Refining the GPS Space Service Volume (SSV) and Building a Multi-GNSS SSV

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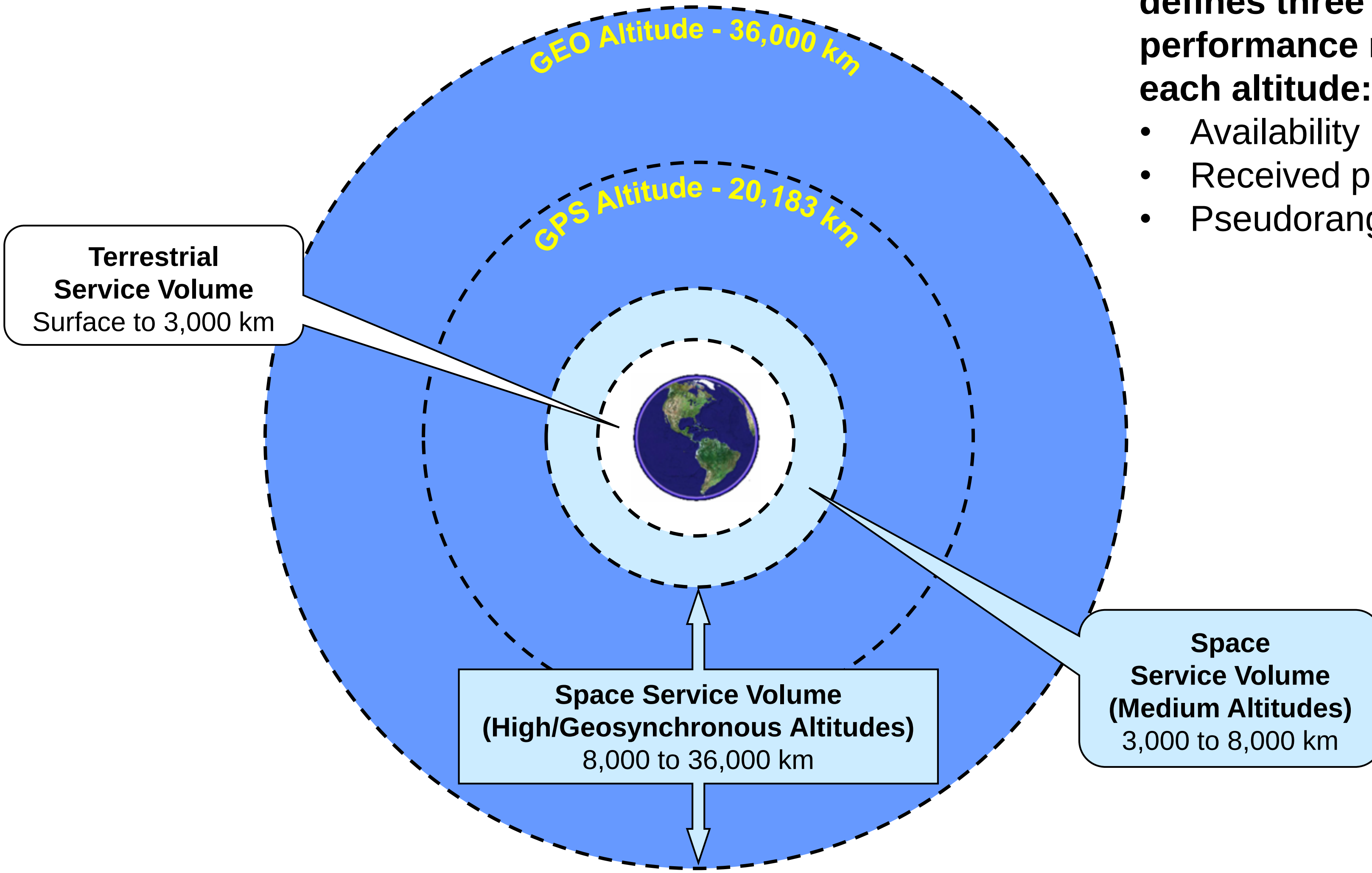
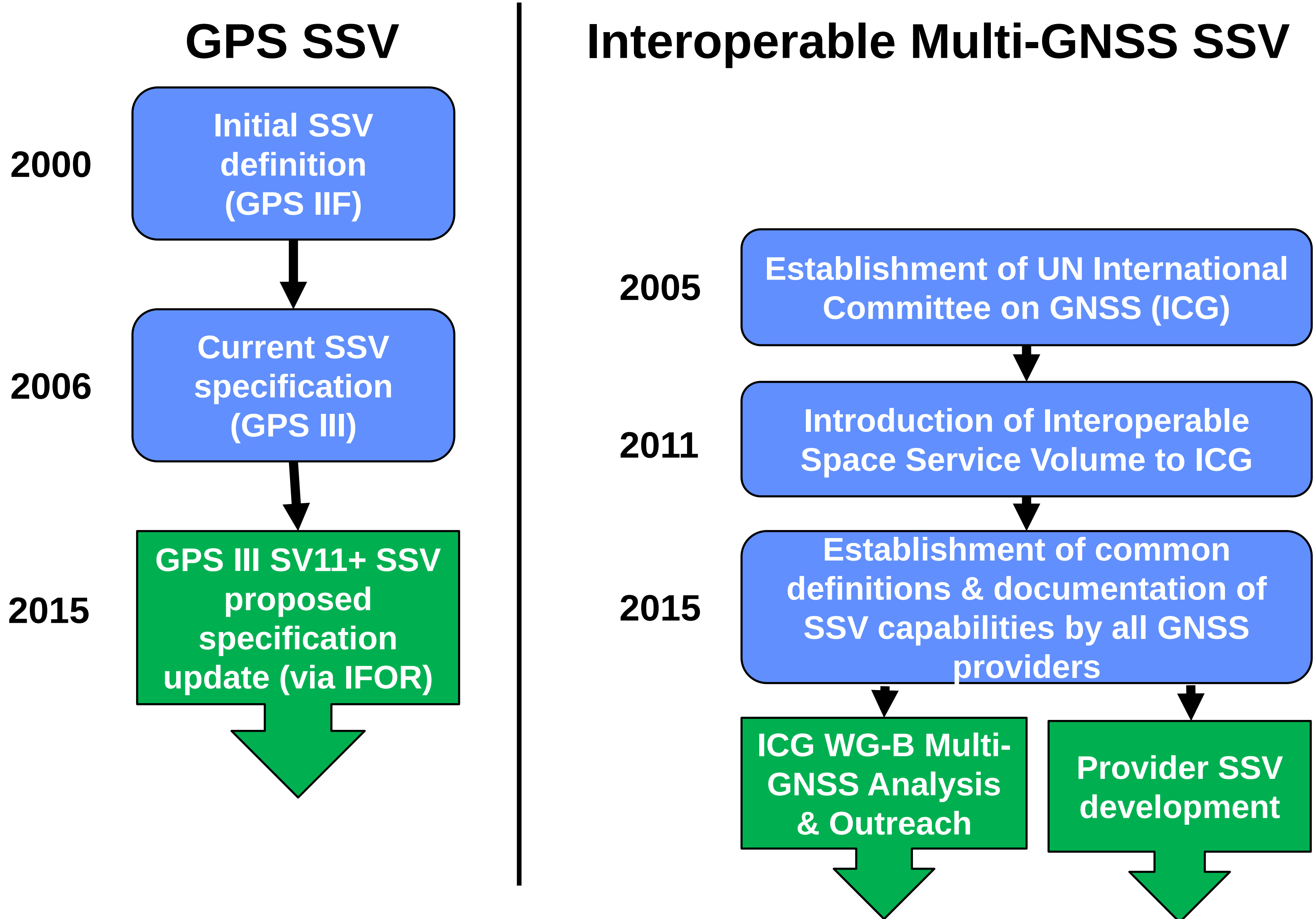
What is a Space Service Volume (SSV)?



The Space Service Volume defines three interrelated performance metrics at each altitude:

- Availability
- Received power
- Pseudorange accuracy

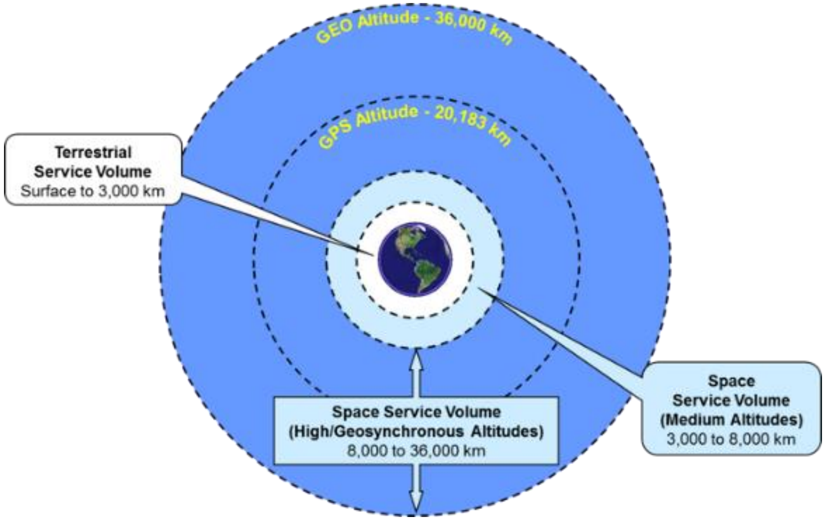
Past and Ongoing Development of the SSV

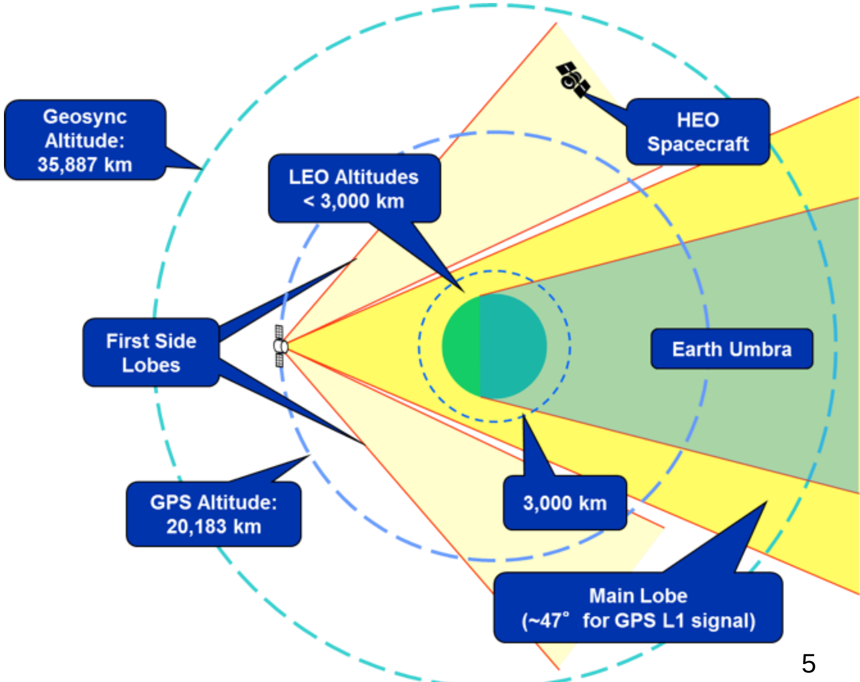


GPS SSV Development

GPS Space Service Volume: 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) of boresight.
- On-orbit data & lessons learned since spec development show **significant PNT performance improvements** when the full aggregate signal is used.
- **Numerous** operational missions in High & 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 space users in HEO/GEO
- Protecting GPS aggregate signal performance **ensures GPS preeminence** in a developing multi-GNSS SSV environment



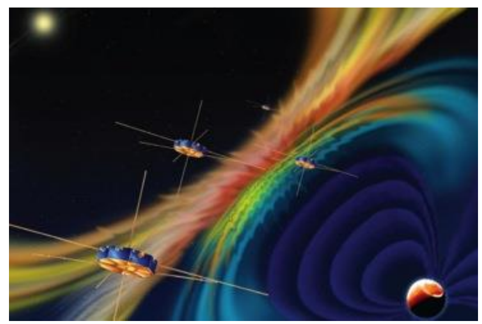


The Promise of using GNSS for Real-Time Navigation in the Space Service Volume

Benefits of nearly-continuous 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:

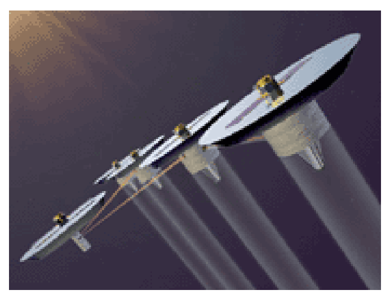
Earth Weather Prediction using Advanced Weather Satellites



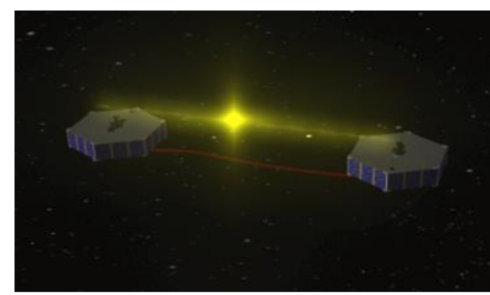
Space Weather Observations

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

Key Civil Stakeholder: GOES-R

- GOES-R, -S, -T, -U: 4th generation NOAA operational weather satellites
- Launch: **19 Nov 2016**, 15-year 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-proposed requirement formulated as **minimum-impact solution** to meet GOES-R performance needs

GOES-R THE FUTURE OF FORECASTING

3X MORE CHANNELS

Improves every product from current GOES Imager and will offer new products for severe weather forecasting, fire and smoke monitoring, volcanic ash advisories, and more.

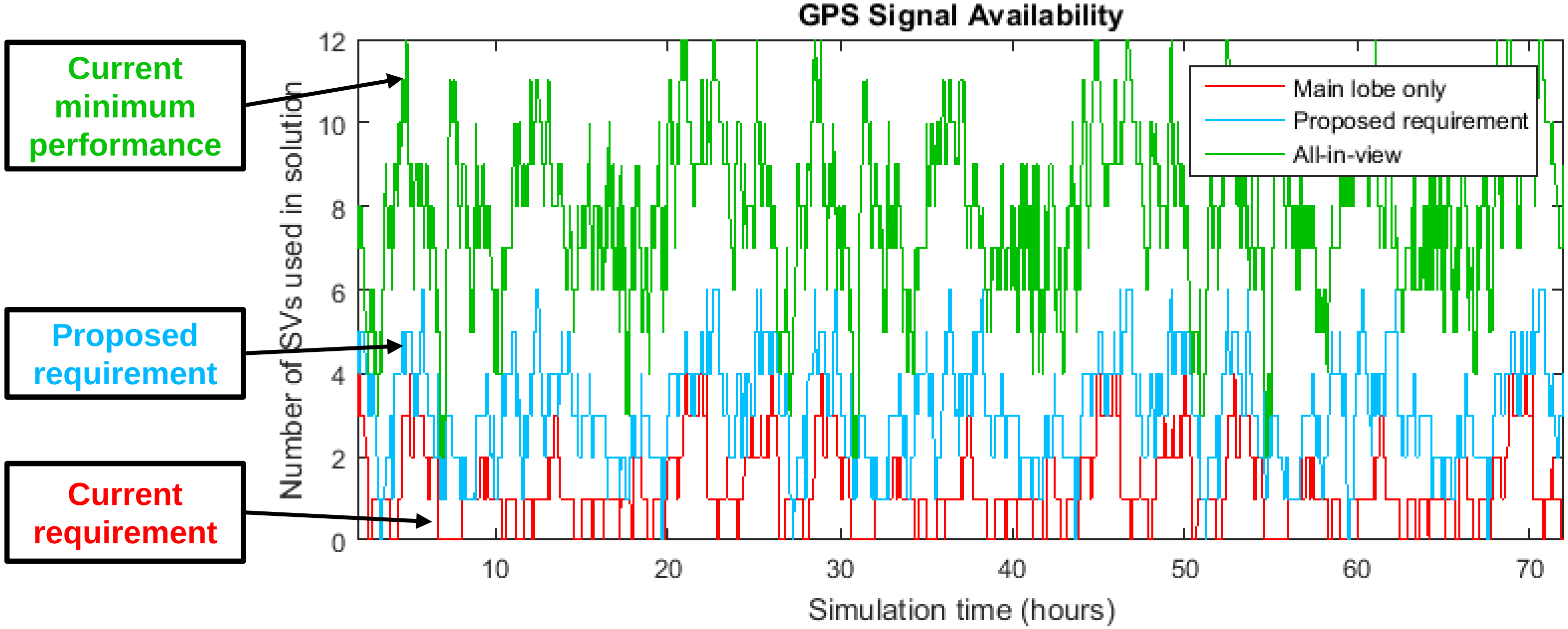
4X BETTER RESOLUTION

The GOES-R series of satellites will offer images with greater clarity and 4x better resolution than earlier GOES satellites.

5X FASTER SCANS

Faster scans every 30 seconds of severe weather events and can scan the entire full disk of the Earth 5x faster than before.

Proposed GPSIII SV11+ SSV Requirement



Signal Availability for GOES-R-class GEO Mission

Independent of pseudorange accuracy

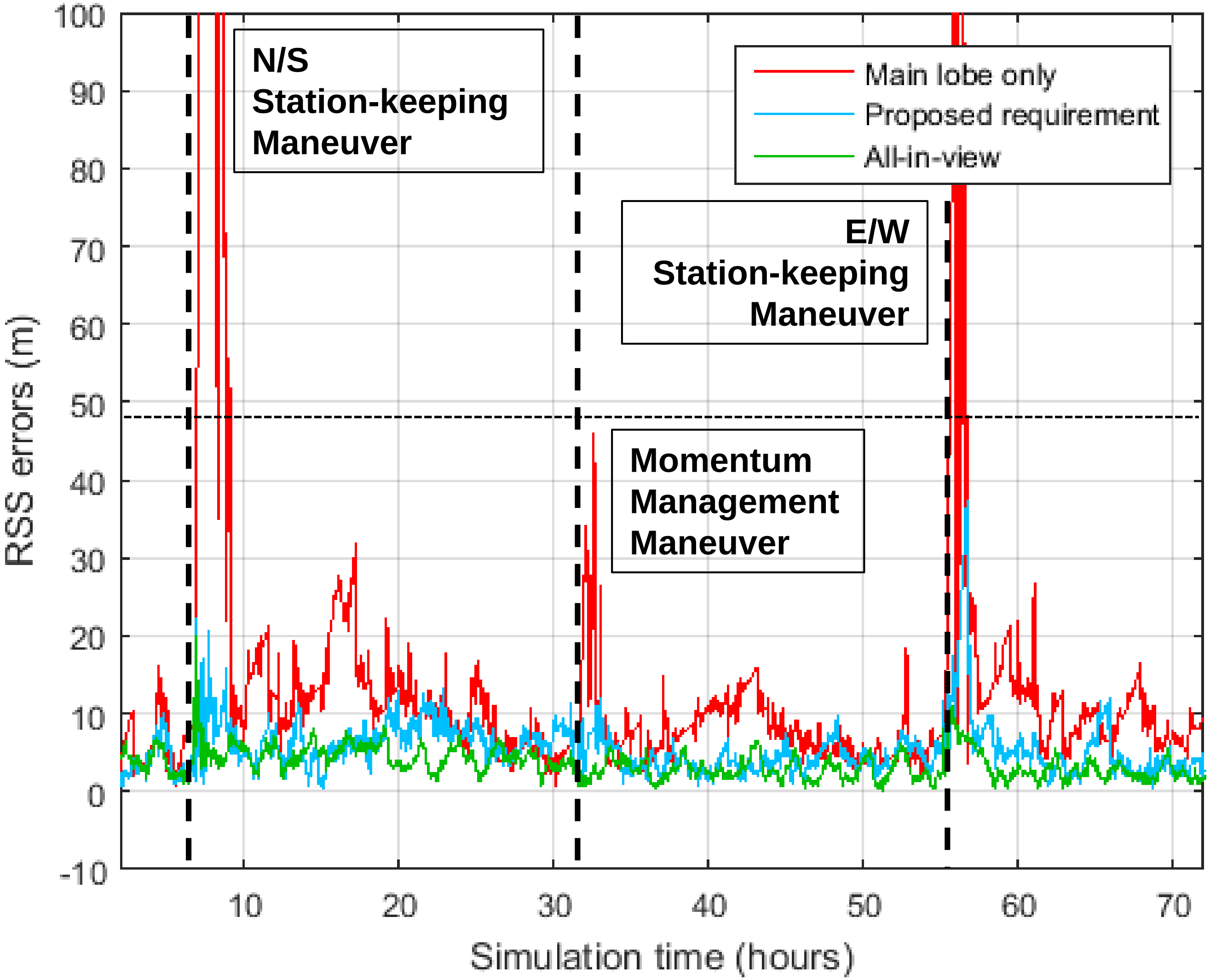
- **Proposed requirement adds second tier of capability specifically for HEO/GEO users**
  - Increased signal availability to nearly continuous for at least 1 signal
  - Relaxed pseudorange accuracy from 0.8m RMS to 4m RMS
  - No change to minimum received signal power
  - Applies to all signals (L1/L2/L5), 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; 4m spec identical for L2/L5

GOES-R Mission Impact

- Modeled each type of GOES-R maneuver at each GPS availability level
- Only 1 signal is necessary to recover nav performance; max outage is key metric
- At current required availability (red), post-maneuver errors exceed requirement in all cases, for up to 3 hours
- Proposed SSV requirement (blue) just bounds errors within GOES-R nav requirement
- RSS requirement is shown for illustration; in actuality, each component meets individually



Errors with respect to simulation truth

Requirement Development at a Glance

- **Spring 2015: GPS ACE & MMS performance definitively demonstrate benefits of sidelobes for space users – socialization begins with GOES-R as example**
- **Aug 2015: Maj Gen Thompson briefed, supports updating GPS SSV requirement through IFOR**
- **Oct 2015–Feb 2016: NASA engages Air Force in IFOR coordination**
  - Monthly IFOR WG meetings w/ NASA, AFSPC, SMC (w/ Aerospace)
  - 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 IFOR WG**
  - NASA delivered final products
  - SMC delivered ROM cost estimate for impact to GPS system; disconnect in expected impacts further discussion
- **26 Feb 2016: SMC/SY endorsement**
- **22 Mar 2016: IFOR Co-Chair preliminary recommendation meeting**
  - Proposed recommendation: objective requirement w/ NASA involvement in acquisition
  - USAF questions on AoA and forward plan led to IFOR-requested HPT
- **12–14 Apr 2016: NASA/AFSPC/SMC HPT**
  - USAF/NASA MoA framework drafted
- **19 Apr 2016: NOAA endorsement**
- **18 May 2016: Brief to PNT Advisory Board**
  - Commitment from Maj Gen Thompson to reengage
- **Oct 2016: AFPSC establishes Independent Strategic Assessment Group to study SSV requirement; outbrief due late Feb 2017**

GPS SSV
Conclusions & Way Forward

- NASA has proposed an updated GPS SSV requirement to **protect high-altitude space users** from risk of reduced future GPS capability.
  - Key civil example user is GOES-R
  - Many other emerging users will require these capabilities in the future
- Available data suggests that the updated requirement can **easily be met** by a minimum-performing constellation of the previous design.
  - If true, cost to implement would be documentation/V&V only, not a hardware change
  - But, in the absence of direct verification data, a risk remains that the requirement would not be met by the current and future designs
- NASA seeks USAF engagement to seek and implement **minimal-impact requirement** based on **best available data** through SV11+ acquisition cycle
- NASA finds the proposed requirement **critical** to support future users in the SSV across the enterprise and is **open to a commitment of funding** based on a validated assessment.
- The proposed requirement is an **innovative, whole-of-government approach** that will protect and encourage next-generation capabilities in space at minimal cost.
- NASA encourages the work of the SSV **Independent Strategic Assessment Group** to provide independent analysis of proposed requirement and path forward.

Interoperable Multi-GNSS SSV Progress

International Committee on GNSS (ICG)

- **Emerged from 3rd UN Conference on the Exploration and Peaceful Uses of Outer Space July 1999**
  - Promote the use of GNSS and its integration into infrastructures, particularly in developing countries
  - Encourage compatibility & interoperability among global and regional systems
- **Members include:**
  - GNSS Providers: (U.S., EU, Russia, China, India, Japan)
  - Other Member States of the United Nations
  - International organizations/associations – Interagency Operations Advisory Group (IOAG) & others
  - 11th annual meeting hosted by Russia in Sochi, November 6-11, 2016

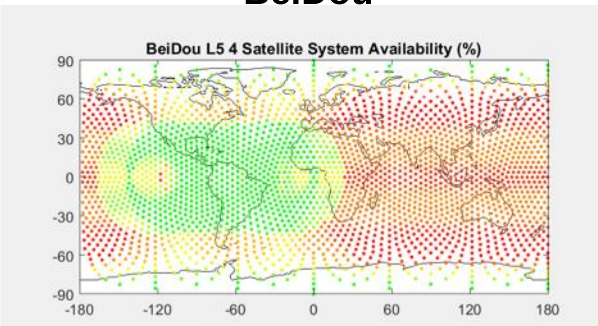
http://www.oosa.unvienna.org/oosa/en/SAP/gnss/icg.html

Summary of ICG Multi-GNSS SSV Development Efforts To-Date

- Interoperable, Multi-GNSS SSV coordination is accomplished as part of **ICG Working Group B (WG-B): Enhancement of GNSS Performance, New Services and Capabilities**
- ICG WG-B discussions have encouraged **GPS, GLONASS, Galileo, BeiDou, QZSS, & NAVIC** to characterize performance for space users to GEO
- **2016 ICG meeting** was held Nov. 6-11, in Sochi, Russia, where:
  - All providers **reaffirmed the criticality** of GNSS for current and emerging space missions
  - Participating members are finalizing a **guidance booklet** on GNSS SSV & are **jointly conducting analyses** to characterize interoperability
  - Stakeholder ICG members will **coordinate a global outreach initiative** to educate & inform policy makers on the importance of a multi-GNSS SSV enabling space users to serve societal needs

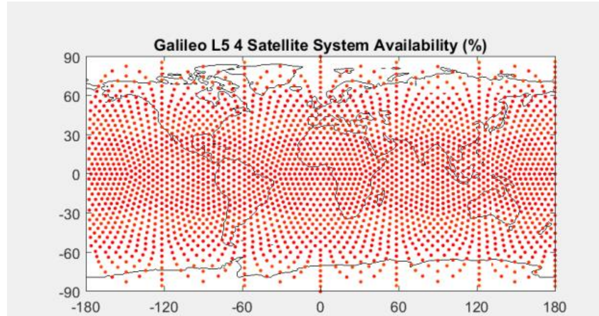
ICG WG-B Phase 1 Results: 4+ Signal Main-Lobe Availability

BeiDou



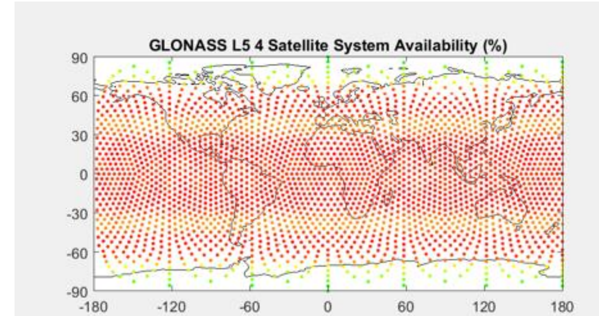
Average 45.4% availability

Galileo



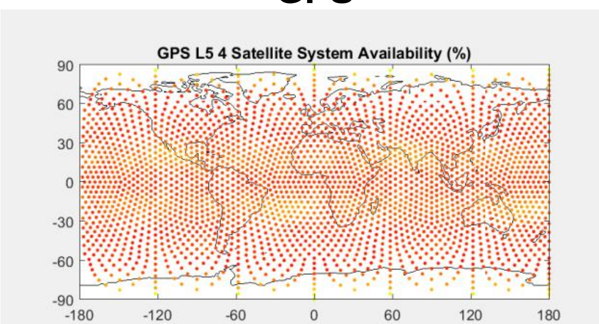
Average 4.2% availability

GLONASS



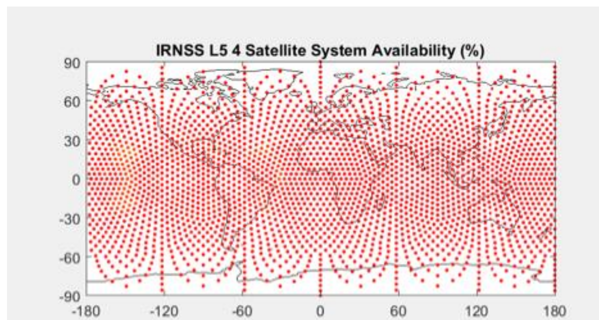
Average 14.5% availability

GPS



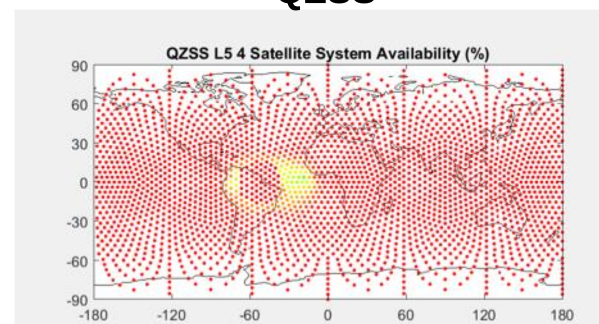
Average 15.6% availability

NAVIC



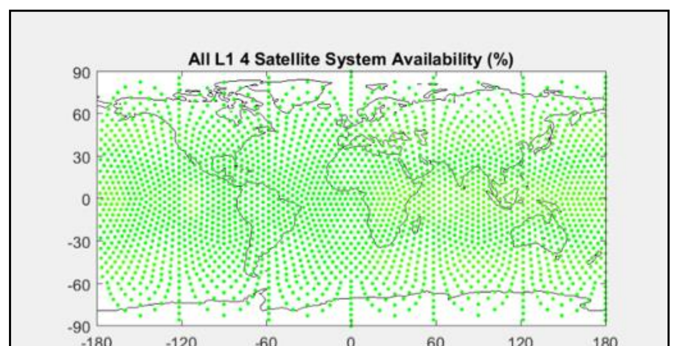
Average 0.6% availability

QZSS



Average 1.5% availability

Interoperable GNSS achieves 100% system availability



Conclusions

- The Space Service Volume, first defined for GPS IIF in 2000, **continues to evolve** to meet high-altitude user needs.
- **GPS led the way** with a formal specification for GPSIII, requiring that GPS provides a core capability to space users.
- Today, we **continue to work** in parallel tracks to ensure that the SSV keeps pace with user demands.
  - For GPS, with its well-characterized performance, we are working to **update the SSV spec** to capture the needs of emerging GPS-only users like GOES-R.
  - In partnership with foreign GNSS providers, we are working jointly to characterize, analyze, document, and publish the capabilities of an **interoperable multi-GNSS SSV** with ultimate goal of provider specification.
- **Both approaches** are equally critical: a robust GPS capability will enable and enhance new missions in single-system applications, while an interoperable GNSS SSV ensures that a wider capability is available as needed.