SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL COORDINATION OFFICE

GPS Modernization, Interoperability & GNSS Space Service Volume

GNSS+2016
Session 1: BDS/GPS/GLONASS/GALILEO Systems
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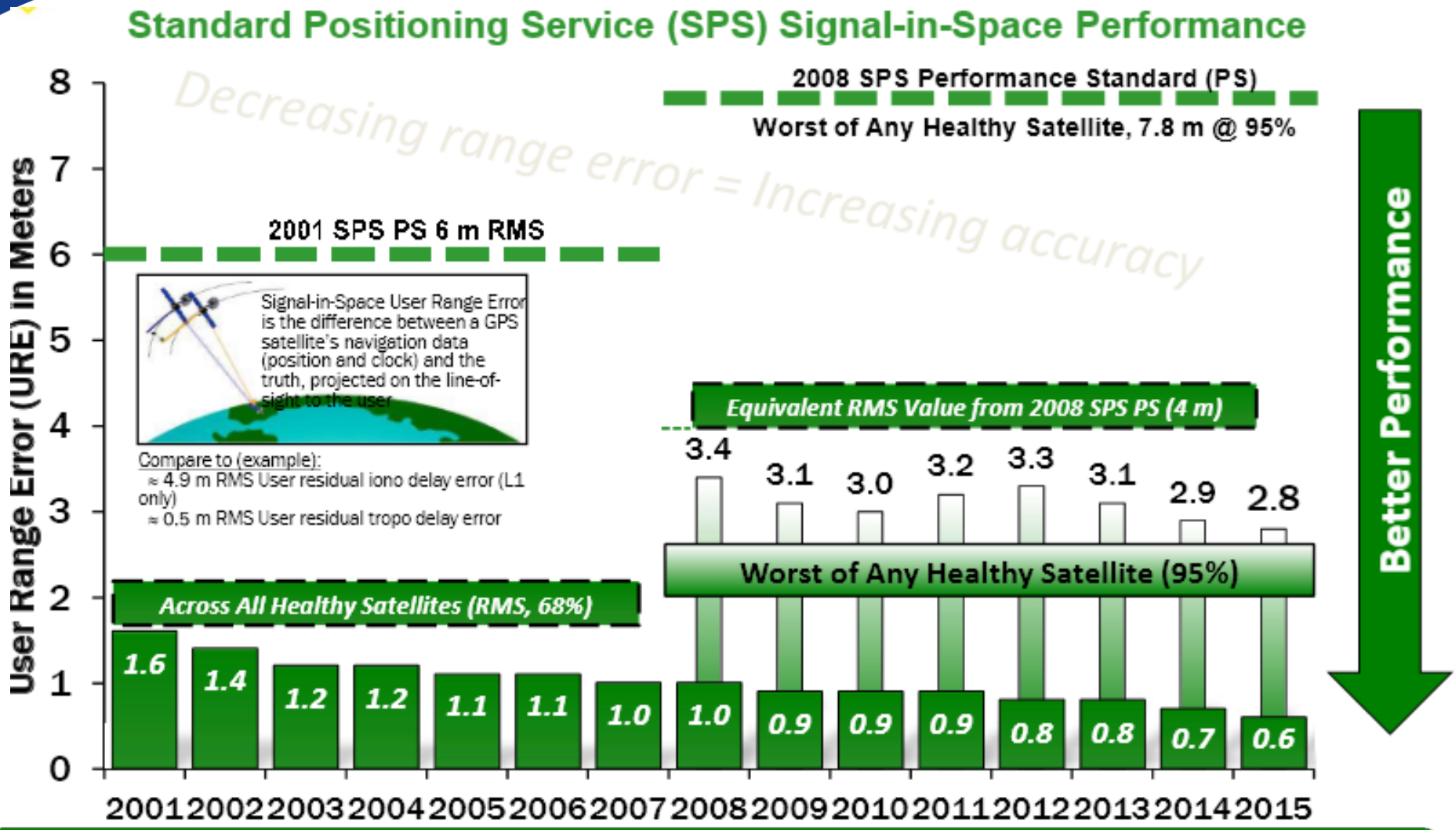
GPS Constellation Status

31 Operational Satellites (Baseline Constellation: 24)

- Robust operational constellation
  - 12 Block IIR: L1 C/A, L1 P(Y), L2 P(Y) signals
  - 7 Block IIR-M: adds L2C, L1M, L2M signals
  - 12 Block IIF: adds L5 signal
- 8 additional satellites in residual status
- Modified battery charge control extending GPS IIR and IIR-M life by 1-2 years per satellite
- Global GPS civil service performance commitment
  - Best single-day user range accuracy (URE) of 38.2 cm observed on 25 April 2016
  - Performance improvements continue as new satellites replace older satellites

Accuracy: Civil Commitments



System accuracy substantially exceeds published standard

GPS III Status

- Newest block of GPS satellites (SVs)
  - 4 civil signals: L1 C/A, L1C, L2C, L5
    - First GPS SVs with interoperable L1C signal
  - 4 military signals: L1/L2 P(Y), L1/L2M
  - 3 improved Rubidium atomic clocks
- SV7/8 contract awarded 31 Mar 14
- SV9/10 purchase planned using current Lockheed contract
- SV 1 thermal vacuum testing complete Dec 2015
- GPS III Non-Flight Satellite Test bed launch processing at Cape Canaveral completed
  - Reduced integration, test and launch processing risk
- First satellite to be available for launch this year

Lockheed-Martin (Waterton, CO) - Prime

Last GPS Block IIF

Ground Segment Status

- Current system Operational Control Segment (OCS)
  - Flying GPS constellation using Architecture Evolution Plan (AEP) and Launch and Early Orbit, Anomaly, and Disposal Operations (LADO) software capabilities
  - Increasing Cyber security enhancements
- Next Generation Operational Control System (OCX)
  - Modernized command and control system
  - Modern civil signal monitoring and improved PNT performance
  - Robust cyber security infrastructure
  - OCX currently in integration and test
  - Block 0 supports launch and checkout for GPS III
  - Block 1 supports transition from current control segment
  - Block 2 to enable new capabilities including civil signal performance monitoring capability

Monitor Station

Ground Antenna

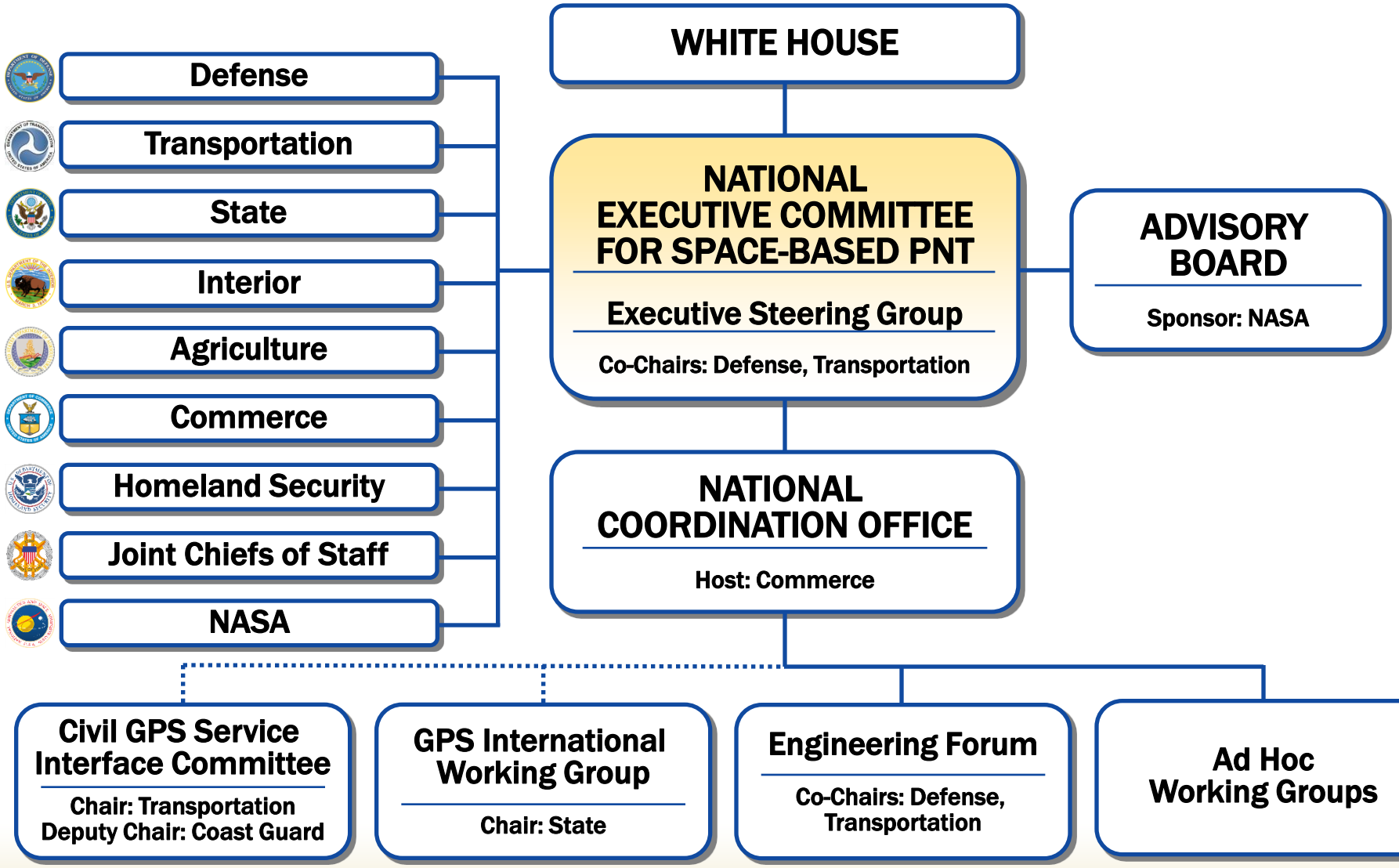
New GPS Civil Signals

- Second civil signal “L2C”
  - Designed to meet commercial needs
  - Higher accuracy through ionospheric correction
- Third civil signal “L5”
  - Designed to meet demanding requirements for transportation safety-of-life services
  - Aeronautical Radio Navigation Service (ARNS) protected band
- L2C & L5 continuously broadcast since Apr 2014
  - L2C message currently set “healthy”
  - L5 message currently set “unhealthy”

Complementary PNT (CPNT)

- Executive Committee (EXCOM) examined need for complement to GPS
  - Assessment driven by many factors: from policy to technology
  - U.S. coverage for GPS outage due to natural or man-made events
- Current Activity: Identify and develop CPNT requirements
  - Assesses a wide range of user requirements
- Decisions support FY18 investment actions
- *Federal Register Notice* issued for public engagement

National Space-Based PNT Organization



U.S. Policy Promotes Civilian GPS Use

- No direct user fees for civil GPS services
  - Provided on a continuous, worldwide basis
- Open, free access to information necessary to use civil GPS and augmentations
  - Anyone can develop applications, user equipment, and value-added services
  - Encourages market-driven competition
- Global compatibility and interoperability with GPS
- Service improvements for civil, commercial, and scientific users worldwide
- Protection of aeronautical radionavigation service (ARNS) spectrum from disruption and interference

Strategic Focus Areas

- GPS Sustainment and Modernization
- International Cooperation
- Spectrum Management
- Critical Infrastructure
- PNT Resilience
- Outreach

GNSS Space Service Volume Update

Presented on behalf of:
NASA and Frank H. Bauer
FBauer Aerospace Consulting Services (FB-ACS) for the
Space Communications and Navigation (SCaN) Program
Human Exploration and Operations Mission Directorate (HEOMD)
National Aeronautics and Space Administration (NASA)

The Promise of using GNSS for Real-Time Navigation in the Space Service Volume (1 of 2)

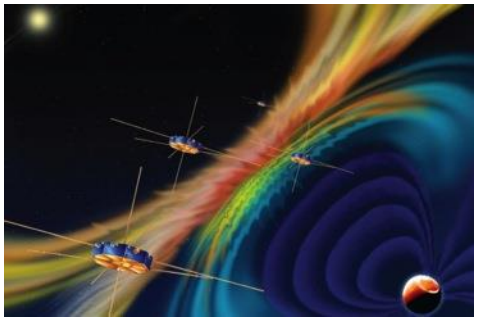
Benefits of GNSS use in Space Service Volume (SSV):

- Significantly improves real-time navigation performance
  - From km-class to meter-class
- Supports quick trajectory maneuver recovery (from: 5-10 hours to minutes)
- GNSS timing reduces need for expensive on-board clocks
  - GNSS timing: $15K to $50K instead of space qualified atomic clocks: $100s K - $1M
- Supports increased satellite autonomy
  - Lowering mission operations costs (saving up to $500-750K/year)

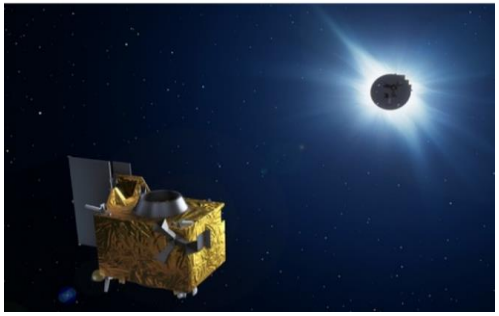
The Promise of using GNSS for Real-Time Navigation in the Space Service Volume (2 of 2)

Enables new/enhanced capabilities and better performance for HEO and GEO missions, including:

Earth Weather Prediction using Advanced Weather Satellites

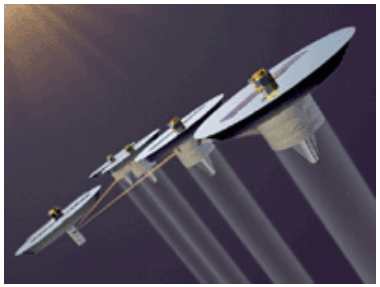


Space Weather Observations

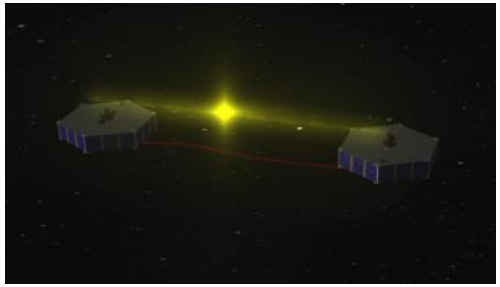


Precise Relative Positioning

Launch Vehicle Upper Stages and Beyond-GEO applications



Formation Flying, Space Situational Awareness, Proximity Operations



Precise Position Knowledge and Control at GEO

Initiatives & Contributions to Ensure an Interoperable, Sustained, Quantified GNSS Capability for Space Users

- Performing additional flight experiments above the constellation (e.g. ACE)
- Developing new weak signal GPS/GNSS receivers for spacecraft in cis-Lunar space (e.g. NASA Goddard Navigator and its commercial variants)
- Working with the GPS Directorate and DoD community to formally document GPS requirements and antenna patterns for space users
- Encouraging international coordination with other GNSS constellations to specify interoperable SSV capabilities
- Developing missions and systems to utilize GNSS signals in the SSV (e.g. MMS, GOES)

GNSS SSV Observations

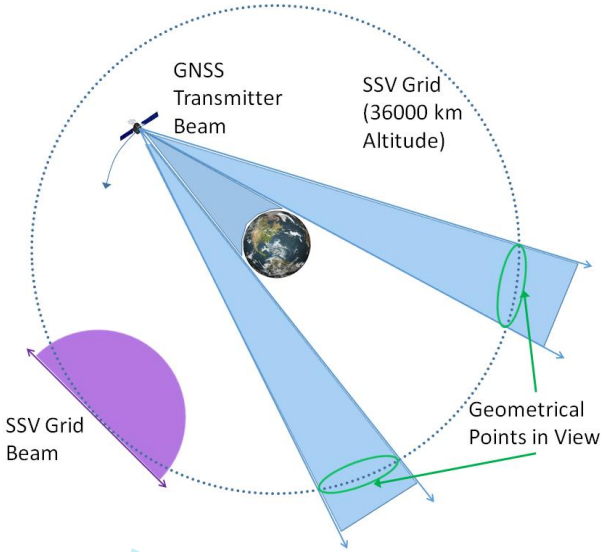
- International Committee on GNSS (ICG) Working Group B
  - Making significant progress in establishing an interoperable Global Navigation Satellite System (GNSS) Space Service Volume (SSV) through
    - Pre-work, Analyses and periodic Teleconferences
- Analyses underway to solidify understanding of HEO/GEO user capabilities using all provider's SSV capabilities
- SSV users should not be relying on capabilities that are not specified
  - Capabilities available now may <u>not</u> be available in the future if not specified

<u>Recommendations</u>

- Encourage all GNSS providers to baseline SSV specifications as part of future constellation developments
- Encourage all providers to participate in ICG WG-B initiatives, including interoperable GNSS analyses

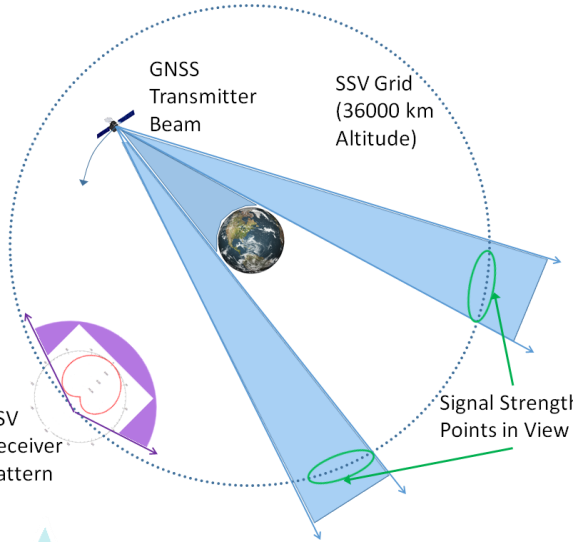
ICG WG-B SSV
Three Phase Analysis Approach

Phase 1:
Geometrical Access

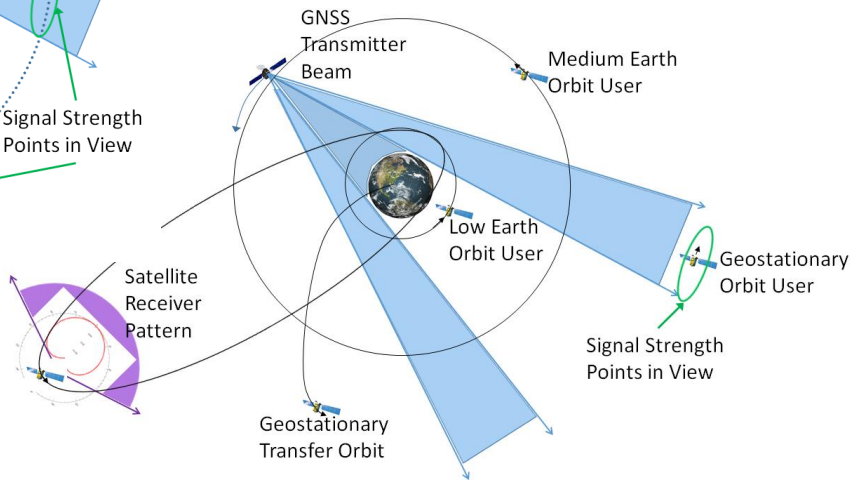


Increasing Fidelity

Phase 2:
Signal Strength Access



Phase 3:
Specific User Missions



Increasing Complexity

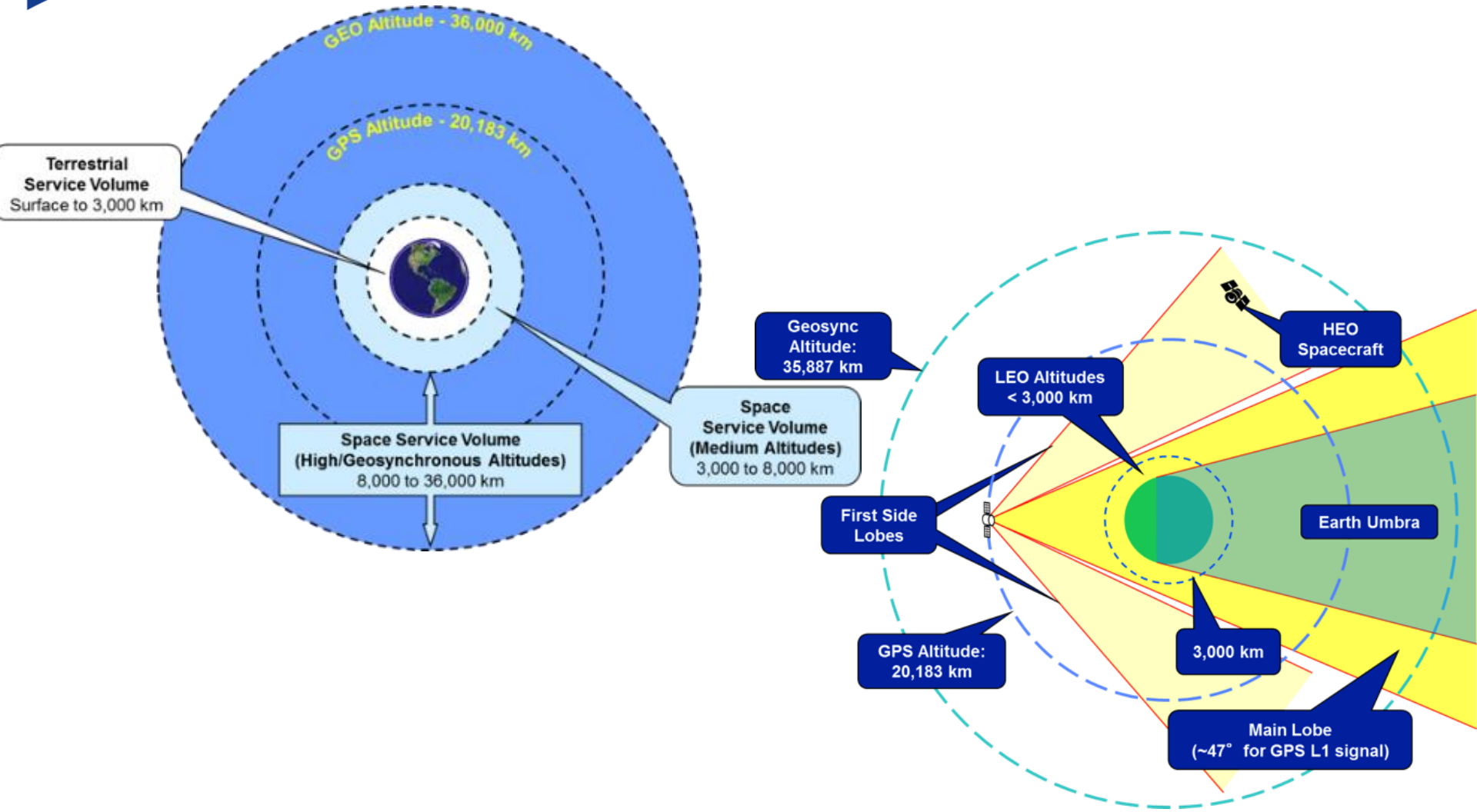
ICG WG-B SSV
Three Phase Analysis Status

Phase 1 Activities	Status
Orbit Propagation Technique	Complete
Geometrical-Based Access Calculation Technique	Complete
Figure of Merit Calculations	Complete
Documentation in ICG WG-B Booklet	In-Work
Phase 2 Activities	**Status**
RF Link Budget Technique	Planning
Geometrical/RF-Based Access Calculation Technique	Not Yet Started
Figure of Merit Calculations	Not Yet Started
Documentation in ICG WG-B Booklet	Not Yet Started
Phase 3 Activities	**Status**
Derive User-Specific Missions	Planning
RF-Based Access Calculation Technique	Not Yet Started
Figure of Merit Calculations	Not Yet Started
Documentation in ICG WG-B Booklet	Not Yet Started

GPS SSV Status and Lessons Learned Summary (1 of 2)

- Current SSV specifications, developed with limited on-orbit knowledge, only capture performance provided by signals transmitted within 23.5° (L1) or 26° (L2/L5) off-nadir angle
- On-orbit data and lessons learned since spec development show significant PNT performance improvements when the full aggregate signal is used
- Numerous operational missions in High and Geosynchronous Earth Orbit (HEO/GEO) utilize the full signal to enhance vehicle PNT performance
  - Multiple stakeholders require this enhanced PNT performance to meet mission requirements
- Failure to protect aggregate signal performance in future GPS designs creates the risk of significant loss of capability, and inability to further utilize performance for civil and military space users in HEO/GEO
- Protecting GPS aggregate signal performance ensures GNSS parity in the SSV

GPS SSV Status and Lessons Learned Summary (2 of 2)



Key Civil Stakeholder: GOES-R

- GOES-R, -S, -T, -U: 4th generation NOAA operational weather satellites
- Launch: 2016, 15-year service life
  - Series operational through 2030s
- Driving requirements:
  - Orbit position knowledge requirement (right)
  - All performance requirements applicable through maneuvers, <120 min/year allowed exceedances
  - Stringent navigation stability requirements
  - Requirements unchanged for GOES-S, -T, -U

Parameter	Requirement (1-sigma)
Radial	33 m
In-track	25 m
Cross-track	25 m

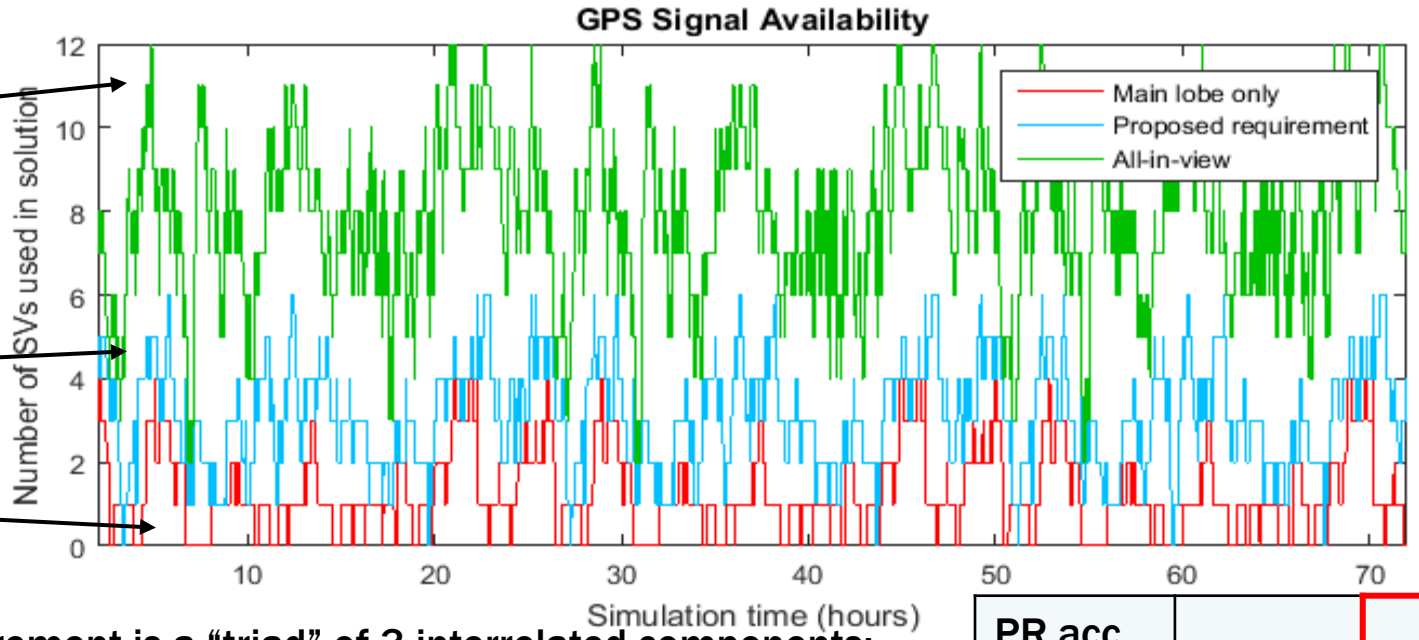
- GOES-R cannot meet stated mission requirements with SSV coverage as currently documented
- NASA-led interagency requirement formulated as minimum-impact solution to meet GOES-R performance needs

NASA Proposed SSV Requirement (In-work)

Current minimum performance

Proposed requirement

Current requirement



- Current requirement is a "triad" of 3 interrelated components:
  - Signal availability (% of time that 1 or 4 GPS signals are available; max outage time)
  - Minimum received signal power at GEO
  - Maximum pseudorange accuracy (equivalent to user range error)
- Proposed requirement adds second tier of capability specifically for HEO/GEO users
  - Increased availability (nearly continuous) for at least 1 signal
  - Relaxed pseudorange accuracy from 0.8m RMS to 4m RMS
  - No change to minimum received signal power
  - Applies to all signals (L1/L2/L5), all codes

PR acc. (rms)	0.8 m	4m
1+ signal	≥ 80%	≥ 99%
4+ signals	≥ 1%	≥ 33%
Max outage	108 min	10 min

SSV L1 HEO/GEO availability

Status on Requirement Formulation Using USAF Interagency Forum for Operational Requirements (IFOR) Process

- Oct 2015–Feb 2016: NASA and USAF IFOR requirements coordination
  - Monthly WG meetings with NASA, USAF, GPS Program Office
  - Major deliverables provided by NASA: Requirement Language, Statement of Need, Analysis of Alternatives
  - NASA coordinating with interagency stakeholders for letters of support/commitment
- 9 Feb 2016: Final Requirements WG Meeting
  - NASA delivers final products
  - GPS Program Office delivers ROM cost estimate
- 26 Feb 2016: Formal SMC/SY (Space Superiority) endorsement of NASA requirement
- 22 Mar 2016: IFOR Co-Chair preliminary recommendation meeting
  - GPS Program Office requests for clarification on Analysis of Alternatives and forward plan leads to Interagency high-level requirements meeting (IFOR HPT)
- 12–13 Apr 2016: NASA/USAF Space Comment/GPS Program Office HPT
  - Drafting of USAF/NASA Memorandum of Agreement
  - Clarification of Analysis of Alternatives items
  - Agreement on forward engagement in GPS SV11+ procurement process
- 19 Apr 2016: Formal NOAA endorsement of NASA requirement
- June 2016: Final IFOR Requirements Co-Chair recommendation meeting

Requirement Not Finalized--Work in Progress

Space Service Volume Summary

- Space users rely on GNSS as a critical space navigation utility over an expanding range of orbital regimes
- Missions using GNSS in HEO/GEO orbits are vulnerable to constellation design changes because availability provided by aggregate signals (main & side lobes) are critically important and should be specified
- NASA has developed a proposed aggregate signal requirement based on documented mission needs that will benefit entire Space Enterprise
- NASA is working through the formal U.S. IFOR requirements process for potential specification for the GPS III SV11+ vehicle build
- GPS requirements update (if successful) for HEO/GEO SSV users will:
  - Maintain critical capabilities employed by users in HEO/GEO
  - Provides a green-light for civil and military space missions considering future operational use of GPS beyond LEO

Protection of GNSS Aggregate Signals (main & side lobes) through Specification is Critically Important for Current and Future Users in the SSV

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Jun 6: Prague Space Security Conference presentation
May 18: Advisory board

GPS Summary

- U.S. policy upholds longstanding commitments to free, continuous, worldwide GPS access and 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 USG
- GPS performance is better than ever and will continue to improve
- U.S. policy promotes open competition and market growth for commercial GNSS
- Protection of GNSS Aggregate Signals (main & side lobes) through Specification is Critical for Current and Future Users in the SSV

GPS: Continuous improvements; predictable, dependable positioning performance

(非常)感谢你

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