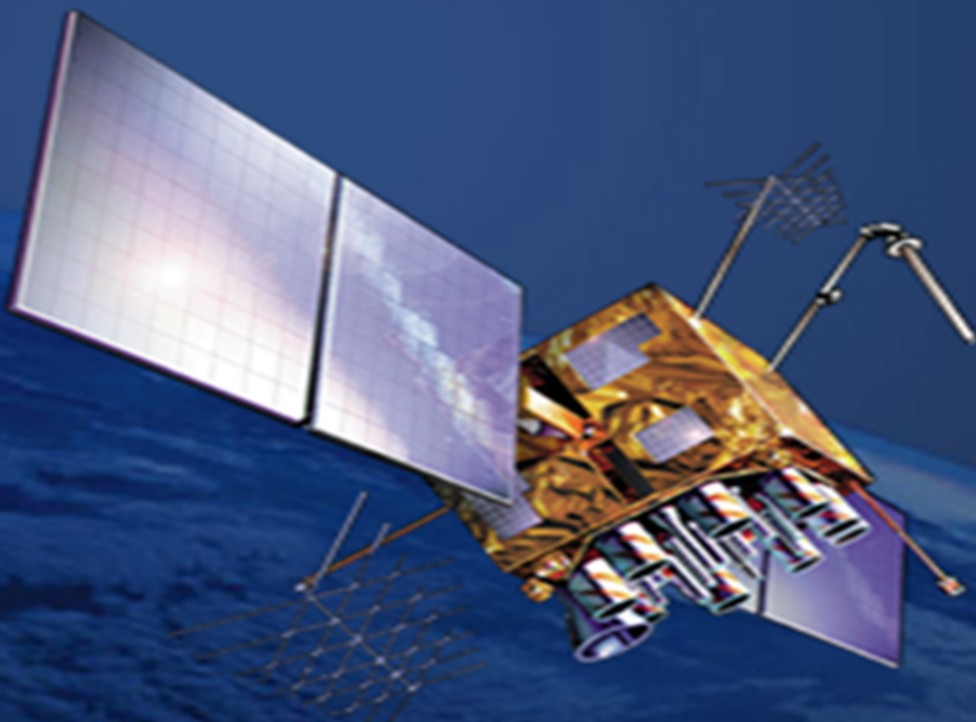
International Committee on Global Navigation Satellite Systems

U.S. Space-Based PNT

Policy and Program Review



December 8-12, 2008

Overview

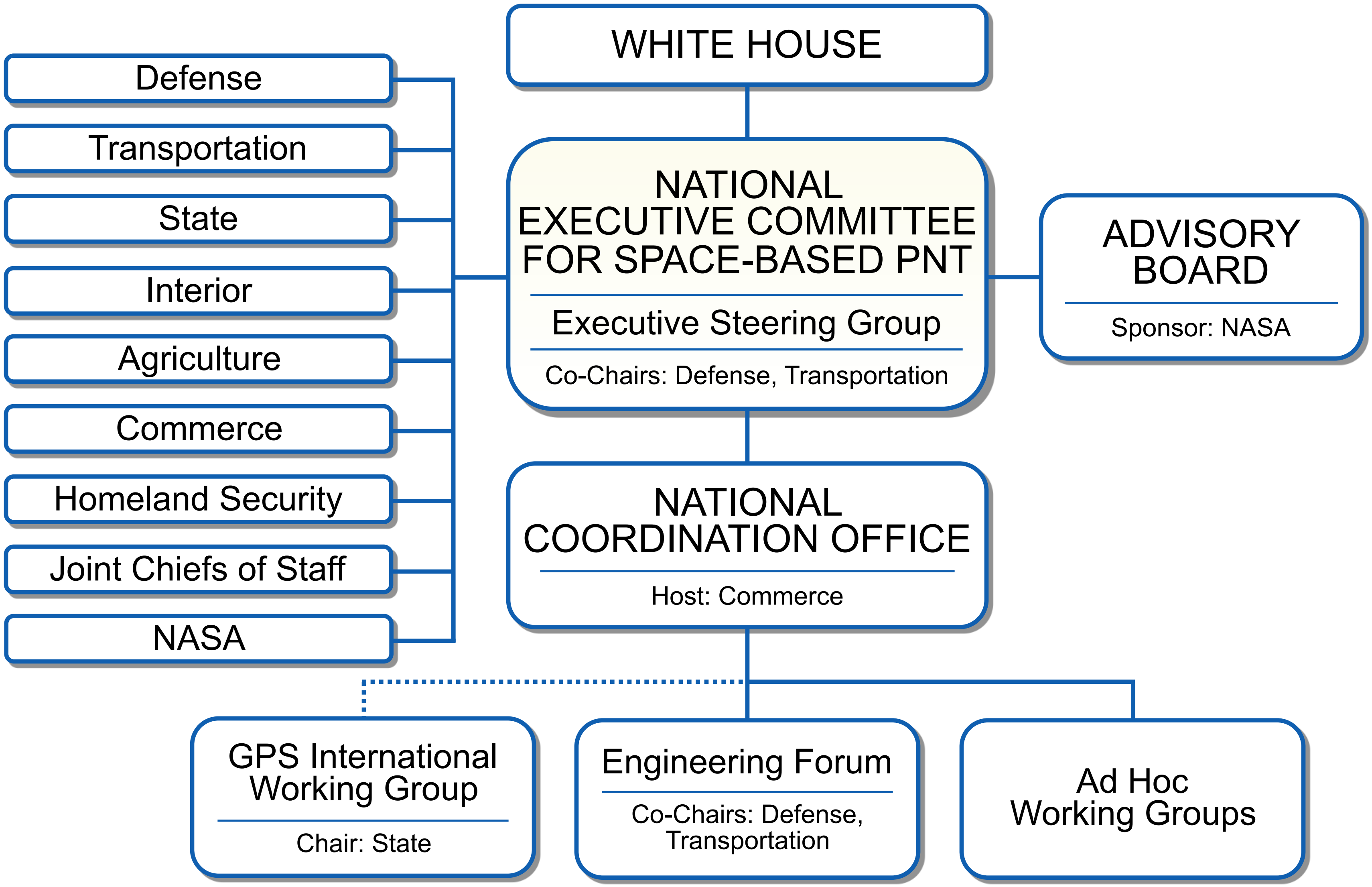
U.S. Space-Based PNT Policy	Michael Shaw
Global Positioning System Description	David Goldstein
GPS Augmentations	Leo Eldredge
Interference Detection and Mitigation	John Merrill
Summary	

U.S. Space-Based PNT Policy

GOAL: Ensure the U.S. maintains space-based PNT services, augmentation, back-up, and service denial capabilities that…

- Provide uninterrupted availability of PNT services
- Meet growing national, homeland, economic security, and civil requirements, and scientific and commercial demands
- Remain the pre-eminent military space-based PNT service
- Continue to provide civil services that exceed or are competitive with foreign civil space-based PNT services and augmentation systems
- Remain essential components of internationally accepted PNT services
- Promote U.S. technological leadership in applications involving space-based PNT services

U.S. Space-Based PNT Organization Structure



U.S. Policy Promotes Global Use of GPS Technology

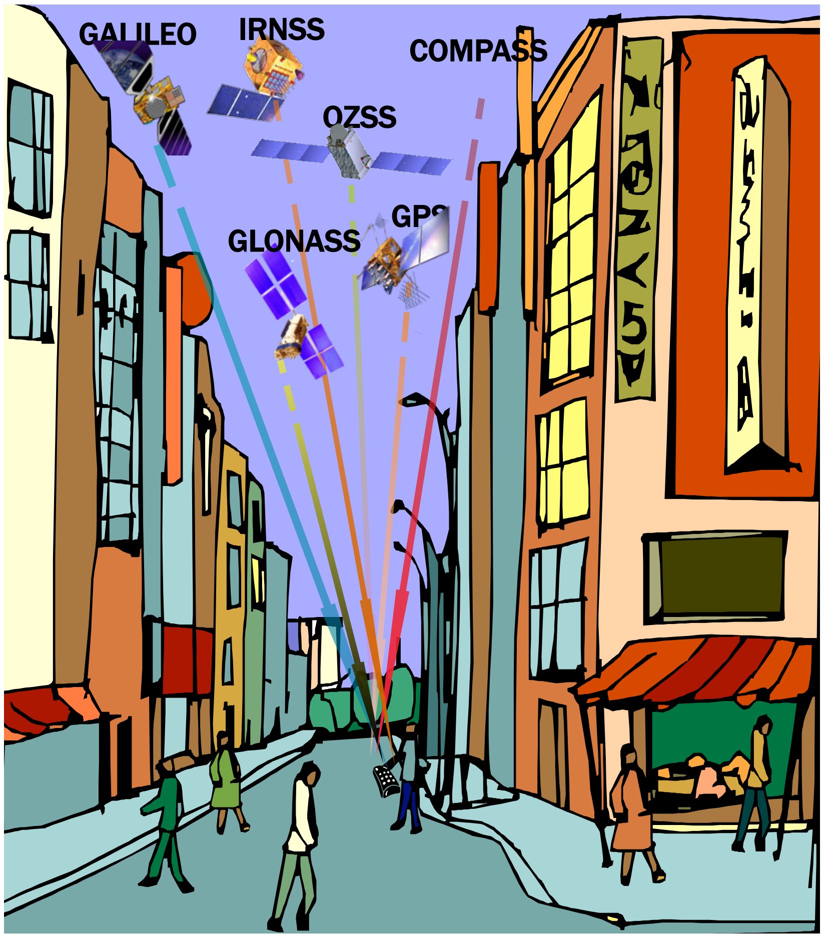
- No direct user fees for civil GPS services
  - Provided on a continuous, worldwide basis
  - Including both current and future civil GPS services
- Open, public signal structures for all civil services
  - Promotes equal access for user equipment manufacturing, applications development, and value-added services
  - Encourages open, market-driven competition
- Service improvements for civil, commercial, and scientific users worldwide
- Protection of radionavigation spectrum from disruption and interference
- Global compatibility and interoperability with GPS

U.S. Objectives in Working with Other GNSS Service Providers

- Ensure **compatibility** — ability of U.S. and non-U.S. space-based PNT services to be used separately or together without interfering with each individual service or signal
  - Radio frequency compatibility
  - Spectral separation between M-code and other signals
- Achieve **interoperability** – ability of civil U.S. and non-U.S. space-based PNT services to be used together to provide the user better capabilities than would be achieved by relying solely on one service or signal
  - Primary focus on the common L1C and L5 signals
- Ensure a level playing field in the global marketplace

Pursue through Bilateral and Multilateral Cooperation

The Goal of GNSS Civil Interoperability



- **Compatibility**
  - Do no harm
- **Ideal interoperability** provides users a PNT solution using signals from different GNSS systems:
  - No additional receiver cost or complexity
  - No degradation in performance

Interoperable = Better Together than Separate

Key Accomplishments
since last ICG meeting in September 2007

- Launched 2 GPS IIR-M satellites
- Permanently eliminated SA from GPS Space and Ground Segments
- Awarded GPS III-A Contract
- Awarded GPS OCX Developmental Contracts
- Announced plan to put CNAV Data on L2C in 2009
- Released 4th Edition of the Standard Positioning Service Performance Standard
- Published Federal Register Notice on civil access to Semi-Codeless
- Released 1st Edition of the Wide Area Augmentation System (WAAS) Performance Standard

Key Accomplishments
since last ICG meeting in September 2007

- Completed National PNT Architecture Report
- Int'l Civil Aviation Organization accepted US GPS/WAAS offer
- Delivered U.S. Government GPS commitment to the International Maritime Organization (IMO)
- 1st U.S.- EC Plenary on GPS and Galileo Cooperation
- Asia Pacific Economic Cooperation (APEC) Summit on GNSS Innovation held in Bangkok, Thailand
- NASA and NOAA Agreements signed with Japan to support QZSS monitoring sites in Hawaii and Guam
- Released public fact sheet on Interference Detection and Mitigation (IDM) Plan

Global Positioning System Description

Briefing to the International Committee on GNSS

LtCol David Goldstein, Chief Engineer
GPS Wing

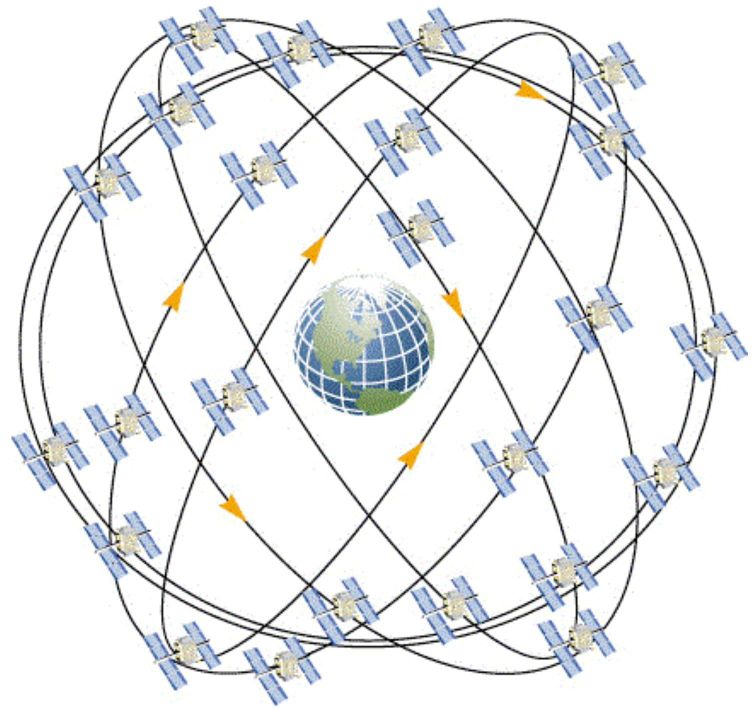
December 10, 2008

Agenda

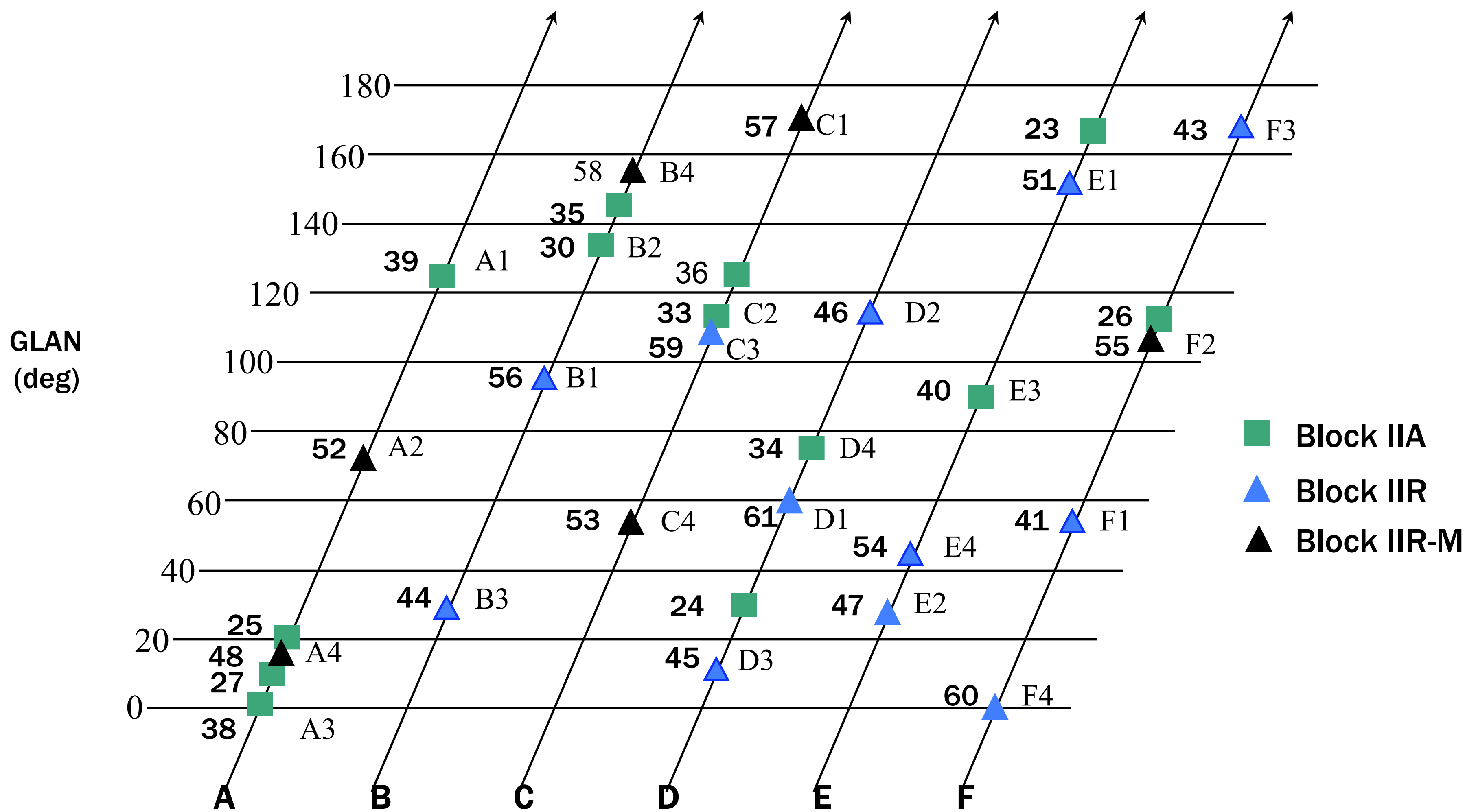
- GPS Constellation
- Ground Segment
- Timing and Geodetic Reference Standards
- Performance
- Signals – Current and Planned
- Specifications
- Capability Deployment

GPS Constellation

- Six planes
- 55 ^{o} inclination
- 20,182 km altitude
- 12 hour orbits
- Twenty four primary slots
- Seven additional satellites (currently)

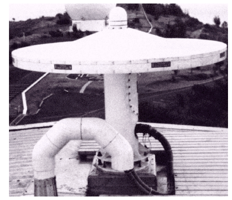


Three Blocks of Satellites in Current GPS Constellation



GPS Ground Segment

L-Band



S-Band

MCS at Schriever AFB, CO
& Alternate MCS at VAFB

16 Monitor Stations
6 OCS + 10 NGA

12 Ground Antennas
4 GPS + 8 AFSCN

MCS
Master Control Station
Schriever AFB

AMCS
Alternate MCS
Vandenberg AFB

GPS Ground Antennas

AFSCN Remote Tracking Stations

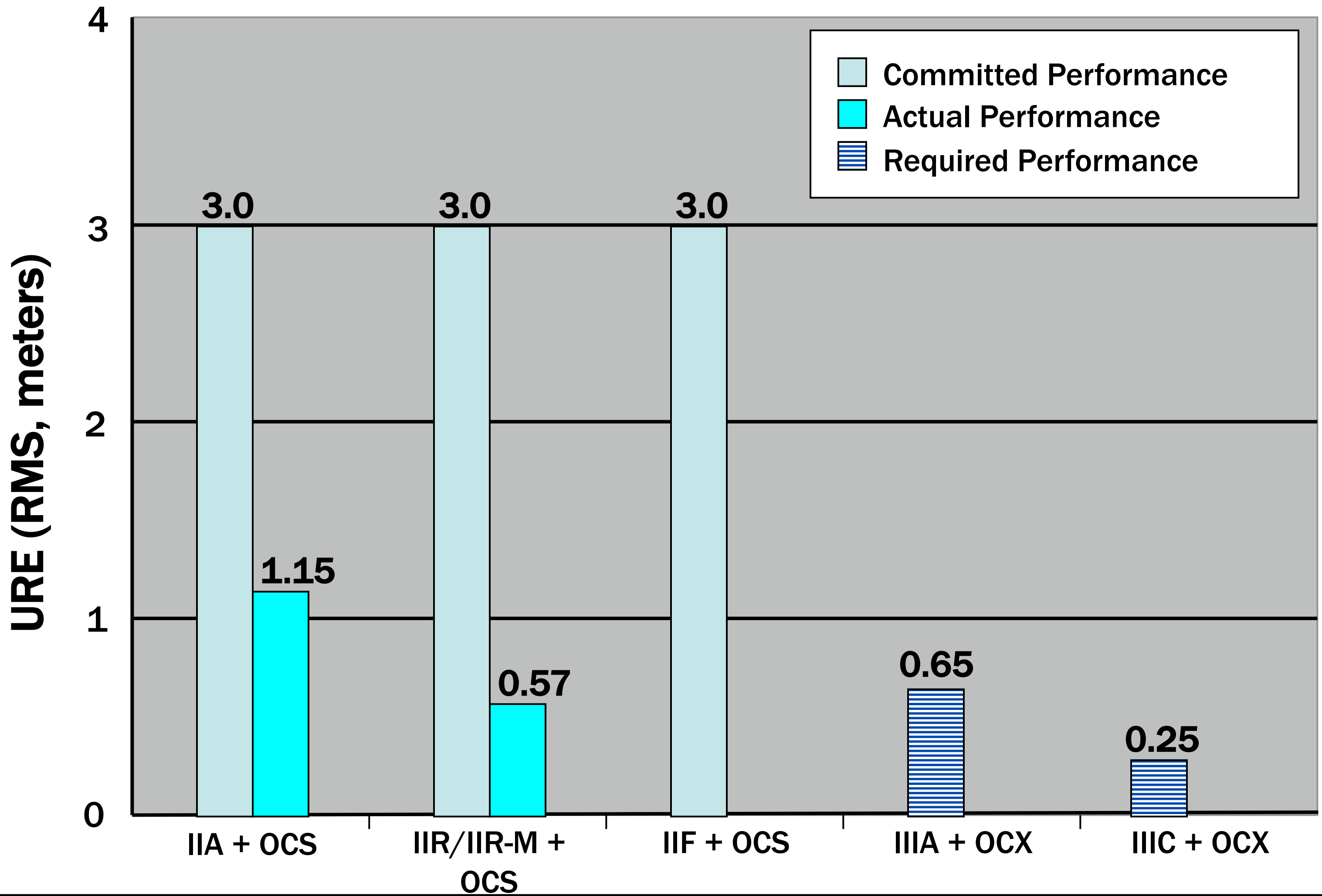
Timing Standards

- Current GPS System required to perform time steering to keep GPS time to within one microsecond (1 sigma) of UTC (USNO)
- GPS III/OCX System Specification calls for the combined space and control segments to perform time steering to keep GPS time within 50 nanoseconds (95% probability) of UTC (USNO)
- GPS time is typically kept to within +/- 10 nanoseconds
- L2C, L5 and L1C will provide GPS/GNSS time offset parameters
  - Current format supports Galileo, GLONASS and up to five additional systems

Reference Frame Standards

- Current system uses Developmental Ephemerides (DE) from JPL for planetary position data, and NGA models for Earth Gravitation
  - DE200
- GPS III and OCX system-level and segment-level specifications call out International Earth Rotation and Reference Systems Service (IERS) 2003 Conventions (Technical Note 32)
  - Intent is to implement Conventions, and utilize DE405 ephemeris (or later) in conjunction with modern conventions endorsed by International Astronomical Union (IAU)
- GPS uses WGS84 geodetic model developed and maintained by NGA
  - Last updated in 2004
  - Consistent with International Terrestrial Reference System
  - Plans are under way to update WGS84 in the 2010 timeframe

URE Accuracy



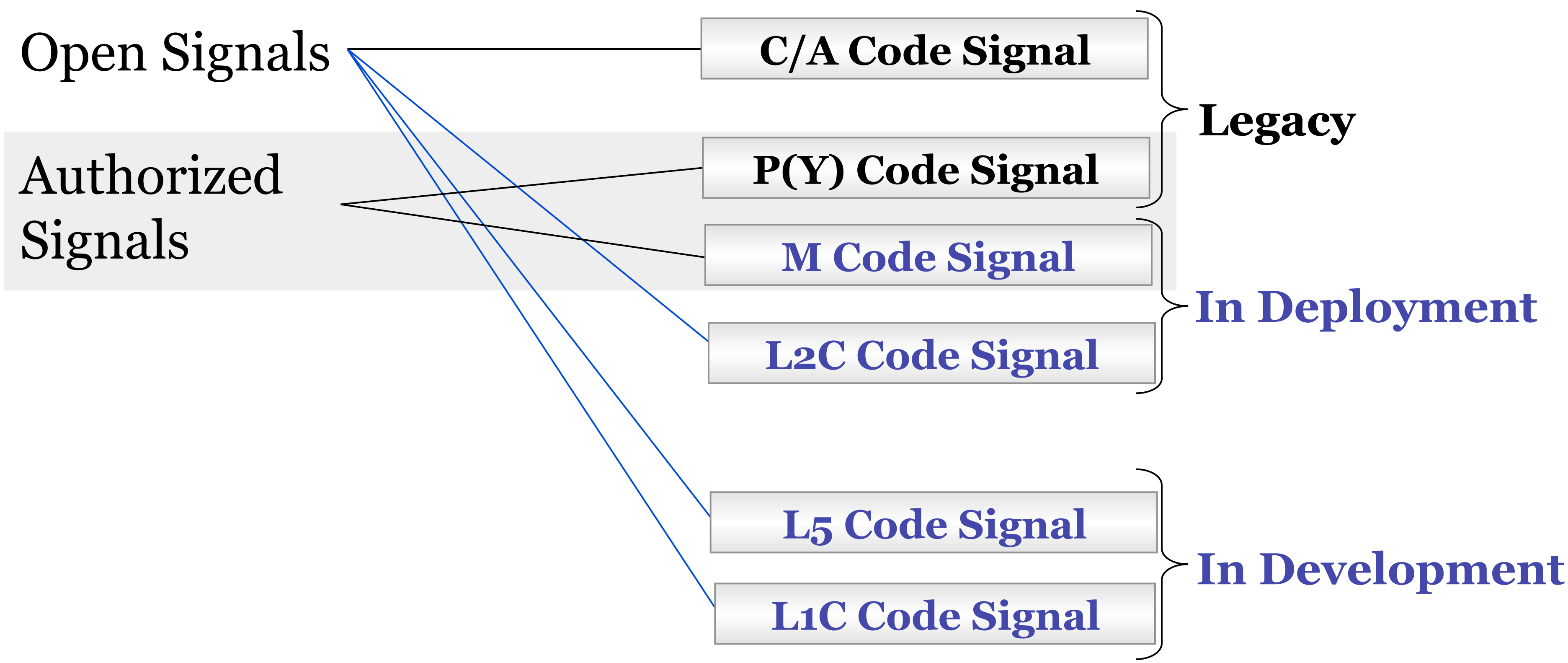
"User Range Error" will continue to dramatically improve

GPS SPS Performance

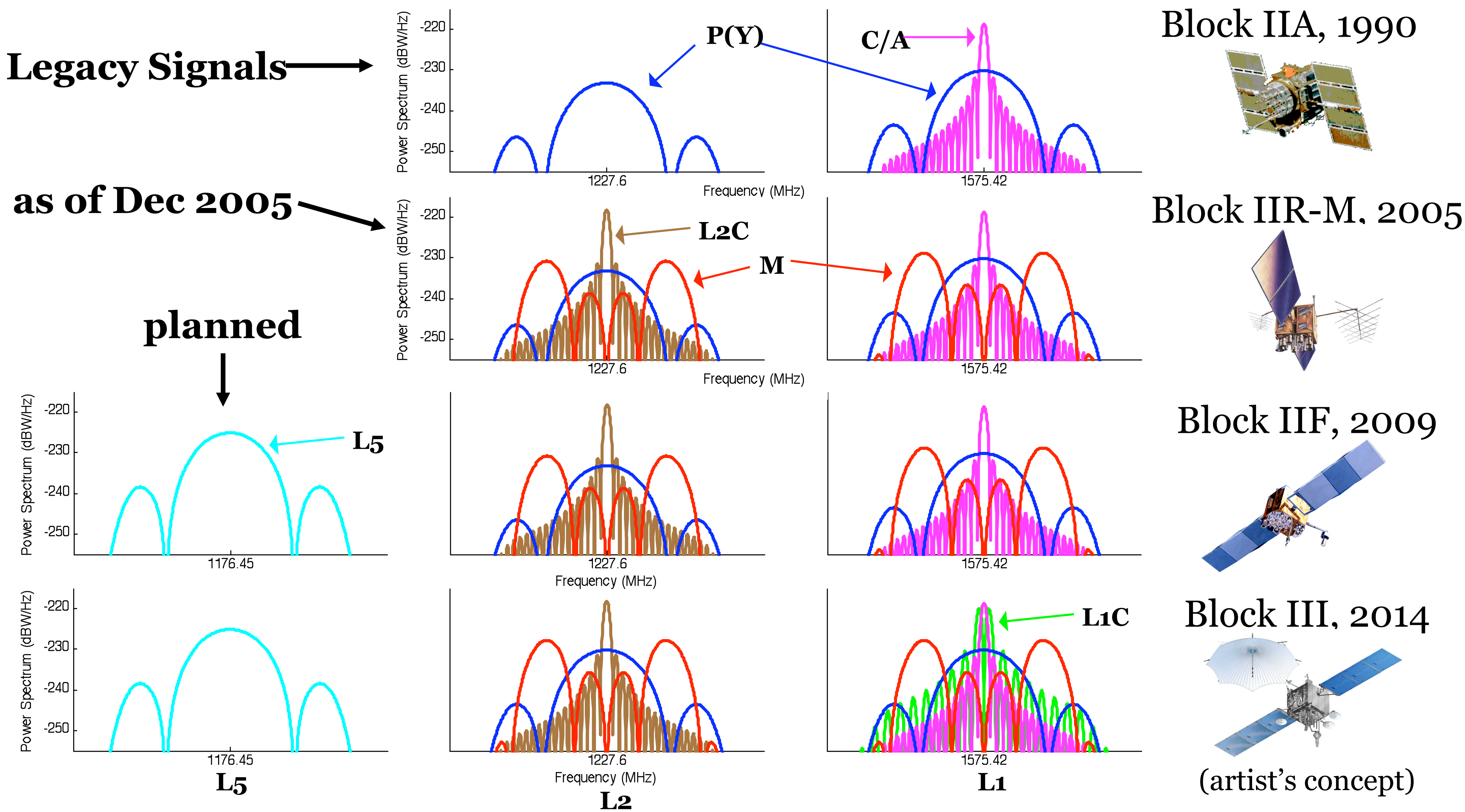
	GPS Performance Standard Metric	SPS Signal Specification June 1995 (user performance)	SPS Performance Standard October 2001 (signal in space)	SPS Performance Standard September 2008 * (signal in space)	CY 2007 Performance**
1	**Global Accuracy** All-in-View Horizontal 95% All-in-View Vertical 95%	≤ 100 meters ≤ 156 meters	≤ 13 meters ≤ 22 meters	≤ 9 meters ≤ 15 meters	2.32 meters 4.45 meters
2	**Worst Site Accuracy** All-in-View Horizontal 95% All-in-View Vertical 95%	≤ 100 meters ≤ 156 meters	≤ 36 meters ≤ 77 meters	≤ 17 meters ≤ 37 meters	3.63 meters 4.95 meters
3	**User Range Error (URE)**	NONE	≤ 6 meters RMS (Constellation RMS URE)	≤ 7.8 meters 95%, (Worst Satellite URE) *equivalent to 4 m RMS*	2.29 meters RMS (Worst Satellite URE)
4	**Geometry (PDOP ≤ 6)**	≥ 95.87% global ≥ 83.92% worst site	≥ 98% global ≥ 88% worst site	≥ 98% global ≥ 88% worst site	99.988% global 98.958% worst site
5	**Constellation Availability**	NONE	≥ 95% Probability of 24 Healthy Satellites ≥ 98% Probability of 21 Healthy Satellites (assumes 24 primary slots)	≥ 95% Probability of 24 Healthy Satellites ≥ 98% Probability of 21 Healthy Satellites ≥ 99.999% Probability of 20 Healthy Satellites (assumes 24 primary slots)	100% Probability of 24 Healthy Satellites 100% Probability of 22 Healthy Satellites in 24 primary slots (FY2008) ***

* Green color indicates improvement in U.S. Government commitment to GPS civil service
** As measured and reported at web site (http://www.nstb.tc.faa.gov/)
*** As measured and reported at web site (http://www.gps.afspc.af.mil/gpsoc/)

GPS Signals


Open Signals
Authorized Signals
C/A Code Signal
P(Y) Code Signal
M Code Signal
L2C Code Signal
L5 Code Signal
L1C Code Signal
Legacy
In Deployment
In Development

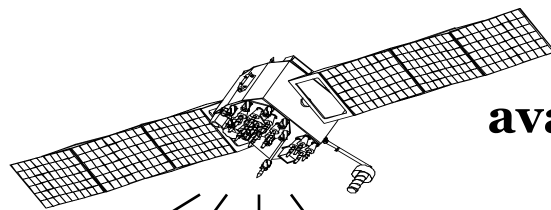
GPS Signals (Cont'd)



Backup

GPS Specifications

Specifications are coordinated through Interface Control Working Group (ICWG) Meetings, which are open to the public



L1 L1 L2 L5

Documents are available free of charge:

http://www.losangeles.af.mil/library/factsheets/factsheet.asp?id=9364

IS-GPS-800
- L1C signal

Current version is 4 Sep 08

IS-GPS-200D
- L1 C/A-code signal
- L2C signal

Current version is 7 Mar 06

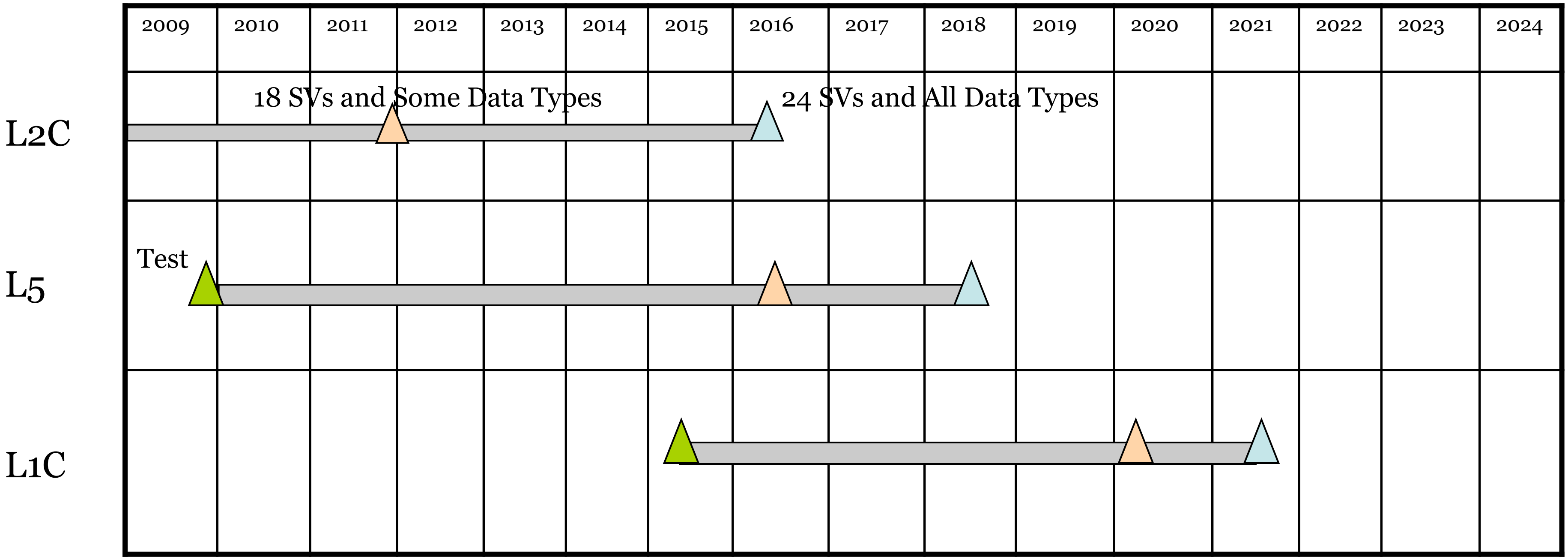
IS-GPS-705
- L5 signal

Current version is 24 Nov 03

Free Services, Open Specifications, Public Processes

Backup

Capability Deployment



- Second civil signal “L2C” at 1227.42 MHz- Designed to meet commercial needs
- Third civil signal “L5” at 1176.45 MHz- - Designed to meet demanding requirements for transportation safety-of-life, and associated integrity
- Fourth civil signal “L1C” at 1575.42 MHz- Designed with international partners for GNSS interoperability

Summary

- GPS continuing its path to success through on-going improvements, public specifications, and open standards
- Compatibility and interoperability with other GNSS is critical to GPS, demonstrated by participation in numerous global, international committees and multiple bi-lateral working groups

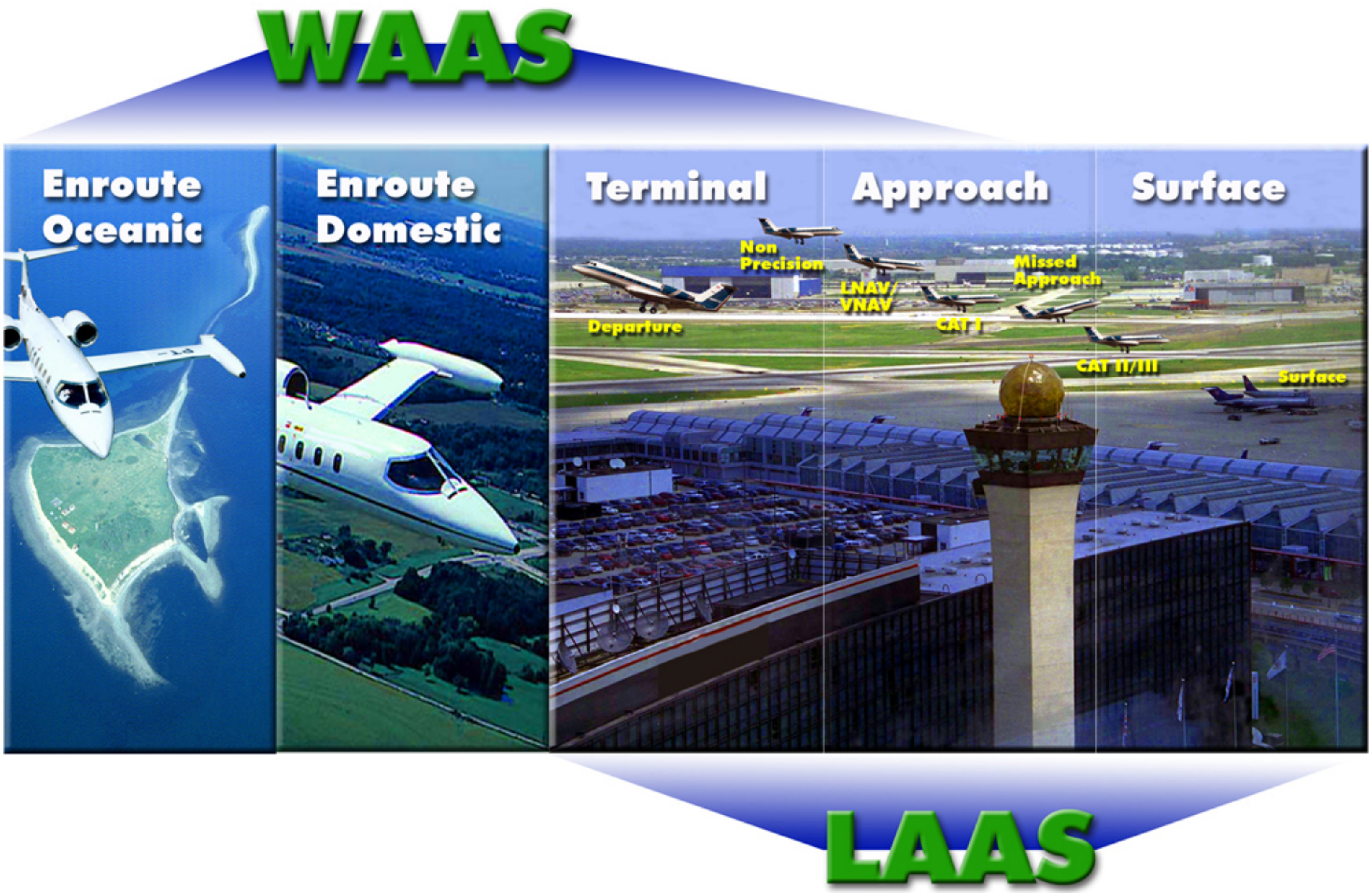
GPS Augmentations

Briefing to the International Committee on GNSS

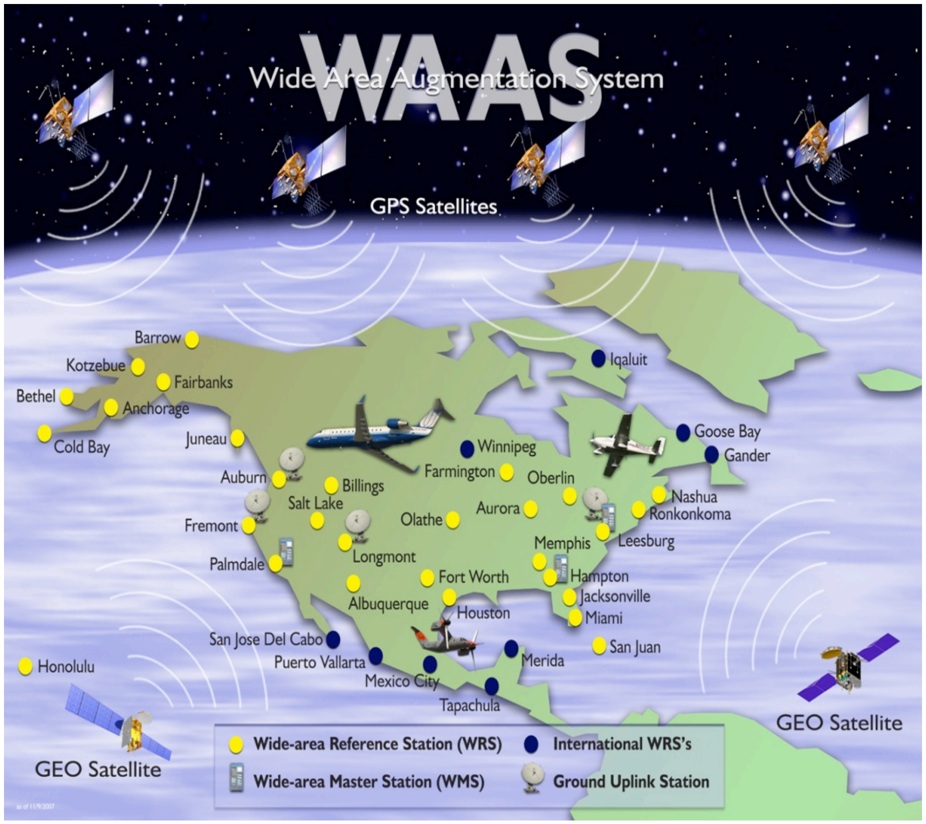
Leo Eldredge, Manager
GNSS Group

December 10, 2008

FAA GPS Augmentation Programs



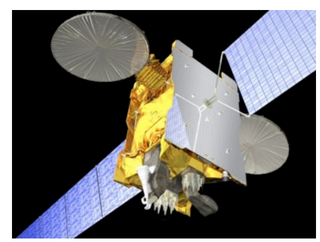
WAAS Architecture



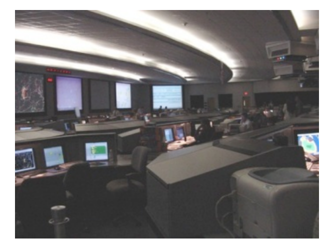
38 Reference Stations

3 Master Stations

4 Ground Earth Stations

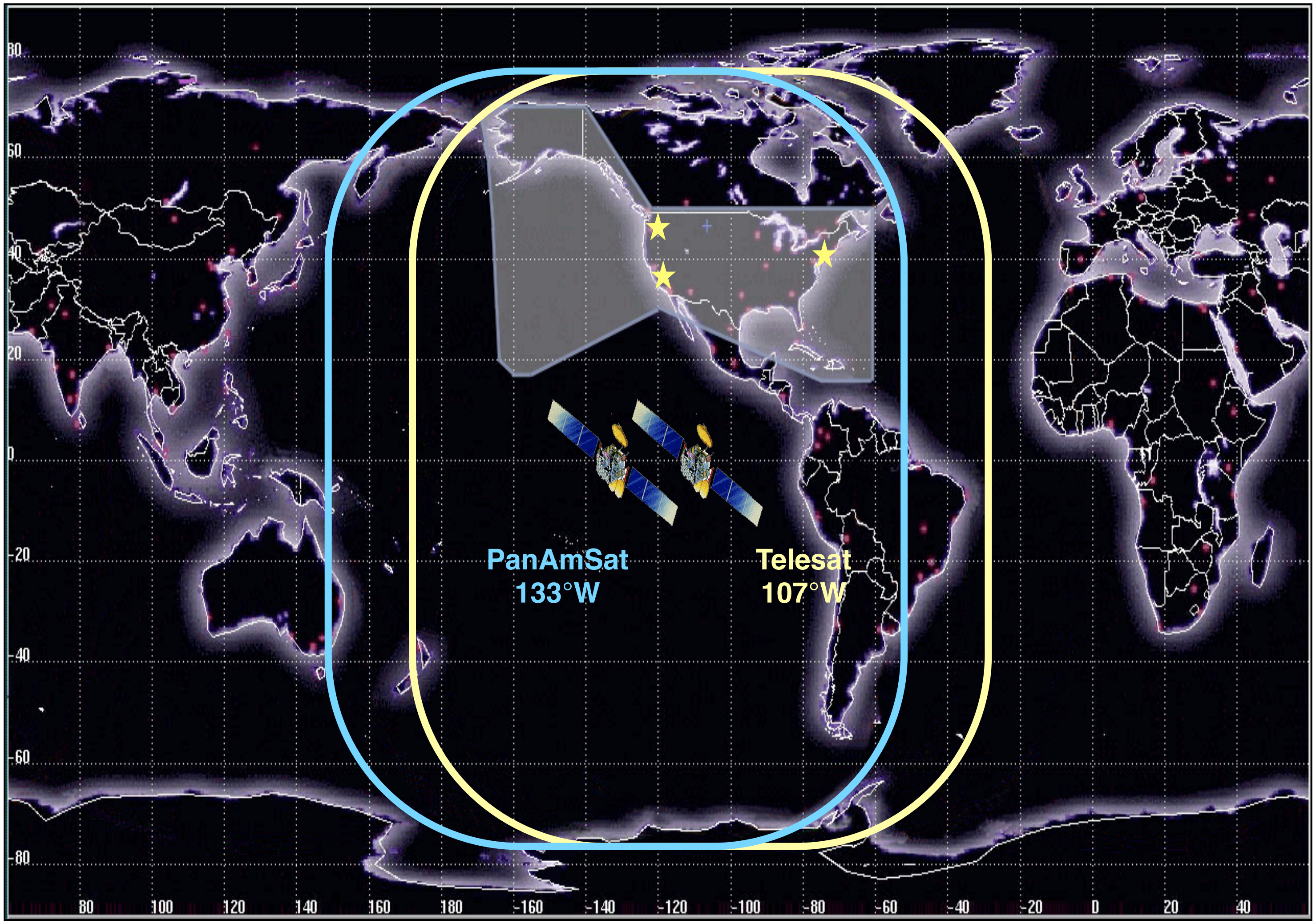


2 Geostationary Satellite Links

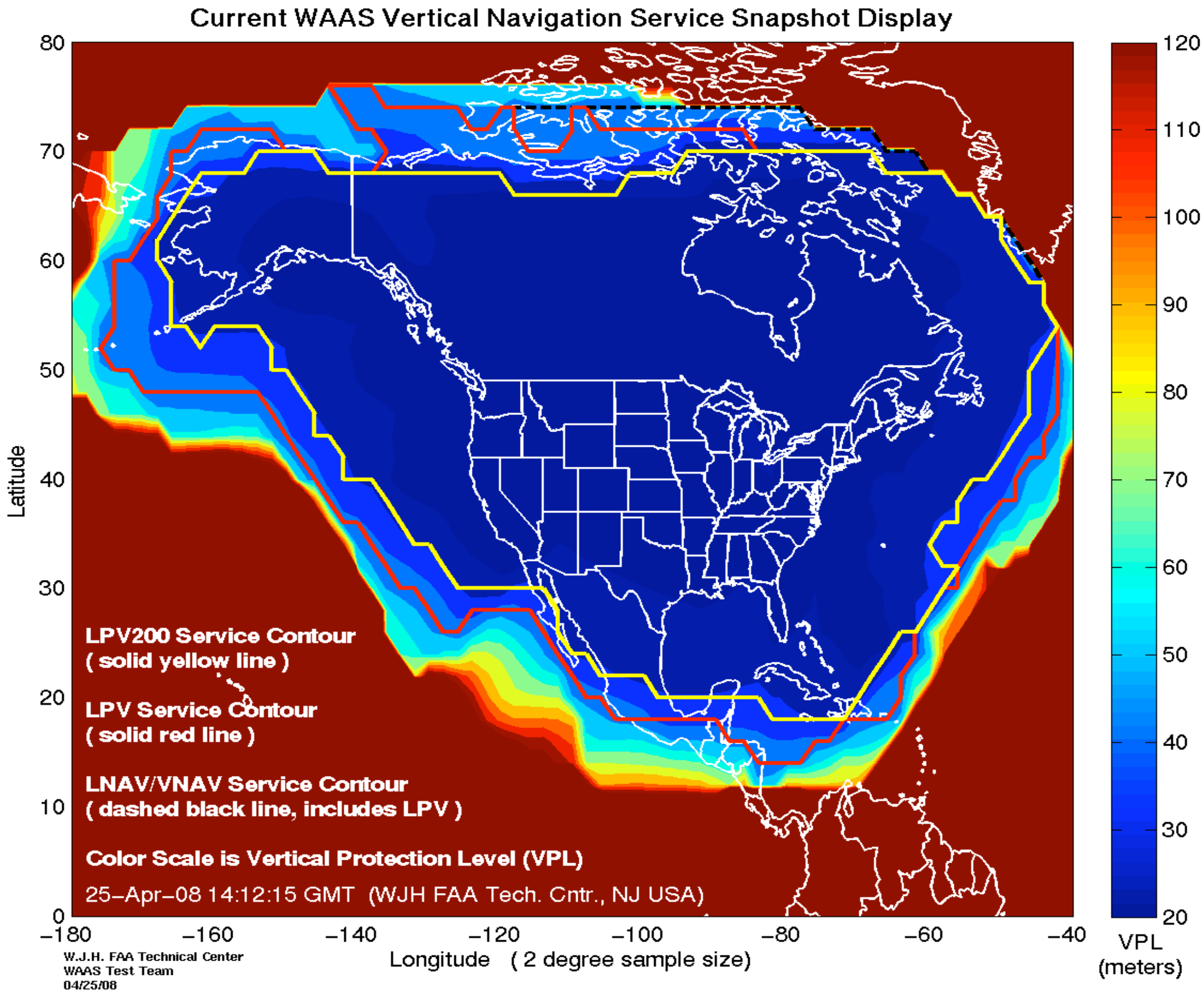


2 Operational Control Centers

Geostationary Satellites (GEO)



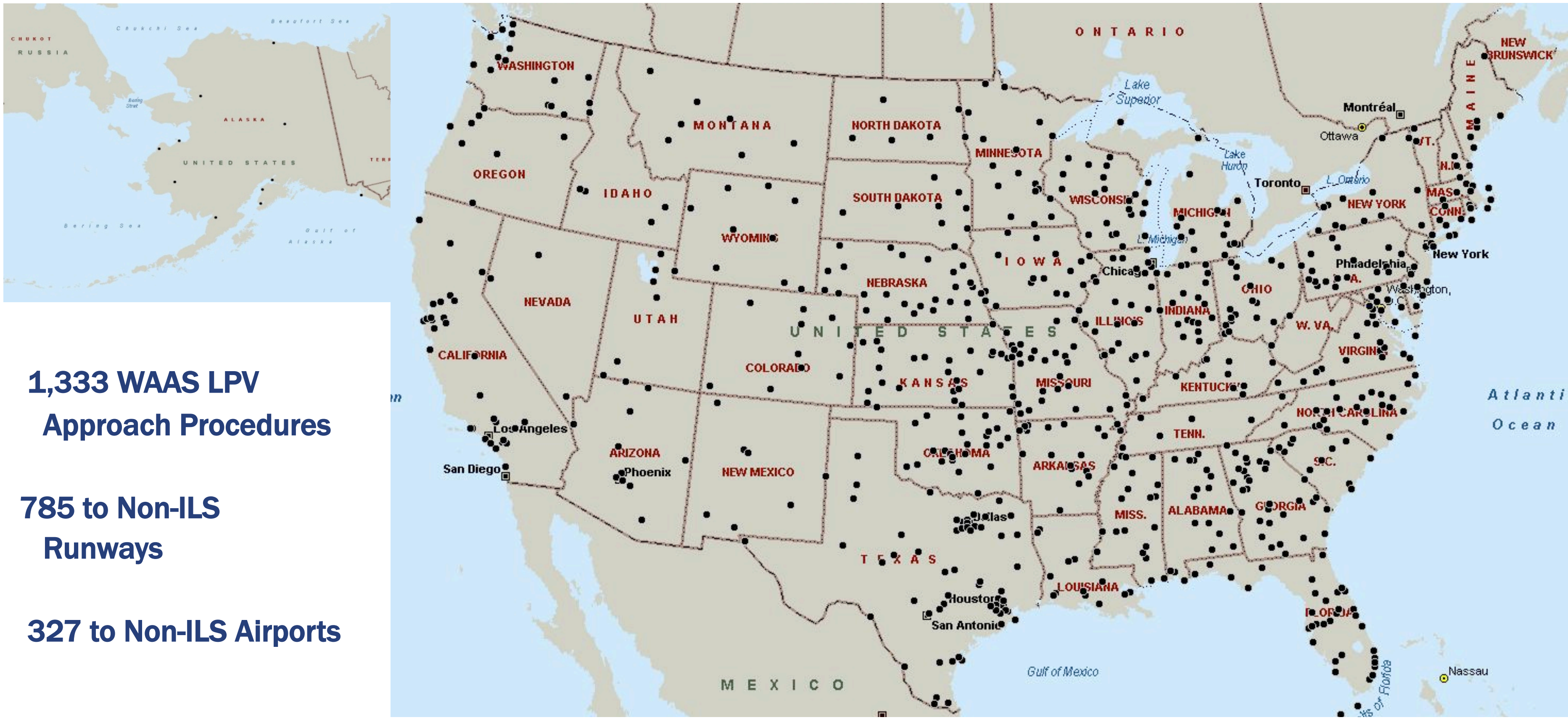
Localizer Performance Vertical (LPV) Coverage



WAAS Approach Procedures

Exceeded Instrument Landing Systems (ILS)

September 2008



1,333 WAAS LPV Approach Procedures

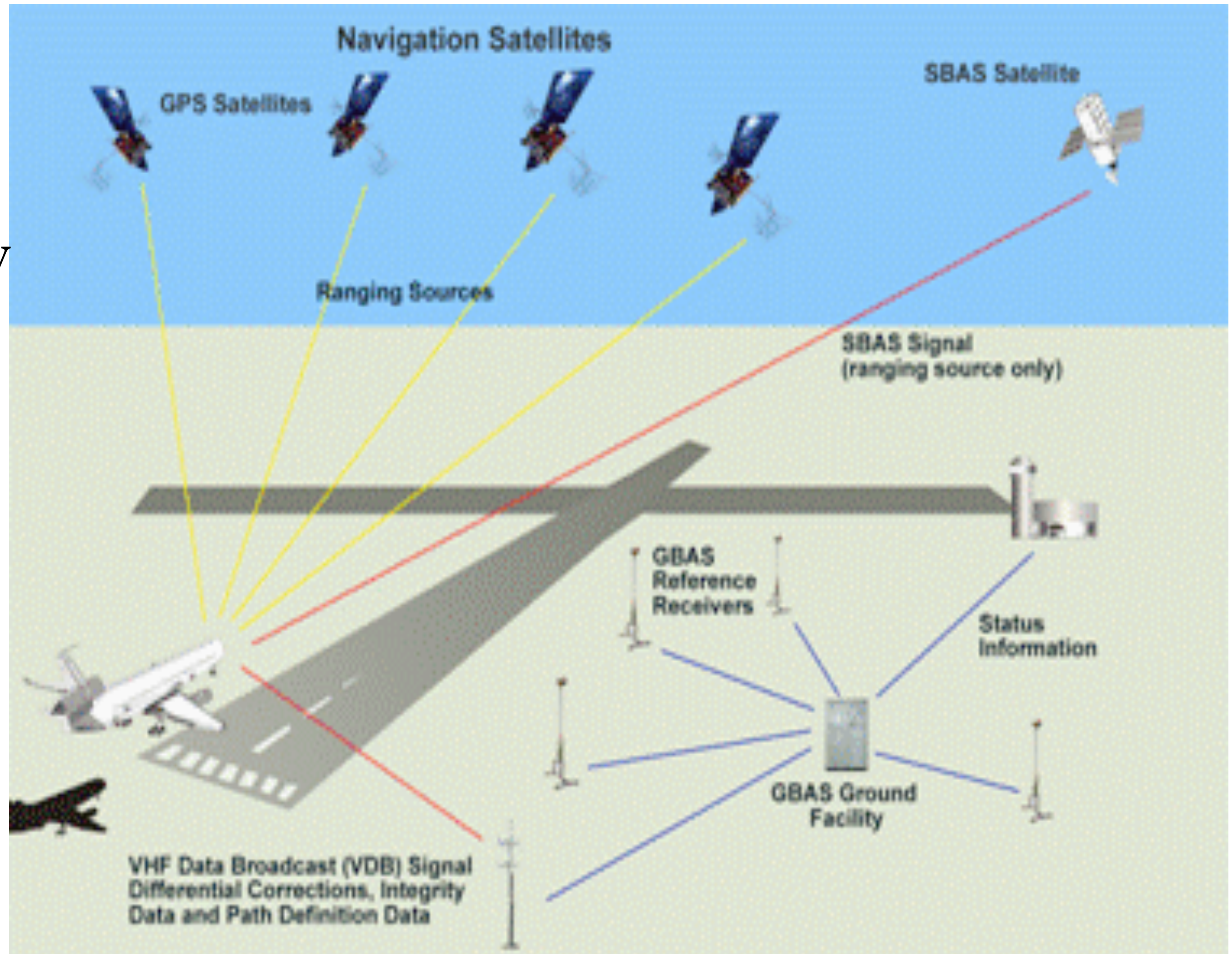
785 to Non-ILS Runways

327 to Non-ILS Airports

WAAS Procedures to be Published to All Instrument Runways in the NAS by 2018

Local Area Augmentation System (LAAS)

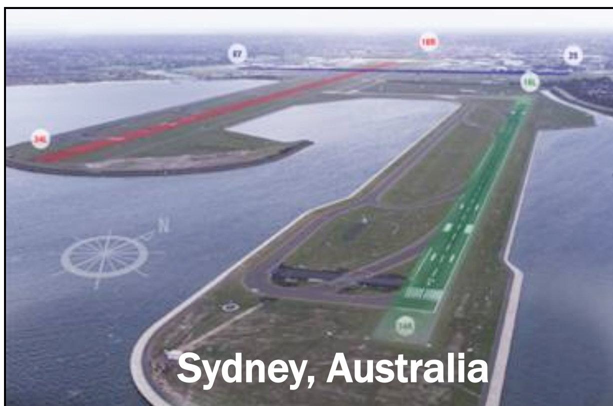
- Precision Approach For CAT- I, II, III
- Multiple Runway Coverage At An Airport
- 3D RNP Procedures (RTA), CDAs
- Navigation for Closely Spaced Parallels
- Super Density Operations



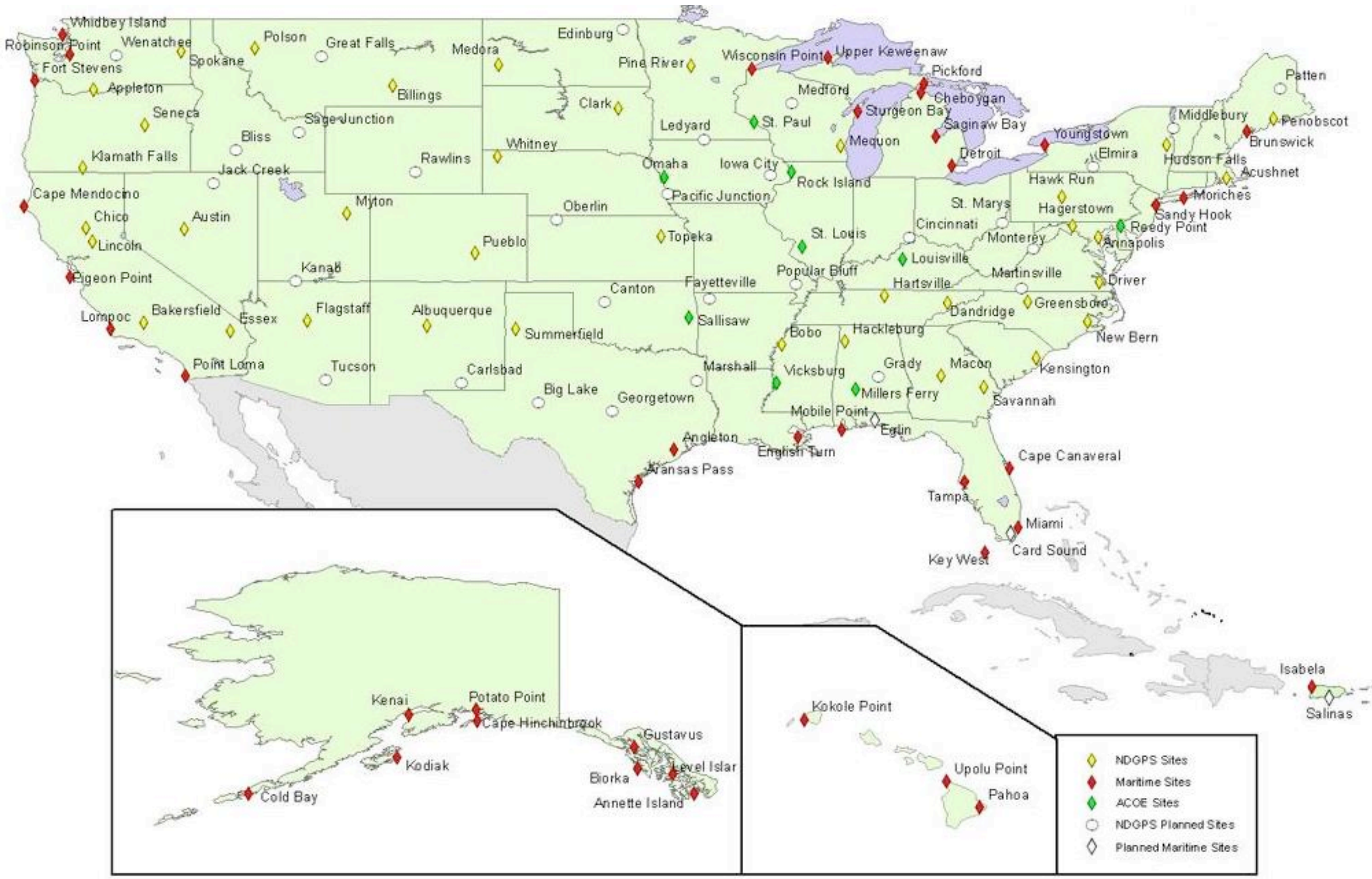
GBAS Pathway Forward

- Cat-I System Design Approval at Memphis – Early 2009
- Cat-III Prototype Validation by - 2010
- Cat-III System Design Approval by - 2012

LAAS/GBAS International Efforts



Nationwide Differential GPS (NDGPS)



October 2007

Domestic Positioning, Navigation, & Timing (PNT) Interference Detection &Mitigation (IDM) Plan

Briefing to the International Committee on GNSS

John Merrill
Office of Applied technology – Geospatial Management Office

December 10, 2008

Presentation Overview

- Background
- IDM Plan Development
- IDM Plan Outline
- Plan Implementation

U. S. Space-Based PNT Policy

- Policy objectives include:
  - Maintain the Global Positioning System (GPS) as a component of multiple sectors of the U. S. Critical Infrastructure

DHS Responsibilities

- Coordinate domestic capabilities to identify, analyze, locate, attribute, and mitigate sources of interference to the GPS and its augmentations
- Collect, analyze, store, and disseminate interference reports from all sources to enable appropriate investigation, notification and enforcement action
- Develop and maintain capabilities, procedures and techniques, and routinely exercise civil contingency responses to ensure continuity of operations in the event that access to the GPS is disrupted or denied.

DHS IDM Plan Development

- December 2004 - DHS assigned responsibility for domestic Space-based PNT IDM planning and coordination
- June 2005 – DHS began Space-Based PNT IDM Plan development starting with existing processes in place for GPS outage reporting, tracking and resolution
- June 2006 – Space-Based PNT IDM Plan coordinated with the U. S. PNT Executive Committee
- August 2007 – Space-Based PNT IDM Plan approved/ signed by the U. S. President

DHS IDM Plan Outline

- Key Policies, Departments and Agencies
  - Departments and Agencies that were assigned responsibilities that impact PNT services
- GPS Interference
  - GPS and the Critical Infrastructure
  - GPS Vulnerabilities and Analysis Studies
  - Categories of Jamming
- Current GPS Interference Reporting Procedures
- Space-Based PNT Interference Detection & Mitigation Plan

DHS IDM Plan Implementation

- DHS Geospatial PNT Executive Committee
  - PNT Work Group
  - Geospatial Work Group
  - DHS Departments and U.S. Agencies with Geospatial and PNT responsibilities are represented
- DHS IDM Implementation Plan
  - Development and maintenance is responsibility of DHS PNT Work Group
  - Development of central data repository requirements
  - Standardized reporting format of interference reports
  - Continuous evaluation of operational procedures

Overview

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Summary

- U.S. Space-Based PNT effort progressing significantly
  - Implementation of U.S. Policy proceeding well
  - International cooperation is a priority
- GPS is better than ever and will continue to improve
  - New civil GPS signal available now
- Augmentations enable even higher performance
  - Many additional upgrades scheduled
- Detecting and mitigating interference is a growing need

As new space-based GNSS emerge globally, interoperability is the key to "success for all"

Web-based Information

- ***PNT.gov*** established to distribute information on the U.S. National Executive Committee to include:
  - U.S. Policy, Executive Committee membership, Advisory Board and frequently asked questions
  - Recent announcement on Selective Availability and offer letter to International Civil Aviation Organization
  - All recent public presentations
- ***GPS.gov*** established for public information about GPS applications
  - Available in English, French, Spanish, Arabic and Chinese
  - Brochure also available in hardcopy upon request
  - Contains additional links to various other web sites

Contact Information

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These presentations and other information available:
www.pnt.gov

[redacted]

Back-Ups

GPS C/A Code Signal Characteristics

- Carrier frequency: L1 (quadrature phase)
- Received Power:
  - Minimum of –158.5 dBW, maximum near –153 dBW
- Spreading modulation: BPSK-R(1)
- Spreading codes: 1023-bit Gold codes
- Data modulation: 50 sps biphase modulation of all spreading code bits
- Overlay codes: none
- Data message structure: NAV message, 50 bps
- Data message channel encoding: no FEC, no interleaving
- Multiplexing
  - Block IIA and IIR satellites: phase quadrature with L1 P(Y)
  - Block IIR-M and IIF satellites: Y, M, C/A Interplex, C/A still in phase quadrature with P(Y)
  - Block III satellites: not yet defined

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GPS P(Y) Code Signal Characteristics

- Carrier frequencies: L1 and L2 (in phase)
- Received Power: L1 and L2: minimum of –161.5 dBW, maximum near –150 dBW (IIR-M and IIF)
- Spreading modulation: BPSK-R(10)
- Spreading codes: P codes or encrypted (Y) codes
- Data modulation: 50 sps biphase modulation of all spreading code bits
- Overlay codes: none
- Data message structure: NAV message; optional no message on L2
- Data message channel encoding: no FEC, no interleaving
- Multiplexing
  - Block IIA and IIR satellites: L1—phase quadrature with C/A, L2—P(Y) or C/A
  - Block IIR-M and IIF satellites: L1—Y, M, C/A Interplex, C/A in phase quadrature with P(Y); L2—Y, M, L2C Interplex
  - Block III satellites: not yet defined

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GPS M-Code Signal Characteristics

- Carrier frequencies: L1 and L2
- Spreading modulation: BOC(10,5)
- Spreading codes: Authorized user only
- Data modulation: 3 rates available—200 sps, 50 sps, no data (time division data multiplexing on every other spreading code bit)
- Overlay codes: none
- Data message structure: MNAV (100 bps, 25 bps, 0 bps)
- Data message channel encoding: ½ rate convolutional code with constraint length 7, interleaving
- Multiplexing
  - Block IIR-M and IIF satellites: L1-Y, M, C/A Interplex, L2-Y, M, L2C Interplex
  - Block III satellites: not yet defined

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Capability Deployment: Second and Third Civil Signals

- Second civil signal "L2C"
  - Designed to meet commercial needs
  - Higher accuracy through ionospheric correction
  - Available since 2005 without data message
  - Phased roll-out of CNAV message starting in 2009
  - Full capability: 24 satellites and full CNAV ~2016

- Third civil signal "L5"
  - Designed to meet demanding requirements for transportation safety-of-life, and associated integrity
  - 1st launch: 2009; 24 satellites and full CNAV ~2018

Return To Briefing

GPS L2C
Signal Characteristics

- Carrier frequency: L2 (quadrature phase—usually)
- Received Power:
  - Minimum of –160.0 dBW, maximum near –155 dBW
- Spreading modulation: BPSK-R(1)
- Spreading codes: 10230 bit L2CM codes and 767250 bit L2CL codes, alternating bits time division multiplexed
- Data modulation: 50 sps biphase modulation of L2CM bits (time division data multiplexing)
- Overlay codes: none
- Data message structure: NAV or L2 CNAV message, 25 bps
- Data message channel encoding: ½ rate convolutional code with constraint length 7, no interleaving
- Multiplexing
  - Block IIR-M and IIF satellites: Y, M, L2C Interplex
  - Block III satellites: not yet defined

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GPS L5
Signal Characteristics

- Carrier frequency: L5 (in-phase and quadrature-phase)
- Received Power:
  - Minimum of –154.9 dBW, maximum near –150.0 dBW (each L5 signal channel)
- Spreading modulation: BPSK-R(10)
- Spreading codes: distinct 10230 bit I5 codes and 10230 Q5 codes, for pilot and data, in phase quadrature, defined in IS-GPS-705
- Data modulation: 100 sps biphase modulation of in-phase spreading code bits (phase division data modulation)
- Overlay codes: 10 bit, 1 kbps Neuman-Hofman code "synchronization sequence" on I5, 20 bit, 1 kbps Neuman-Hofman code "synchronization sequence" on Q5, defined in IS-GPS-705
- Data message structure: L5 CNAV message, 50 bps
- Data message channel encoding: ½ rate convolutional code with constraint length 7, no interleaving
- Multiplexing: no other GPS signals on L5

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Capability Deployment: Fourth Civil Signal (L1C)

Under trees

Urban Canyons

- Designed with international partners for interoperability, at L1 frequency
  - More robust navigation across a broad range of user applications
  - L1 C/A retained for backward compatibility
- Specification developed in cooperation with industry, recently completed
- Launches with GPS III in 2014
- On 24 satellites by ~2021

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GPS L1C
Signal Characteristics

- Carrier frequency: L1
- Received Power: Minimum of –157 dBW, maximum near –154 dBW (–150 dBW for receiver design purposes)
- Spreading modulation
  - Baseline: BOC(1,1) for both pilot and data components
  - Option: Multiplexed BOC, MBOC(6,1,1/11); TMBOC(6,1,4/33) on pilot component, BOC(1,1) on data component
- Spreading codes: distinct 10230-bit Weil-based codes for pilot and data
- Data modulation: 100 sps biphase modulation of data component
- Overlay code on pilot: 1800 bits long at 100 bps
- Data message structure: CNAV2 message, 50 bps
- Data message channel encoding: half-rate Low Density Parity Check (LDPC) FEC, block interleaving
- Multiplexing on Block III satellites: not yet defined

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