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GNSS Space Service Volume & Space User Data Update
ICG Providers Forum

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Space User/Space Service Volume Summary from ICG-8 (Dubai) Working Group-B

- **Discussions**
  - Significant progress has been made in establishing an interoperable Global Navigation Satellite System (GNSS) Space Service Volume (SSV) through pre-work, presentations, and additional robust contributions from the administrations of the Russian Federation and China
  - The Working Group further discussed the benefits of an interoperable GNSS SSV
  - All WG-B participants believe that a fully interoperable GNSS SSV will result in significant benefits for future space users as it will allow for performance no single system can provide on its own
- **Recommendations from ICG-8**
  - **SSV Template Completion**: recommend all providers complete and formally submit SSV template. (Russia, China, Japan completed the templates, but not formally submitted)
  - **Definition Maturations**: Develop standard definitions of minimum number of satellites, constellation geometry, etc (this will help to perform unified GNSS SSV analysis)
  - **Spaceborne GNSS Receivers**: Build multi-frequency, and multi-constellation GNSS receivers to exploit the SSV
  - **Antenna / Electronics Characterization**: Measuring satellite transmit antenna patterns (pseudorange and phase vs. angle), and designing spacecraft electronics with strict requirements on phase and group delay coherence

U.S. Contributions to the International Community to Ensure an Interoperable, Sustained, Quantified GNSS Capability for Space Users

Space Service Volume (SSV)

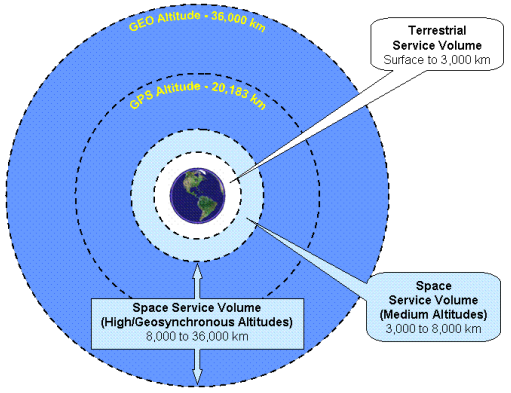
- Development and specification of a SSV and solidification of specifications that define signal strength and availability of GPS signals in space for all locations and all users within the SSV

GPS Antenna Pattern Publication

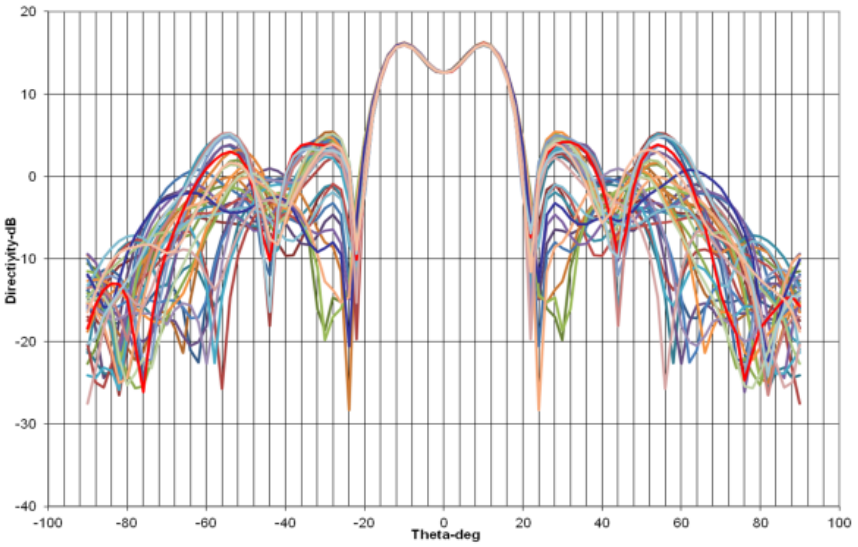
- GPS Block II-R and II-R(M) antenna pattern pre-flight testing & post-flight publication
  - Quantifies antenna characteristics, including main & side lobe gain
  - Enables space users to perform pre-flight analyses to determine end-to-end navigation performance and signal availability
  - Enables space users to leverage side lobe information (per SV) to enhance GPS availability, particularly for space missions above the GPS constellation, including missions in High Earth Orbit (HEO) & Geostationary/ Geosynchronous Orbit (GEO/GSO)

International Forward Work

- Highly encourage GNSS, and regional navigation systems, partners to participate
  - Complete SSV templates
  - Develop SSV specification for your constellation
  - Publish your constellation antenna data



Average IIR L1 roll pattern, Theta cuts every 10 deg

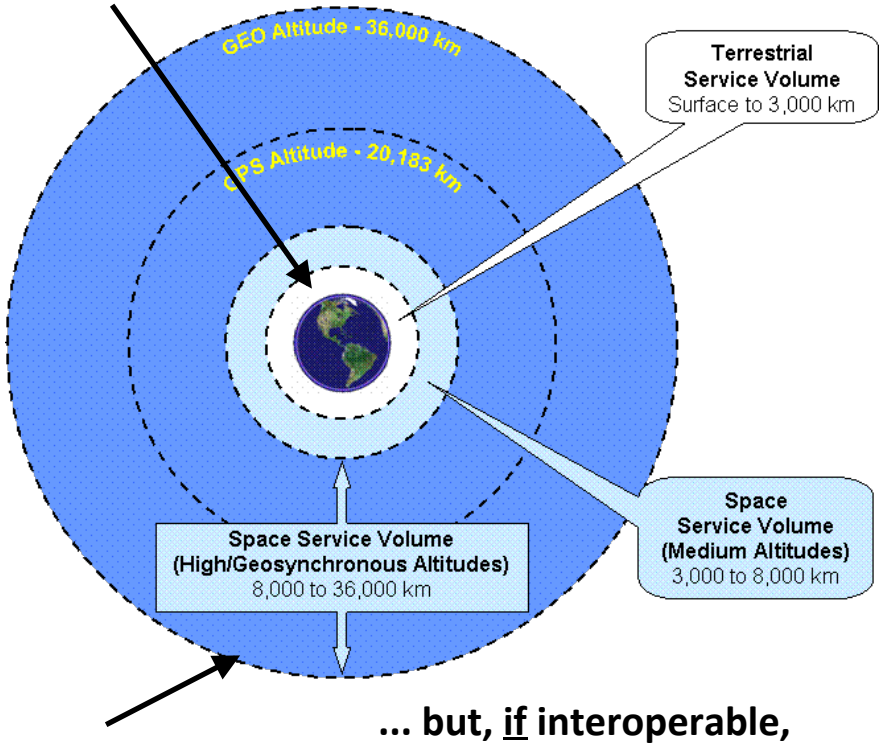


Partners: Galileo, GLONASS, Beidou, & IRNSS

Expanding the GPS SSV into a multi-GNSS SSV

- At least four GNSS satellites in line-of-sight are needed for on-board real-time autonomous navigation
  - GPS currently provides this up to 3,000 km altitude
  - Enables better than 1-meter position accuracy in real-time
- At GEO/GSO only one GPS satellite will be available at any given time.
  - **GPS-only** positioning still possible with on-board filtering, but only up to approx. 100-meter absolute position accuracy.
  - **GPS** + **Galileo** combined would enable 2-3 GNSS sats in-view at all times.
  - **GPS** + **Galileo** + **GLONASS** would enable at least 4 GNSS sats in-view at all times.
  - **GPS** + **Galileo** + **GLONASS** + **Beidou** would enable > 4 GNSS sats in view at all times. This provides best accuracy and, also, on-board integrity.
- However, this requires:
  - Interoperability among these the GNSS constellations; and
  - Common definitions/specifications for use of GNSS signals within the Space Service Volume (3,000 km to GEO/GSO altitudes)

≥ 4 GPS satellites in line-of-sight here (surface to 3000 km)



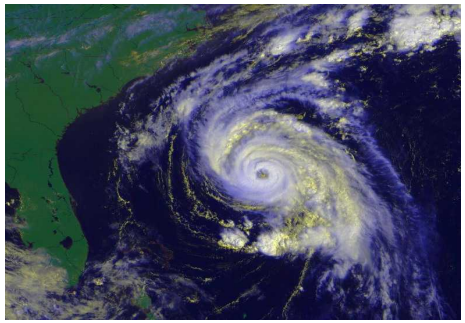
Only 1-2 GPS satellites in line-of-sight at GEO/ GSO altitudes

... but, if interoperable, then GPS + Galileo + GLONASS + Beidou provide > 4 GNSS sats in line-of-sight at GEO/GSO altitudes

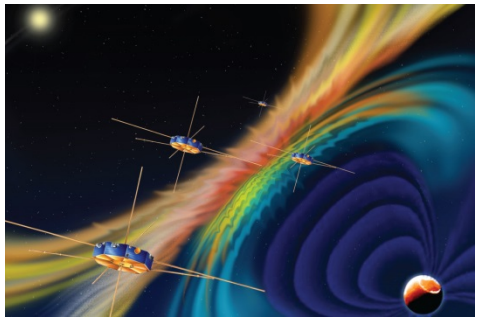
Why is an Interoperable Space Service Volume Important?

Global, interoperable SSV specifications are crucial for real-time GNSS navigation solutions in High Earth Orbit

- **Supports increased satellite autonomy for missions, lowering mission operations costs**
- **Enables new/enhanced capabilities for HEO and GEO/GSO future missions, such as:**



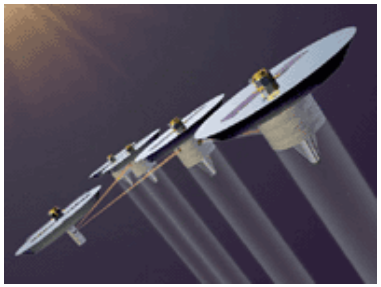
Improved Weather Prediction using Advanced Weather Satellites



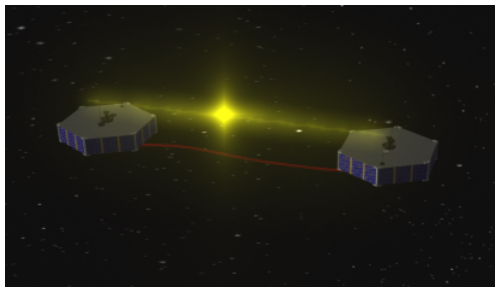
Space Weather Observations

Astrophysics Observations

En-route Lunar Navigation Support



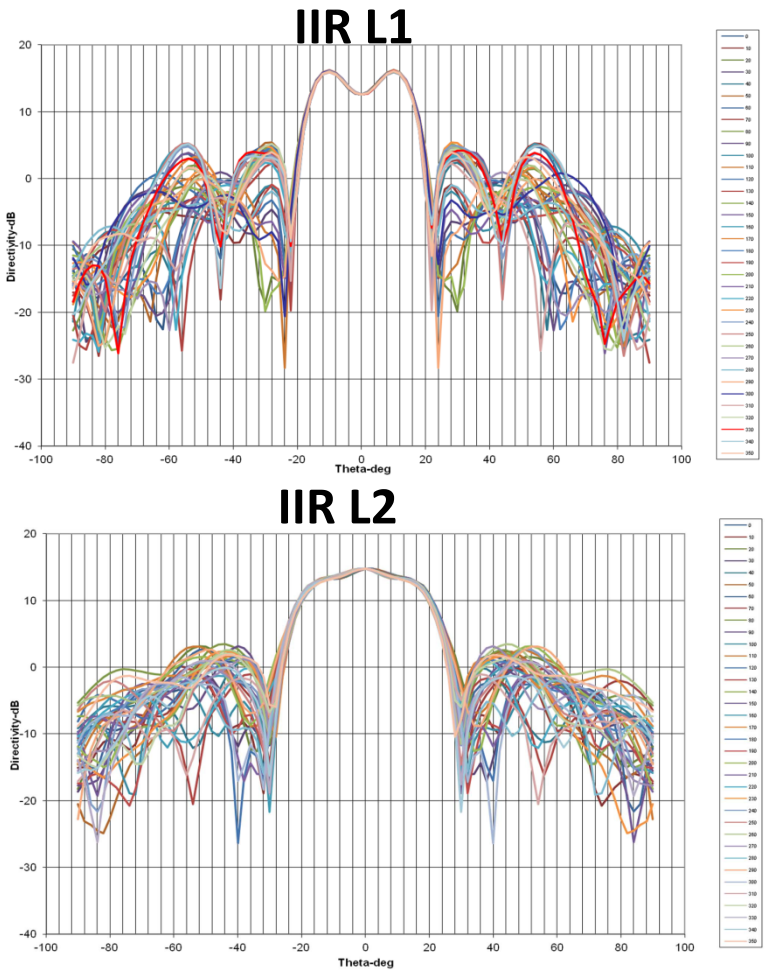
Formation Flying & Constellation Missions



Closer Spacing of Satellites in Geostationary Arc

U.S. Publication of GPS Block IIR & IIR(M) Antenna Patterns

- Substantial pre-flight ground measurement of IIR & IIR(M) antenna patterns performed by Lockheed Martin for each GPS spacecraft
- Data now publically released. To access: www.gps.gov & click on support, technical documentation, GPS antenna patterns
- Hemispherical gain patterns for each GPS satellite can be developed by combining data along (+/- 90 degrees) and around (0-360 degrees) antenna boresight
- Enables high fidelity analyses and simulations for HEO/GEO missions
- Information bolsters confidence in developing new mission types
- Enhances navigation performance capabilities of current missions



Special thanks to Willard Marquis/Lockheed Martin & Air Force GPS Program for publicly releasing this information!!