

# ICAO EUR/MID Radio Navigation Symposium

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

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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 (2<sup>nd</sup> 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

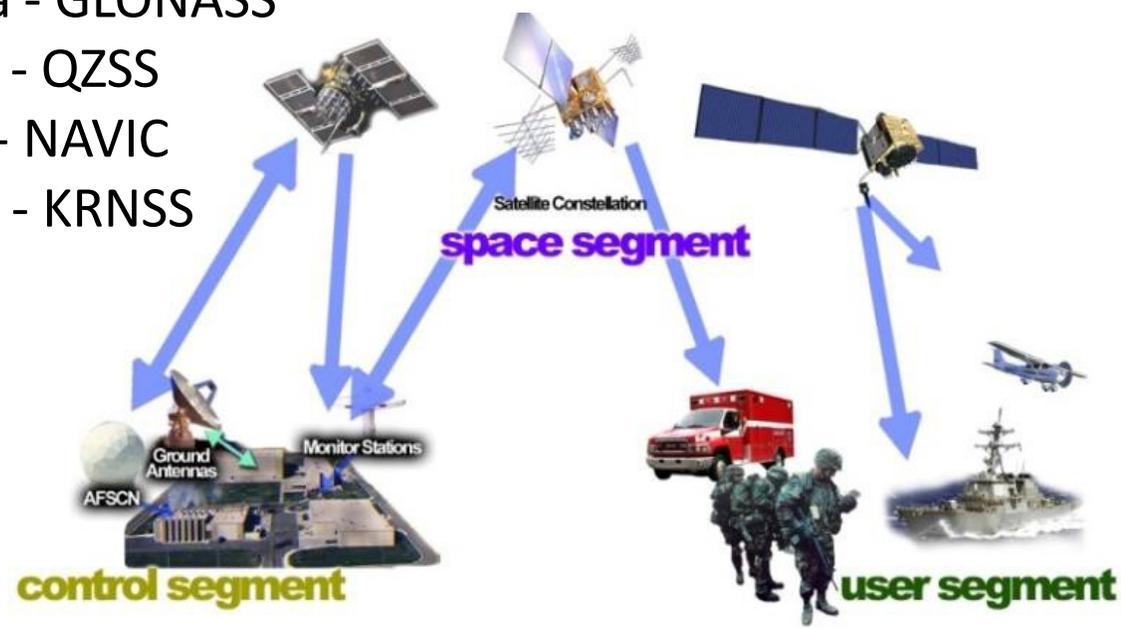
## International Cooperation

57 Authorized Allied Users

- 25+ Years of Cooperation

GNSS

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



# GPS Modernization

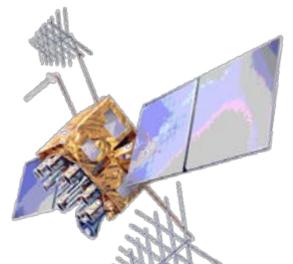
## SPACE SEGMENT (SATELLITES)

### 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 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



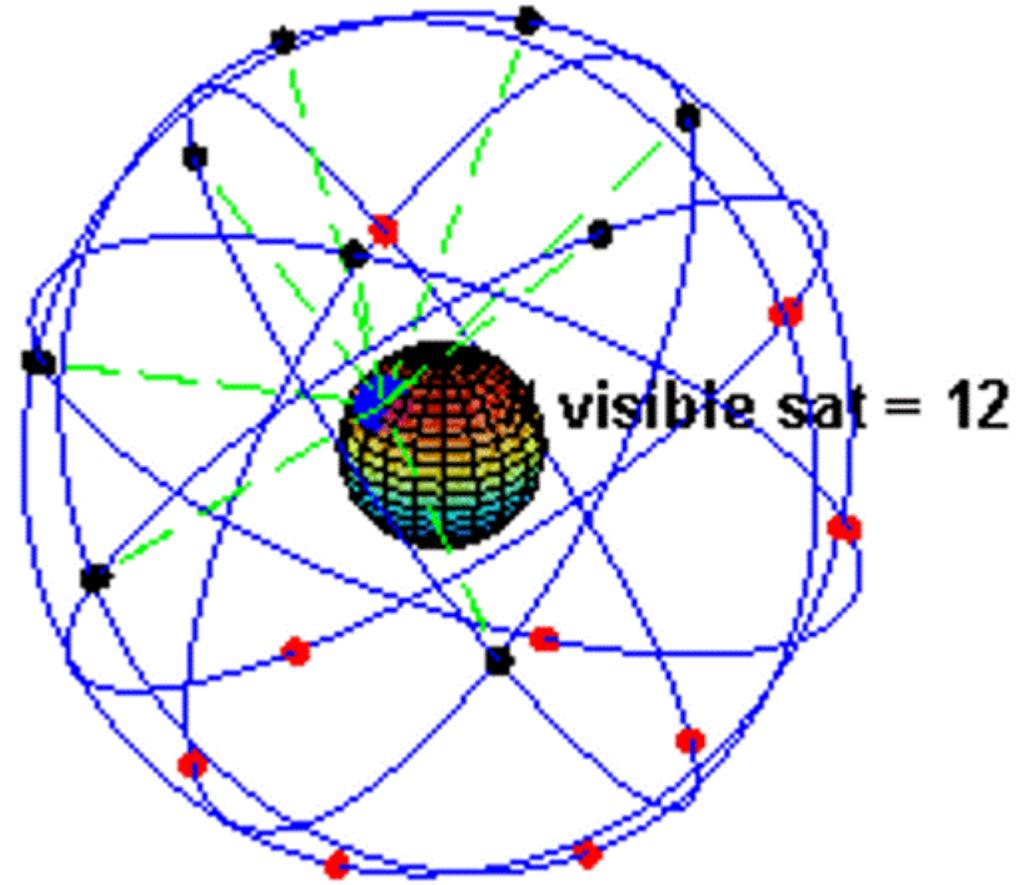
# GPS Signal in Space Performance

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)

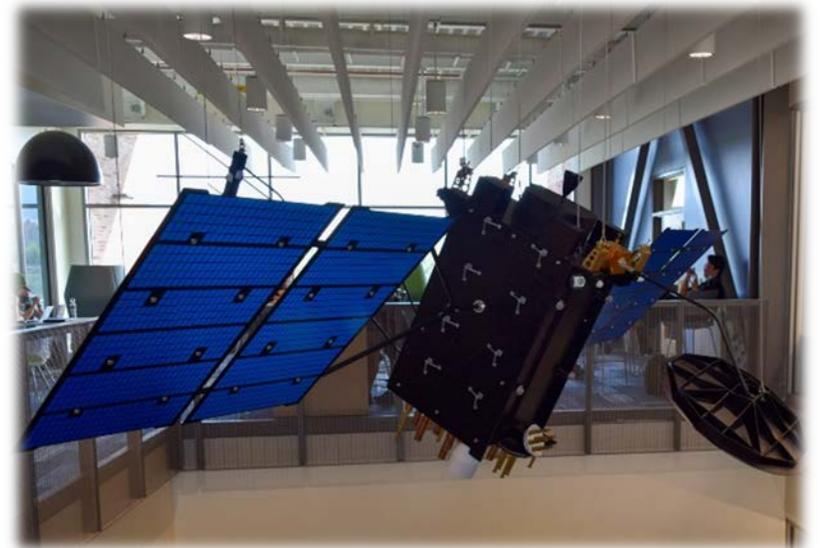
\* All User Range Errors (UREs) are 95% Root Mean Squared values



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

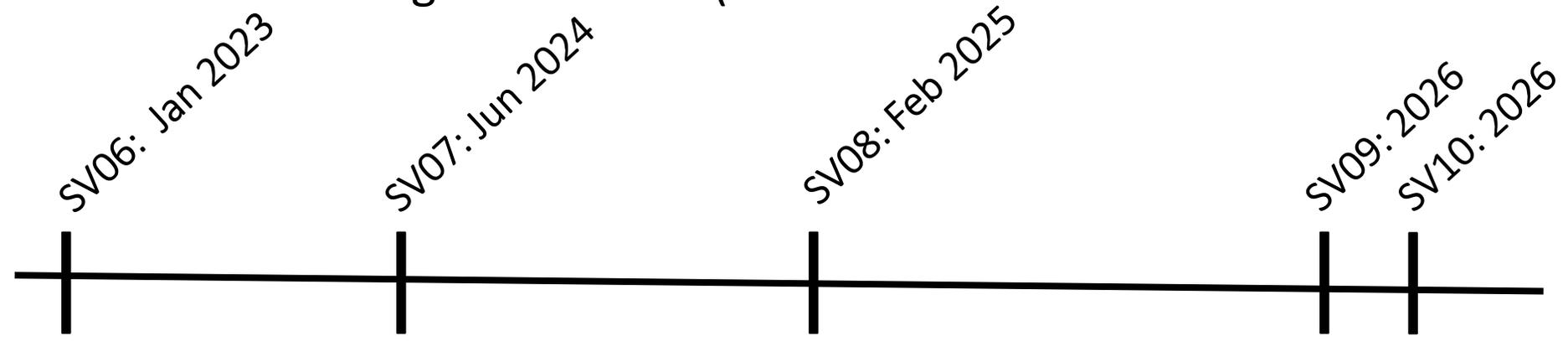
## GPS IIF Program

- ❖ 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 IIF SV11 available for launch planned for 2026

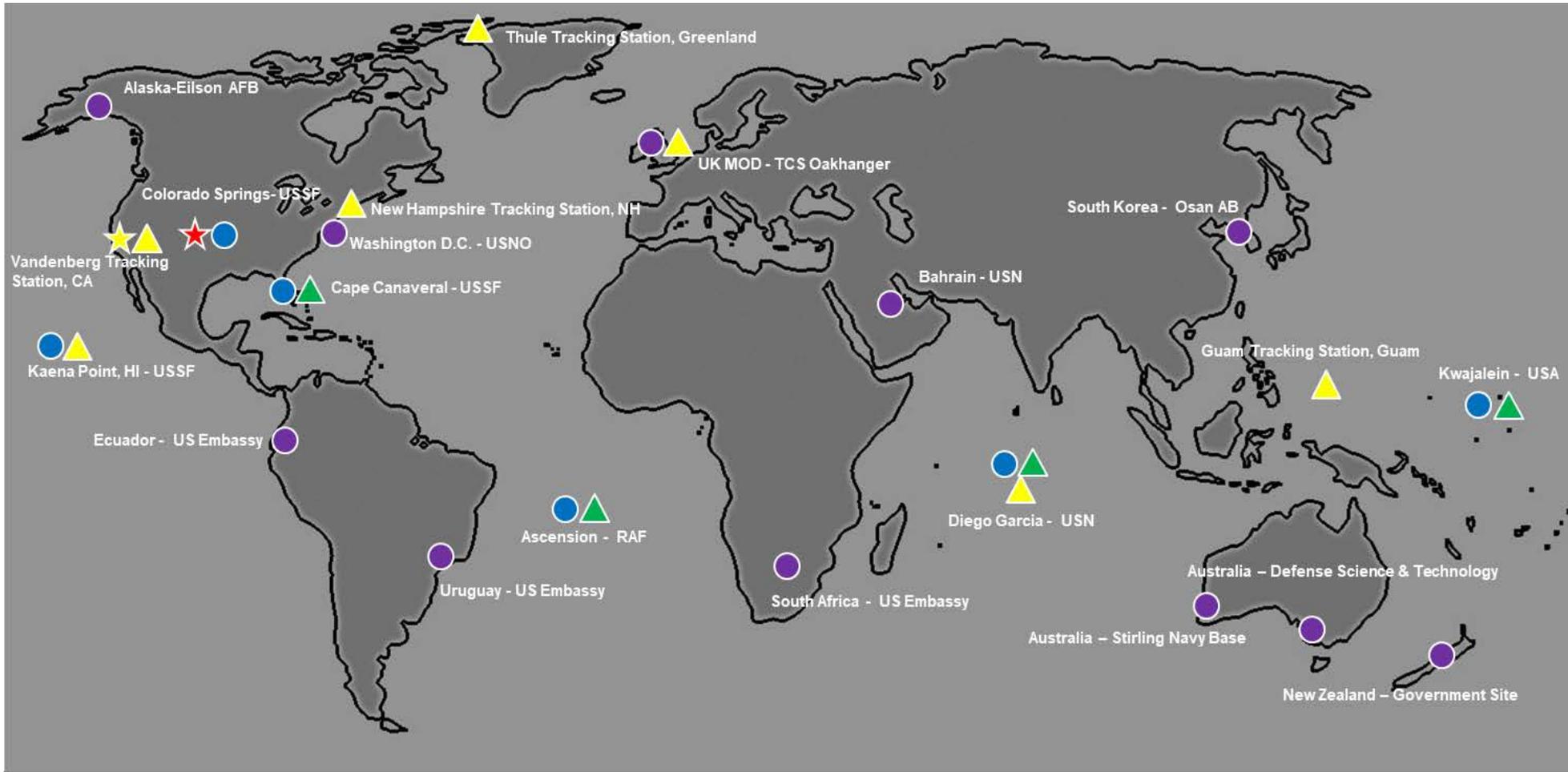


# GPS Launch Schedule

- ❖ 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



- ★ Master Control Station (MCS)
- ★ Alternate Master Control Station (AMCS)
- ▲ Ground Antenna
- ▲ Satellite Control Network (SCN) Remote Tracking Station
- Nat. Geospatial Intelligence Agency Monitor Stations
- Space Force Monitor Station

## 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

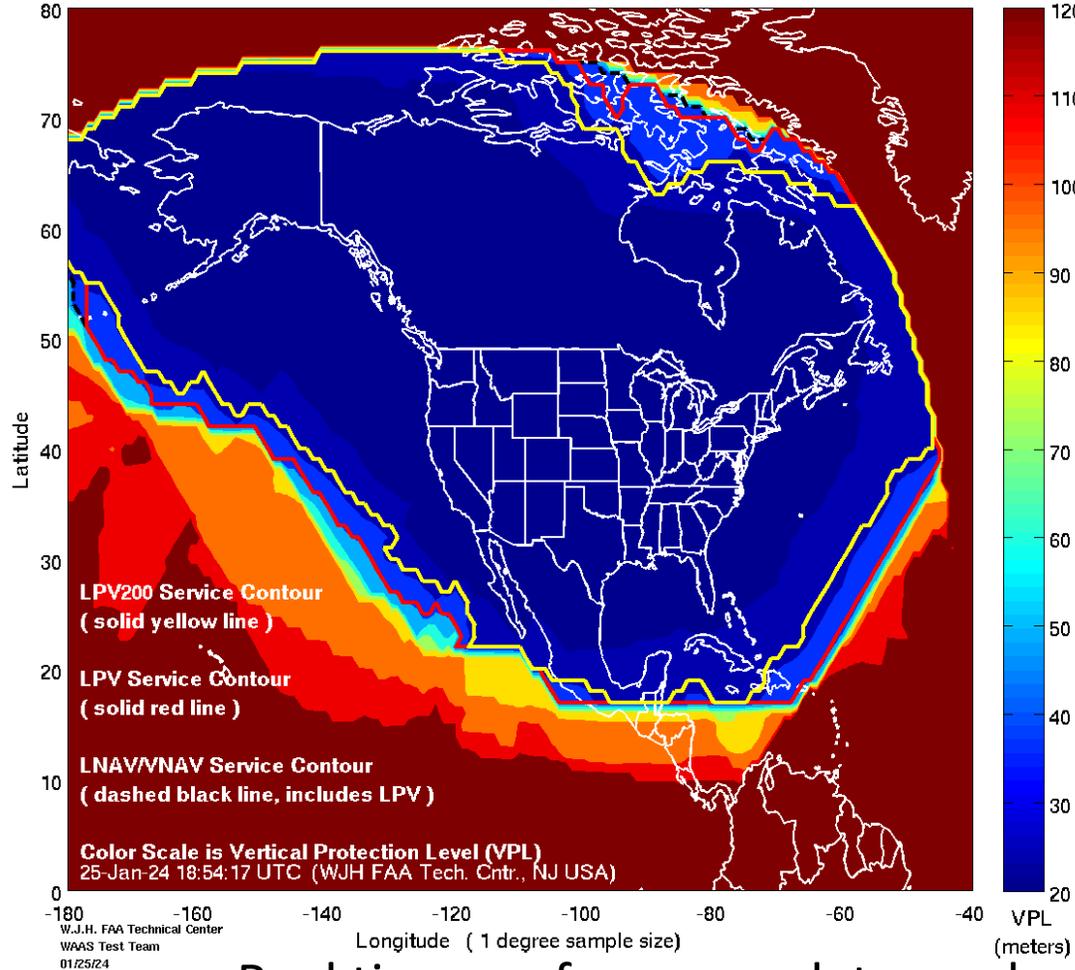
### ❖ L2C Signal

### ❖ L5 – Safety of Life Signal

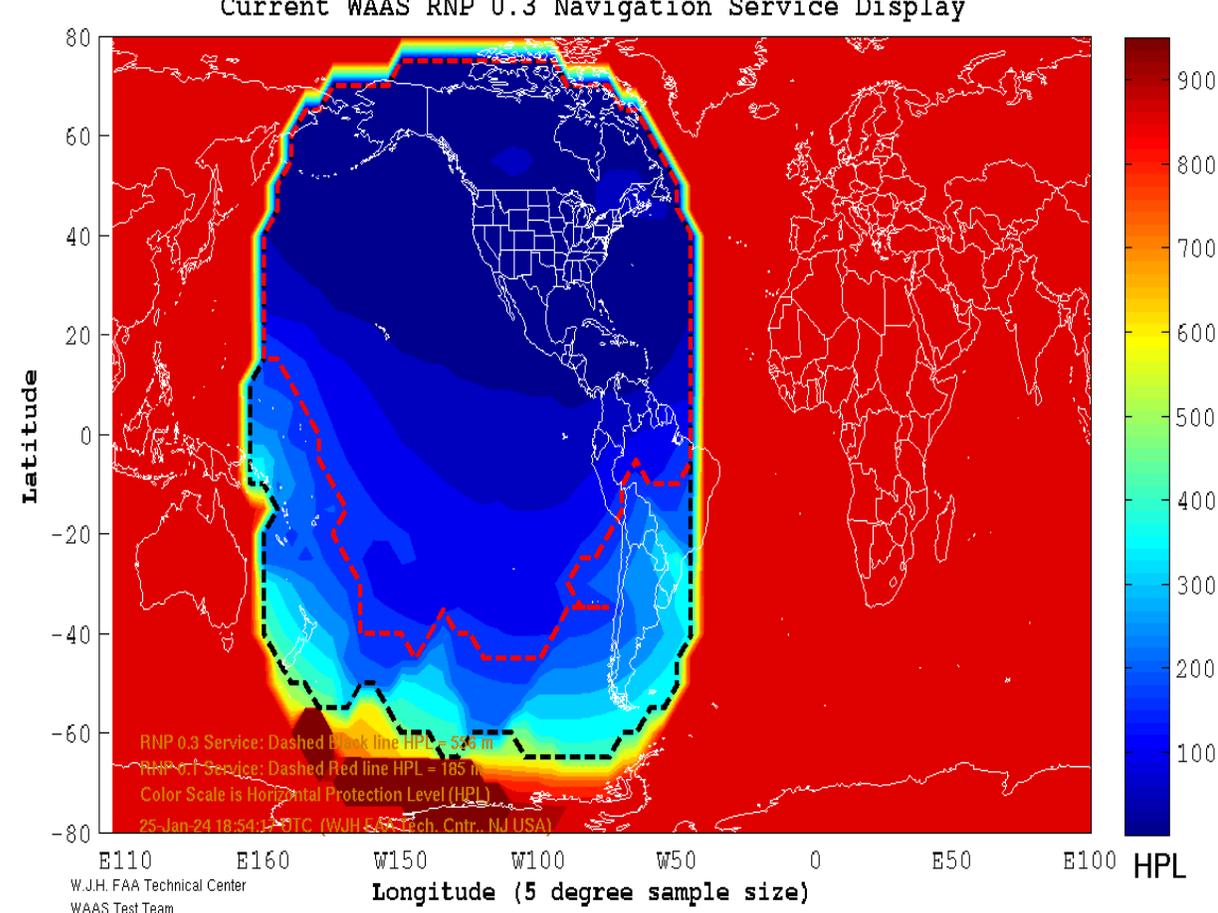
- Safety-of-life for transportation and other high-performance applications
- When combined with L1 C/A in a dual-frequency receiver, L5 (like L2C enables ionospheric corrections, which can increase accuracy; users with dual-frequency GPS receivers can achieve the same accuracy as a military user
- Improved 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

Current WAAS Vertical Navigation Service Snapshot Display



Current WAAS RNP 0.3 Navigation Service Display

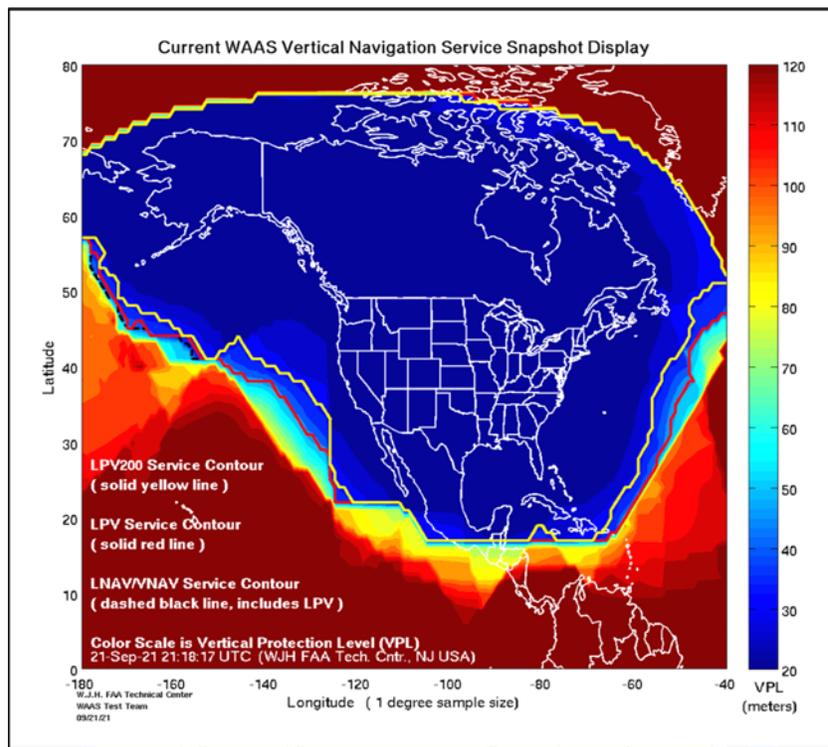


Real time performance data can be accessed at: <https://nstab.faa.gov>

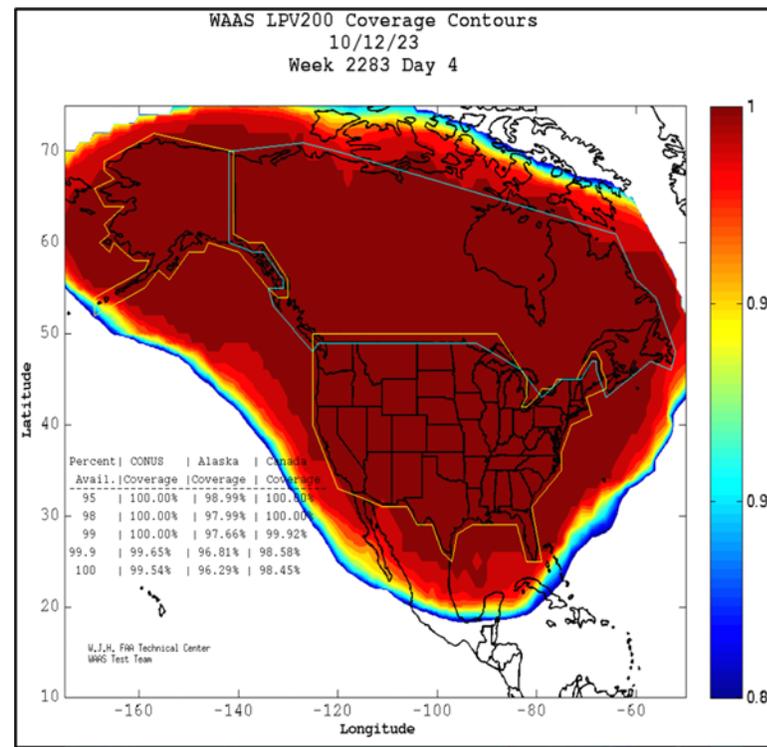
# Ionosphere Impacts

- ❖ 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

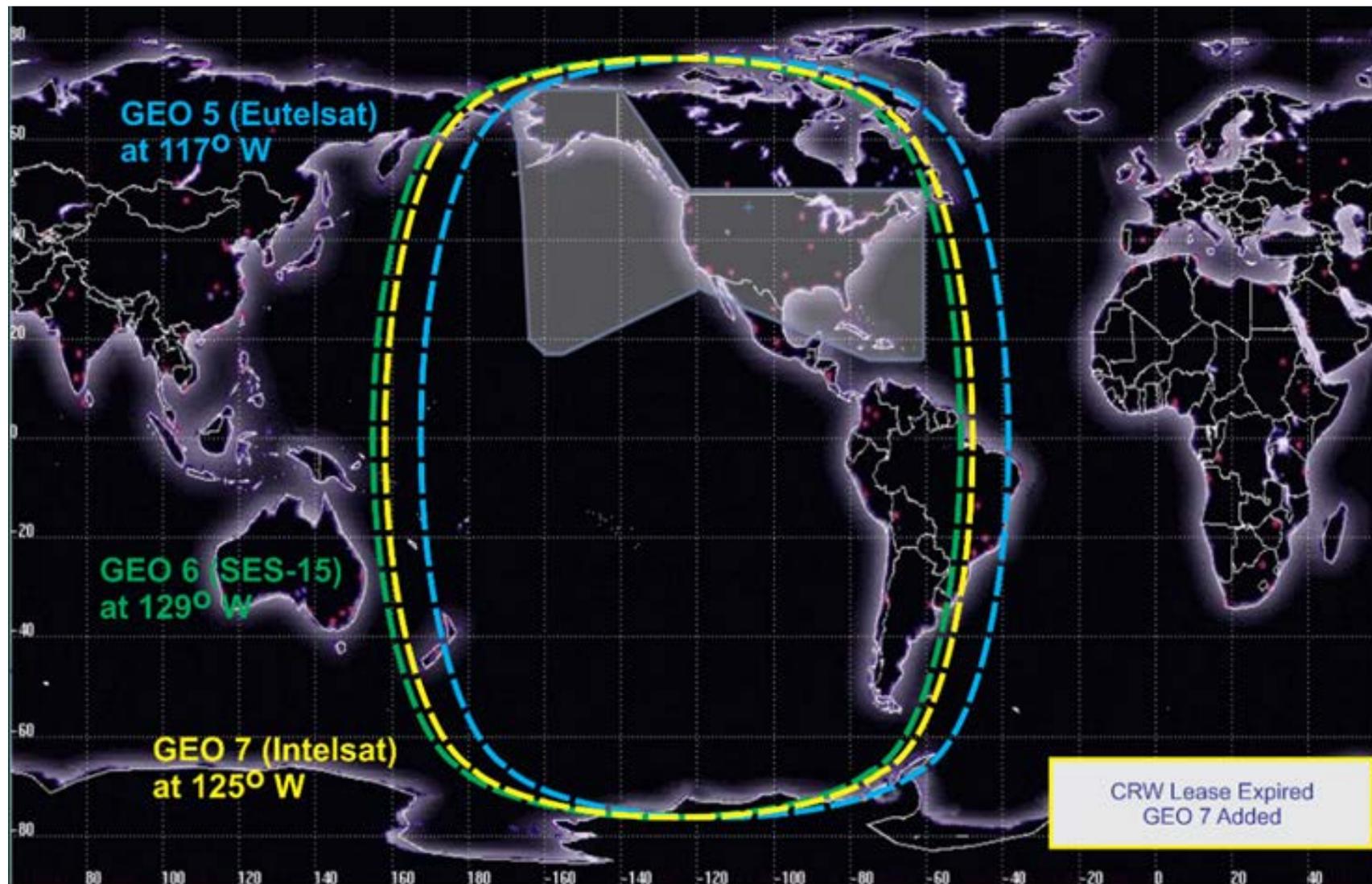
## Typical WAAS LPV Coverage



## WAAS LPV Coverage April 23, 2023 Iono event



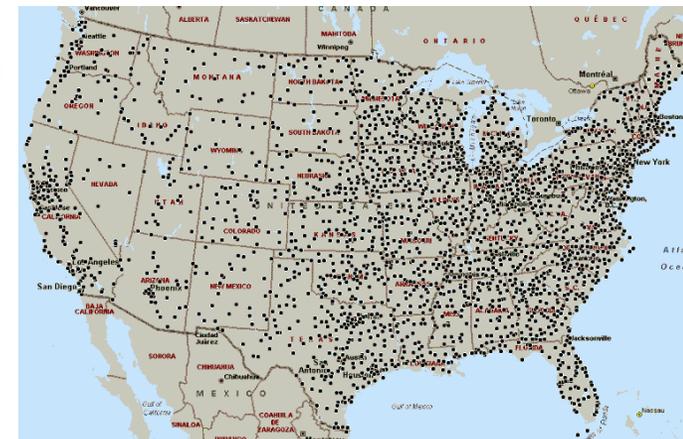
## Current WAAS GEO Constellation



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

## 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 Multi-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)



## WAAS Current Status

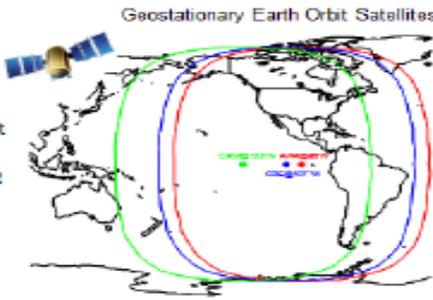
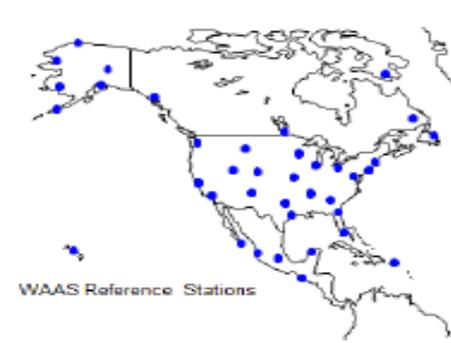
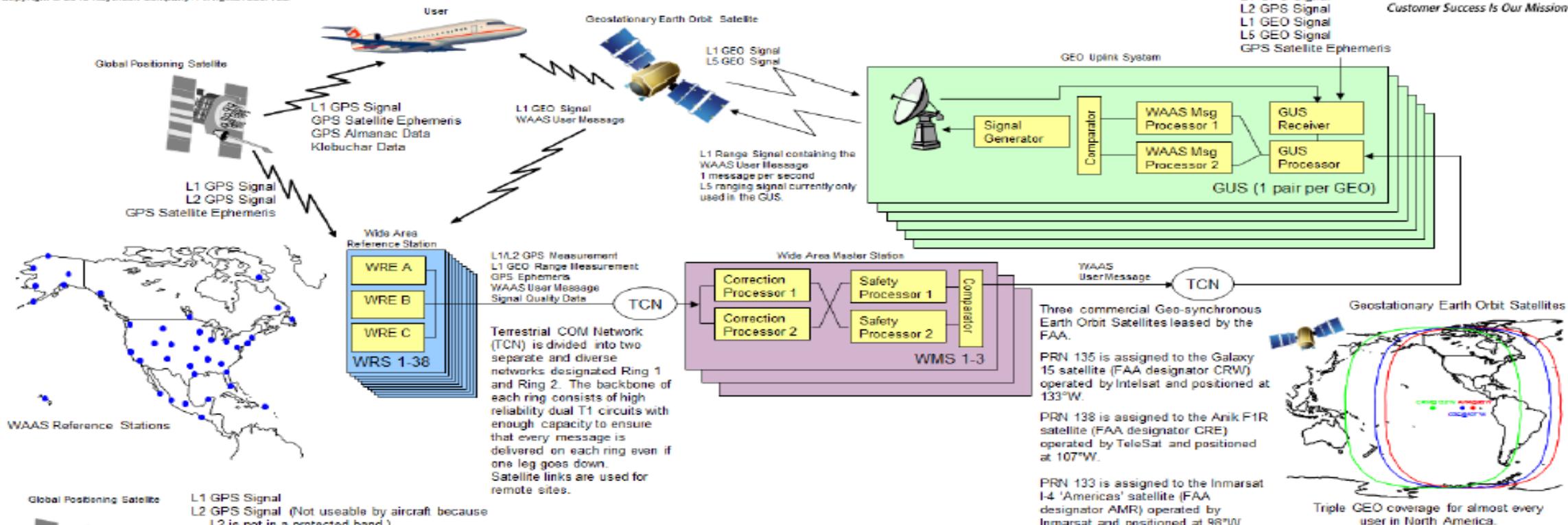
- ❖ WAAS provides high availability service to aviation users in North America
- ❖ Developing Dual Frequency WAAS
  - Will enable high availability of WAAS vertical service during ionospheric disturbances
- ❖ GEO Sustainability
  - Currently maintaining 3 GEO constellation
- ❖ WAAS Modernization Efforts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

# WAAS System Architecture

V1.5  
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## WAAS Architecture

**Raytheon**  
 Customer Success Is Our Mission



Global Positioning Satellite  
 L1 GPS Signal  
 L2 GPS Signal (Not useable by aircraft because L2 is not in a protected band.)  
 GPS Satellite Ephemeris ('Precise' Orbit Information)  
 GPS Almanac Data (Rough orbit estimates of all satellites)

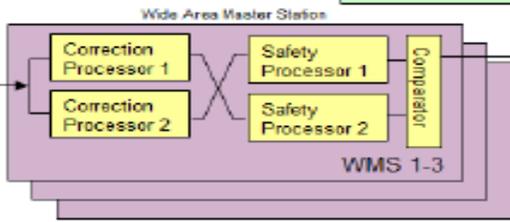
24 Satellites (21 active, 3 spare); (Currently 31).  
 12 hour orbit @ 7,000 mph (20,000 km or 12,000 miles altitude)  
 6 orbital planes, 55° inclination  
 Satellites repeat the same track and configuration over any point every 24 hours. (Their orbital period is 11 hr 58 minutes so they shift arrival time by four minutes every 24 hours)  
 At least five to eight satellites are visible anywhere on the Earth at any time (usually more).

Wide Area Reference Station  
 WRE A  
 WRE B  
 WRE C  
 WRS 1-38

L1/L2 GPS Measurement  
 L1 GEO Range Measurement  
 GPS Ephemeris  
 WAAS User Message  
 Signal Quality Data

TCN

Terrestrial COM Network (TCN) is divided into two separate and diverse networks designated Ring 1 and Ring 2. The backbone of each ring consists of high reliability dual T1 circuits with enough capacity to ensure that every message is delivered on each ring even if one leg goes down. Satellite links are used for remote sites.



User equipment is compatible with RTCA-DO229C or D. Various user configurations:  
 Beta - Position with Integrity provided to an integrated navigation system.  
 Gamma - Beta system plus a navigation function which provides path deviations relative to the selected path.  
 Delta is a Beta system plus a navigation function but no pilot controls and can not be used for RNAV.

All configurations support RAIM operations if WAAS is not available or an insufficient number of WAAS corrected satellites are in view. Similarly, if WAAS Ionospheric corrections are unavailable the user can use Klobuchar data. User equipment must track two GEO satellites if available. Corrections can be mixed across GEOs for enroute navigation, but not precision approach. Each WAAS message includes a 24 bit CRC to ensure that garbled messages do not result in HMI.

Three commercial Geo-synchronous Earth Orbit Satellites leased by the FAA.  
 PRN 135 is assigned to the Galaxy 15 satellite (FAA designator CRW) operated by Intelsat and positioned at 133°W.  
 PRN 138 is assigned to the Anik F1R satellite (FAA designator CRE) operated by TeleSat and positioned at 107°W.  
 PRN 133 is assigned to the Inmarsat I-4 'Americas' satellite (FAA designator AMR) operated by Inmarsat and positioned at 98°W.

	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!