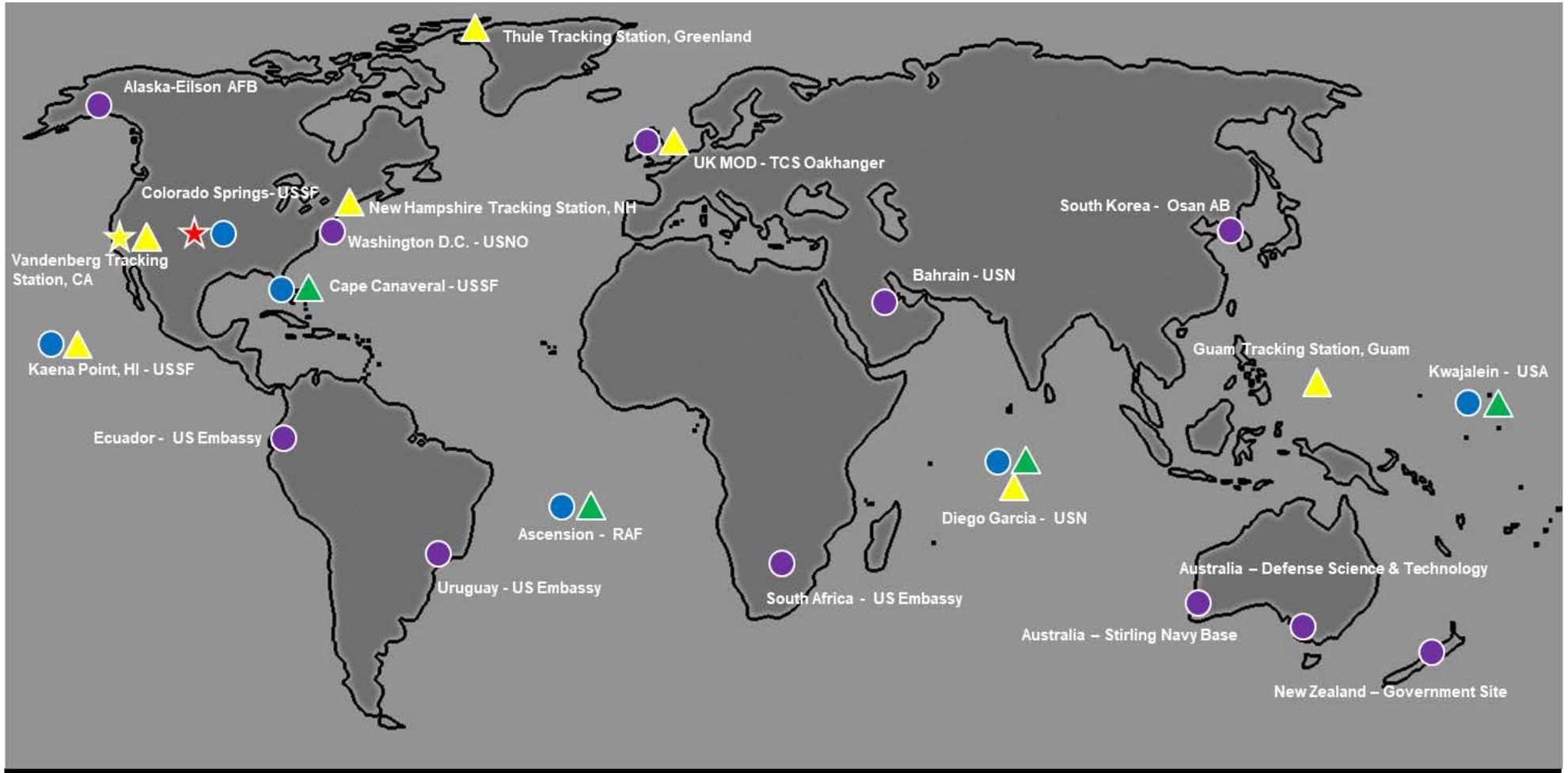


GPS Launch Schedule

- U.S. will launch (4) GPS-III satellites over the next 2 years
- GPS III-F satellites begin launch in 2026; After checkout, launches are planned every four months starting in mid 2027 (9 satellite added to constellation in 2.5 years)



GPS Global Architecture

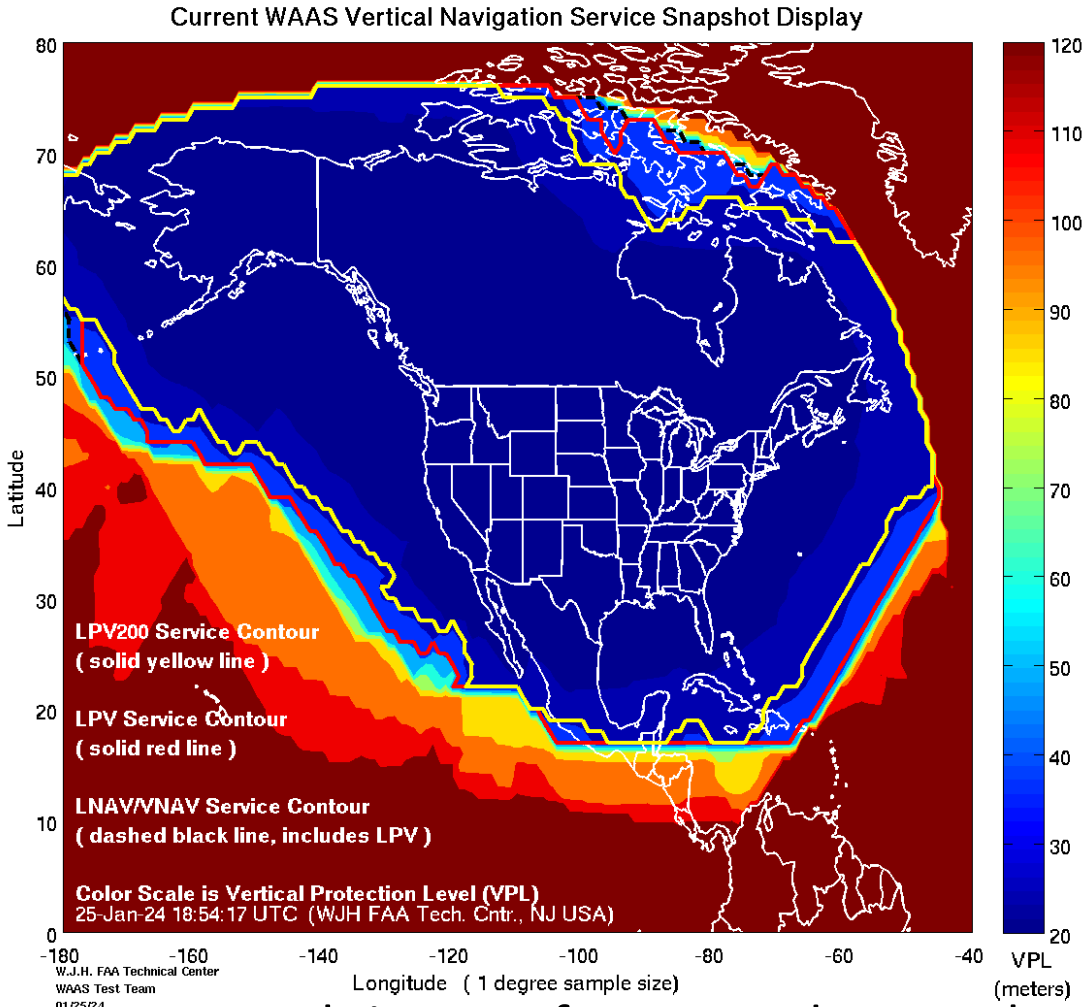


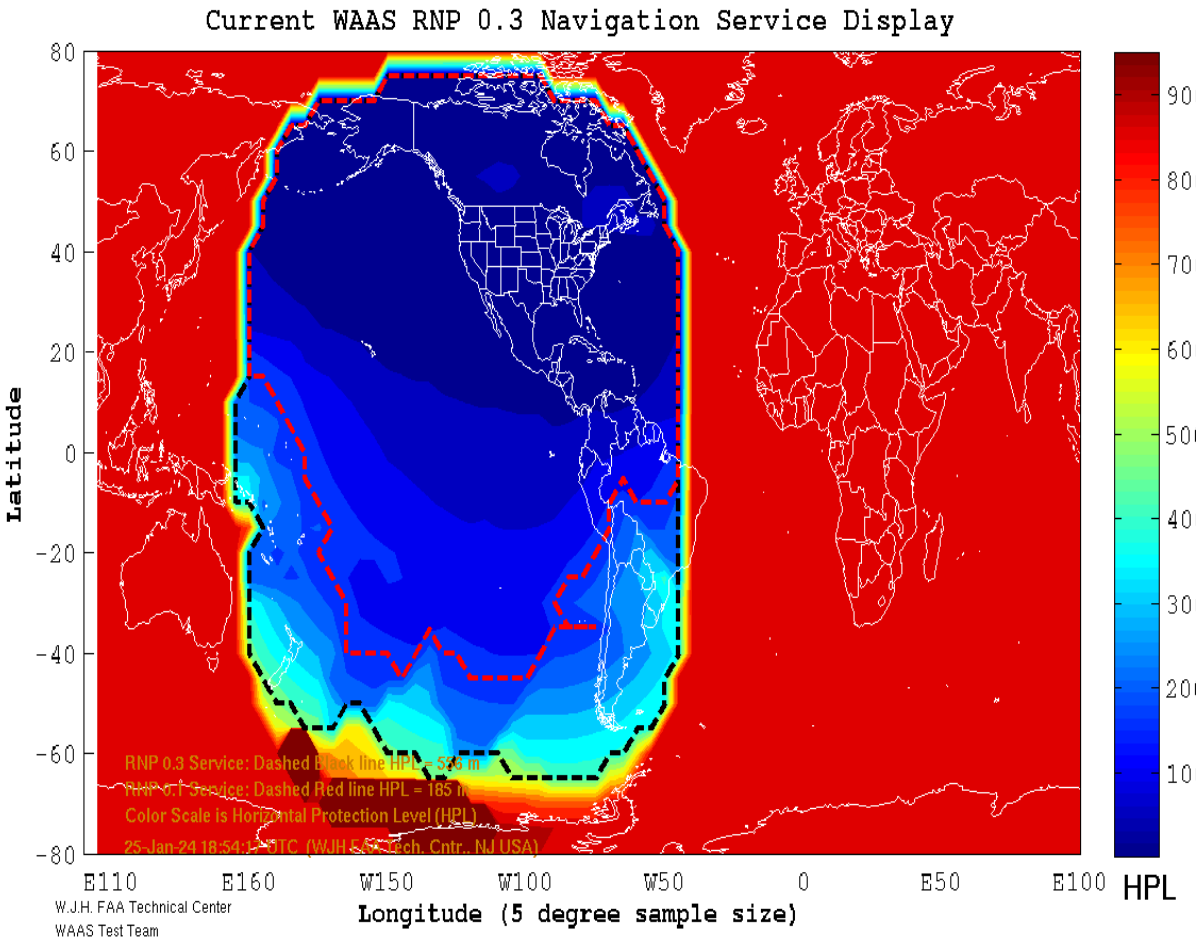
New Civil Signals

- **L1C Signal**
  - Enable interoperability
  - Common civil signal for GPS and Galileo
  - Japan's Quasi-Zenith Satellite System (QZSS) and China's BeiDou system are adopting L1C-like signals
  - Improve GPS reception in cities and other challenging environments
- **L2C Signal**
- **L5 – Safety of Life Signal**
  - Safety-of-life for transportation and other high-performance applications
  - When combined with L1 C/A in a dual-frequency receiver, L5 (like L2C enables ionospheric corrections, which can increase accuracy; users with dual-frequency GPS receivers can achieve the same accuracy as a military user
  - Improved signal structure for enhanced performance
  - Higher transmitted power than L1/L2 signal (~3 dB, or 2× as powerful)
  - Wider bandwidth signal provides a 10× processing gain at the receiver
  - Signal is in the ITU and Aeronautical Radionavigation Services (RNSS) protected band

Wide Area Augmentation System (WAAS)

Real-Time Performance - January 25, 2024



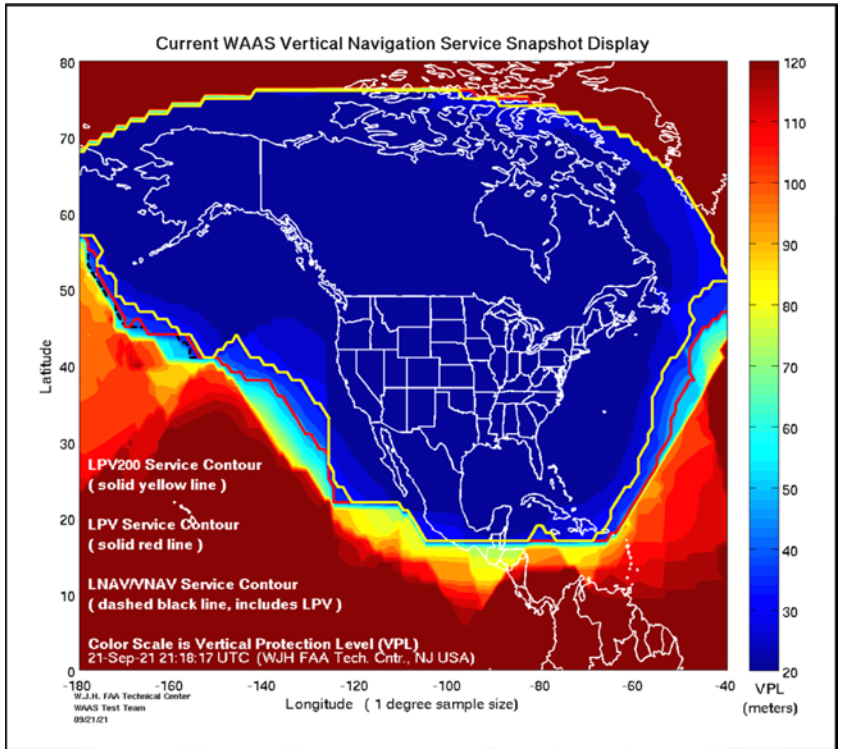


Real time performance data can be accessed at: https://nstb.tc.faa.gov

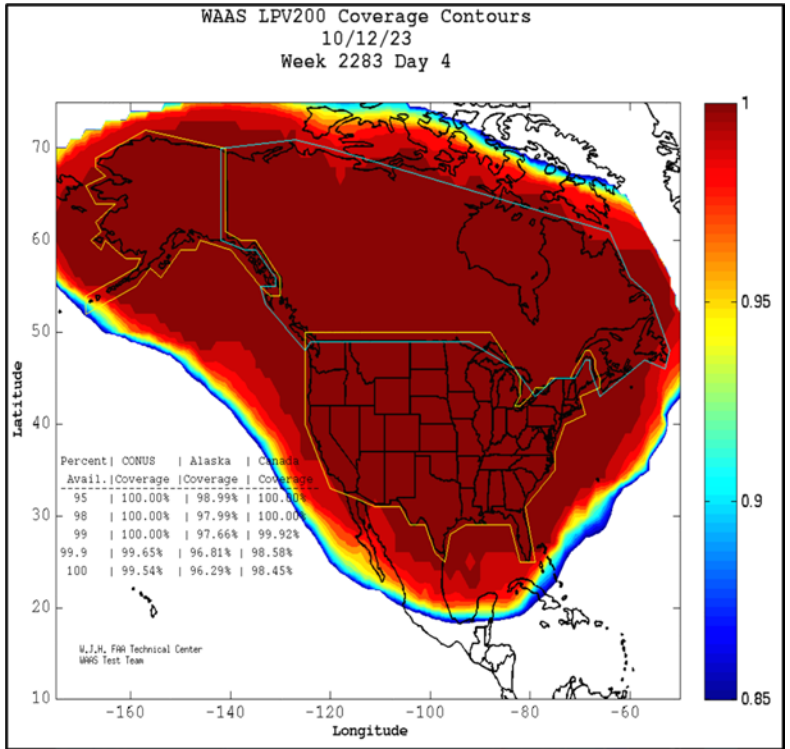
Ionosphere Impacts

- Solar ionospheric disturbances impacted LPV availability on multiple days in 2023
  - Feb 26/27, March 23/24, April 23 (shown below)
  - Feb 15, March 15, May 20 (not shown)
  - Elevated errors present on many of these days

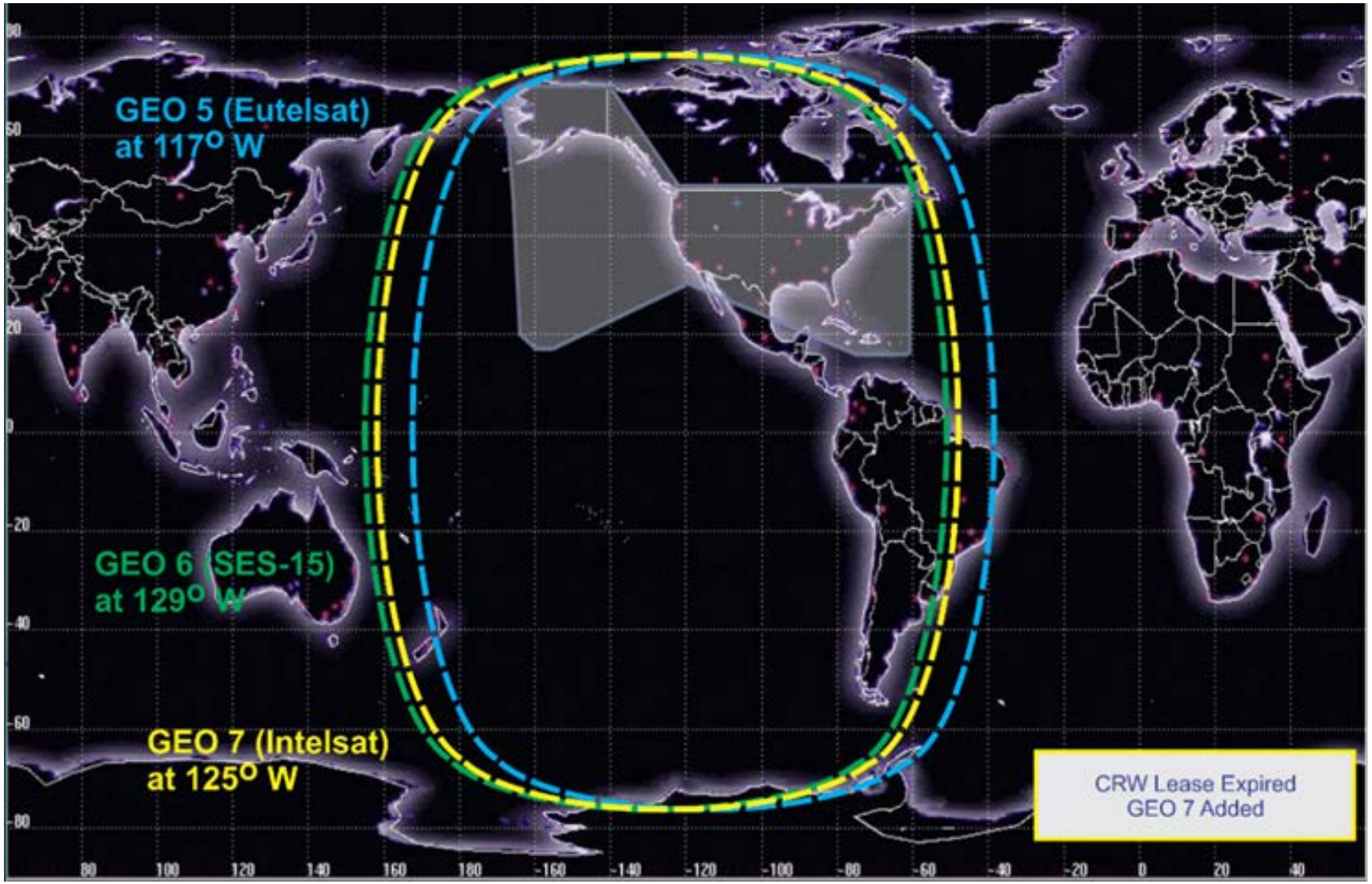
Typical WAAS LPV Coverage



WAAS LPV Coverage April 23, 2023 Iono event



Current WAAS GEO Constellation



- Eutelsat 117 WB (GEO 5)
  - March 27, 2018
- SES-15 (GEO 6)
  - June 15, 2019
- Intelsat Galaxy 30 (GEO 7)
  - April 26, 2022

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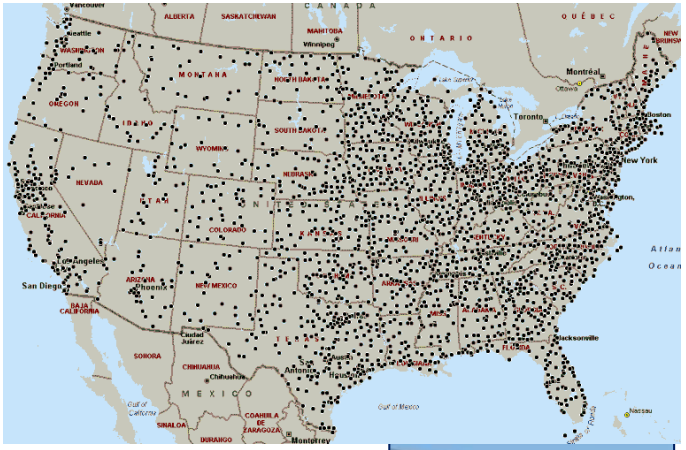
WAAS Avionics Equipage Status



- Procedures:
  - 4,127 Localizer Performance with Vertical Guidance (LPV) approaches in U.S. National Airspace
    - 1,116 provide CAT I (200’) equivalent performance
- Equipage
  - General Aviation
    - Over 131,000 equipped aircraft in U.S. NAS
  - Airline integration using Muti-Mode Receivers (MMRs)
    - A220 is primary aircraft equipped with SBAS navigation in U.S.
- WAAS is an enabling technology for FAA NextGen
  - Automatic Dependent Surveillance-Broadcast (ADS-B)
  - Performance Based Navigation (PBN)

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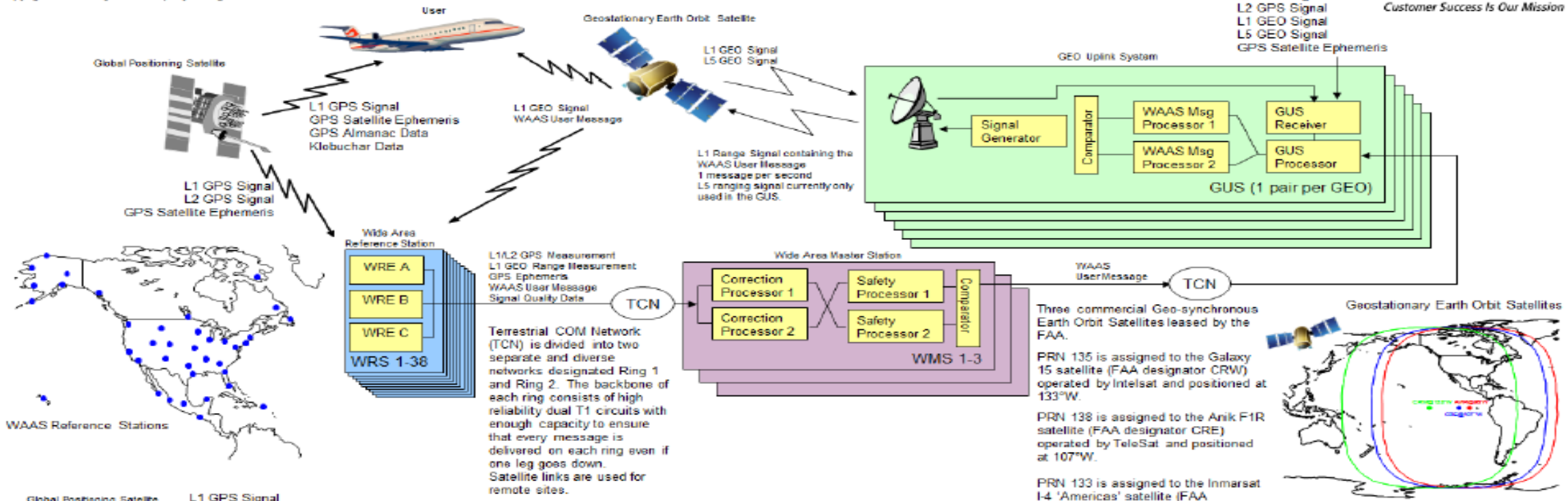
WAAS Current Status

- WAAS provides high availability service to aviation users in North America
- Developing Dual Frequency WAAS
  - Will enable high availability of WAAS vertical service during ionospheric disturbances
- GEO Sustainability
  - Currently maintaining 3 GEO constellation
- WAAS Modernization Efforts
  - Dual Frequency Multi-Constellation (DFMC)
  - Advanced Receiver Integrity Monitoring (ARAIM)
  - Authentication/Resiliency
  - Transition to IP based communications network
  - Security Upgrades

WAAS System Architecture

WAAS Architecture

Raytheon
Customer Success Is Our Mission



	WAAS Requirement	System Performance
Horizontal 95% Accuracy	1.5 m	0.5 m
Vertical 95% Accuracy	2.0 m	1.0 m
CONUS 99% LPV Availability	100% of CONUS	100% of CONUS
Alaska 95% LPV Availability	75% of Alaska	98% of Alaska
Alaska 99% LPV Availability	No Requirement	91% of Alaska

WAAS Full LPV final Test, May 2008

U.S. Ground Based Augmentation System (GBAS) Overview

- GBAS ground systems in U.S. are managed as “non-Federal” facilities (i.e., not owned or operated by the FAA)
  - GBAS equipment manufacturers apply to FAA for non-Federal System Design Approval (SDA) for new systems and modifications to previously approved systems
  - Non-Federal entities (e.g., airports, airport authorities, municipalities) own and operate FAA approved GBAS equipment
  - FAA provides oversight and inspection of GBAS implementations and operations
- GBAS design approvals, integration tasks, and operations are managed by:
  - FAA Technical Operations,
  - Operations Support,
  - NAS Modernization Group,
  - Advanced Systems Design Service (ASDS) Team, FAA Air Traffic Organization

Ongoing FAA Work Activities

- Ionospheric Vigilance
  - Long Term Ionospheric Anomaly Monitoring (LTIAM) Tool (emphasis on 2023 active iono days)
  - Continued evaluation of ionosphere activity to ensure GBAS ionosphere threat models remain valid
- Obstruction Evaluation/Airport Airspace Analysis (OE/AAA) database reviews for operational and planned GBAS sites
  - Ensures systems are sited properly and to avoid any negative impact on other NAS equipment
  - Ensures existing GBAS sites are protected from negative impacts of new construction
- Support planning/implementation meetings held by sponsors/potential sponsors
  - Sponsors are non-Federal owners/operators of the approved GBAS equipment
  - NY Procedure Working Group (Airlines, PANYNJ, FAA) looking to implement GLS approaches for EWR, LGA and JFK base upon initial implementation overlays for long-term airspace optimization using GLS and RNP to GLS; Ongoing SFO procedure development for standard and innovative GLS procedures
- Support International GBAS Working Group (IGWG)
  - IGWG provides forum for airlines, airframe manufacturers, airports, ANSPs, etc. to discuss GBAS technical and operational topics; IGWG-23 is scheduled for 4-7 June 2024 in Frankfurt, Germany
- Enabling improved guidance for GBAS air traffic status displays (planned)

Current U.S. Installations

FAA Approved GBAS

- Honeywell SLS-4000 GAST-C (CAT I) GBAS is the only GBAS approved by the FAA for use
- Approved design includes options for:
  - Fiber optic connectivity between GPS reference receivers and GBAS shelter
  - Space Based Augmentation System (SBAS) receiver

Public Honeywell SLS-4000 Block IIS sites

- Newark Int'l Airport (EWR)
- George Bush Intercontinental Airport (IAH)
- San Francisco Int'l Airport (SFO)

Private Honeywell SLS-4000 Block II sites

- Grant County Int'l Airport ('Moses Lake', MWH)

Planned Implementations

- John F. Kennedy Int'l Airport (JFK)
- LaGuardia Int'l Airport (LGA)
- Minneapolis-St Paul International (MSP)
- Detroit Metro Wayne County Airport (DTW)

Evaluating/Business Case Development

- Denver International Airport (DEN)
- Salt Lake City International Airport (SLC)

GLS Ops January-Dec 2023 Airlines & Aircraft GLS (EWR-IAH-SFO)

EWR	IAH	SFO
1607	195	86 (Jan-Jul)

B737-8/9	B737Max	B787	B747-8	A321	A 330	A350	A 380
United	United	United	LH	JetBlue	TAP	Cathay	Emirates
Delta		BA	Cargolux	TAP		LH	
		AirCanada		Delta		Quatar	
		SAS		BA			
		El Al					
		French Bee					
		ANZ					
		ANA					
		AFR					

Thank You!

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