FAA WAAS Update

Presented by: Deborah Lawrence, FAA Manager of Navigation Programs

Presented to: Munich Satellite Navigation Summit

Date: March 2015

Topics

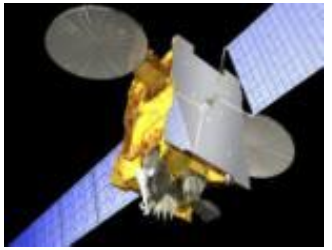
- **WAAS Program Status**
- **WAAS Performance**
- **User Segment Update**

Wide Area Augmentation System

38 Reference Stations

3 Master Stations

6 Ground Earth Stations



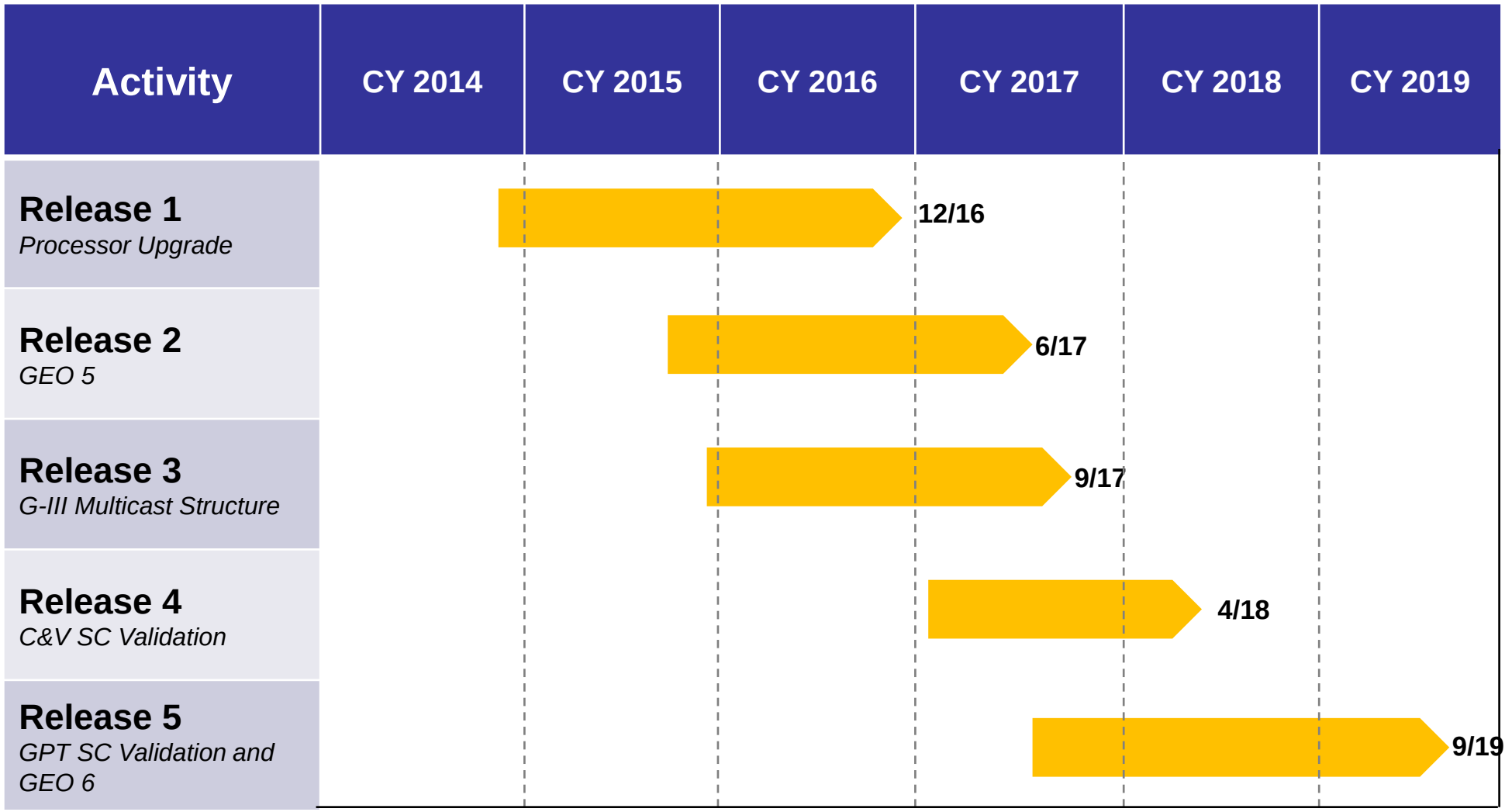
3 Geostationary Satellite Links

2 Operational Control Centers

WAAS Development Phases

- **Phase I: IOC (July 2003) Completed**
  - Included Development of a robust safety architecture
  - Included establishment of WAAS expert panel to evaluate potential integrity threats
- **Phase II: Full LPV (FLP) (2003 – 2008) Completed**
  - Completed a Safety Risk Management Decision (SRMD) to support LPV-200 (VAL of 35m)
  - Expanded WAAS coverage to Mexico and Canada while modifying the System to address observed Ionospheric threats
- **Phase III: Full LPV-200 Performance (2009 – 2013)**
  - Completed System updates to improve performance during moderate ionospheric activity
  - Supported continuous monitoring of system data that contributes to continued integrity assurance
  - Began transition of Second Level Engineering from contractor based to organic FAA capability
- **Phase IV: Dual Frequency (L1,L5) Operations (2014 – 2044)**
  - Includes the transition from use of L2 to L5 in WAAS reference stations
  - Infrastructure modifications to support future L1/L5 user capability
  - Support sustainment of WAAS GEOs

WAAS Phase IV Ground Segment Development



WAAS Phase IV Dual Frequency Operations

- **Original WAAS plan was to enter DF phase in 2014 with a completion date by 2019**
  - New dual frequency L1/L5 service needed to further improve WAAS availability and continuity
- **Due to the changes to the GPS L5 launch schedule, the WAAS Program Office reassessed its DF integration schedule, dividing it into two segments**
  - Segment 1 (5-7 year effort)
    - Develop infrastructure improvements to enable use of L5
    - G-III Reference Receiver Integration, Communications Infrastructure Upgrade, Safety Computer Integration
    - The Federal Aviation Administration awarded the Wide Area Augmentation System (WAAS) Dual Frequency Operations (DFO) Segment 1 contract to Raytheon Company on September 26, 2014
  - Segment 2 (5-7 year effort)
    - Implementation of L1/L5 user capability (follows L5 FOC)
      - Algorithm updates to use L5 and implement dual frequency service
      - Dual Frequency Messaging
- **Program re-baseline approved by FAA's Joint Resource Council (JRC), May 2014**
- **'Sunset' of L2 P(Y) compels WAAS to use another signal to maintain current service**
  - Change required independent of decision on whether to implement a dual frequency service
- **GEO sustainment planned for rest of WAAS service life**
  - Maintain minimum of dual coverage over WAAS service area
  - GEO Sustainment currently planned until 2044

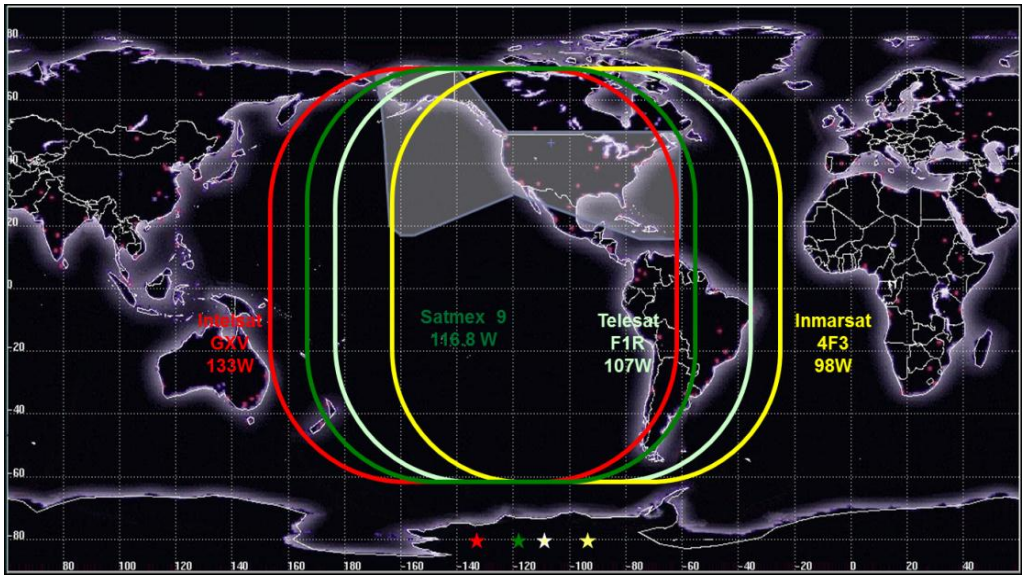
Federal Register Notice

- **L1/L2 Sunset**
  - In 2008 the Office of Space Commercialization produced a Federal Register Notice detailing the U.S. Government's plan to no longer guarantee L2 P(Y) phase relationship necessary for codeless and semi-codeless use beyond 12/31/2020.
  - FAA interest to maintain semi-codeless technique for two years following 24 L5 satellites on orbit to provide transition time
  - Will review 2014 FRP language

GEO Activities

- **Current WAAS GEO satellites**
  - Intelsat Galaxy XV (CRW)
  - Anik F1R (CRE)
  - Inmarsat I4F3 (AMR) *

  * - *AMR is a non-ranging satellite*



- **GEO 5/6 Acquisition**
  - Contract awarded September 2012
  - Eutelsat 117 West B (Satmex-9) satellite will host the WAAS GEO 5 Satellite Payload
    - Orbital slot (116.8º West) will provide full coverage
    - Scheduled for operations by Oct 2017
  - GEO 6 Satellite opportunities currently under investigation

G-III Comm Integration

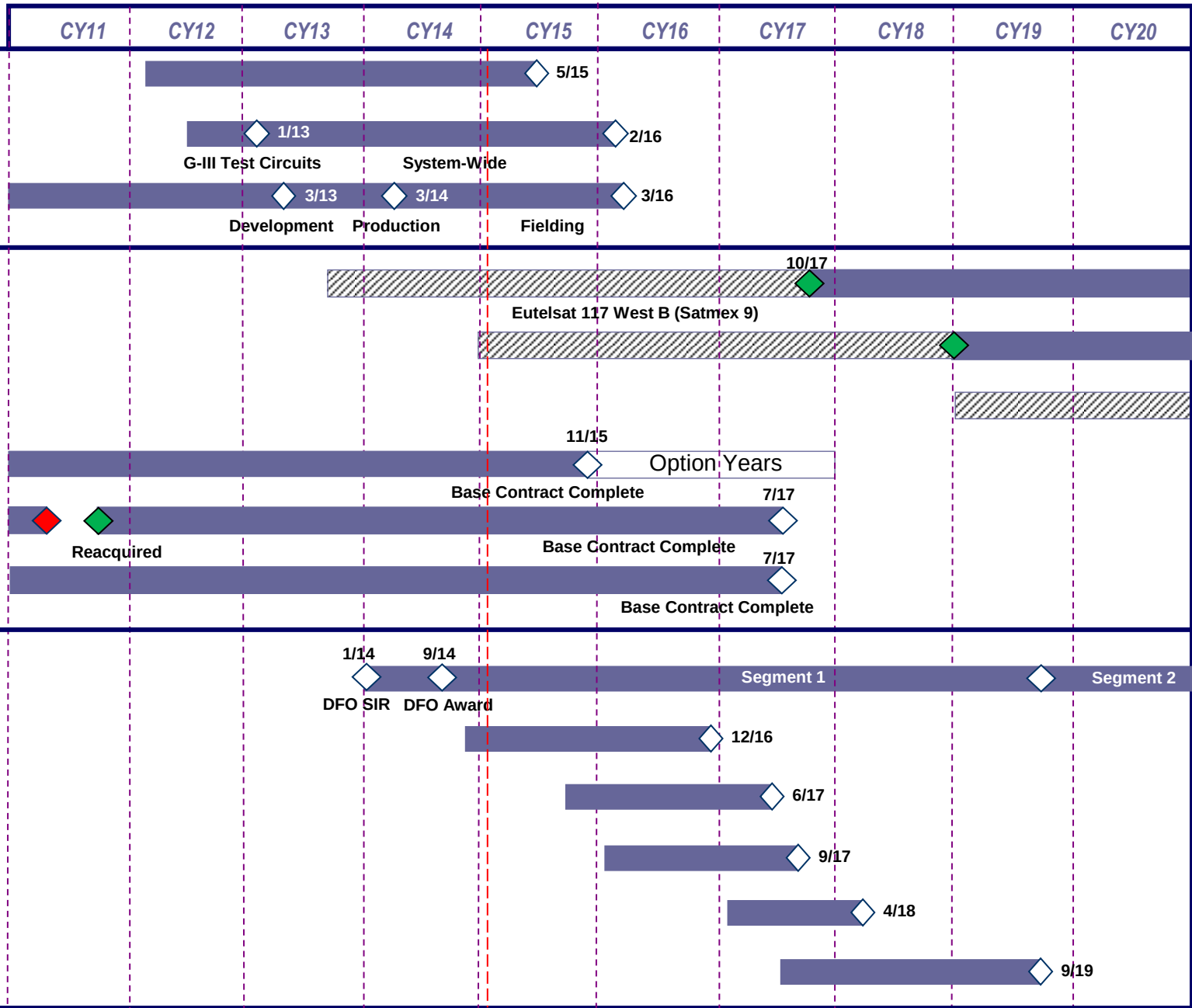
- **Test Bed Operational**
  - Shadow system became operational December 9, 2014
  - To be completed by May 2015
- **G-III Software Integration Completed March 2015**
- **Cutover of Network 1 and Network 2 CORE Comm**
  - Scheduled to be completed August, 2015
- **Cutover of First WRS site (ZLA) projected operational September 2015**
  - All WRS sites cutover by July 2016

WAAS Phase IV Investigations

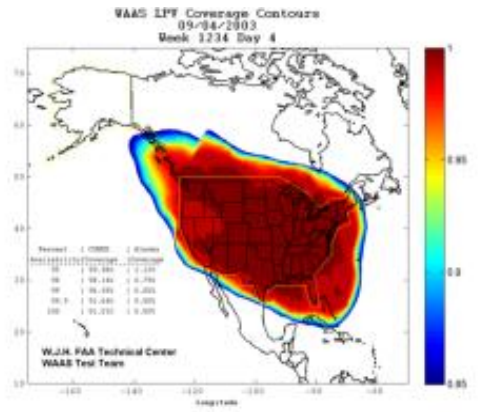
- **Dual-Frequency Multi-constellation Capability**
  - International Focus is on taking advantage of other GPS like constellations
    - International Civil Aviation Organization (ICAO) Navigation Systems Panel (NSP) has developed work plan that supports development of future standards for use of other Global Navigation Satellite Systems (GNSS)
  - User Equipment Standards for Dual-Frequency Operations
    - Minimum Operation Performance Standards (MOPS) for Dual-frequency GPS currently looking to obtain stakeholder involvement
    - 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
    - RTCA is amending SC-159 Terms of Reference (ToR) to include MOPS work on GPS/GLONASS, GPS/SBAS DF and enabling Multi-Constellation (MC), GPS/GBAS DF
- **Advanced RAIM (ARAIM)**
  - Avionics-centric approach to dual-frequency multi-constellation
  - US/EU technical group finalizing concept definition the 3rd Milestone of their work plan
    - Milestone 3 will address stakeholder input to the concept and proposed architecture alternatives
    - It will also include a road map outlining a path toward requirements development, validation and implementation inline with current industry avionics development plans

WAAS Schedule

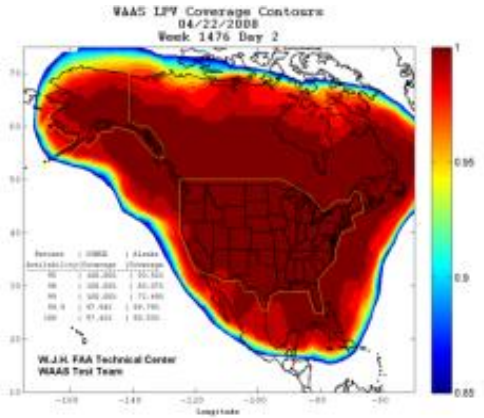
Legend	
◇	Milestone
◆	Service Ended
◆	Service Started
▨	Satellite Development



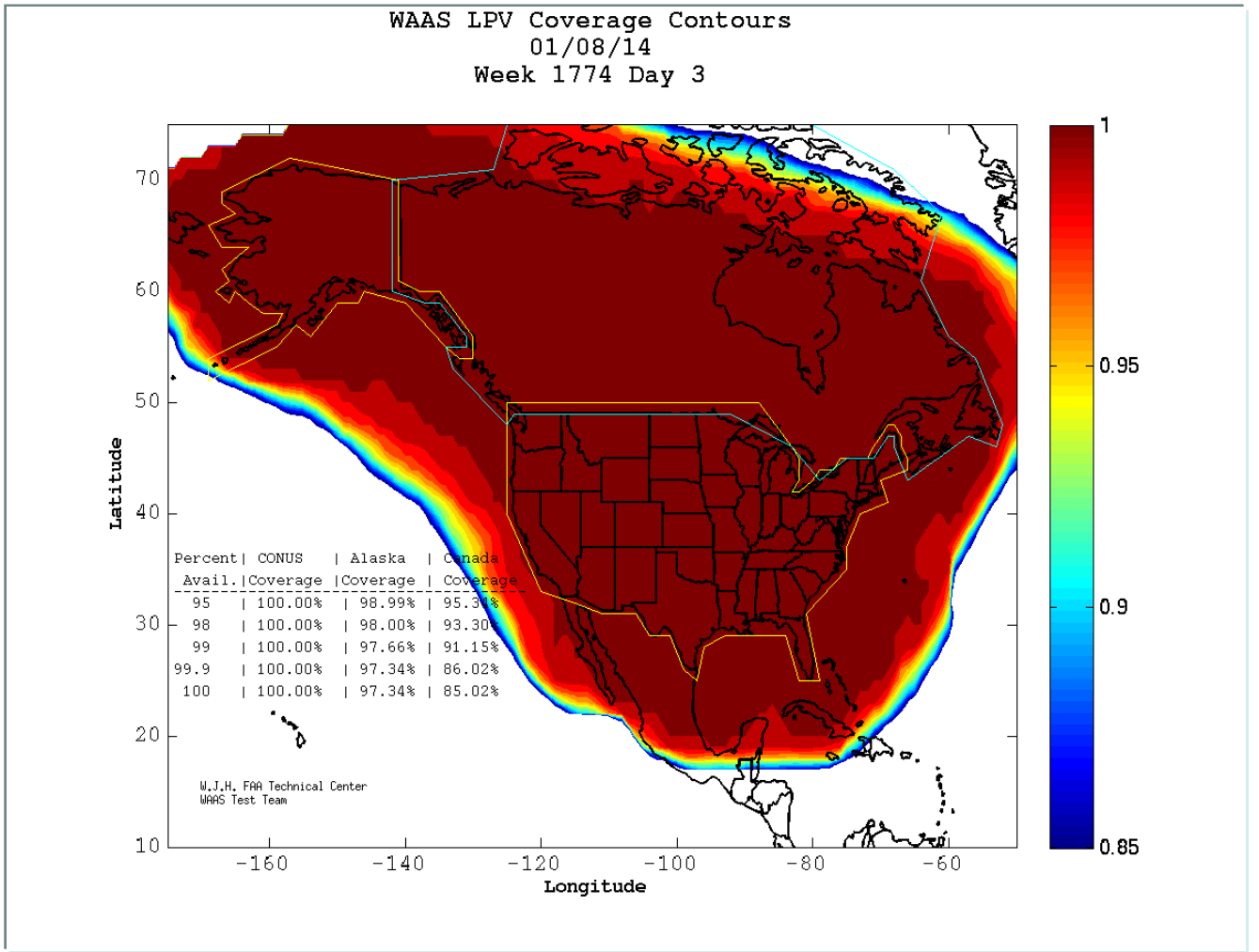
WAAS Coverage



2003 IOC – LPV Coverage in lower 48 states only

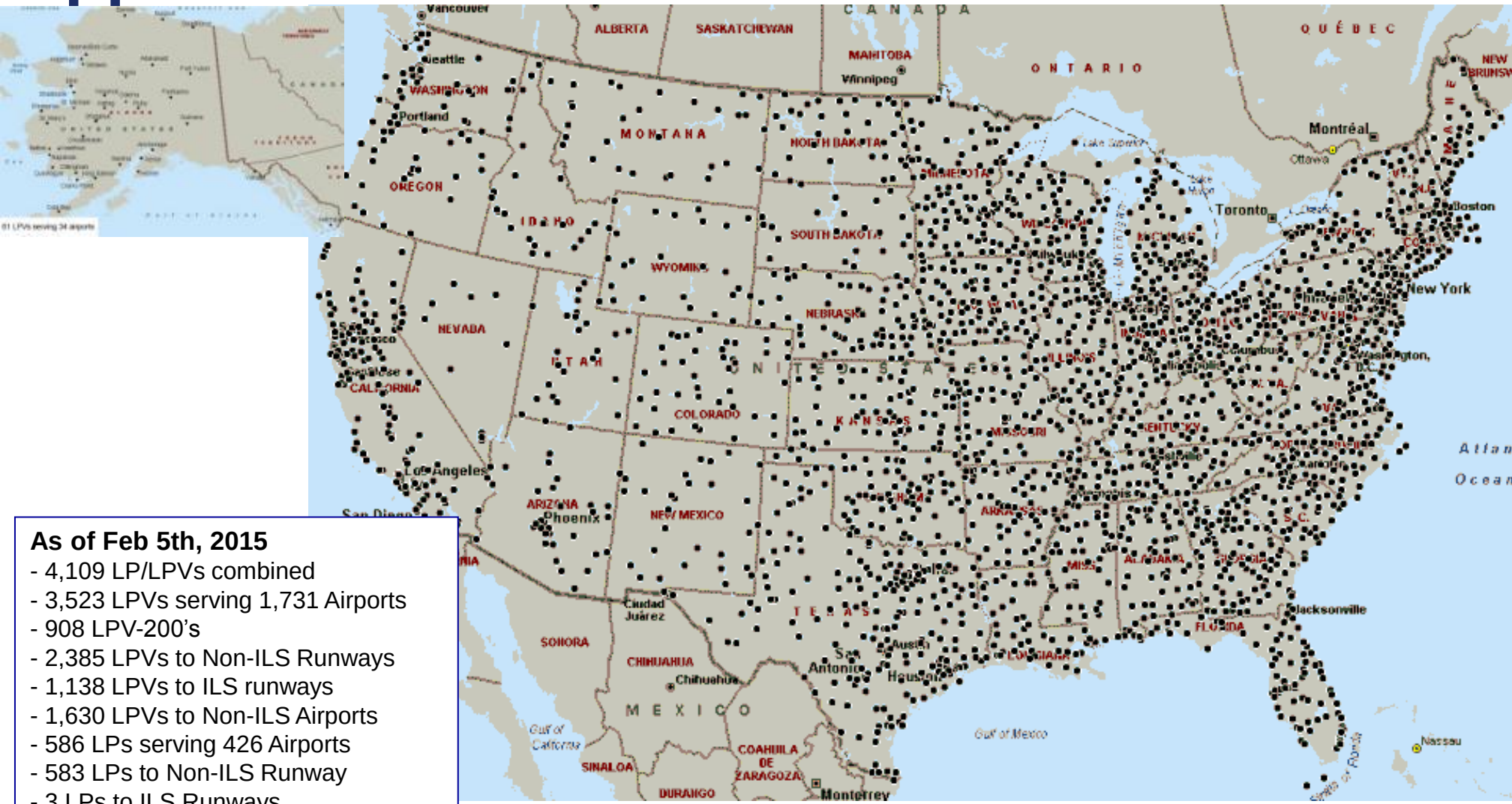


2008 Coverage - Full LPV 200 Coverage in CONUS (2 Satellites)



2013 Coverage - Full LPV 200 Coverage in CONUS (3 Satellites)

Airports with WAAS LPV/LP Instrument Approaches



As of Feb 5th, 2015

- 4,109 LP/LPVs combined
- 3,523 LPVs serving 1,731 Airports
- 908 LPV-200's
- 2,385 LPVs to Non-ILS Runways
- 1,138 LPVs to ILS runways
- 1,630 LPVs to Non-ILS Airports
- 586 LPs serving 426 Airports
- 583 LPs to Non-ILS Runway
- 3 LPs to ILS Runways

WAAS STC Aircraft December 2014 (Estimate)

Garmin – 73,184 aircraft
- GA Aircraft (See FAA Garmin Approved Model List (AML)). Most GA Part 23 aircraft.
- GTN series – Lear 35/35A, 36/36A,24 – Phenom300 with G-3000

Universal Avionics – 2,380 aircraft
- 122 fixed wing and 12 helicopter types and models

RockwellCollins – 1,930 aircraft
- 39 Types and models
- Latest Aircraft – Embraer Legacy 500

Honeywell /CMC Electronics) – 921 aircraft
- 22 types and models

Avidyne – 238 aircraft
- 6 types and models (Cirrus SR 20 & 22, Piper Matrix & Mirage, Piper Saratoga NX, and EA-500)
- IFD 540 WAAS LPV - (STC complete July 2014 – AML STC approved for over 1,000 aircraft makes and models)

Genesys Aerosystems (Chelton) – 247 aircraft
- Bell-407 & 412, Cessna 501, 550, Piper PA-42, Beechcraft C-90&A, EurocopterAS-350, AgustaAW109SP, Beechcraft T-34B, Kawsaka

Innovative Solutions & Support (IS&S) – 200 aircraft
- Eclipse 550/500
- Boeing 737-400 (pending)

Thales – 5 aircraft
- Airbus A300-600ST (Beluga)
- Airbus A400M (Military)
- Airbus A350XWB - pending

TOTAL Estimated WAAS LPV Equipped Aircraft – 79,105

Questions

GNSS Enables PBN and ADS-B

		Navigation (≥ 99.0% Availability)		Surveillance (≥99.9% Availability)			Positioning
		Accuracy (95%)	Containment (10^{-7})	Separation	NACp (95%)	NIC (10^{-7})	GNSS PNT (99.0 – 99.999%)
APNT	En Route	*10 nm	20 nm	5 nm	185.2m (7)	1 nm (5)	GPS
		*4 nm	8 nm				
		*2 nm	4 nm				
	Terminal	*1 nm	2 nm	3 nm	92.6m (8)	0.6 nm (6)	DME Only GAP
	LNAV	*0.3 nm	0.6 nm				
	RNP (AR)	*0.1 nm	**0.1 nm	2.5 nm DPA	92.6m (8)	0.2 nm (7)	SBAS
	LPV	16m/4m	40m/50m	2.5 nm DPA	92.6m (8)	0.2 nm (7)	
	LPV-200	16m/4m	40m/35m				
	GLS Cat-I	16m/4m	40m/10m	2.0 nm IPA	92.6 m (8)	0.2 nm (7)	GBAS
	GLS Cat-III	16m/2m	40m/10m				

* Operational requirements are defined for total system accuracy, which is dominated by fight technical error. Position accuracy for these operations is negligible.

** Containment for RNP AR is specified as a total system requirement; value representative of current approvals.

Dependent Parallel Approach (DPA)
Independent Parallel Approach (IPA)

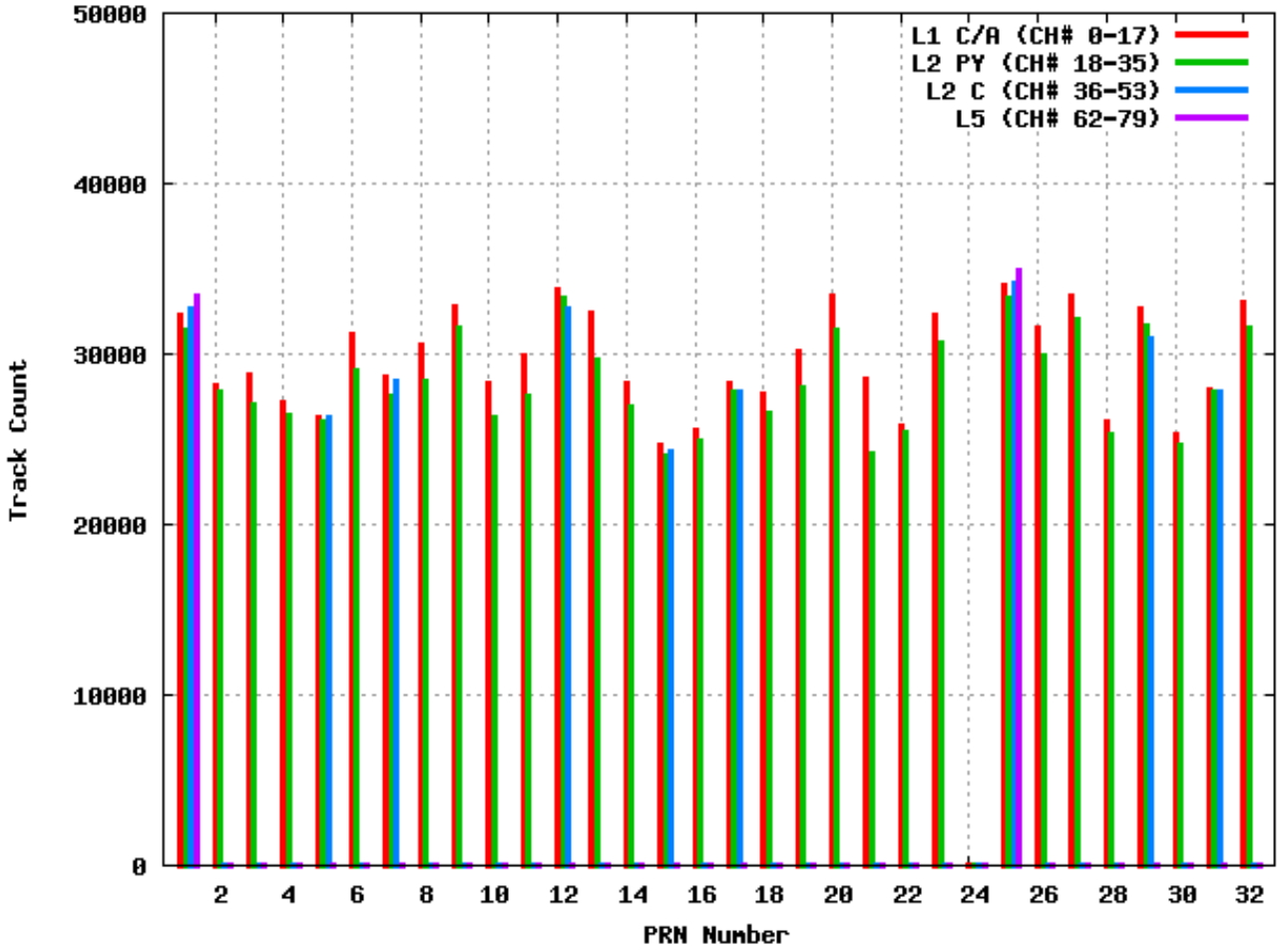
Surveillance Integrity Level (SIL)
Navigation Integrity Category (NIC)

Navigation Accuracy Category for Position (NACp)

G-III Capabilities

- **Satellite Tracking**
  - 18 GPS, 8 SBAS
  - Upgradable for Galileo, COMPASS…with additional cards
- **Signal Tracking**
  - L1 C/A, L1C, L2P(Y), L2C and L5
    - L1C; track pilot, L1C for data demodulation
    - L2C; track CL, CM for data demodulation
    - L5; track Q5, I5 for data demodulation
    - L5 SBAS; configurable with default as track/demodulate with I5
  - Non-standard codes
    - Loaded via data interface at startup
    - L1 C/A, L1C, L2CM and L5 loaded as memory codes
    - L2CL loaded as shift register value (same polynomial)

Live Satellite Tracking (L1 C/A, L2PY, L2C & L5)



Message Type 12 Overview (MT12)

- **Message Type 12 (MT12) is a optional function standardized in Annex 10 (App. B, Section 3.5.7.6.1)**
  - It is defined to carry UTC timing parameters
- **Alternate Position Navigation and Timing (APNT) program considering MT 12 as potential timing reference in absence of GPS signal**
  - WAAS could populate MT-12 with the GPS–UTC offset parameters with simple modification to the system
  - WAAS Network Time (WNT) offset from GPS time is well within 50 ns limit defined by Annex 10 (Ch. 3, Section 3.7.3.4.5)
- **Timing reference accuracy for APNT user anticipated to be within 25 ns once implemented (to be validated)**
  - Proposal to use beam forming techniques to maintain tracking of GEO signals during interference conditions

SBAS Network Time / UTC Message (MT-12)

- **8 parameters identical to GPS**
- **4 for leap second**
  - Converts GPS time to UTC
  - (15 sec, 16 sec on 1 July)
- **4 to correct bias and drift**
  - Small, correction ~ 10 nsec
- **WAAS MT-12 has additional information**
  - GPS Time of Week (sec)
  - GPS Week Number (WN)
  - UTC Standard Identifier (ie USNO)
  - GLONASS indicator (whether data will be provided)
  - GLONASS offset data (optional)

GPS

Subframe 4,Page 18		
Field	Bit	LSB
A_0	32*	2^{-30}
A_1	24*	2^{-50}
dt_{LS}	8*	1
t_{ot}	8	2^{12}
WN_t	8	1
WN_{LSF}	8	1
DN	8	1
dt_{LSF}	8	1

Bias

Drift

Leap Sec

Reference Time

Ref Week

Adjustment Week

Day Number

"Future" Leap Sec

HOW

WN from Subframe 1

GPS Week

WAAS

Message Type 12		
Field	Bit	LSB
A_{0WNT}	32*	2^{-30}
A_{1WNT}	24*	2^{-50}
dt_{LS}	8*	1
t_{0t}	8	2^{12}
WN_t	8	1
WN_{LSF}	8	1
DN	8	1
dt_{LSF}	8	1
GPS TOW	20	1
WN	10	1
UTC Ident	3	
GLONASS	1	
GLONASS	71	TBD

$$dt_{utc} = dt_{LS} + A_0 + A_1 * (t_{GPS} - t_{ot} + 604800 * (WN - WN_t))$$

$$t_{utc} = t_{GPS} - dt_{utc}$$

*two's complement, sign bit MSB

Questions