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

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ICG12

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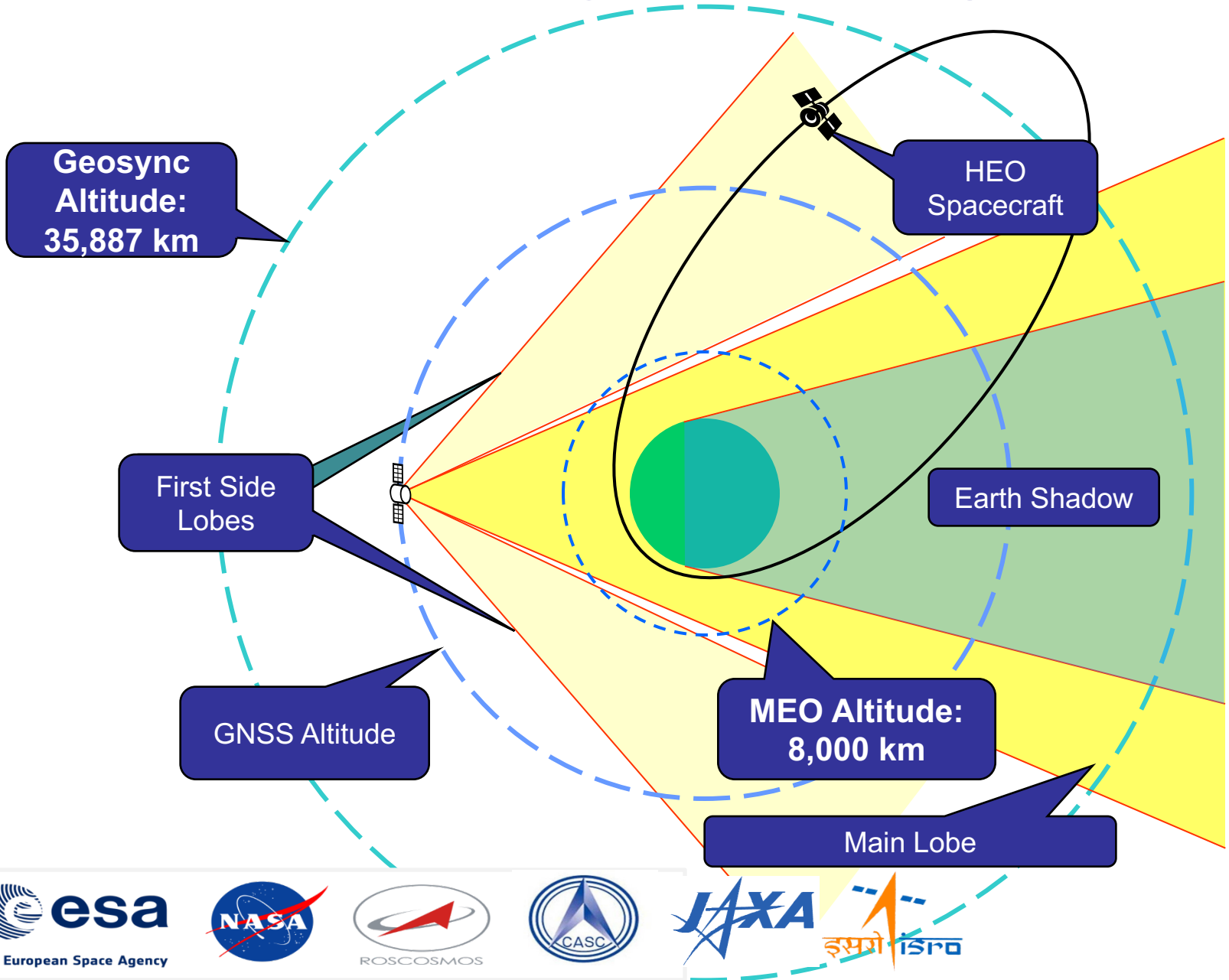
International Committee on Global Navigation Satellite Systems

ICG WG-B Action Group on GNSS SSV

- Action group on GNSS 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
  - Perform simulations for agreed reference missions in order to demonstrate advantages of an interoperable GNSS SSV
  - Generation of a booklet as the reference for all parties interested in the GNSS SSV

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

Reception Geometry for GNSS Signals in Space



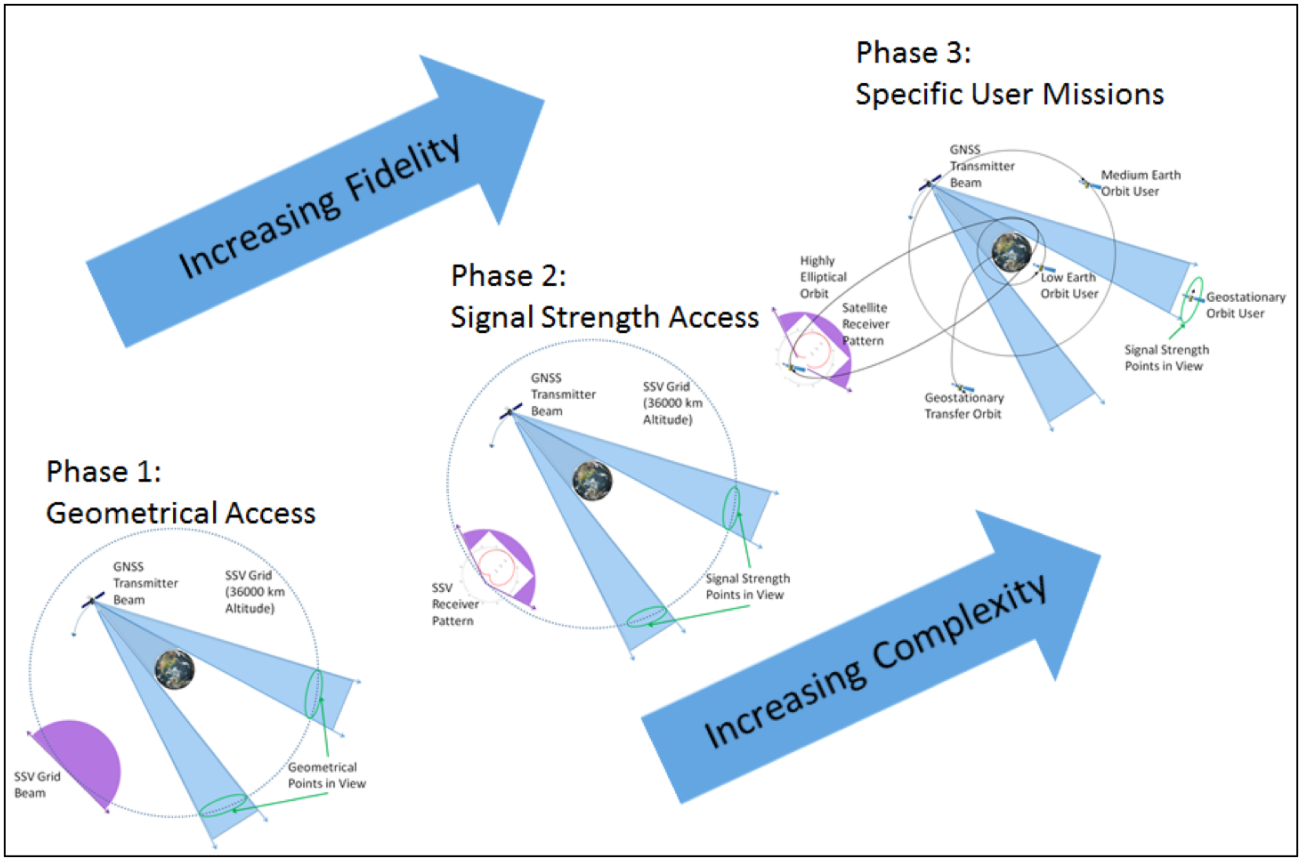
Space Service Volume Template included in Booklet

- Action group agreed on a common template to specify the SSV support of every GNSS 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 Simulations – 3 Phases

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



Phase 3 Simulation – Objectives and Status

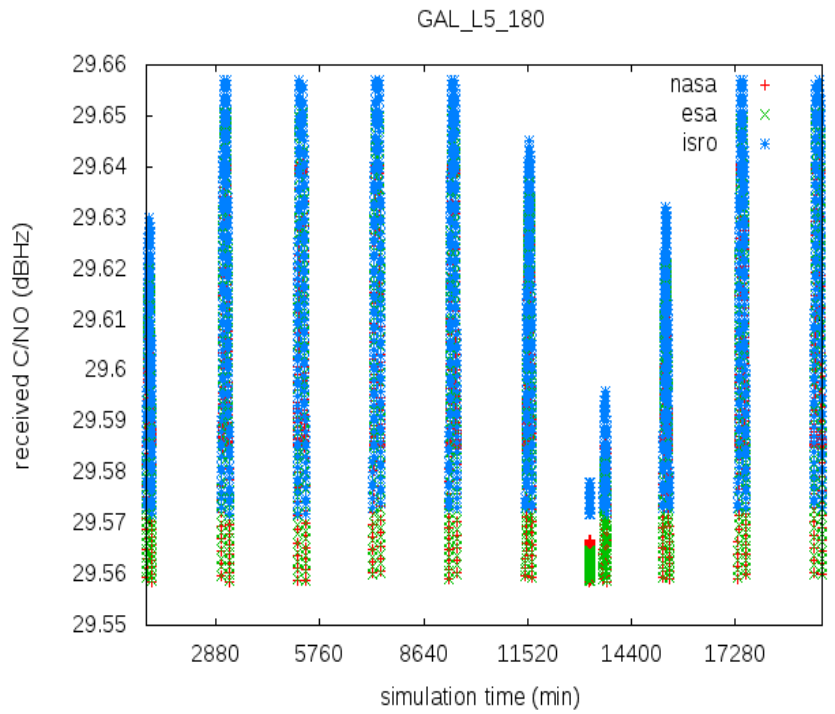
- Objectives
  - Simulation of availability and outage periods for realistic, representative missions
- Selected Reference Missions for Simulations
  - GEO - 6 satellites 60 deg separated in longitude
  - Scientific HEO - perigee height 500 km, apogee 58625 km
  - Lunar Mission - transition between Earth, Moon parking orbits
- Assumptions for Simulations of Reference Missions
  - Real user antenna gain patterns
  - Consideration of satellite attitude and antenna location
  - Visibility is calculated based on link-budget
- All Phase 3 Simulations were successful completed in Nov. 2017

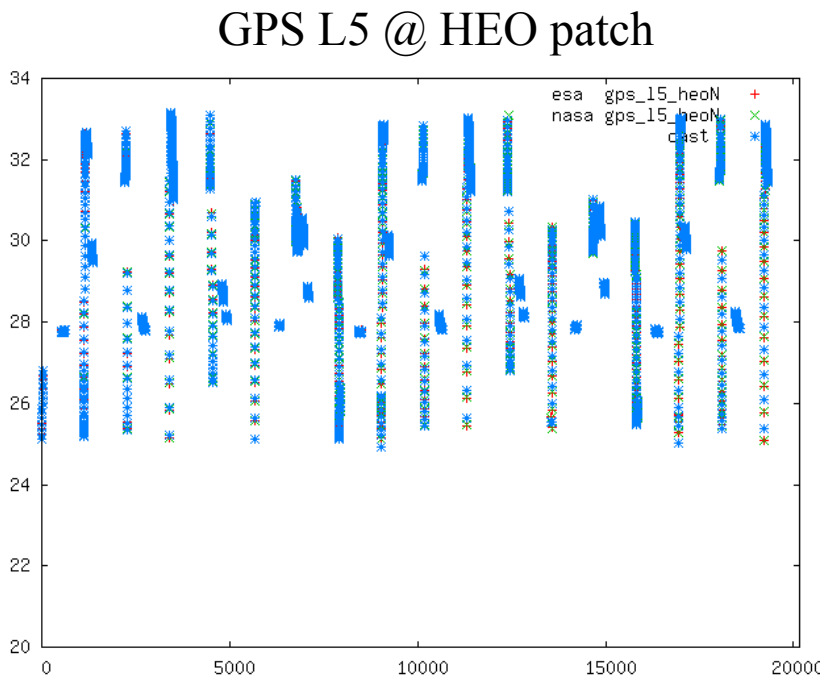
Phase 3 Simulation – Set-Up and Validation

- 14-day simulation period for all GNSS satellites
  - BDS, Galileo, GLONASS, GPS, NavIC, QZSS
  - signals simulated at L1/E1/B1 and L5/L3/E5a/B2
  - half-cone angles and EIRP as specified by operators
  - Acquisition threshold in all scenarios: 20 dBHz
- Validation of Results: – Results cross checked by different Agencies

	GEO	HEO	lunar
CAST		X	
ESA	X	X	X
ISRO	X		
NASA	X	X	X

Phase 3 Simulation – Example for Comparison





- All compared signal strength results match within 0.02 dBHz
- All visibility patterns match within 1 simulation time step

Phase 3 Simulation – Statistics

- Variables
  - Time — 1 minute steps over 14 days (20161 points)
  - Constel./sat — BDS/32, GAL/24, GLO/24, GPS/27, IRN/11, QZS/4
  - Frequencies — B1/E1/L1 and B2/E5a/L3/L5
  - Antennas — High-gain (all) nadir, patch (HEO, lunar) zenith
  - Users — 6 (GEO), 1 (HEO), 1 (lunar transit)
- Number of simulated user signals: **49.192.840**
- Data organized in 120 tables
- Comparisons involved rearranging of data in ~56,000 files
- Amount of data generated, compared and analysed ~25 GB

Phase 3 Simulation – Results GEO

Individual GNSS constellations – depending very much on longitude of user in GEO:

- Vast majority of user in GEO - Visibility of >= 4 SVs
  - L1/E1/B1: < 10%
  - L5/L3/E5A/B2: < 45%
- User in specific lon in GEO: Visibility of 4 SVs is up to 100%, based on BDS, NavIC, QZSS constellation characteristic

Combined GNSS constellations:

- Visibility of >= 4 SVs in GEO orbit
  - L1/E1/B1: > 93%
  - L5/L3/E5A/B2: 100%

	L1/E1/B1				L5/L3/E5A/B2			
lon 180	vis1	vis4	mod1	mod4	vis1	vis4	mod1	mod4
BDS	91.85%	0.94%	27	722	100.00%	10.37%	0	263
GAL	63.40%	0.00%	82	20160	86.43%	0.00%	41	20160
GLO	84.93%	0.72%	41	3805	100.00%	44.08%	0	195
GPS	82.15%	3.31%	73	697	94.28%	14.55%	50	425
IRN	n/a	n/a	n/a	n/a	100.00%	0.00%	0	20160
QZS	0.00%	0.00%	20160	20160	0.00%	0.00%	20160	20160
combined	100.00%	93.24%	0	41	100.00%	100.00%	0	0

	L1/E1/B1				L5/L3/E5A/B2			
lon 300	vis1	vis4	mod1	mod4	vis1	vis4	mod1	mod4
BDS	100.00%	50.50%	0	142	100.00%	100.00%	0	0
GAL	63.12%	0.00%	82	20160	86.55%	0.00%	41	20160
GLO	90.47%	5.02%	33	939	100.00%	52.96%	0	94
GPS	79.43%	3.68%	103	462	91.81%	9.19%	66	419
IRN	n/a	n/a	n/a	n/a	67.78%	0.00%	216	20160
QZS	100.00%	0.00%	0	20160	100.00%	0.00%	0	20160
combined	100.00%	100.00%	0	0	100.00%	100.00%	0	0

Phase 3 Simulation – Results HEO

Individual GNSS constellations:

- Visibility of >= 4 SVs
  - L1/E1/B1: < 17%
  - L5/L3/E5A/B2: < 56%

Combined GNSS constellations:

- Visibility of >= 4 SVs
  - L1/E1/B1: 94.5%
  - L5/L3/E5A/B2: 100%

		Nadir				Zenith				Combined			
Band	Constellation	At least 1 signal		4 or more signals		At least 1 signal		4 or more signals		At least 1 signal		4 or more signals	
		Avail. (%)	MOD (min)	Avail. (%)	MOD (min)	Avail. (%)	MOD (min)	Avail. (%)	MOD (min)	Avail. (%)	MOD (min)	Avail. (%)	MOD (min)
L1/E1/B1	GPS	87.3	70	14.4	1036	7.4	1066	4.3	1086	87.3	70	12.7	1036
	GLONASS	98.8	12	13.4	992	7.1	1059	4.4	1080	98.8	12	14.1	986
	Galileo	74.2	85	9.2	1027	7.4	1059	4.1	1085	74.3	85	9.9	1026
	BDS	88	51	15.3	1031	10.1	1031	6	1076	88.1	51	16.1	1008
	QZSS	22.1	1042	1.1	4537	5.7	2264	1.4	2296	27.5	1031	2.5	2175
	Combined									**100**	**0**	**94.5**	**47**
L5/L3/E5a/B2	GPS	94.7	53	17.3	911	7.9	1059	4.9	1079	94.7	53	17.4	911
	GLONASS	100	0	55.2	133	8.3	1046	6.1	1061	100	0	55.5	133
	Galileo	87.1	63	11	990	8	1051	4.9	1075	87.1	63	11.6	980
	BDS	96.9	30	25.6	925	10.7	1026	7	1065	96.9	30	26	925
	QZSS	27.5	1083	2.2	2238	6.5	1130	2	2284	32.1	1021	5.8	1091
	NavIC	32.7	1023	3.1	1098	5.7	1130	3.3	2262	35.1	989	5.8	1091
	Combined									**100**	**0**	**100**	**0**

Phase 3 Simulation – Results Lunar

Individual GNSS constellations:

•Visibility of >= 4 SVs: <= 5%

Combined GNSS constellations:

•Visibility of >= 4 SVs

- L1/E1/B1: 9%
- L5/L3/E5A/B2: 16%

•Important:

•Antenna threshold of 20 dBHz for acquisition of signals is considered as conservative, signals > 15 dBHz available to much greater heights

•Maximum outage not relevant here

Band	Constellation	Signal Availability (%)		Max Outage Duration (min)
		At least 1 signal	4 or more signals	At least 1 signal
L1/E1/B1	GPS	9%	1%	5330
	GLONASS	8%	0%	5200
	Galileo	14%	1%	4870
	BDS	14%	3%	5350
	QZSS	1%	0%	6300
	Combined	**21%**	**9%**	**4870**
L5/L3/E5a/B2	GPS	12%	1%	5010
	GLONASS	33%	1%	3420
	Galileo	16%	1%	5060
	BDS	18%	5%	5170
	QZSS	4%	0%	4940
	NavIC	4%	1%	5960
	Combined	**36%**	**16%**	**3420**

Phase 3 Simulation – Conclusions

- Three realistic scenarios were simulated: GEO, HEO, lunar transit
- About 49 million signals have been simulated and compared
- ESA, NASA, CAST, ISRO results for phase 3 consistent within 0.015 dBHz
- All scenarios show significant improvement in signal availability if combined GNSS constellations are used
- All GEO longitudes show 100% availability for >= 4 SVs
- HEO show 100% availability for >= 4 SVs
- Lunar trajectory can be supported to great heights but requires better antenna gain than 20 dBHz

Important

- All results are considered conservative: no side lobes considered

Booklet Status

- Significant work has been done by all parties involved in the generation of this Booklet since Vienna meeting in June 2017
- Draft of Booklet is available
- Intention is to generated within ICG12 the Final Draft of the Booklet

Next Steps

- **Short term objectives**
  - Generation of Final Draft of GNSS SSV Booklet at ICG12
  - Submission of Final Draft to ICG – Request for approval
- **Medium term objectives**
  - Submission of ICG12 approved GNSS SSV Booklet to all Service Providers for final authorisation to publish the Booklet
  - Publication of the GNSS SSV Booklet by mid 2018
  - Additional outreach activities - conferences, papers, etc.
  - Update of GNSS SSV Booklet – if needed
  - Increase involvement of GNSS SSV Users by specific events
- **Long term objectives**
  - Follow up implementation and possible evolution of SSV at service provider level
  - Conduct additional simulations/analysis as needed

Acknowledgement

Thank you very much to all the Organisations and the committed individuals they contributed to these significant achievements (many of them are not on this picture)!!!