# ICG WG-B Achievements on Interoperable GNSS Space Service Volume (SSV)

November, 2016
Sochi, Russian Federation

International Committee on Global Navigation Satellite Systems

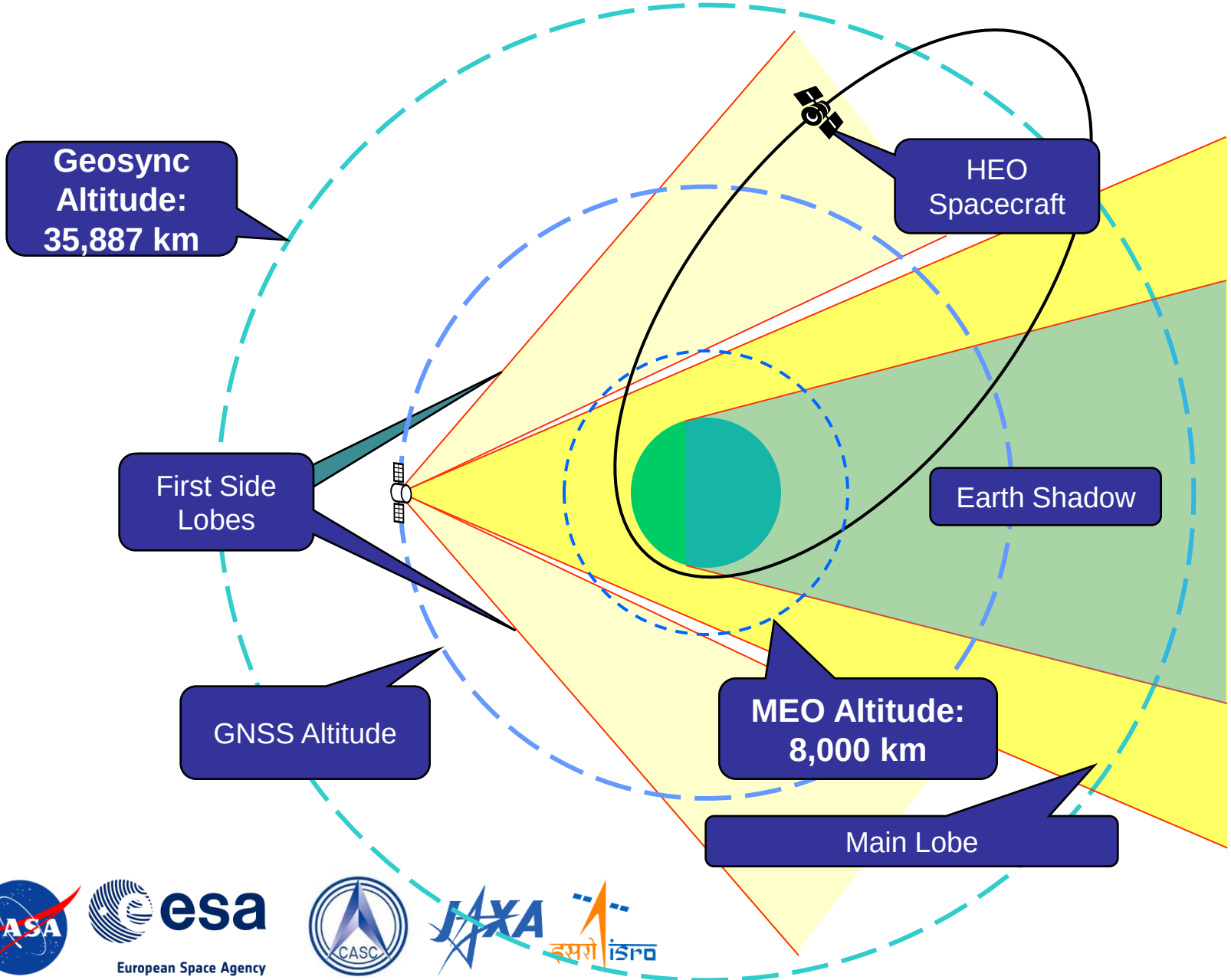
# ICG WG-B Action Group on SSV

- Action group on SSV was formed within WG-B in order to
  - Establish an Interoperable GNSS Space Service Volume (SSV)
  - Promote the relevance of SSV for users and to the service providers
  - Identify SSV support of every service provider for the benefit of users and receiver manufacturers
  - Harmonize and deepen the mutual understanding on SSV
  - Establish an SSV booklet

- Work of the Action Group is supported by all GNSS service providers

- Special thank to all Space Agencies very actively supporting the work through simulations and SSV Booklet preparation which is close to completion

# Reception Geometry for GNSS Signals in Space



# The Interoperable GNSS SSV

- Benefits to User - Performance Aspects
  - Nearly continuous on-board Position, Velocity and Time (PVT) capability
  - Interoperable GNSS SSV allows development of new Precise Orbit Determination concepts with high accuracy
- Benefits to User – Operational Aspects
  - New operations concepts with reduced Ground interaction
  - Increase of on-board autonomy
  - Increase of robustness of spacecraft navigation and operations resilience
- Benefits to User - Technology Aspects
  - Enabler for new mission and service concepts
  - Development of GNSS Receiver core technology, applicable for a variety of missions
  - Capability to provide satellite orbit, attitude and time with one sensor

# Space Service Volume Template

- Action group agreed on common template to specify the SSV support of every system.
- Template includes
  - For every Open Service signal minimum user received power at max. off-boresight angle at GEO altitude
  - Ranging accuracy at max off-boresight angle at GEO altitude
  - Availability for 1 and 4 signals incl. max. outage period

- Template information can be easily scaled for particular user missions and receiver characteristics

# SSV Template of all Service Providers

- All Service Providers filled the SSV template (Details see backup slides)

GPS

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 0.8 meters | |
| **Signal Center Frequency** | | |
| L1 C/A, L1C | 1575.42 MHz | |
| L2C | 1227.60 MHz | |
| L5 (I5 or Q5) | 1176.45 MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L1 C/A | -184.0 dBW | 23.5 deg |
| L1C | -182.5 dBW | 23.5 deg |
| L2C | -183.0 dBW | 26 deg |
| L5 (I5 or Q5) | -182.0 dBW | 26 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | **At least 1 signal** | **4 or more signals** |
| L1 | 100% | >97% |
| L2, L5 | 100% | 100% |
| Upper Space Service Volume (HEO/GEO) | **At least 1 signal** | **4 or more signals** |
| L1 | >80% | >1% |
| L2, L5 | >92% | >6.5% |

GLONASS

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 1.4 meters | |
| **Signal Center Frequency** | | |
| L1 | 1605.375 MHz | |
| L2 | 1248.625 MHz | |
| L3 | 1201 MHz | |
| **Minimum Received Civilian Signal Power (GEO)** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L1 | -185 dBW | 20 deg |
| L2 | -184.4 dBW | 28 deg |
| L3 | -184 dBW | 28 deg |
| **Signal availability** | | |
| MEO at 8000 km | **At least 1 signal** | **4 or more signals** |
| L1 | 59.1% | 64% |
| L2, L3 | 100% | 66% |
| Upper Space Service Volume (HEO/GEO) | **At least 1 signal** | **4 or more signals** |
| L1 | 70% | 2.7% |
| L2, L3 | 100% | 29% |

# SSV Template of all Service Providers

- All Service Providers filled the SSV template (Details see backup slides)

Galileo

| Parameters | Typical Characteristics of Nominal GSAT02xx Satellites | |
|---|---|---|
| **User Range Error** | 1.1 meters | |
| **Signal Center Frequency** | | |
| E1B/C | 1575.42 MHz | |
| E6B/C | 1278.75 MHz | |
| E5b | 1206.45 MHz | |
| E5 AltBOC | 1191.795 MHz | |
| E5a | 1176.45 MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| E1B/C | -182.5 dBW | 20.5 deg |
| E6B/C | -182.5 dBW | 21.5 deg |
| E5b | -182.5 dBW | 22.5 deg |
| E5 AltBOC | -182.5 dBW | 23.5 deg |
| E5a | -182.5 dBW | 23.5 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | **At least 1 signal** | **4 or more signals** |
| E1B/C | 100% | 99% |
| E6B/C | 100% | 100% |
| E5b | 100% | 100% |
| E5a or E5 AltBOC | 100% | 100% |
| Upper Space Service Volume (GEO/HEO) | **At least 1 signal** | **4 or more signals** |
| E1B/C | ≥ 64% | 0% |
| E6B/C | ≥ 72% | 0% |
| E5b | ≥ 80% | 0% |
| E5a or E5 AltBOC | ≥ 86% | 0% |

BDS

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 2.5 meters | |
| **Signal Center Frequency** | | |
| B1 | 1575.42 MHz | |
| B2 | 1191.795MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| B1 (MEO) | -184.2 dBW | 25 deg |
| B1 (GEO/IGSO) | -185.9 dBW | 19 deg |
| B2 (MEO) | -182.8 dBW | 28 deg |
| B2(GEO/IGSO) | -184.4 dBW | 22 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | At least 1 signal | 4 or more signals |
| B1 | 100% | 100% |
| B2 | 100% | 100% |
| Upper Space Service Volume (GEO/HEO) | At least 1 signal | 4 or more signals |
| B1 | 97.4% | 24.1% |
| B2 | 99.9% | 45.4% |

# SSV Template of all Service Providers

- All Service Providers filled the SSV template (Details see backup slides)

QZSS

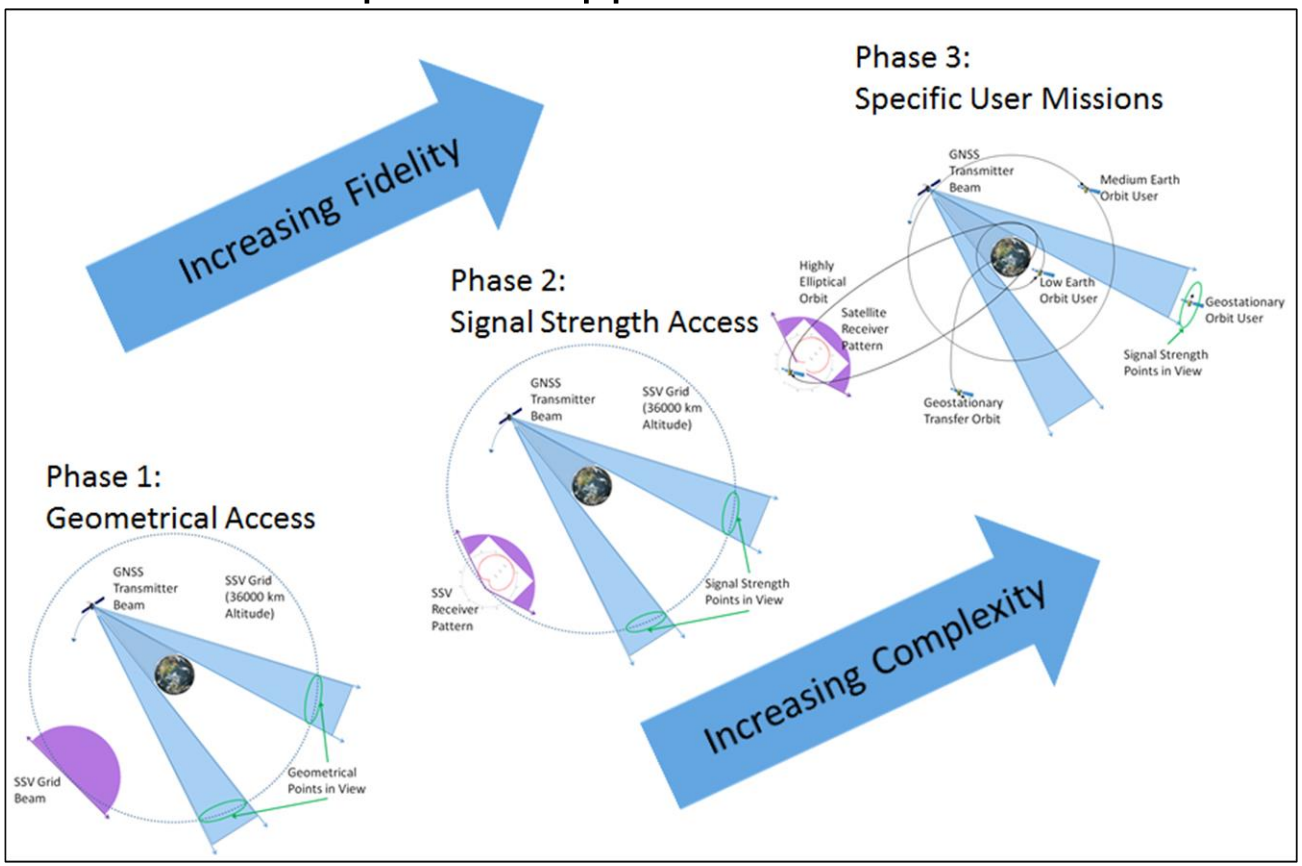
| Parameters | Value | |
|---|---|---|
| **User Range Error** | 2.6 meters (95%) | |
| **Signal Center Frequency** | | |
| L1 C/A | 1575.42 MHz | |
| L1C | 1575.42 MHz | |
| L2 C | 1227.60 MHz | |
| L5 (I5 or Q5) | 1176.42 MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L1 C/A | -185.3 dBW | 22 deg |
| L1C | -185.3 dBW | 22 deg |
| L2 C | -188.7 dBW | 24 deg |
| L5 (I5 or Q5) | -180.7 dBW | 24 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | **At least 1 signal** | **4 or more signals** |
| L1 | 100% | N/A |
| L2, L5 | 100% | N/A |
| Upper Space Service Volume (GEO/HEO) | **At least 1 signal** | **4 or more signals** |
| L1 | ≥ 54% | N/A |
| L2, L5 | ≥ 54% | N/A |

IRNSS

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 2.11 meters | |
| **Signal Center Frequency** | | |
| L5 | 1176.42 MHz | |
| **Minimum Received Civilian Signal Power, in dBW** | 0 dBi RCP antenna at GEO | Reference Off-Boresite Angle |
| L5 | -184.54 | 16 deg |
| **Signal Availability** | | |
| **Lower Space Service Volume (MEO)** | **At least 1 signal** | **4 or more signals** |
| L5 | 98.00% | 51.40% |
| **Upper Space Service Volume (HEO/GEO)** | **At least 1 signal** | **4 or more signals** |
| L5 | 36.9% | 0.6% |

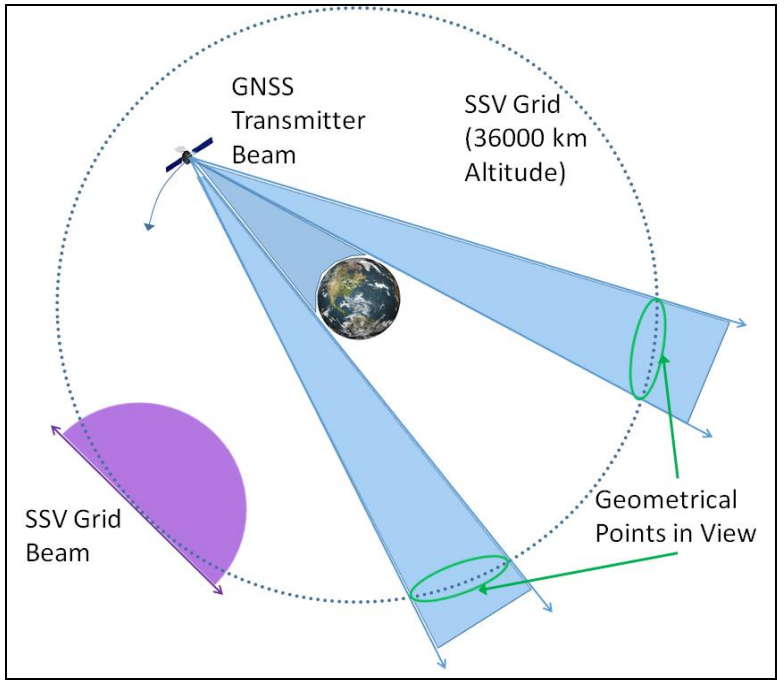
# SSV Simulations – 3 Phases

- SSV simulations conducted by the group involving 5 independent simulation tools in a phased approach



# Phase 1 Simulation – Objectives and Setup

- Objectives
  - Ensure unambiguous interpretation of SSV template parameters
  - Identify and agree on details for performance evaluation metrics
  - Alignment of simulation tools and identification of error sources
- Setup
  - Availability purely geometry based, no assumptions on user antenna
  - All systems with nominal constellations
  - Signals: L1 and L5
  - User locations: Equal area-based grid at GEO and MEO (8000 km) altitude



# Phase 1 Simulation Results - GEO

| L1 | BDS | Galileo | GLONASS | GPS | IRNSS | QZSS | All |
|---|---|---|---|---|---|---|---|
| 1 Satellite System Availability (%) | 97.4 | 78.5 | 59.1 | 90.5 | ----- | 26.7 | **99.9** |
| 4 Satellite System Availability (%) | 24.1 | 1.2 | 0.5 | 4.8 | ----- | 0.8 | **94.4** |
| 1 Satellite Maximum Outage (minutes) | 45 | 98 | 134 | 111 | ----- | (SD) | **39** |
| 4 Satellite Maximum Outage (minutes) | (SD) | (SD) | (SD) | (SD) | ----- | (SD) | **97** |

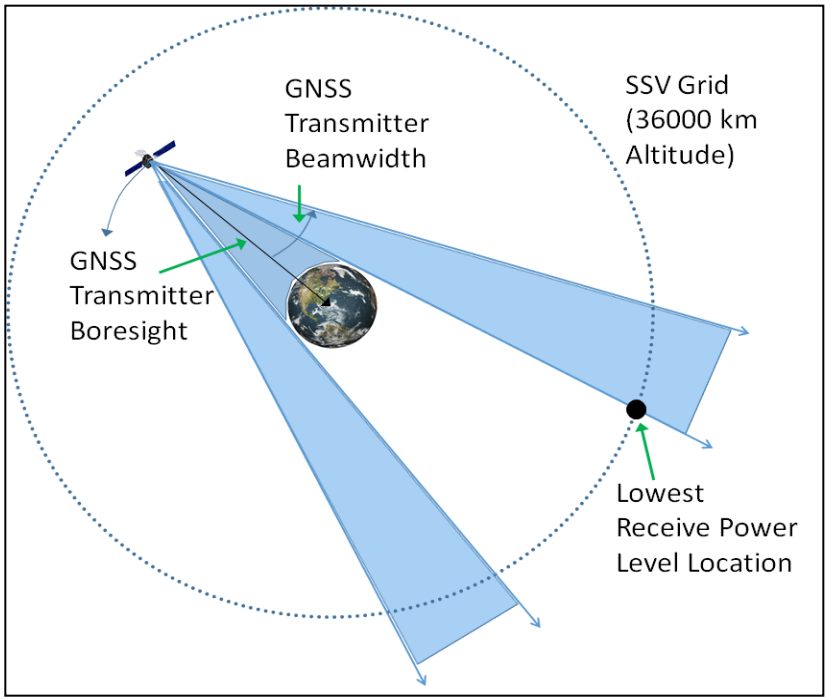
- No single constellation can provide high availability of 4 ranging signals on its own, but all constellations together can do so!

(SD) Scenario Duration

# Phase 2 Simulation – Objectives and Setup

- Objectives
  - Introduce user antenna gain characteristics and receiver operational thresholds for availability evaluation
  - Bridging towards Phase 3 while not affecting the validated orbit propagation of Phase 1

- Setup changes wrt. Phase 1
  - Introduction of antenna gain figures
  - Availability evaluation at different receiver operational thresholds
  - Focus on GEO altitude users only

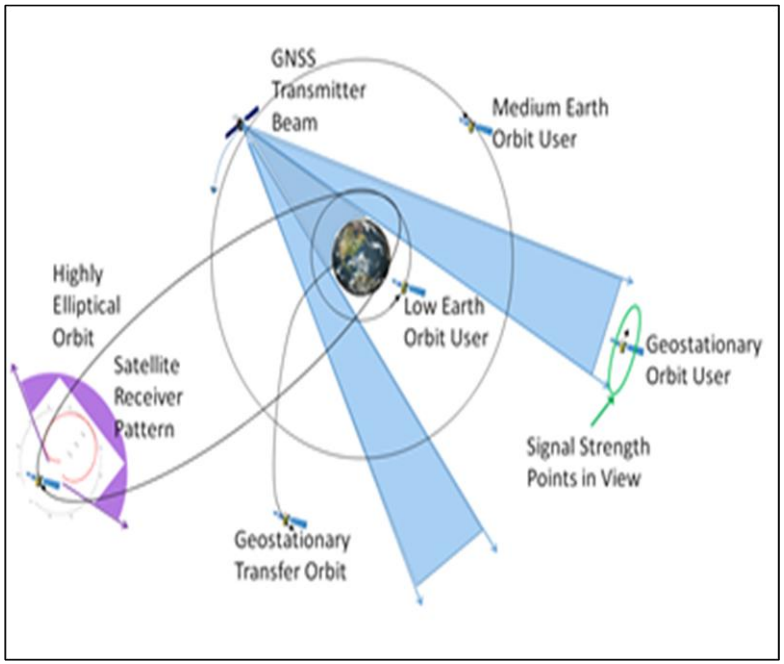


# Phase 2 Simulation Results- GEO - L1

| | BDS | Galileo | GLONASS | GPS | QZSS | All |
|---|---|---|---|---|---|---|
| **20 dBHz** | | | | | | |
| 1+ Availability | 69% | 78% | 0% | 90% | 0% | **99%** |
| Max 1+ Outage | 70 | 98 | (SD) | 111 | (SD) | **49 min** |
| 4+ Availability | 0% | 1% | 0% | 4% | 0% | **62%** |
| Max 4+ Outage | (SD) | (SD) | (SD) | (SD) | (SD) | **223 min** |
| **15 dBHz** | | | | | | |
| 1+ Availability | 97% | 78% | 59% | 90% | 26% | **99%** |
| Max 1+ Outage | 45 | 98 | 134 | 111 | (SD) | **39 min** |
| 4+ Availability | 24% | 1% | 0% | 4% | 0% | **94%** |
| Max 4+ Outage | (SD) | (SD) | (SD) | (SD) | (SD) | **97 min** |

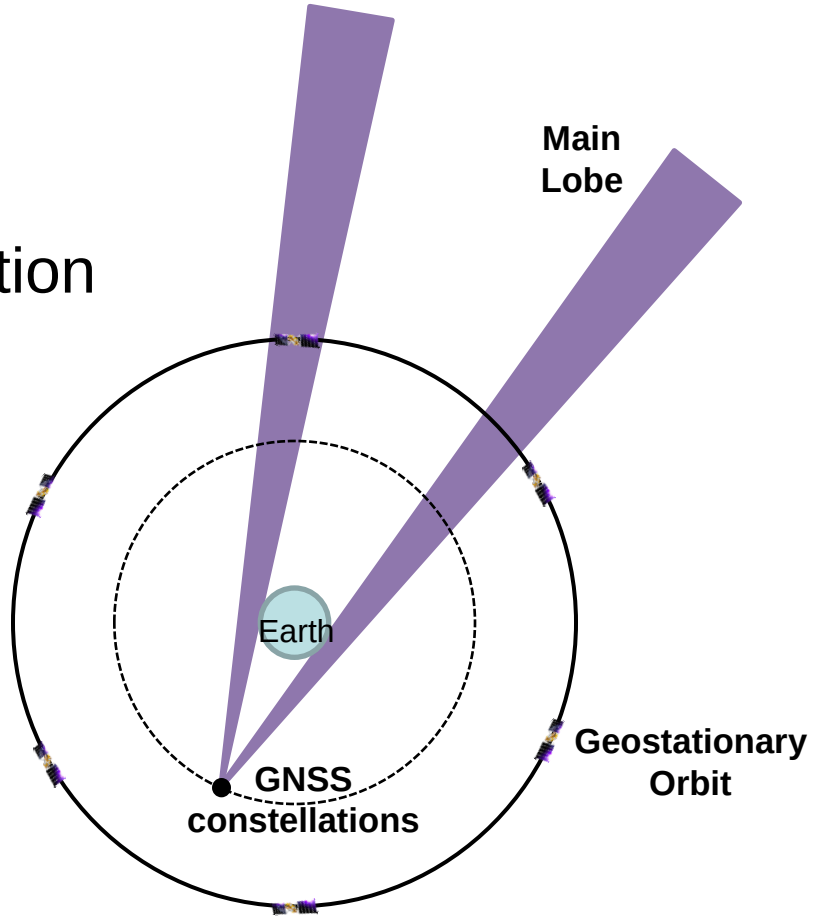
# Phase 3 Simulation – Objectives and Setup

- Objectives
  - Simulation of availability and outage periods for realistic, representative missions
- Setup changes wrt. Phase 2
  - User trajectory instead of user grid
    - GEO
    - Scientific HEO
    - Lunar Mission
  - Real user antenna gain patterns
  - Consideration of satellite attitude and antenna location
- Phase 3 scenarios are defined and will be simulated in the very near future



# Phase 3 GEO Mission Setup

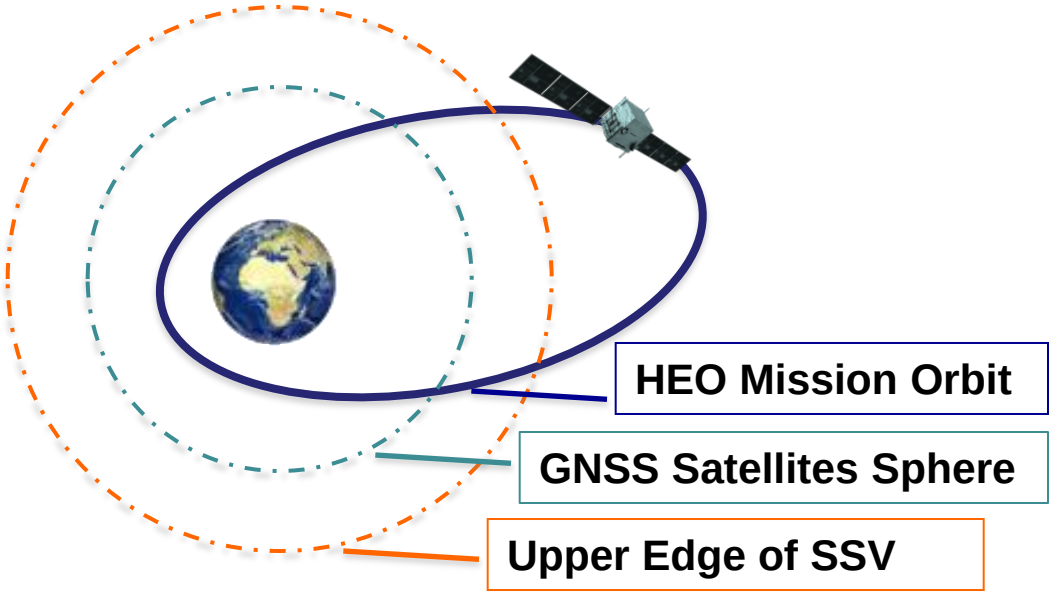
- GEO user will be placed in six different locations in GEO
- Satellite is Nadir pointing
- Antenna is also in Nadir direction



# Phase 3 Scientific HEO Mission Setup

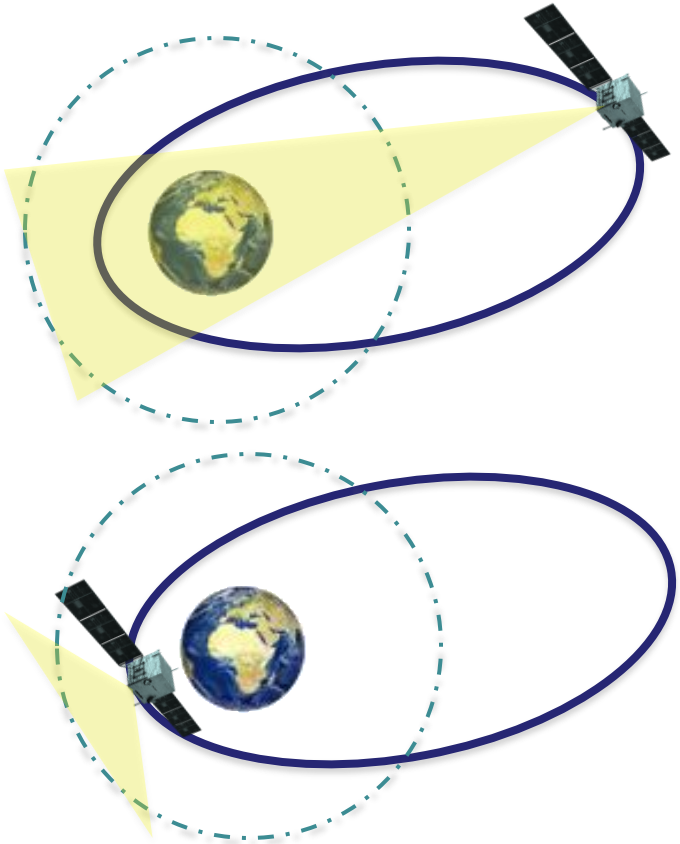
## Mission: SSV-HV1

| | |
|---|---|
| **Perigee** | 500 km |
| **Apogee** | 65000 km |
| **Inclination** | 63.4° |



# Phase 3 Scientific HEO Mission Setup

Mission: SSV-HV1

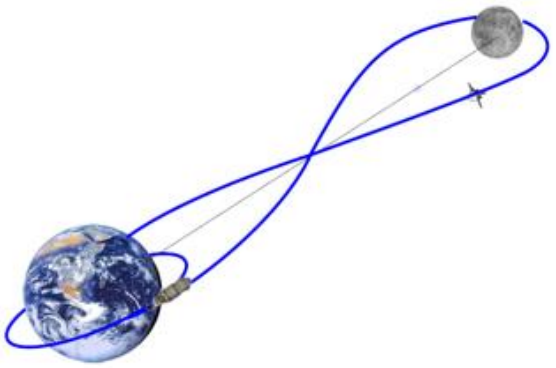


- GNSS antennas: NADIR and Zenith facing
- During the apogee period: Reception through NADIR pointing antenna
- During the perigee period: Reception through Zenith pointing antenna

# Phase 3 Lunar Mission Setup: Exploration Mission 1 (EM-1)

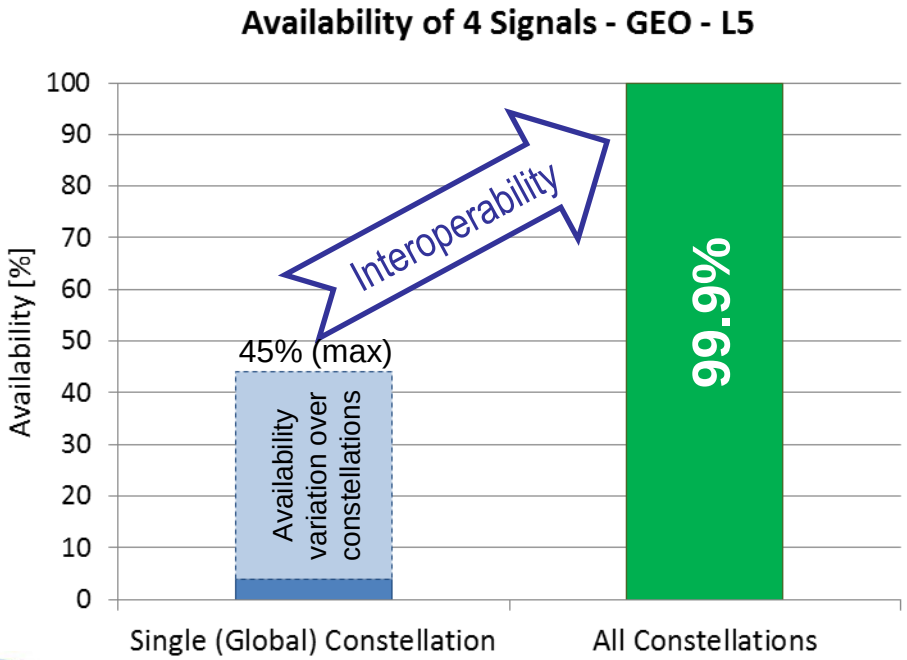
Basic Info:

| | |
|---|---|
| **Mission** | Exploration Mission 1 (EM-1) |
| **Description** | Free-return lunar trajectory with optional lunar orbit phase |
| **Perigee** | 391 km |
| **Apogee** | 378 021 km |
| **Inclination** | 28.5° |
| **Duration** | 10 d |
| **Attitude profile** | TBD (simplification: nadir-pointing) |
| **Receive antenna** | High-gain |



# Findings

- High altitude space users particularly benefit from an interoperable GNSS SSV as
  - No single constellation can provide high availability
  - Interoperable GNSS SSV can ensure high availability



# Findings

- Work of the SSV Action group
  - Demonstrates the benefits and importance of the Interoperable GNSS SSV
  - Generates awareness on the relevance of GNSS interoperability
  - Fosters the cooperation between Service Providers and Space Agencies on SSV
  - Establishes a commonly shared unambiguous interpretation of the SSV template and its parameters
  - Provides relevant material for space receiver manufacturers

# WG-B Sessions During ICG11

ICG WG-B sessions on SSV during ICG11 in room “Camelia”

- Tuesday, 08/11, 14:00 – 18:00
- Wednesday, 09/11, 11:20 – 15:40

# BACKUP MATERIAL

# SSV Booklet

- SSV booklet under finalisation by the Action Group covers
  - SSV general aspects incl. benefits for users
  - Single point of entry regarding SSV support from every service provider (beneficial for users and receiver developers) incl. statements on future plans
  - Simulation scenarios and performance evaluation underlining the benefits of interoperability of GNSS for space users
  - Conclusions and next steps
- SSV booklet will be made available on ICG website and interested service provider websites

# Space Service Volume Characteristics

**Medium Earth Orbit (MEO)**

- 3,000-8000 km
- Four GNSS signals typically available; One-meter orbit accuracies
- Wide range of received GNSS signal strength
- GNSS signals received from NADIR and Zenith direction
- Signals over the limb of the Earth become increasingly important

**High Earth Orbit/Geosynchronous Earth Orbit (HEO/GEO)**

- 8,000-36,000 km
- Nearly all GNSS signals received over the limb of the Earth
- Users will experience periods when no satellites are available
- User will highly benefit from interoperable GNSS SSV for availability
- Will require specially designed high sensitivity receivers
- Properly designed receiver should be capable of tens to hundreds of meters accuracy with performance depending upon GNSS signal availability, receiver sensitivity and clock stability

# GPS Support to SSV

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 0.8 meters | |
| **Signal Center Frequency** | | |
| L1 C/A, L1C | 1575.42 MHz | |
| L2C | 1227.60 MHz | |
| L5 (I5 or Q5) | 1176.45 MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L1 C/A | -184.0 dBW | 23.5 deg |
| L1C | -182.5 dBW | 23.5 deg |
| L2C | -183.0 dBW | 26 deg |
| L5 (I5 or Q5) | -182.0 dBW | 26 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | **At least 1 signal** | **4 or more signals** |
| L1 | 100% | >97% |
| L2, L5 | 100% | 100% |
| Upper Space Service Volume (HEO/GEO) | **At least 1 signal** | **4 or more signals** |
| L1 | >80% | >1% |
| L2, L5 | >92% | >6.5% |

# U.S. Support to Ensure GNSS Interoperability for Space Users

- Performing additional flight experiments above the constellation to characterize signals in cis-Lunar space
- Developing new weak signal GPS/GNSS receivers for spacecraft in cis-Lunar space through government technology developments (e.g. NASA Goddard Navigator, NavCube) and commercial procurements
- Working with the GPS Directorate and DoD community to formally document GPS requirements and antenna patterns for space users
- Developing missions and systems to utilize GNSS signals in the SSV (e.g. MMS, GOES, Orion)
- Supporting ICG WG-B SSV initiative through sustained technical guidance, SSV booklet development & leadership of SSV analysis
- Encouraging international coordination with other GNSS constellations (e,g, Galileo, GLONASS, BDS) to specify interoperable SSV capabilities

# GLONASS Support to SSV

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 1.4 meters | |
| **Signal Center Frequency** | | |
| L1 | 1605.375 MHz | |
| L2 | 1248.625 MHz | |
| L3 | 1201 MHz | |
| **Minimum Received Civilian Signal Power (GEO)** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L1 | -185 dBW | 20 deg |
| L2 | -184.4 dBW | 28 deg |
| L3 | -184 dBW | 28 deg |
| **Signal availability** | | |
| MEO at 8000 km | **At least 1 signal** | **4 or more signals** |
| L1 | 59.1% | 64% |
| L2, L3 | 100% | 66% |
| Upper Space Service Volume (HEO/GEO) | **At least 1 signal** | **4 or more signals** |
| L1 | 70% | 2.7% |
| L2, L3 | 100% | 29% |

# Galileo Support to SSV

| Parameters | Typical Characteristics of Nominal GSAT02xx Satellites | |
|---|---|---|
| **User Range Error** | 1.1 meters | |
| **Signal Center Frequency** | | |
| E1B/C | 1575.42 MHz | |
| E6B/C | 1278.75 MHz | |
| E5b | 1206.45 MHz | |
| E5 AltBOC | 1191.795 MHz | |
| E5a | 1176.45 MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| E1B/C | -182.5 dBW | 20.5 deg |
| E6B/C | -182.5 dBW | 21.5 deg |
| E5b | -182.5 dBW | 22.5 deg |
| E5 AltBOC | -182.5 dBW | 23.5 deg |
| E5a | -182.5 dBW | 23.5 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | **At least 1 signal** | **4 or more signals** |
| E1B/C | 100% | 99% |
| E6B/C | 100% | 100% |
| E5b | 100% | 100% |
| E5a or E5 AltBOC | 100% | 100% |
| Upper Space Service Volume (GEO/HEO) | **At least 1 signal** | **4 or more signals** |
| E1B/C | ≥ 64% | 0% |
| E6B/C | ≥ 72% | 0% |
| E5b | ≥ 80% | 0% |
| E5a or E5 AltBOC | ≥ 86% | 0% |

# Galileo Support to SSV

- Galileo SSV Characteristics are provided for Galileo FOC (GSAT02xx) satellites
- The Galileo SSV parameters presented above are derived from on-ground and in-orbit measurement campaigns
- The Galileo SSV parameters do not represent a commitment from the European Commission to comply with such characteristics for the already launched or future satellites.
- Official information related to SSV characteristics of Galileo will be published through the Galileo OS Service Definition Document in the future

# BDS Support to SSV

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 2.5 meters | |
| **Signal Center Frequency** | | |
| B1 | 1575.42 MHz | |
| B2 | 1191.795MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| B1 (MEO) | -184.2 dBW | 25 deg |
| B1 (GEO/IGSO) | -185.9 dBW | 19 deg |
| B2 (MEO) | -182.8 dBW | 28 deg |
| B2(GEO/IGSO) | -184.4 dBW | 22 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | At least 1 signal | 4 or more signals |
| B1 | 100% | 100% |
| B2 | 100% | 100% |
| Upper Space Service Volume (GEO/HEO) | At least 1 signal | 4 or more signals |
| B1 | 97.4% | 24.1% |
| B2 | 99.9% | 45.4% |

# BDS Support to SSV

- SSV parameters obtained from simulation and test results of new-generation BDS satellites deployed in 2015
- URE value is from BDS_OS_PS1.0. Current system accuracy is better than published standard. And it will be further improved with the construction of global BDS
- BDS is taking actions in SSV performance characterization and specification
- Official information related to SSV characteristics will be published in the future through BDS Standard Document

# QZSS Support to SSV

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 2.6 meters (95%) | |
| **Signal Center Frequency** | | |
| L1 C/A | 1575.42 MHz | |
| L1C | 1575.42 MHz | |
| L2 C | 1227.60 MHz | |
| L5 (I5 or Q5) | 1176.42 MHz | |
| **Minimum Received Civilian Signal Power** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L1 C/A | -185.3 dBW | 22 deg |
| L1C | -185.3 dBW | 22 deg |
| L2 C | -188.7 dBW | 24 deg |
| L5 (I5 or Q5) | -180.7 dBW | 24 deg |
| **Signal Availability** | | |
| Lower Space Service Volume (MEO) | **At least 1 signal** | **4 or more signals** |
| L1 | 100% | N/A |
| L2, L5 | 100% | N/A |
| Upper Space Service Volume (GEO/HEO) | **At least 1 signal** | **4 or more signals** |
| L1 | ≥ 54% | N/A |
| L2, L5 | ≥ 54% | N/A |

# IRNSS Support to SSV

| Parameters | Value | |
|---|---|---|
| **User Range Error** | 2.11 meters | |
| **Signal Center Frequency** | | |
| L5 | 1176.42 MHz | |
| **Minimum Received Civilian Signal Power, in dBW** | 0 dBi RCP antenna at GEO | Reference Off-Boresight Angle |
| L5 | -184.54 | 16 deg |
| **Signal Availability** | | |
| **Lower Space Service Volume (MEO)** | **At least 1 signal** | **4 or more signals** |
| L5 | 98.00% | 51.40% |
| **Upper Space Service Volume (HEO/GEO)** | **At least 1 signal** | **4 or more signals** |
| L5 | 36.9% | 0.6% |

# IRNSS Support to SSV

- The IRNSS is an ISRO initiative to build an independent satellite navigation system to provide PVT solutions to users over the Indian region and a region extending 1500km around India.
- All IRNSS satellites are pointing (Nadir) towards $83^0$E and $5^0$N on Earth.
- IRNSS SSV parameters do not represent a commitment. Official information related to SSV will be published in the future through the IRNSS Service Volume Document

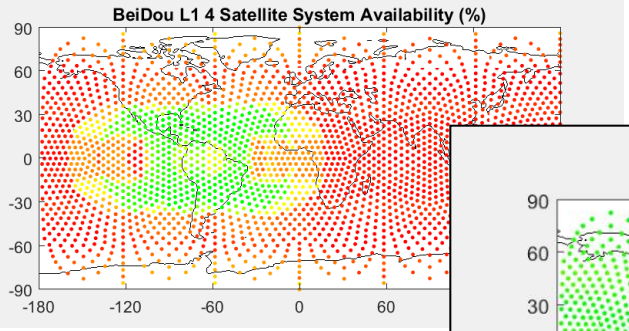
# Phase 1 Simulation Results - GEO

| L1 | BDS | Galileo | GLONASS | GPS | IRNSS | QZSS | All |
|---|---|---|---|---|---|---|---|
| 1 Satellite System Availability (%) | 97.4 | 78.5 | 59.1 | 90.5 | ----- | 26.7 | **99.9** |
| 4 Satellite System Availability (%) | 24.1 | 1.2 | 0.5 | 4.8 | ----- | 0.8 | **94.4** |
| 1 Satellite Maximum Outage (minutes) | 45 | 98 | 134 | 111 | ----- | (SD) | **39** |
| 4 Satellite Maximum Outage (minutes) | (SD) | (SD) | (SD) | (SD) | ----- | (SD) | **97** |

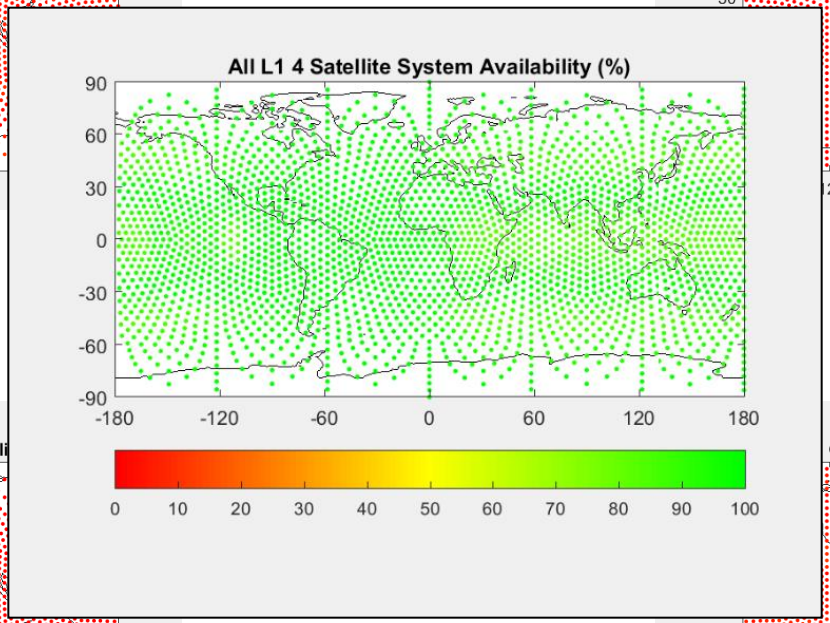
| L5 | BDS | Galileo | GLONASS | GPS | IRNSS | QZSS | All |
|---|---|---|---|---|---|---|---|
| 1 Satellite System Availability (%) | 99.9 | 93.4 | 98.3 | 96.9 | 36.9 | 30.5 | **100** |
| 4 Satellite System Availability (%) | 45.4 | 4.2 | 14.5 | 15.6 | 0.6 | 1.5 | **99.9** |
| 1 Satellite Maximum Outage (minutes) | 7 | 55 | 35 | 77 | (SD) | (SD) | **0** |
| 4 Satellite Maximum Outage (minutes) | 644 | (SD) | 2252 | 1180 | (SD) | (SD) | **35** |

(SD) Scenario Duration

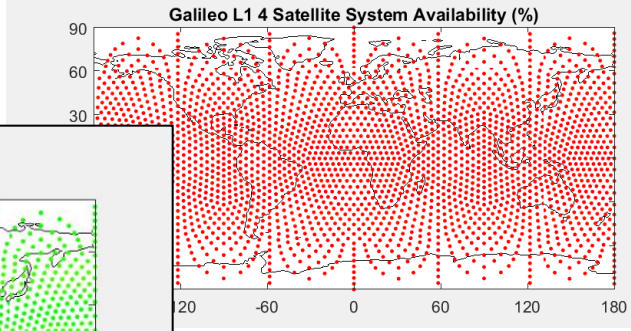
# Phase 1 Simulation Results - GEO



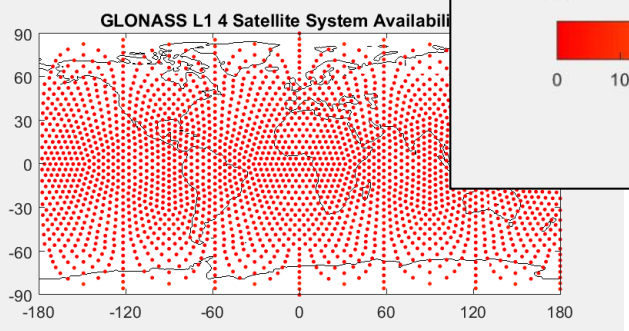

BDS



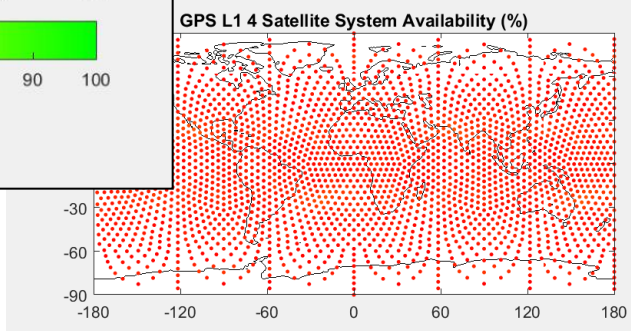

ALL




Galileo




GLONASS




GPS

L1 4-signal availability: individual and combined

# Phase 1 Simulation Results - MEO

| | BDS | Galileo | GLONASS | GPS | IRNSS | QZSS | All |
|---|---|---|---|---|---|---|---|
| **L1, Omni-Directional Antenna** | | | | | | | |
| 1 Satellite System Availability (%) | 100 | 99.9 | 94.0 | 100 | ---- | 99.6 | **100** |
| 4 Satellite System Availability (%) | 100 | 95.0 | 41.4 | 99.6 | ---- | 79.4 | **100** |
| 1 Satellite Maximum Outage (minutes) | 0 | 11 | 60 | 0 | ---- | 197 | **0** |
| 4 Satellite Maximum Outage (minutes) | 0 | 60 | 345 | 45 | ---- | Max SD | **0** |
| **L5, Omni-Directional Antenna** | | | | | | | |
| 1 Satellite System Availability (%) | 100 | 100 | 100 | 100 | 98.0 | 99.6 | **100** |
| 4 Satellite System Availability (%) | 100 | 100 | 100 | 99.9 | 51.4 | 79.4 | **100** |
| 1 Satellite Maximum Outage (minutes) | 0 | 0 | 0 | 0 | 348 | 197 | **0** |
| 4 Satellite Maximum Outage (minutes) | 0 | 0 | 0 | 16 | Max SD | Max SD | **0** |

(SD) Scenario Duration

# Phase 2 Simulation Results – GEO - L5

| | BDS | Galileo | GLONASS | GPS | IRNSS | QZSS | All |
|---|---|---|---|---|---|---|---|
| **25 dBHz** | | | | | | | |
| 1+ Availability | 0% | 0% | 0% | 0% | 0% | 0% | **0%** |
| 4+ Availability | 0% | 0% | 0% | 0% | 0% | 0% | **0%** |
| **20 dBHz** | | | | | | | |
| 1+ Availability | 99% | 93% | 98% | 96% | 1% | 30% | **100%** |
| Max 1+ Outage | 7 | 55 | 35 | 77 | (SD) | (SD) | **0 min** |
| 4+ Availability | 32% | 4% | 14% | 15% | 0% | 1% | **99%** |
| Max 4+ Outage | 644 | (SD) | 2252 | 1180 | (SD) | (SD) | **35 min** |
| **15 dBHz** | | | | | | | |
| 1+ Availability | 99% | 78% | 98% | 96% | 36% | 30% | **100%** |
| Max 1+ Outage | 7 | 55 | 35 | 77 | (SD) | (SD) | **0 min** |
| 4+ Availability | 45% | 1% | 14% | 15% | 0% | 1% | **99%** |
| Max 4+ Outage | 644 | (SD) | 2252 | 1180 | (SD) | (SD) | **35 min** |

# Phase 3 GEO Mission Setup

| Characteristic | Details |
|---|---|
| Spacecraft Orbit | • GEO Users will be located at six locations, separated by 60 deg<br>• Format for Orbit representation: Kepler state vector - CCSDS format |
| Spacecraft Attitude | • Nadir pointing spacecraft Attitude<br>• Format for Attitude representation: quaternion - CCSDS-AEM format |
| Receiver Antenna Pattern | High-gain |
| Receiver Antenna Orientation | Nadir pointing antenna |
| Receiver Threshold | 20 dBHz |

# Phase 3 Lunar Mission Setup: Exploration Mission 1 (EM-1)

| Characteristic | Details |
|---|---|
| Spacecraft Orbit | Outbound ephemeris in CCSDS-OEM v1 format. Optional orbit phase + return. |
| Spacecraft Attitude | Attitude ephemeris in CCSDS-AEM quaternion format. |
| Receiver Antenna Pattern | High-gain |
| Receiver Antenna Orientation | TBD |
| Receiver Threshold | TBD |