Multi-GNSS for Space Service Volume

Arunkumar Rathinam

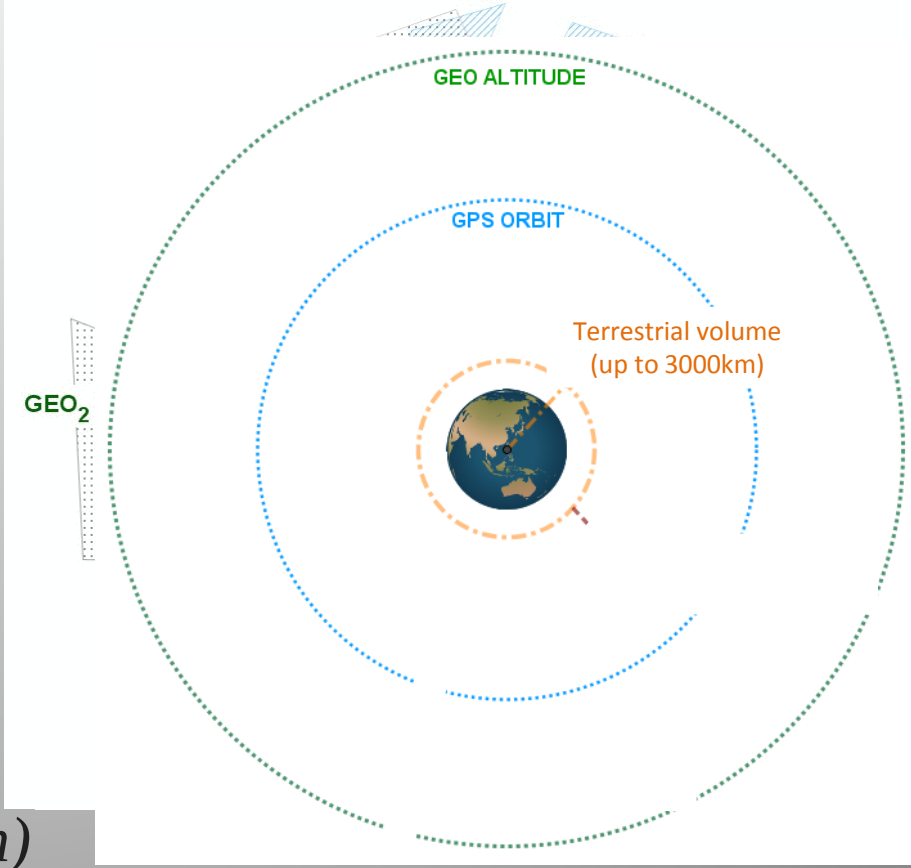
PhD Student (ACSER)

Never Stand Still | Faculty of Engineering | Australian Centre for Space Engineering Research (ACSER)

GNSS - Service regions

- **Terrestrial Service Volume**
  - *Earth Surface*
  - *LEO (up to 3000 km)*

- **Space Service Volume**
  - *MEO (3000 ~ 8000 km)*
    - direct access to GNSS
  - *HEO/GEO (8000 ~ 36000km)*
    - depends on GNSS signals available over Earth's limb



Positioning significance in SSV

Primary motivation: *Satellite autonomy*

	Current	*Achievable*
• Real-time navigation performance	km	meter
• Trajectory manoeuvre recovery	5-10 hrs	minutes
• Reduce expensive on-board clocks	$100sK - 1M	$15K - 50K
• Mission operations costs	$500 - 750K/yr	(savings)

Source: www.gps.gov/governance/advisory/meetings/2016-05/parker.pdf

Multi-GNSS

- **Global Navigation Systems**
  - *GPS (US), GLONASS (Russia)*
  - *Galileo (Europe), BEIDOU (China)*
- **Regional Navigation/Support Systems**
  - *QZSS (Japan)*
  - *NavIC (India)*
- **SBAS (Augmentation Systems)**
  - *EGNOS (Europe), WAAS (US), MSAS (Japan), GAGAN (India), SDCM (Russia)*
- **110 satellites in orbit (at present)**

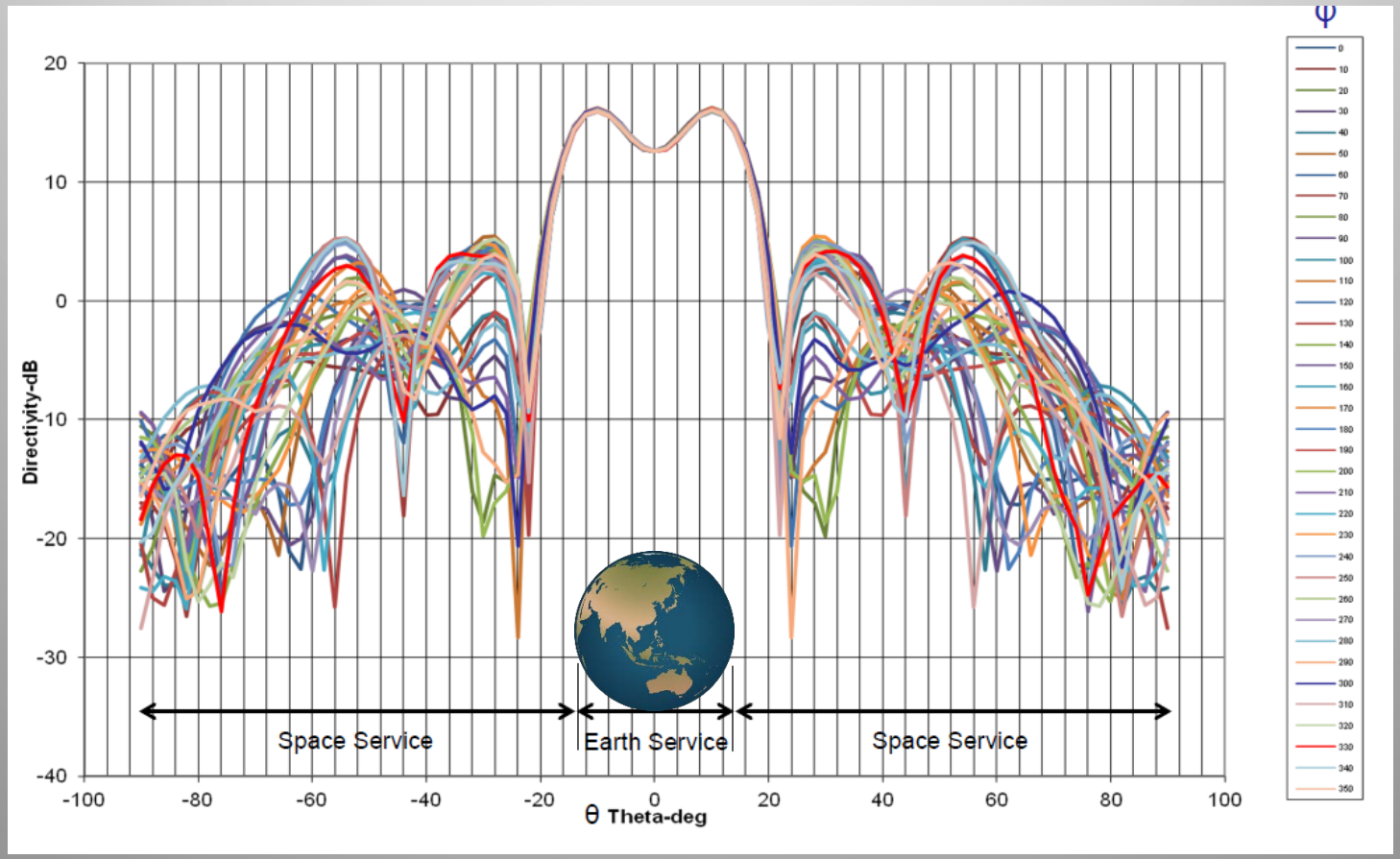
SSV Positioning - Performance

- **Primary parameters**
  - ***Minimum received power level***
    - dominated by path loss
  - ***Signal availability***
    - transmitting pattern and orbital characteristics
  - ***Pseudorange accuracy***
    - Phase center
    - Non-availability of phase variations (at larger angles)
- **Secondary parameters**
  - *Dilution of precision*

Received signal power level

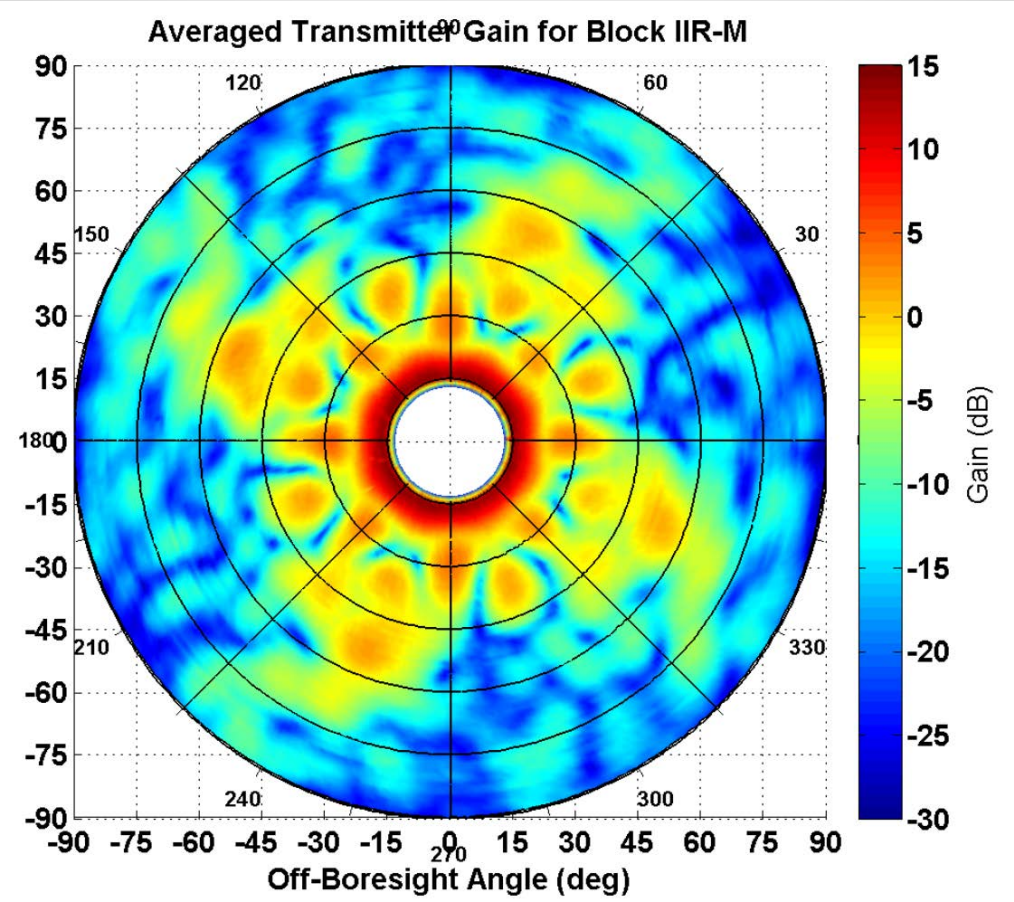
	Signal	Ref. off boresight angle (Main) (Degrees)	Min. Received Power (0 dBi RCP ant. at GEO) dBW	URE
GPS	L1	23.5°	-184	~1.1 m
	L2	26°	-183	
	L5	26°	-182	
Glonass	L1	20°	-185	~1.4 m
	L2	28°	-184.4	
	L3	28°	-184	
Galileo	E1	20.5°	-182.5	~1.1 m
	E5	23.5°	-182.5	
	E6	21.5°	-182.5	
Beidou	B1	24° & 18°	-184.1 & -185.8	~1.4 m
	B2	26° & 21°	-182.7 & -184.4	
	B3	26° & 21°	-184.5 & -186.2	
QZSS	L1	22°	-185.3	~1.3 m
	L2	24°	-188.7	
	L5	24°	-180.7	

Signal availability - Antenna Pattern



GPS Block IIR and IIR-M Legacy Antenna Pattern L1

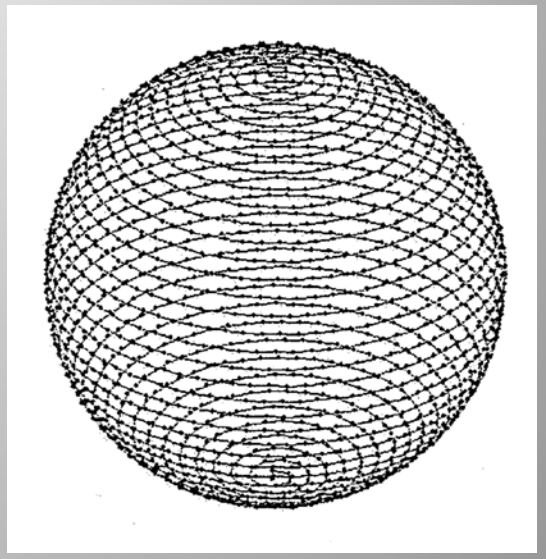
Signal availability - Antenna Pattern



Source: Martzen, Phillip, et al. "GPS Antenna Characterization Experiment (ACE): Receiver Design and Initial Results." (2015).

SSV simulation – past

- Based on GPS constellation
- Gridded points
  - approx. 6° equatorial grid spacing
- Specific altitudes(in steps)
  - data are interpolated for middle region
- defined time periods
  - simulated for 24 hours
  - not enough to cover the synchronous with GNSS orbital period
- side lobe signals were not simulated



Bauer, F. H., et al. "The GPS space service volume." (2006).

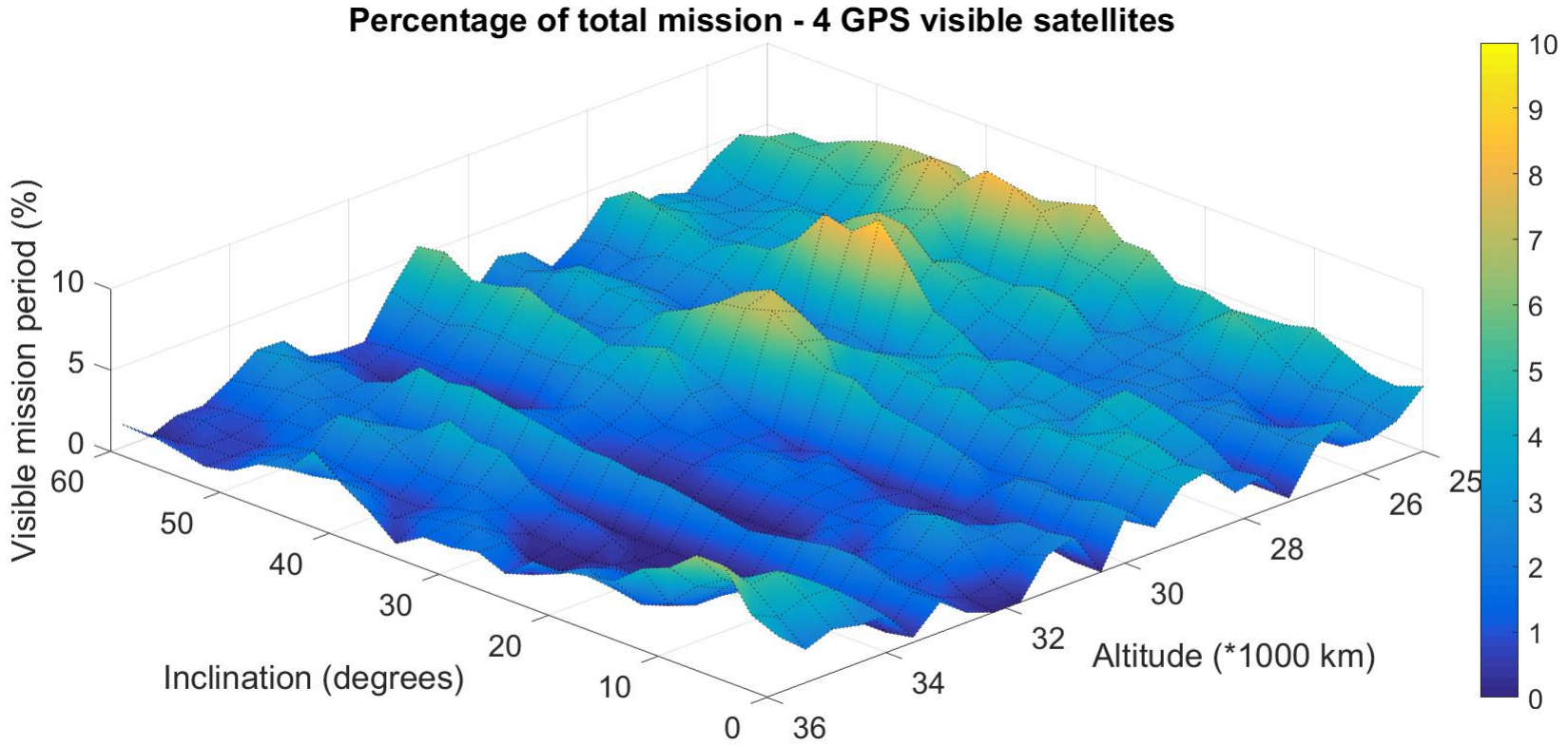
SSV simulation

- **Line of Sight Visibility**
  - *fn (Synodic Period, Receiver ant. beam width, Transmitting ant. beam width, Signal Power)*

- **Altitude vs Inclination vs Mission duration**
  - *Mainly for HEO/GEO SSV*
    - Altitudes varies from 25,000 ~ 35,800 km (every 450 km)
    - Inclinations varies from 0° ~ 60° (every 2.5°)
    - 25 x 25 array (Each point corresponding one synodic period)

GPS availability

Only Main lobe considered for this simulation (23.5° L1)



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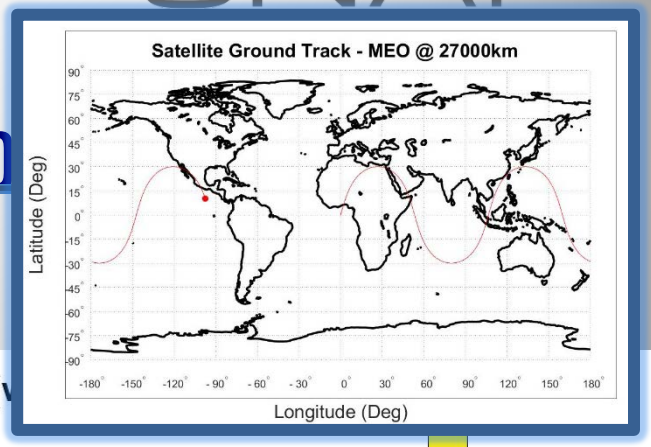
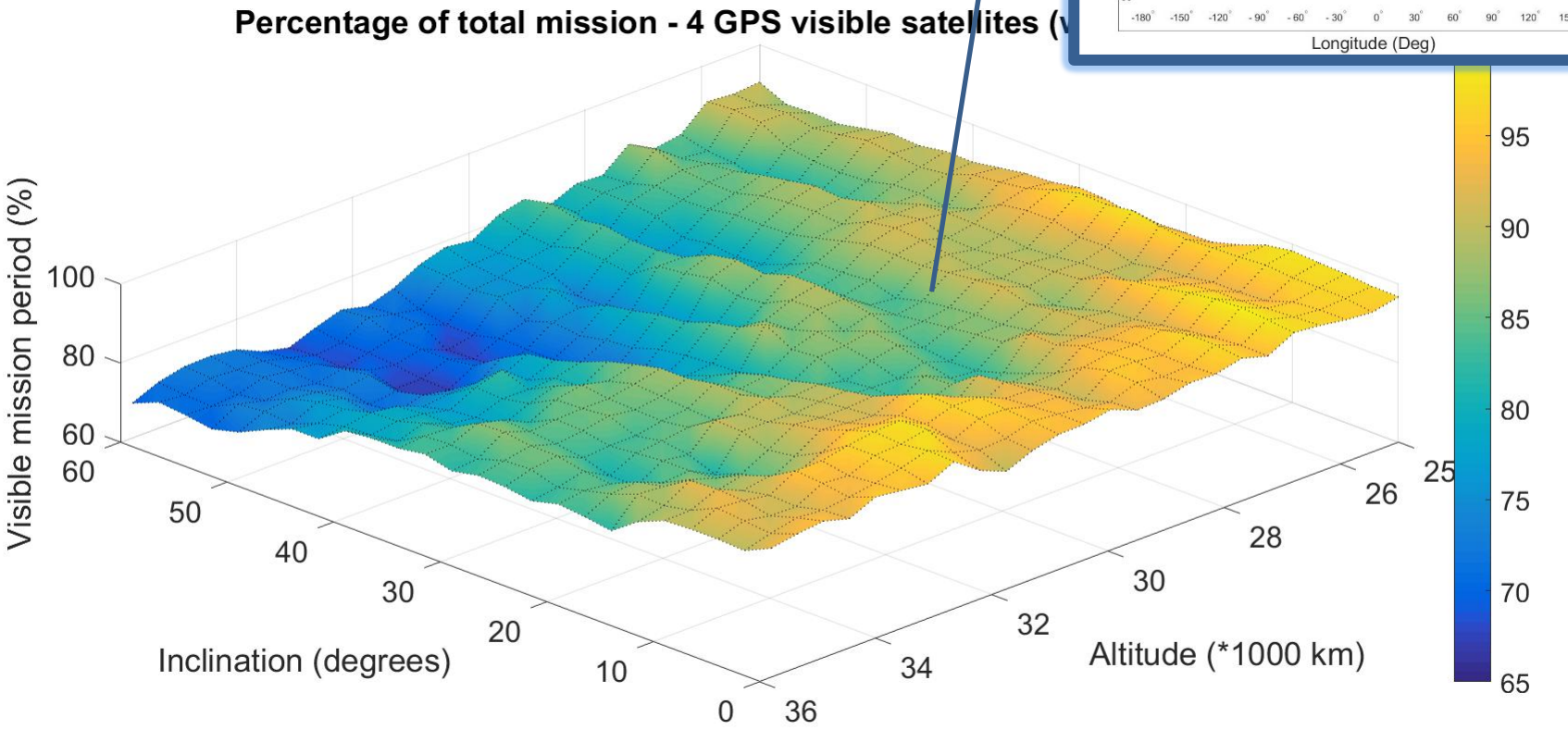
GPS availability w/side lob

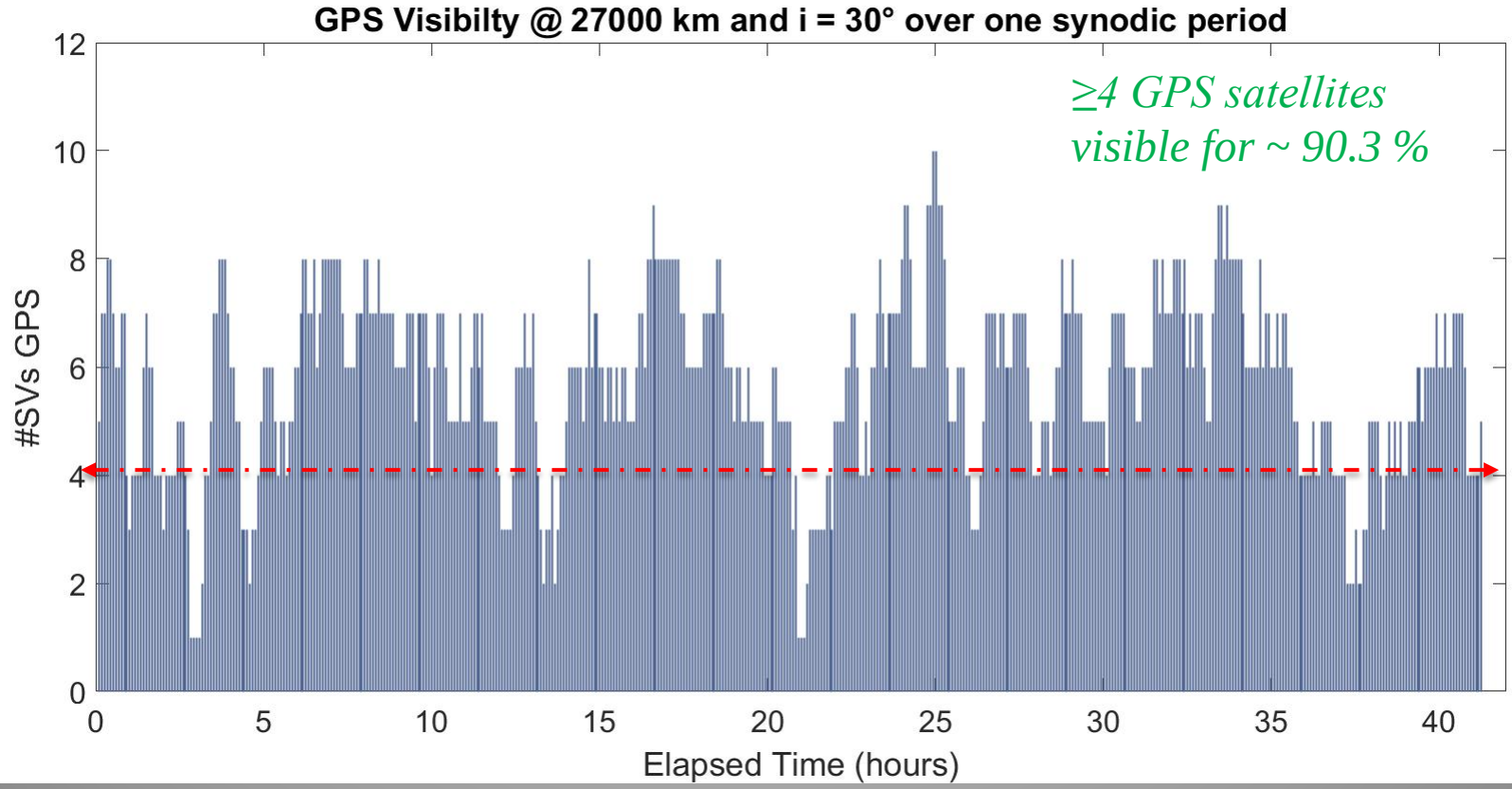
Side lobe signals (28° - 36°)



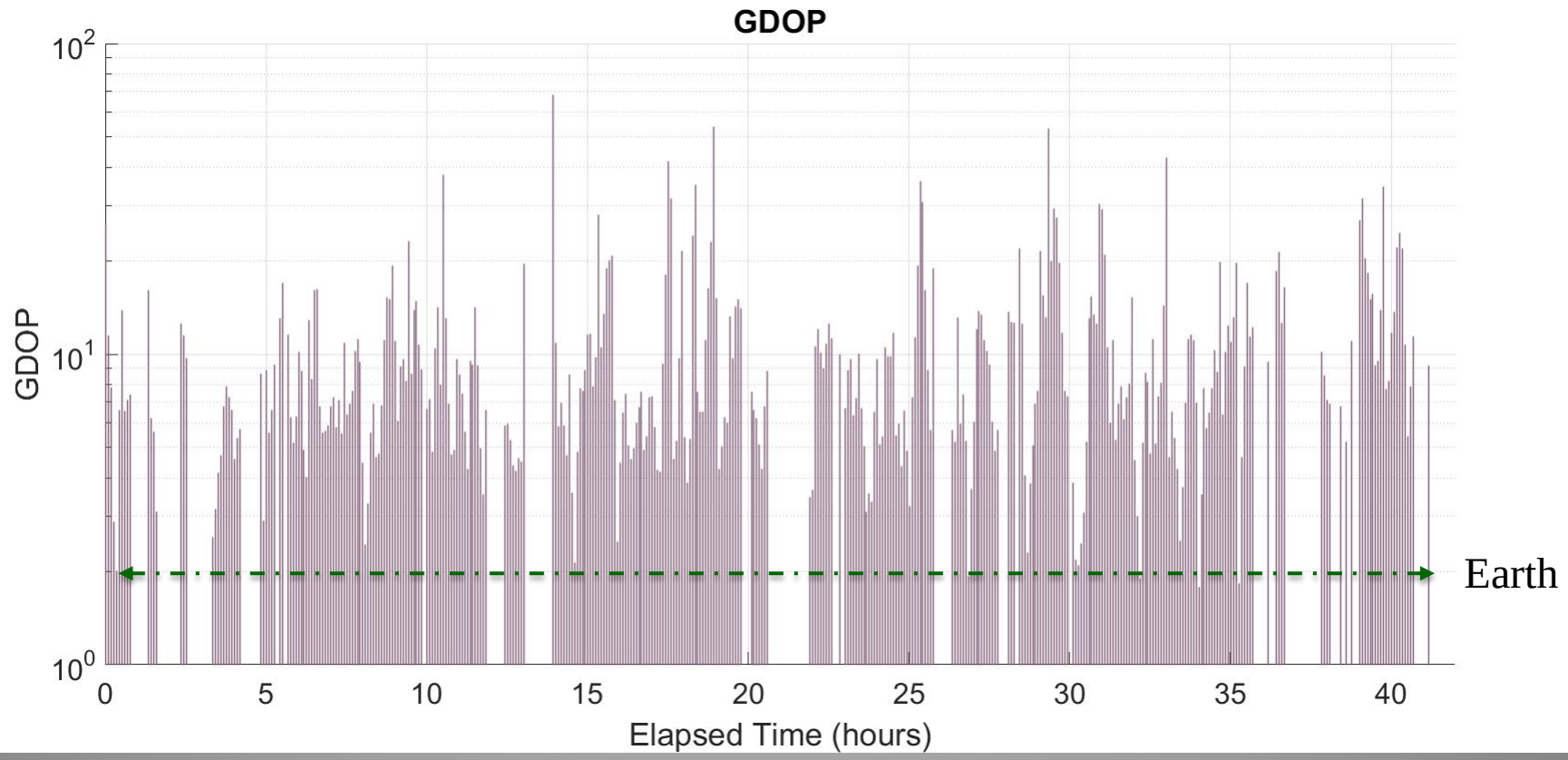


GPS availability w/side lobes

No of visible satellites recorded at 5-minute resolution



GPS availability & GDOP

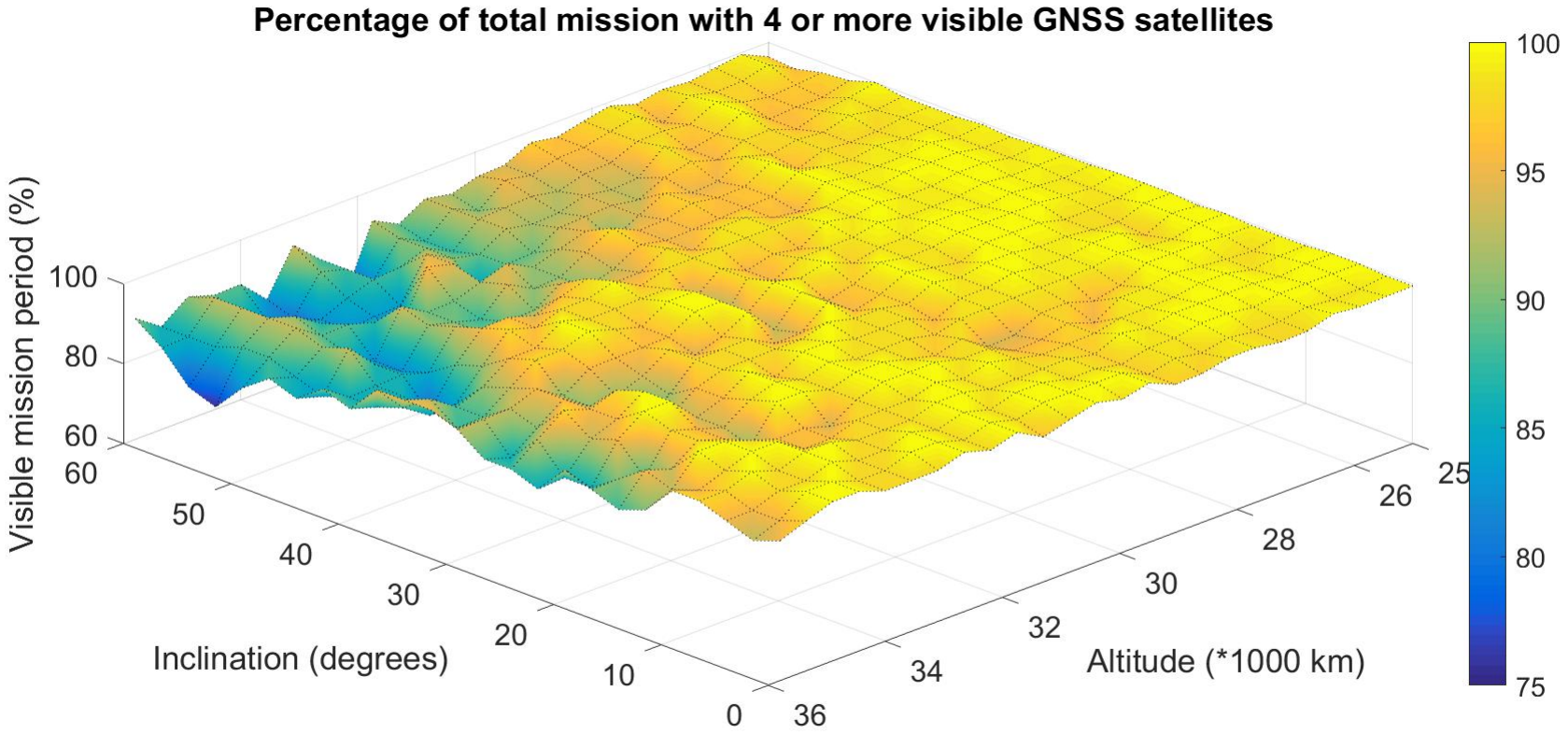


Multi GNSS – Simulation

- **Design Trade-off**
  - *Dual antenna design - receiver*
    - Zenith pointed - isotropic antenna
    - Nadir pointed - directional gain antenna
  - *Dual frequency receivers*
    - eliminates ionospheric mask requirement
  - *Different Constellation combinations*
    - GPS, GLONASS, Galileo, Beidou, QZSS, SBAS
    - Theoretically preferred : constellations at higher altitudes and larger beam width antennas

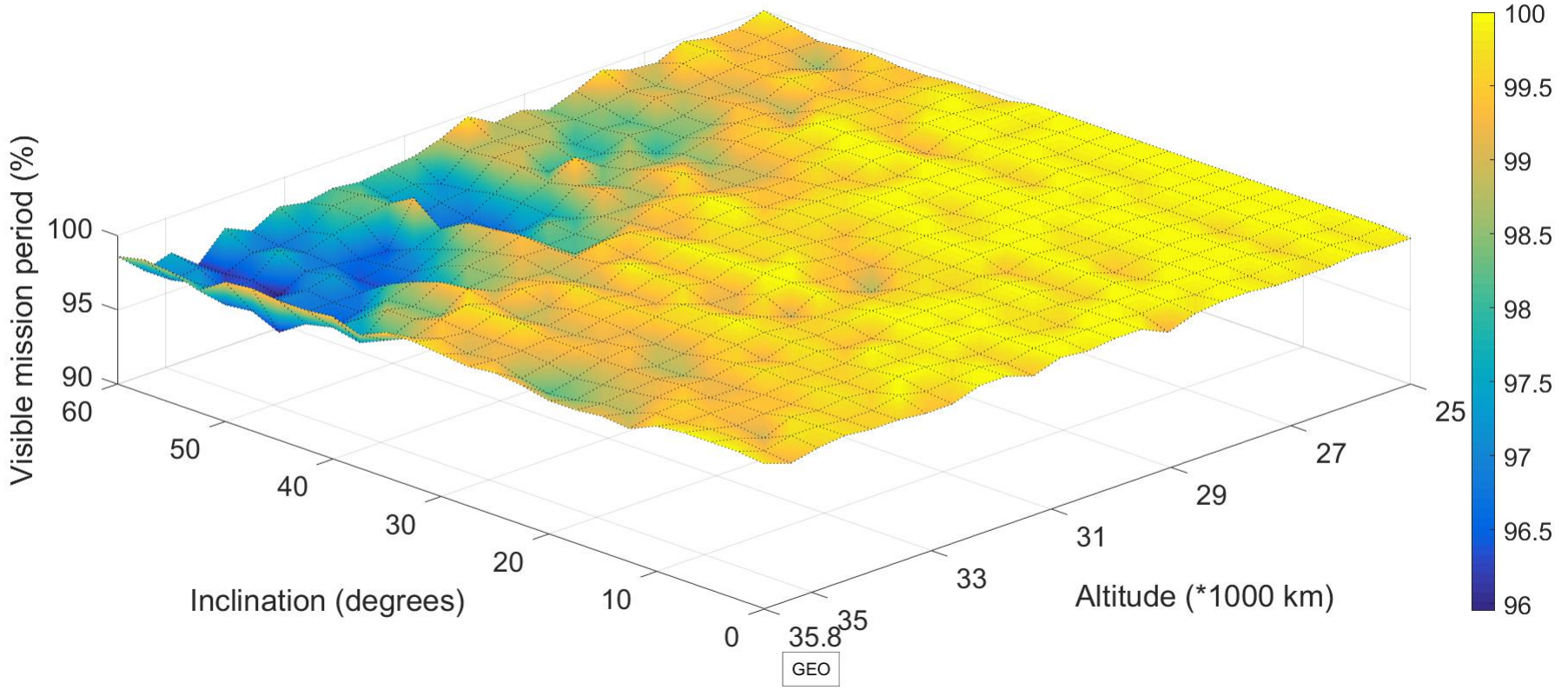
Multi GNSS – Results (I)

Minimum number of systems – GPS + GLONASS + QZSS + SBAS



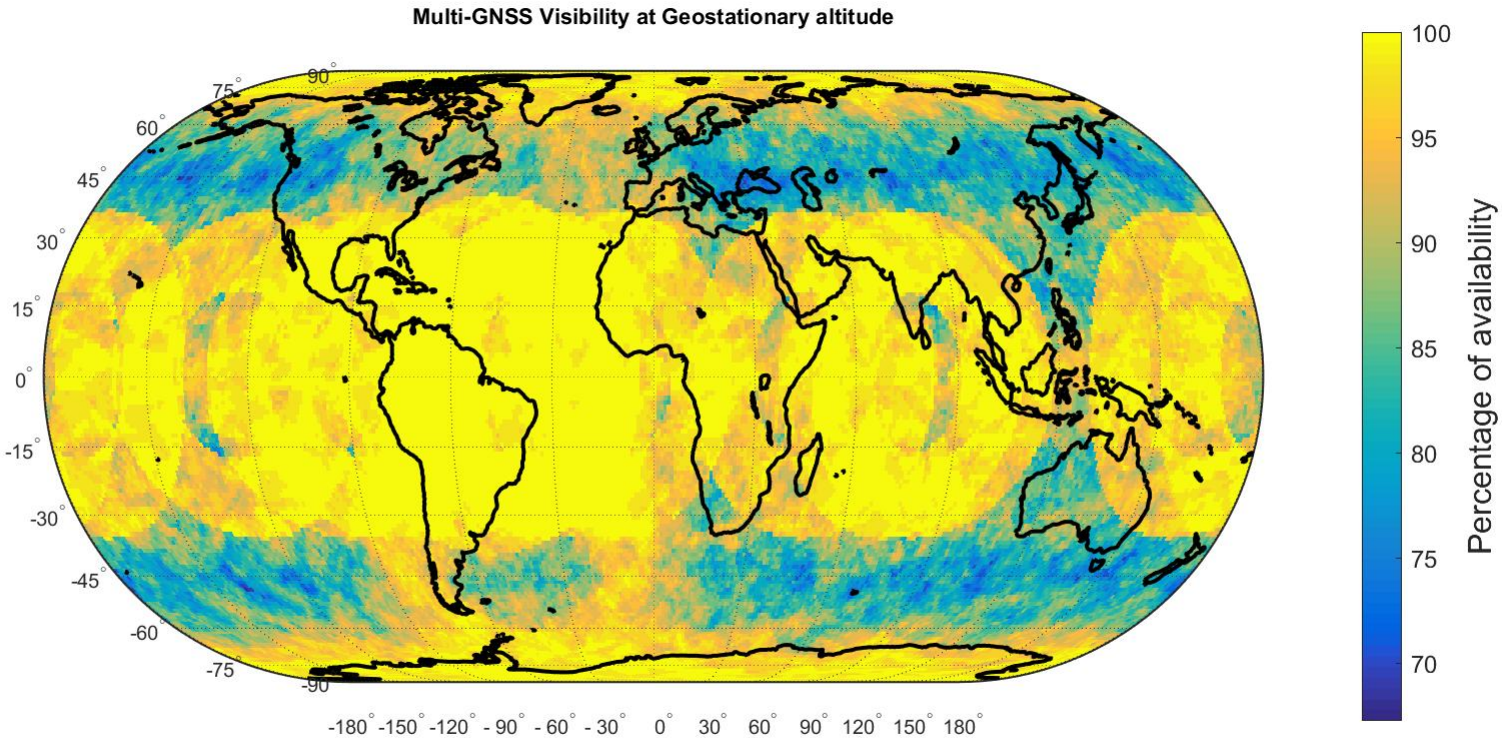
Multi GNSS – Results (2)

GPS + GLONASS + GALILEO + QZSS + SBAS



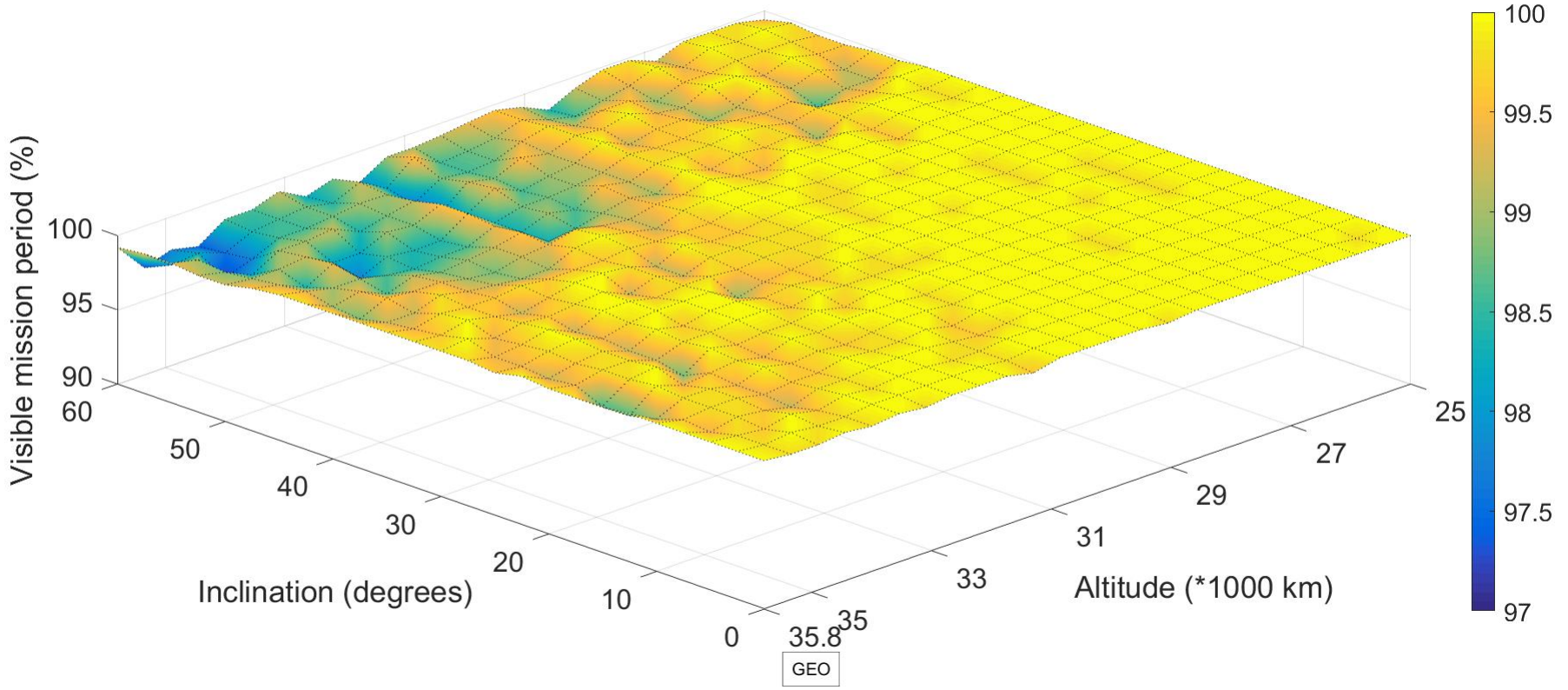
Multi GNSS – Results (3)

GPS + GLONASS + GALILEO + QZSS + SBAS (@ GEO altitude)



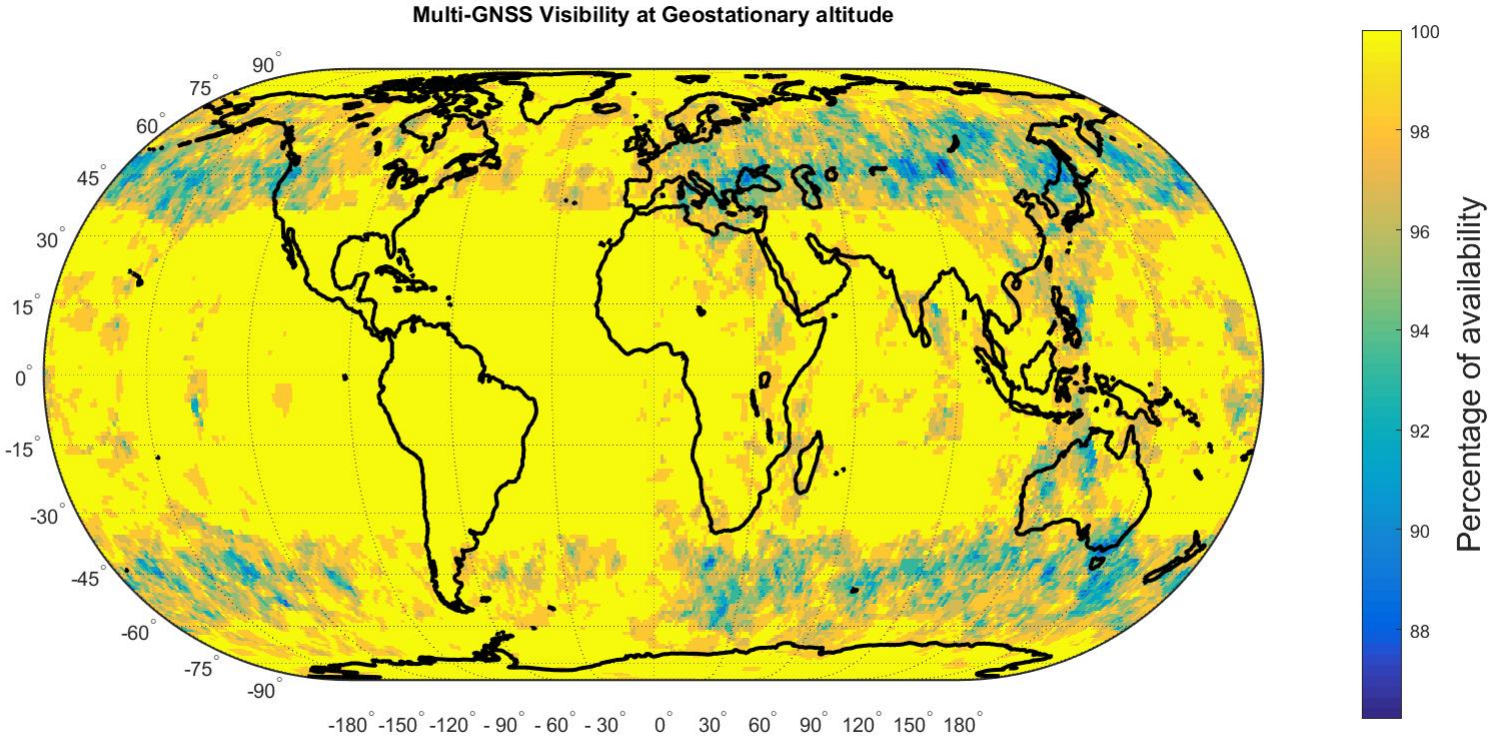
Multi GNSS – Results (4)

GPS + GLONASS + BEIDOU + QZSS + SBAS



Multi GNSS – Results (5)

GPS + GLONASS + BEIDOU + QZSS + SBAS (@ GEO altitude)



Conclusion

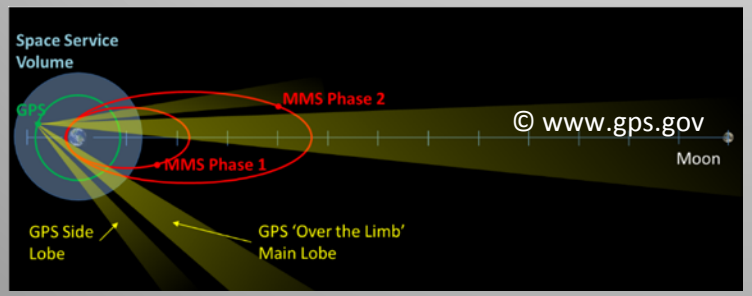
- Combined GNSS offers **better options** for positioning in higher altitudes

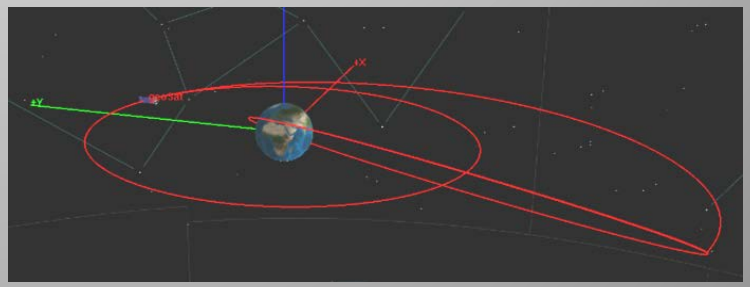
- For best solution
  - Careful selection of **GNSS constellation and frequency combinations are necessary** based on mission scenario

- GNSS Side Lobe Signals specification is **critical**
  - Not only increases availability for positioning in SSV
  - Opens wide array of opportunities for low cost missions

Conclusion

- **Future**
  - Extended the Scope to Even higher orbits such as 76,000 km altitudes
  - Specifically for mission scenarios
    - such as formation flying & Geo-Transfer Orbit Scenarios





  - Possible state estimation process with <4 satellites available

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SNAP Lab

THANKS !

GNSS space receivers (ESA missions)

Application		Mission Examples	Orbit
Absolute Navigation (Platform Rx)	LEO Orbit	PLEIADES, UK-DMC, all ESA Earth Obs. (Explorers, Copernicus, MetOp), GlobalStar, Proba-2, Demeter, TDS-1	LEO
	GEO/GTO/HEO Orbit	STENTOR, SkyLAN, IntelSat, GMP, SmallGEO, MTG, STE-QUEST, Proba-3	GEO/HEO
	Re-entry	ARD, Pre-X	LEO to ground
	Launcher	Ariane V, VEGA	Ground to GTO
Relative Navigation (Platform Rx)	Rendevous	ATV	LEO
	Formation Flying	GRACE, PRISMA, Proba-2, MMS, TerraSAR-x, FF Xeus, NGGM	LEO/HEO GEO
EO/Scientific Instruments	Support to POD	ESA Explorers (GOCE, SWARM, ...), Copernicus Sentinels, MetOp-SG, MetOp, CHAMP, GRACE	LEO
	Atm. Sounding	MetOp, CHAMP, Jason-CS, MetOp-SG	LEO HEO
	Reflectometry	UK-DMC, TDS-1, GEROS-ISS	LEO HEO
Support to Other Systems	Attitude	PLEIADES, ROCSAT, ALPHABUS	LEO GEO
	Timing	GEO telecom, GlobalStar, Iridum, MTG	LEO GEO

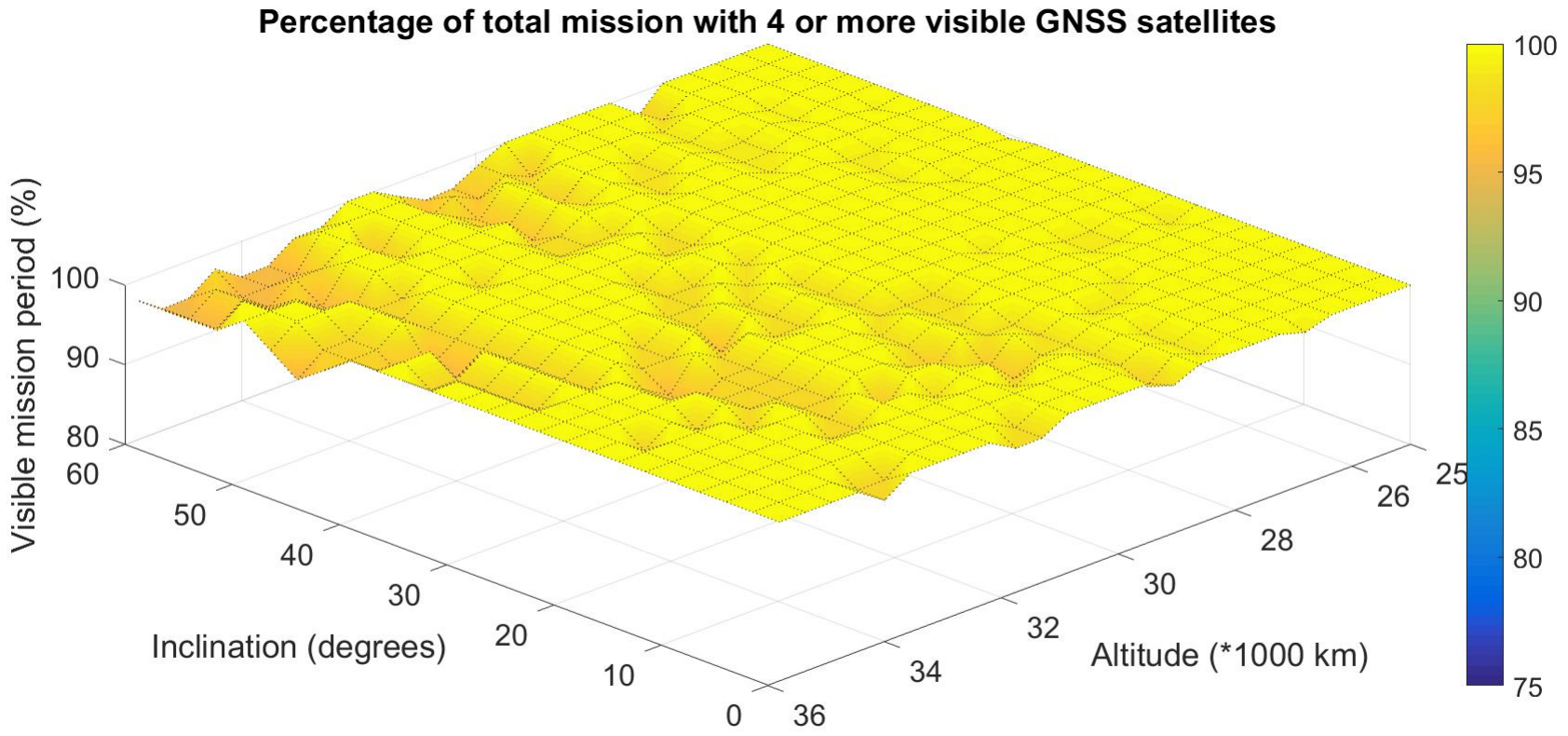
SSV Requirements (based on GPS)

- Current requirement
  - Signal availability
  - Minimum received signal power at GEO
  - Maximum pseudo range accuracy

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

Multi-GNSS

GPS **(main + side)** + GLONASS + GALILEO + BEIDOU + QZSS



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