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GNSS Space Service Volume Update

Providers' Forum

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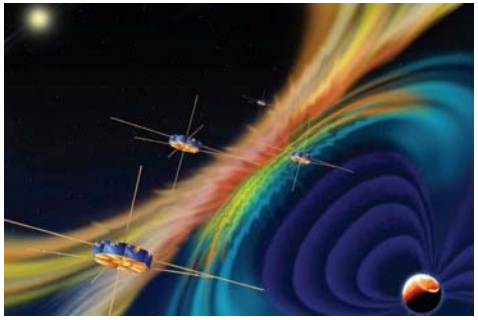
The Promise of using GNSS for Real-Time Navigation in the Space Service Volume

Benefits of GNSS use in 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** (from: $100sK-$1M to: $15K–$50K)
- Supports **increased satellite autonomy**, lowering mission operations costs (savings up to $500-750K/year)
- Enables new/enhanced capabilities and better performance for **HEO and GEO missions,** such as:

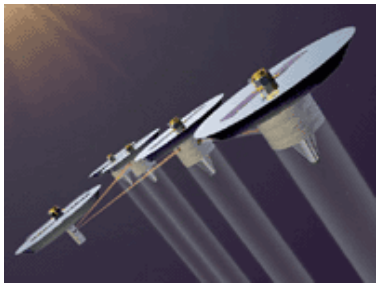
Earth Weather Prediction using Advanced Weather Satellites



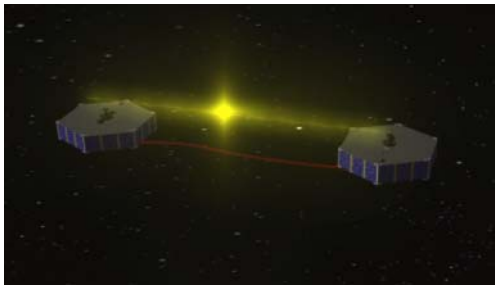
Space Weather Observations

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

U.S. 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 (e,g, Galileo, GLONASS, BeiDou) to specify interoperable SSV capabilities
- Developing missions and systems to utilize GNSS signals in the SSV (e.g. MMS, GOES)

GNSS SSV Observations

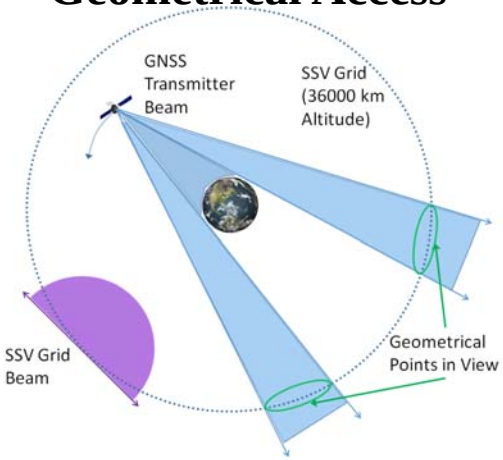
- WG-B is making significant progress in establishing an interoperable Global Navigation Satellite System (GNSS) Space Service Volume (SSV) through pre-work, analyses and periodic teleconferences
- WG-B Analyses underway to solidify understanding of HEO/GEO user capabilities using all provider's SSV capabilities (BeiDou, Galileo, GLONASS, GPS, IRNSS, QZSS)
- Despite this, SSV users should not be relying on **capabilities** that are **not specified**
  - Capabilities available now may not be available in the future if not specified

Recommendations

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

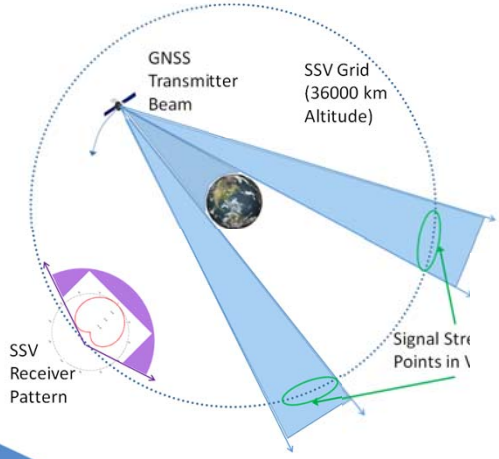
WG-B SSV
3 Phase Analysis Approach

Phase 1:
Geometrical Access

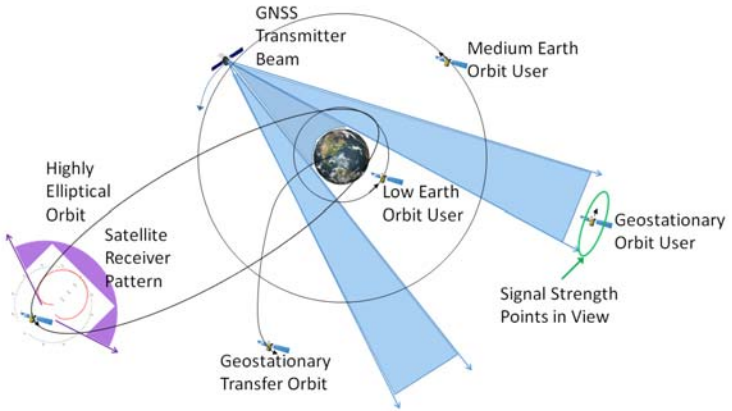


Increasing Fidelity

Phase 2:
Signal Strength Access



Phase 3:
Specific User Missions



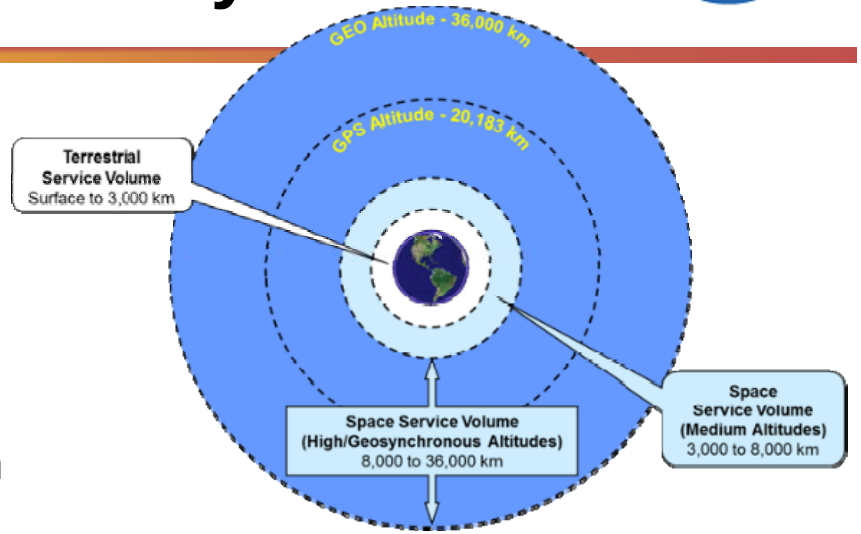
Increasing Complexity

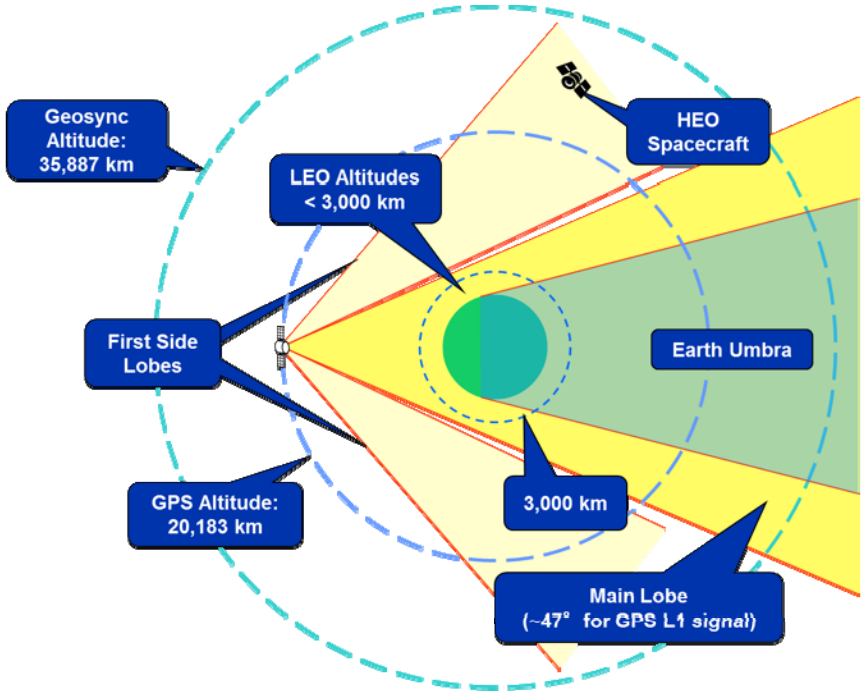
WG-B SSV
3 Phase Analysis Status

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

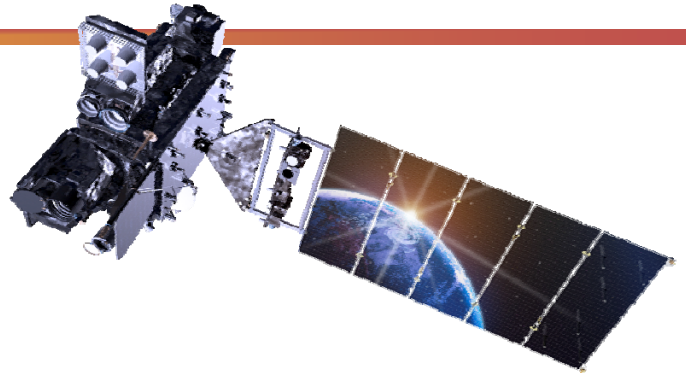
GPS SSV Status and Lessons Learned: Executive Summary

- 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 & lessons learned since spec development **show significant PNT performance improvements** when the full aggregate signal is used.
- **Numerous** Military & Civil operational missions in High & Geosynchronous Earth Orbit (HEO/GEO) utilize the full signal to enhance vehicle PNT performance
  - **Multiple** military & civil 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**





Key Civil Stakeholder: GOES-R

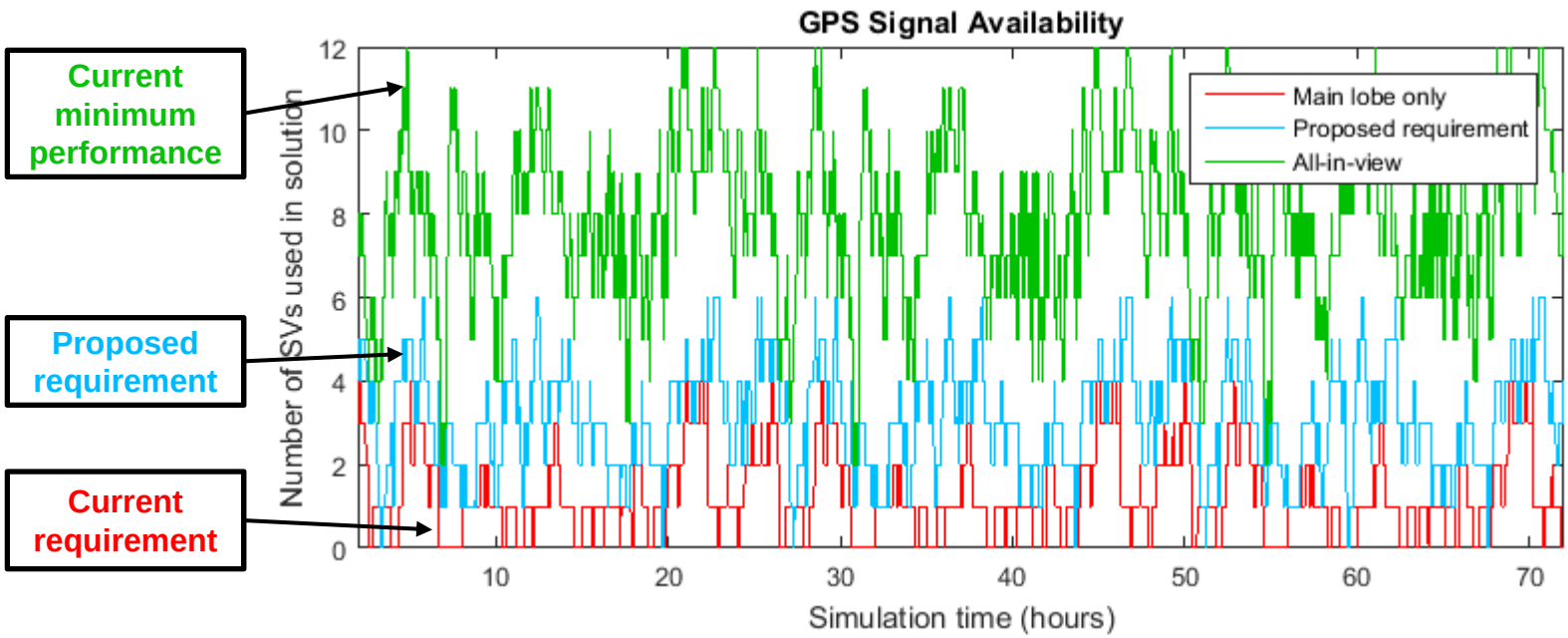


- GOES-R, -S, -T, -U: 4th generation NOAA operational weather satellites
- Launch: 2016, 15-year service life
  - Series operational through 2030s
- Driving requirements:
  - **Orbit position knowledge** requirement (right)
  - All performance requirements **applicable through maneuvers**, **<120 min/year**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

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

- 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 requirement is a "triad" of three 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 signal availability to 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 USA Interagency Forum for Operational Requirements (IFOR) Process

- Oct 2015–Feb 2016: NASA and Air Force coordinate through IFOR process
  - Monthly IFOR WG meetings w/ NASA, AFSPC, SMC (Aerospace as “honest broker”)
  - Major deliverables provided by NASA:
    1. Requirement Language
    2. Statement of Need
    3. Analysis of Alternatives
  - NASA coordinating with interagency stakeholders for letters of support/commitment
- 9 Feb 2016: Final IFOR WG Meeting
  - NASA delivers final products
  - SMC delivers ROM cost estimate for impact to GPS system
- 26 Feb 2016: Formal SMC/SY (Space Superiority) endorsement of NASA requirement
- 22 Mar 2016: IFOR Co-Chair preliminary recommendation meeting
  - SMC requests for clarification on AoA and forward plan leads to IFOR-requested HPT
- 12–13 Apr 2016: NASA/AFSPC/SMC HPT
  - Drafting of USAF/NASA MoA
  - Clarification of AoA items
  - Agreement on forward engagement in SV11+ procurement process
- 19 Apr 2016: Formal NOAA endorsement of NASA requirement
- June 2016: Final IFOR Co-Chair recommendation meeting

Requirement Not Finalized--Work in Progress

Closing Remarks

- 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 formal IFOR process for potential specification for the GPS III SV11+ vehicle build
- If successful, GPS requirements update 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