Combined Global Navigation Satellite Systems in the Space Service Volume

Besides providing position, velocity, and timing (PVT) for terrestrial users, the Global Positioning System (GPS) is also being used to provide PVT information for earth orbiting satellites. In 2006, F. H. Bauer, et. al., defined the Space Service Volume in the paper "GPS in the Space Service Volume", presented at ION's 19th international Technical Meeting of the Satellite Division, and looked at GPS coverage for orbiting satellites. With GLONASS already operational, and the first satellites of the Galileo and Beidou/COMPASS constellations already in orbit, it is time to look at the use of the new Global Navigation Satellite Systems (GNSS) coming into service to provide PVT information for earth orbiting satellites. This presentation extends "GPS in the Space Service Volume" by examining the coverage capability of combinations of the new constellations with GPS

GPS was first explored as a system for refining the position, velocity, and timing of other spacecraft equipped with GPS receivers in the early eighties. Because of this, a new GPS utility developed beyond the original purpose of providing position, velocity, and timing services for land, maritime, and aerial applications. GPS signals are now received and processed by spacecraft both above and below the GPS constellation, including signals that spill over the limb of the earth. Support of GPS space applications is now part of the system plan for GPS, and support of the Space Service Volume by other GNSS providers has been proposed to the UN International Committee on GNSS (ICG). GPS has been demonstrated to provide decimeter level position accuracy in real-time for satellites in low Earth orbit (centimeter level in non-real-time applications). GPS has been proven useful for satellites in geosynchronous orbit, and also for satellites in highly elliptical orbits.

Depending on how many satellites are in view, one can keep time locked to the GNSS standard, and through that to Universal Time as long as at least one satellite is in view (the longest duration with no satellites in view is important in determining the maximum clock drift from GNSS time). Instantaneous position requires four satellites in view, but because orbital motion is predictable, it is possible to build up knowledge of the orbital position gradually through time without a need for constant four satellite coverage. However, it is desirable to have four satellite coverage when performing satellite maneuvers, since there can be significant changes in velocity, leading to large changes in orbit parameter, causing substantial divergence in position over time.

The Space Service Volume has been defined as the volume between three thousand km altitude and geosynchronous altitude, and can be divided into medium orbit services between three thousand km altitude and eight thousand km altitude, and high orbit services above eight thousand km. The Terrestrial Service Volume includes the Earth's surface, the atmosphere, and space below the altitude of three thousand km. The Terrestrial Service Volume is the volume within which the GNSS systems will have very similar performance to the Earth surface, and satellites need only use the signals specified to provide terrestrial performance. Above three thousand km the use of signals passing by the Earth's limb becomes important, so it is desirable to have additional information on signal strength, phase delay, and group delay covering wider beam angles than are needed for terrestrial service (and which can be obtained by monitoring GNSS signals from the Earth's surface).

This presentation will look at each of the new GNSS constellations in combination with GPS (GLONASS with GPS, Galileo with GPS, Beidou/COMPASS with GPS), and also at the combination of all four GNSS systems.

The presentation will largely follow the format of "GPS in the Space Service Volume", presenting data on the availability of one, two, three, or four of the various combinations of GNSS constellation satellites at approximately two thousand grid points evenly spaced and fixed in longitude and latitude, the duration of the longest single-fold outages (intervals when no satellites are available), and the duration of the longest four-fold outages (intervals when fewer than four satellites are available) at several altitudes. Following the original paper, we will use the altitudes of three hundred km (typical LEO satellite, and within the Terrestrial Service Volume), at three thousand km (border between Terrestrial Service Volume and Space Service Volume), at eight thousand km (the border between medium and high orbit service within the Space Service Volume), at fifteen thousand km (just below the GNSS constellations), at twenty five thousand km (just above the GNSS constellations), at thirty six thousand, five hundred km (limit of Space Service Volume definition, geosynchronous altitude), and at seventy thousand km (to show the potential usefulness of GNSS beyond geosynchronous altitude).

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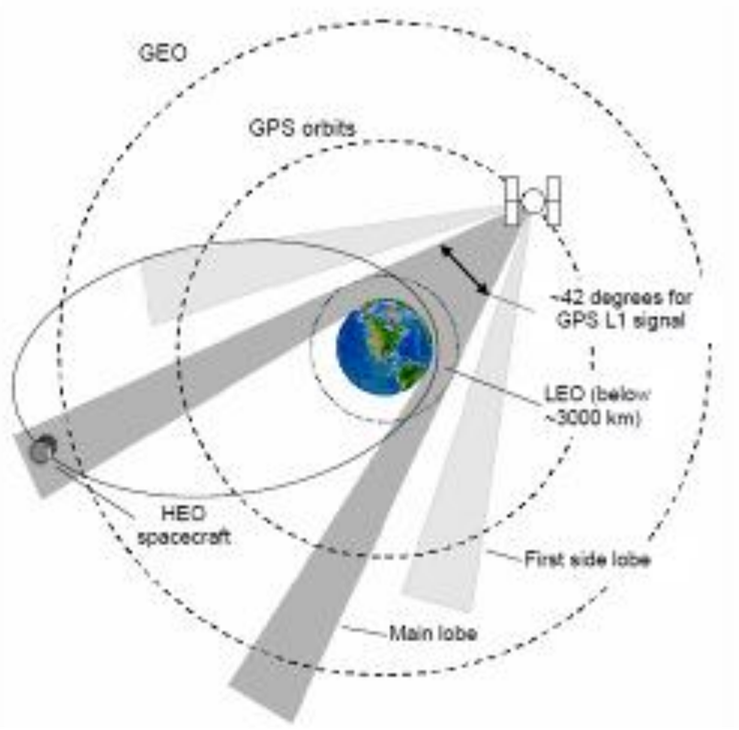
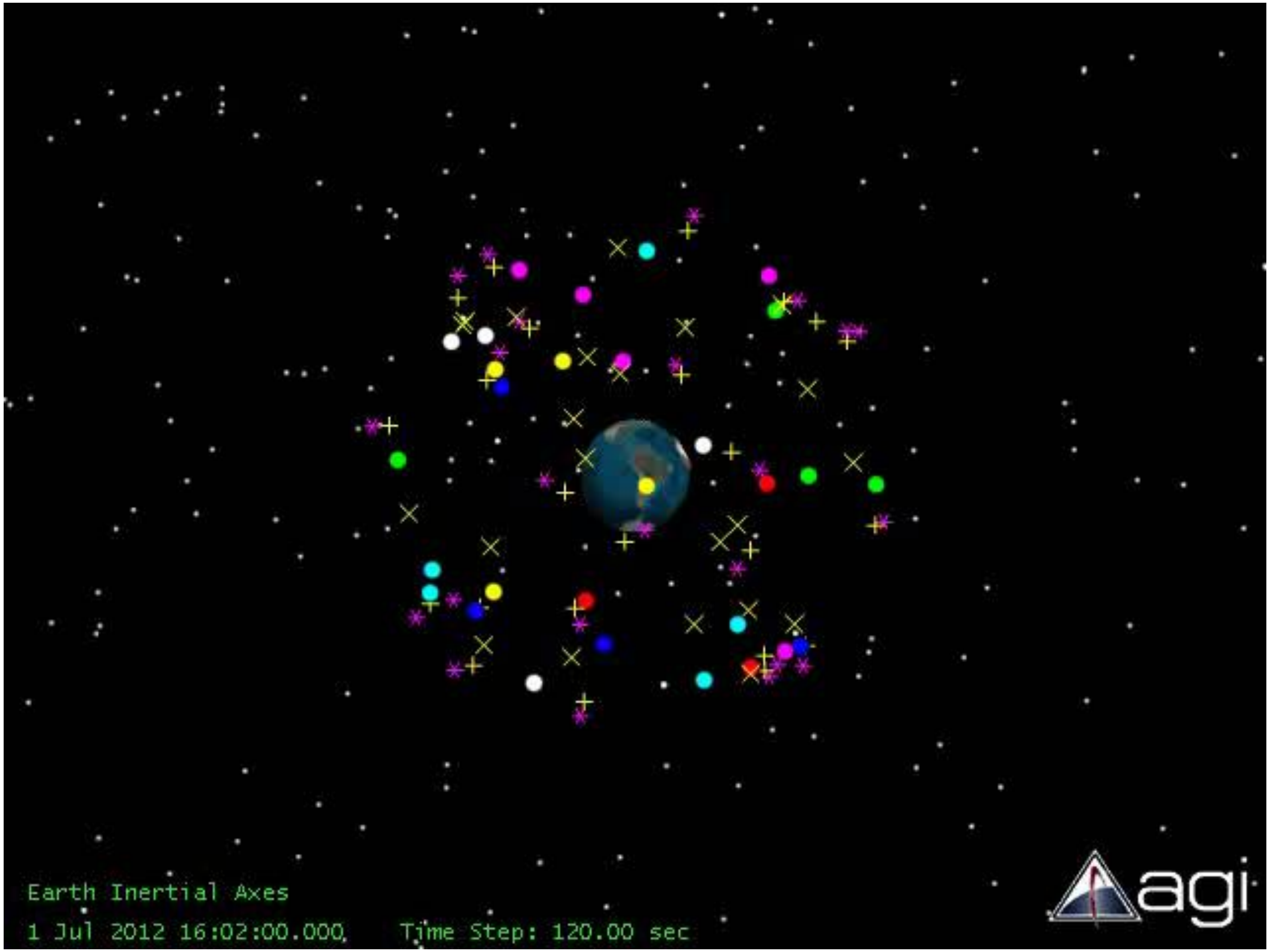
Geometry of Reception of GNSS Signals by Satellites

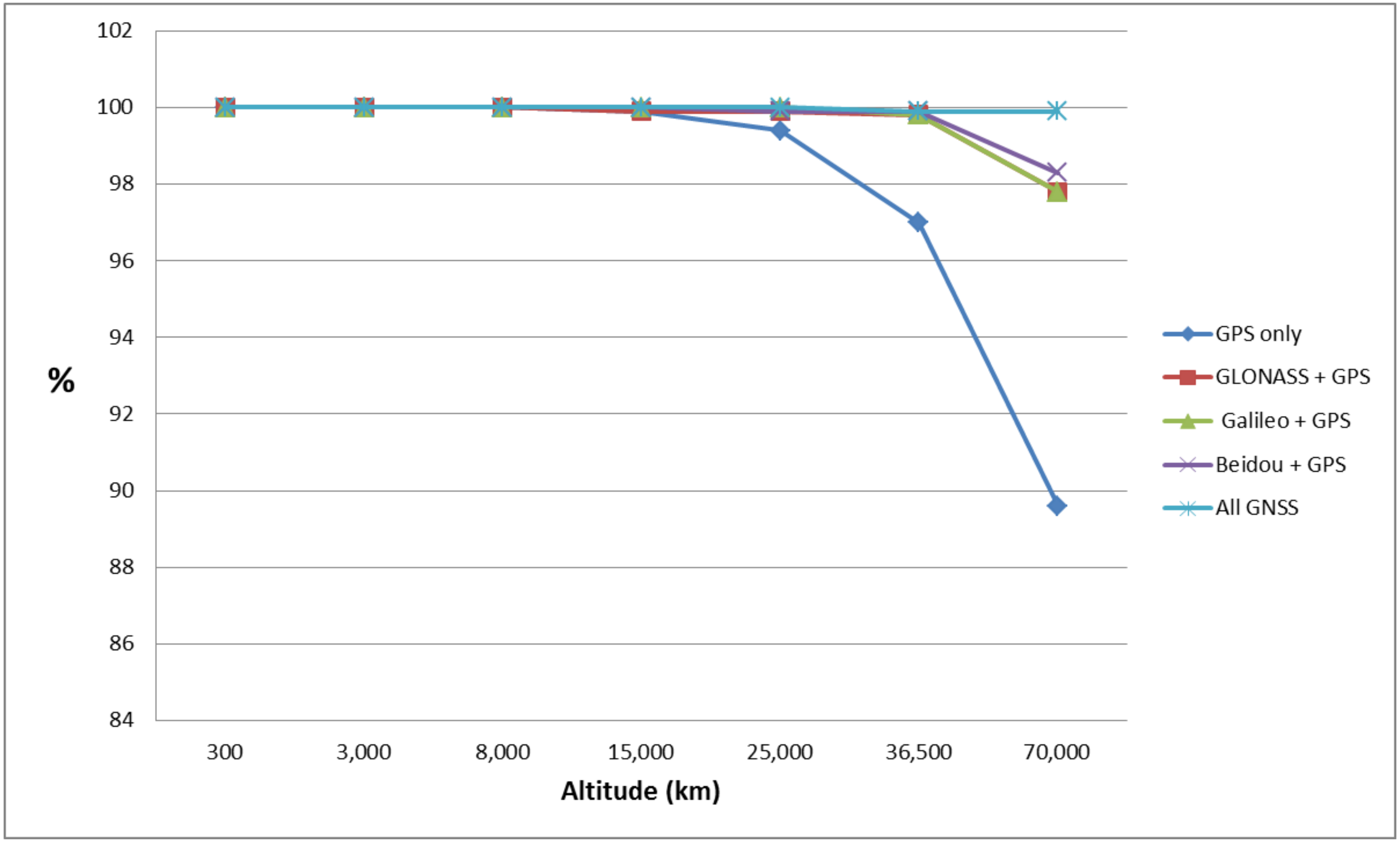


Terrestrial and Space Service Volumes

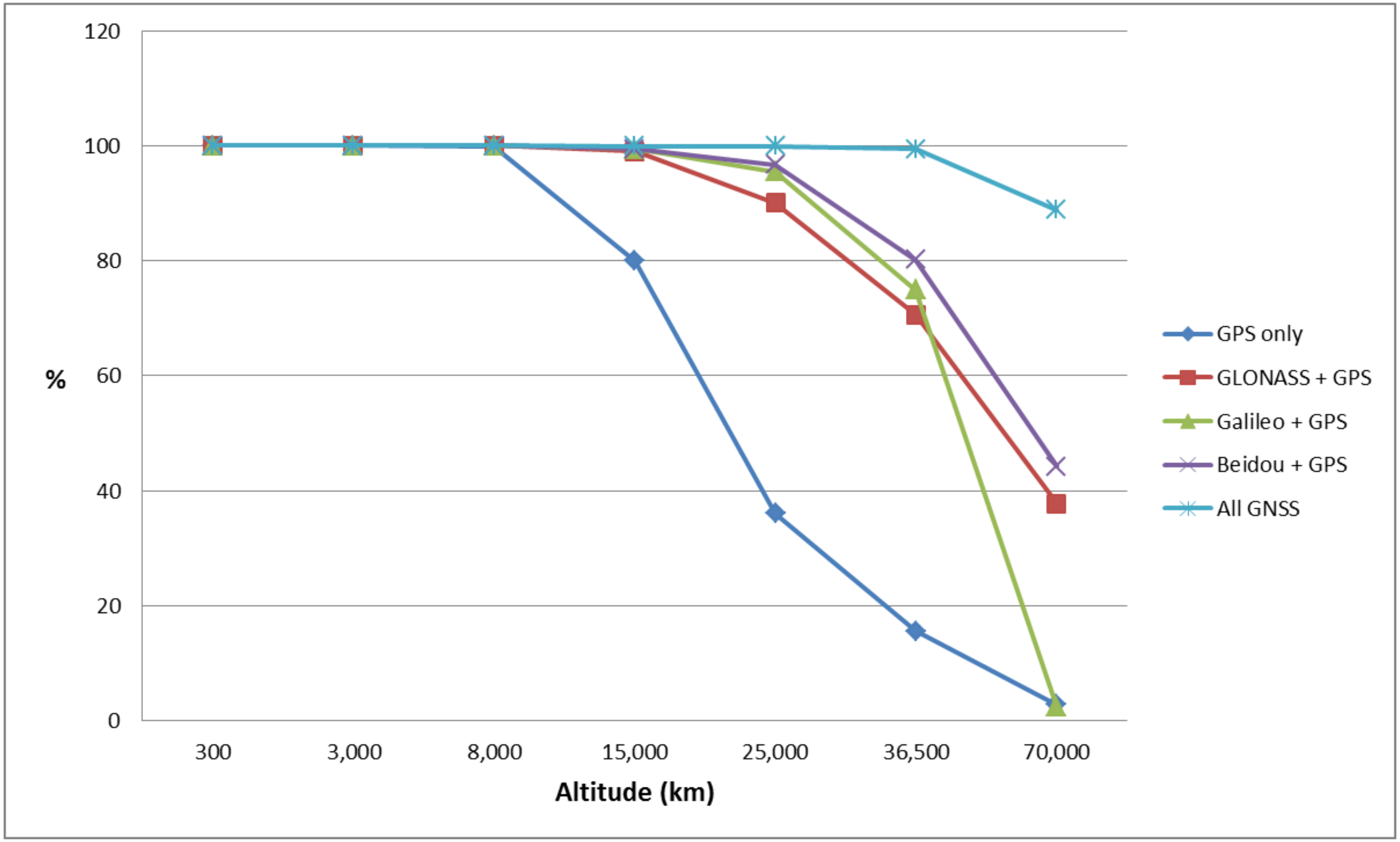
All GNSS Constellations



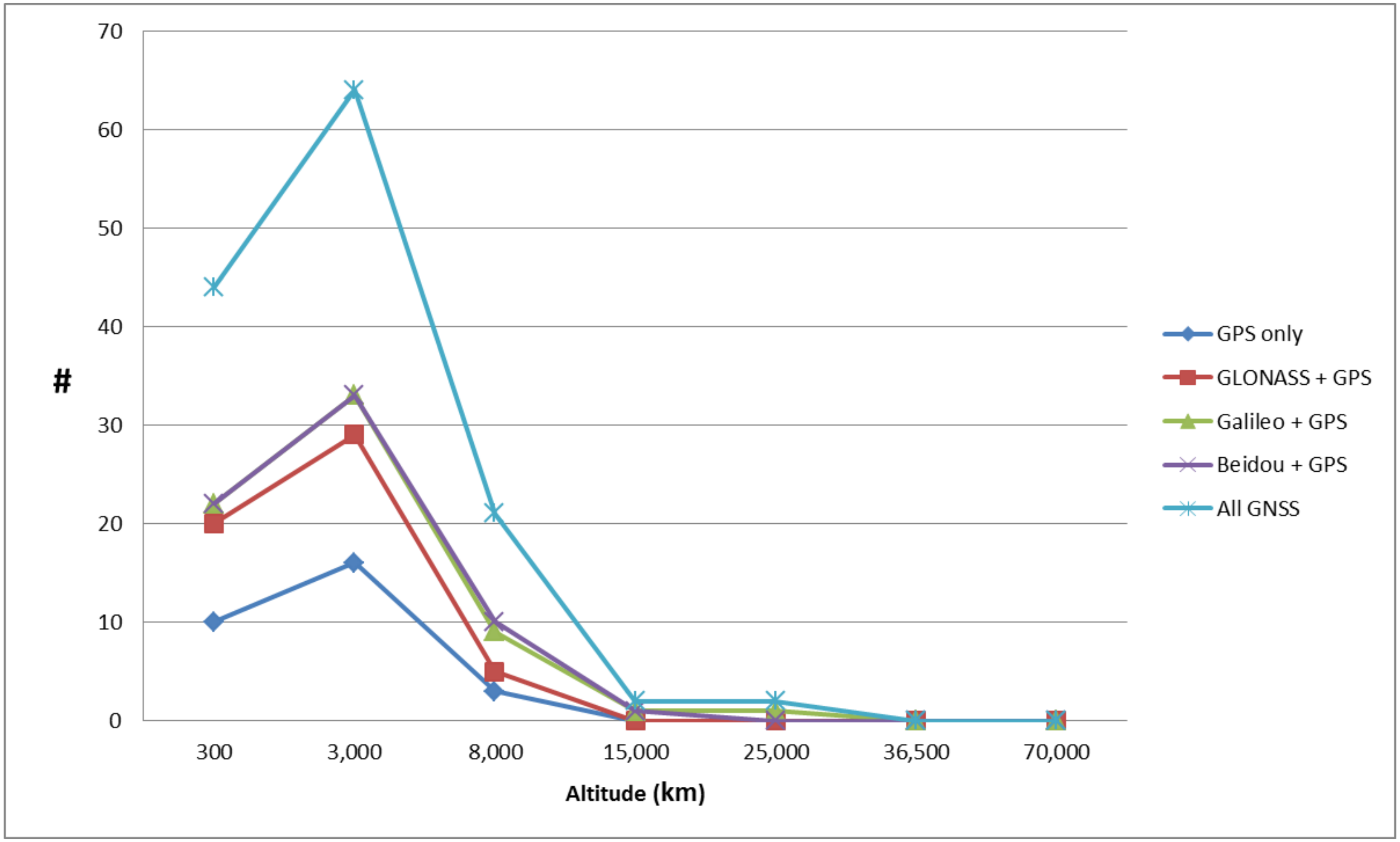
Single-Fold GNSS Coverage



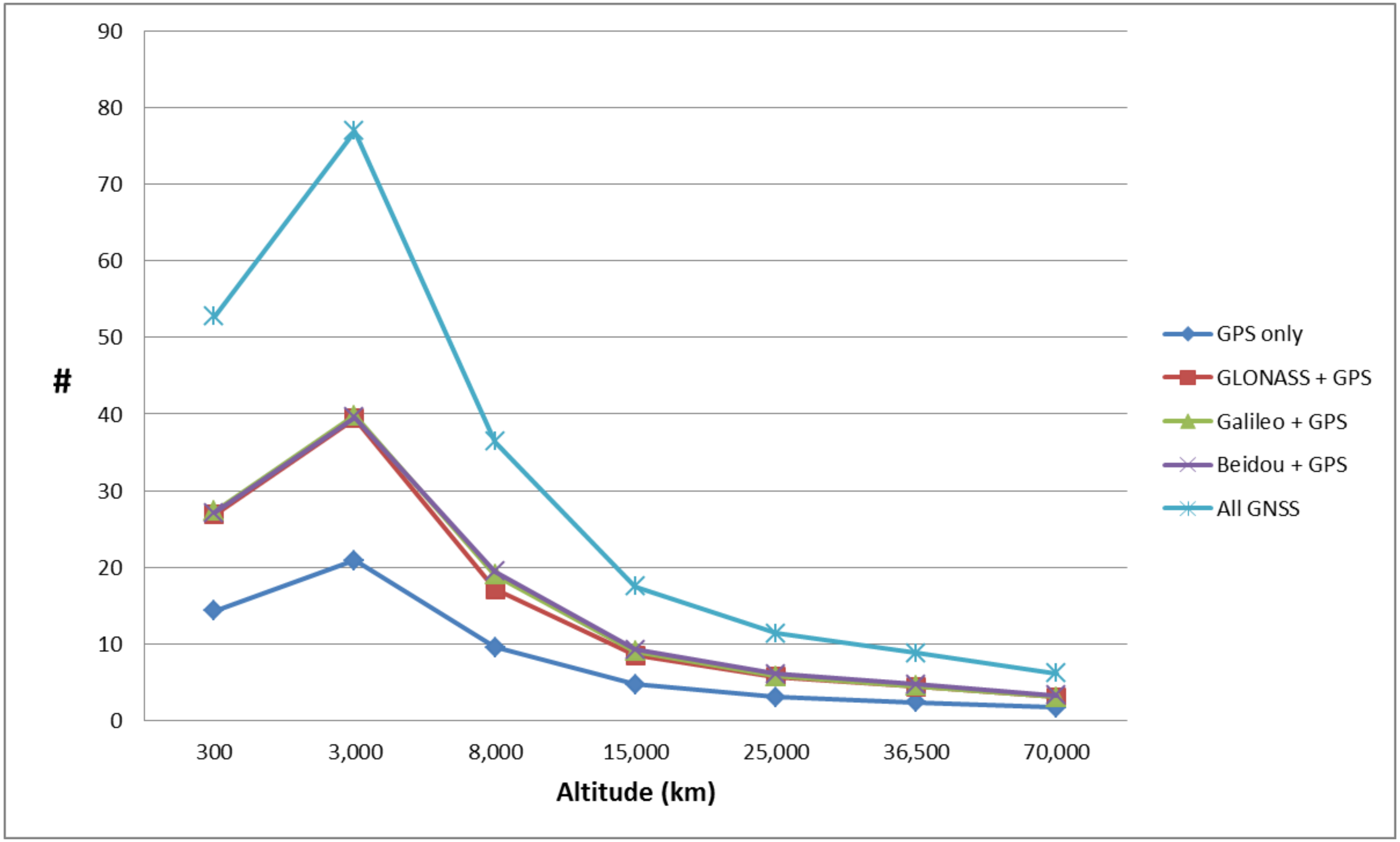
Four-Fold GNSS Coverage



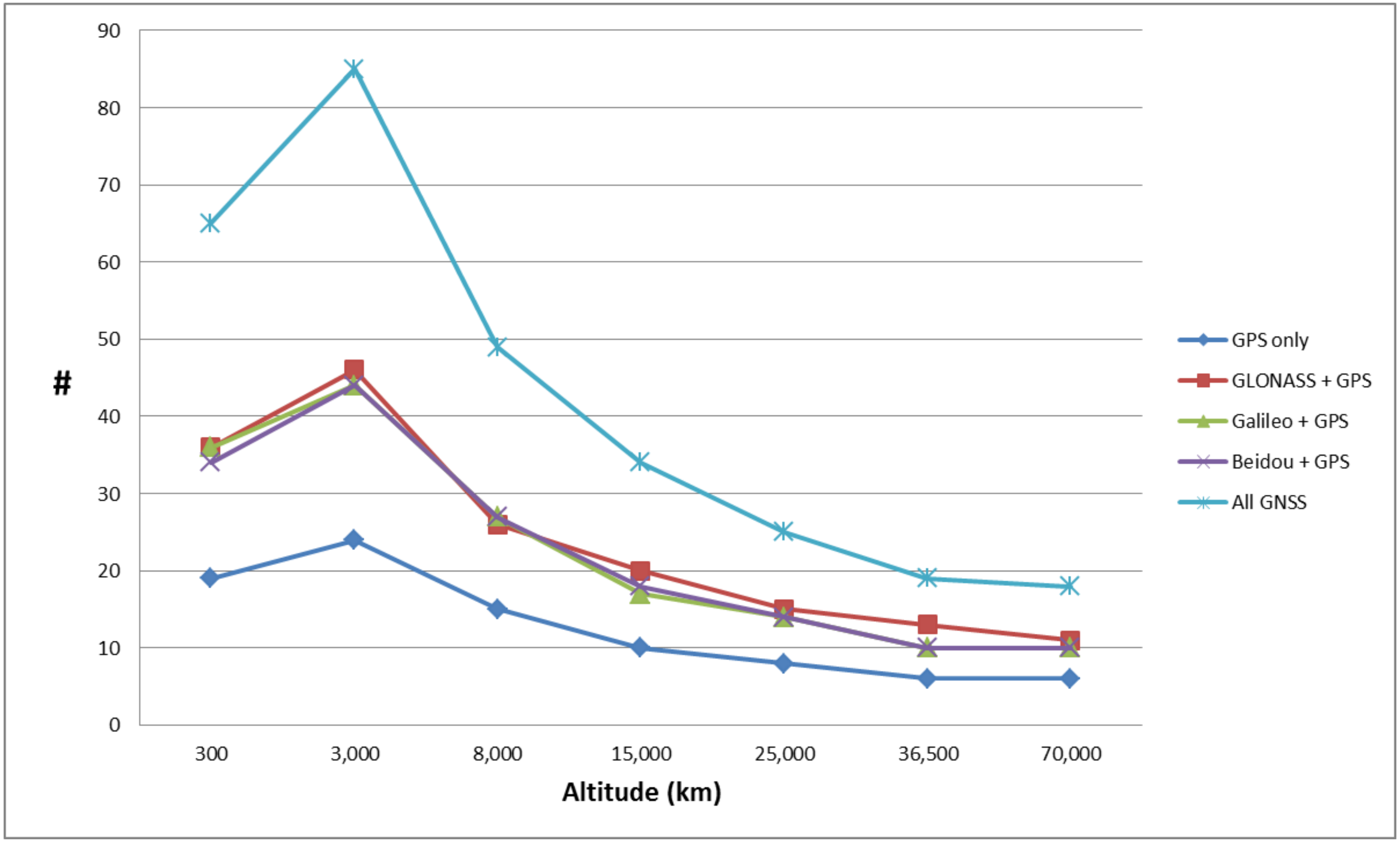
Minimum Number of GNSS Satellites Providing Coverage



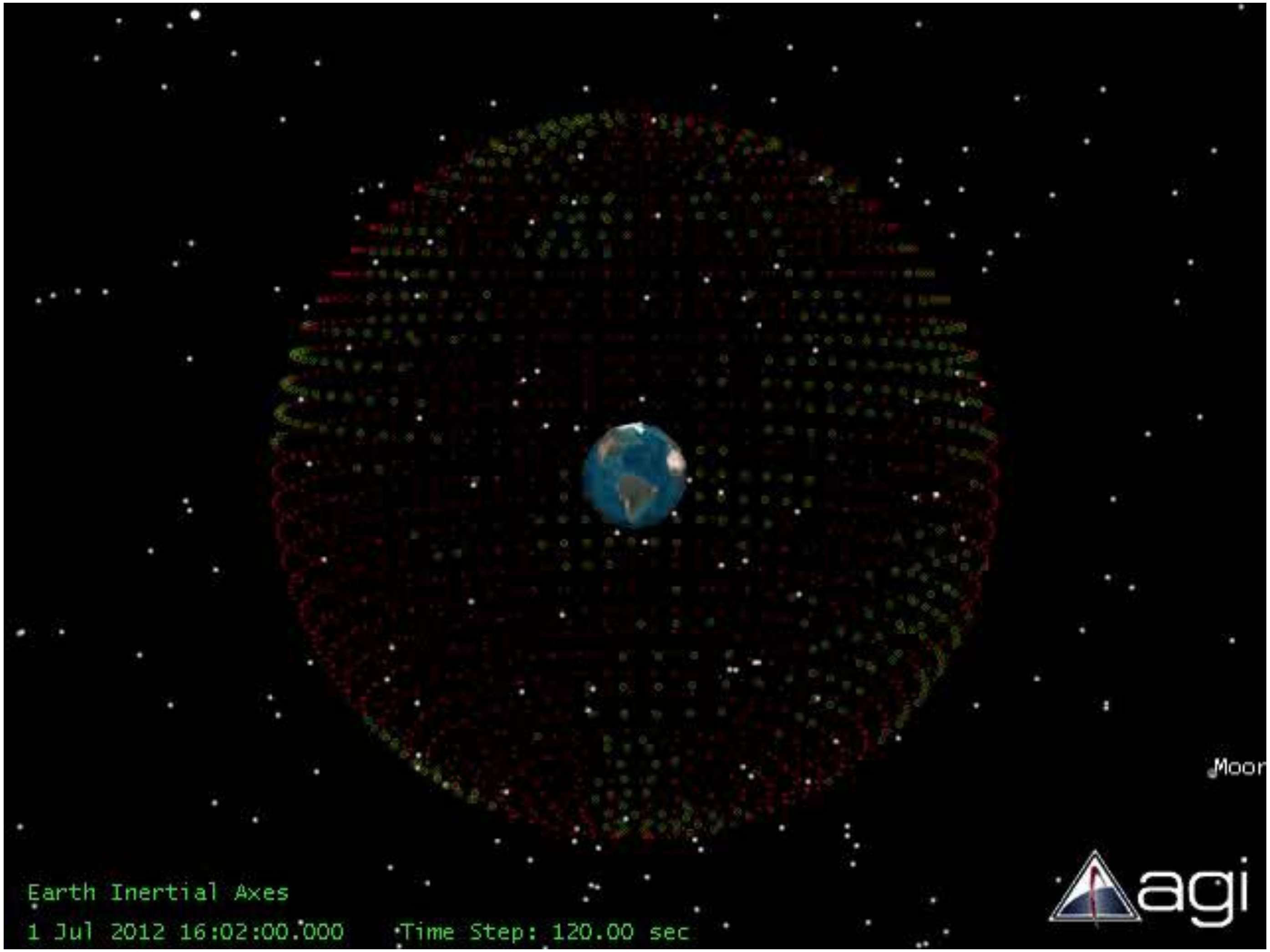
Average Number of GNSS Satellites Providing Coverage



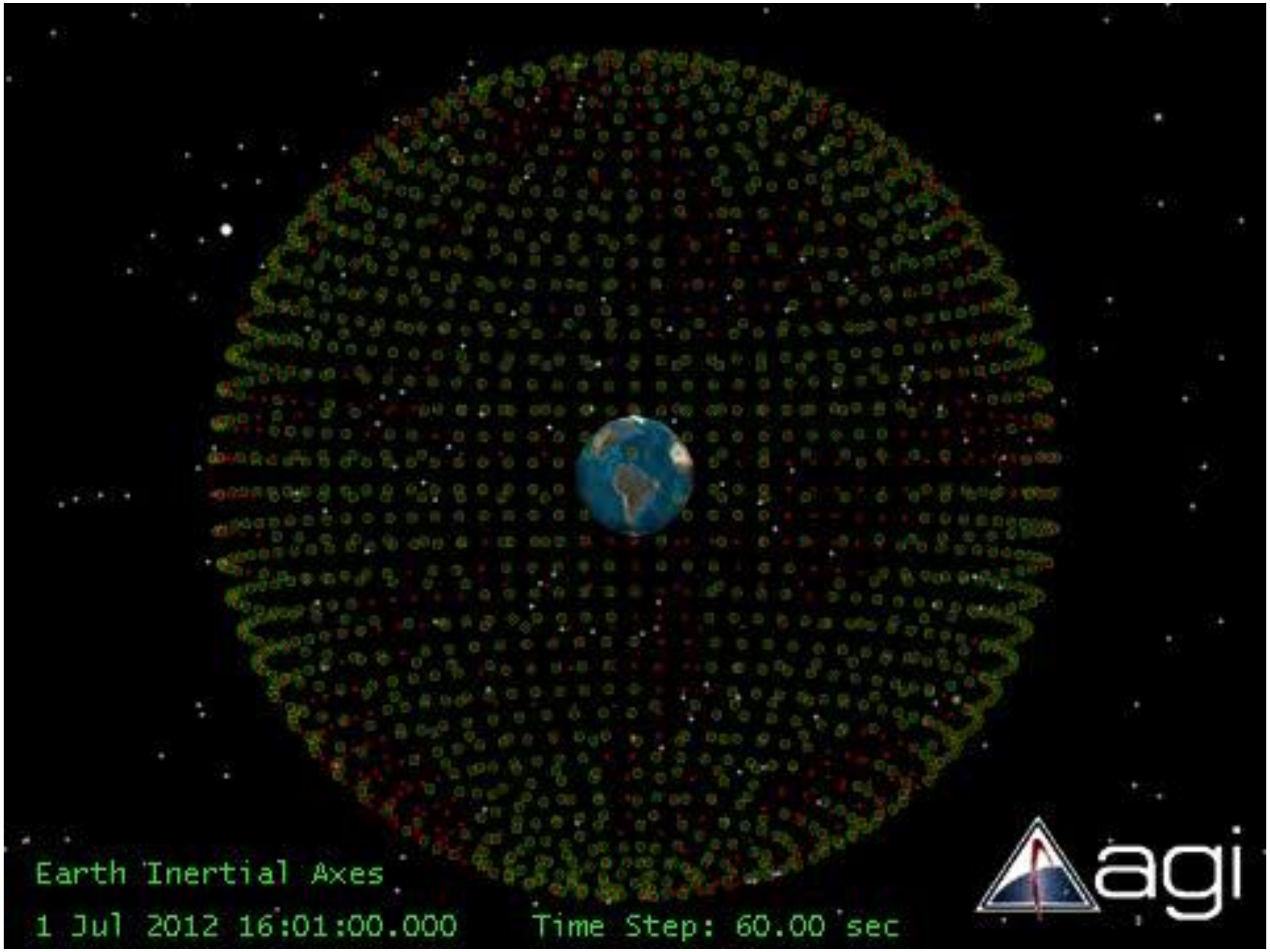
Maximum Number of GNSS Satellites Providing Coverage



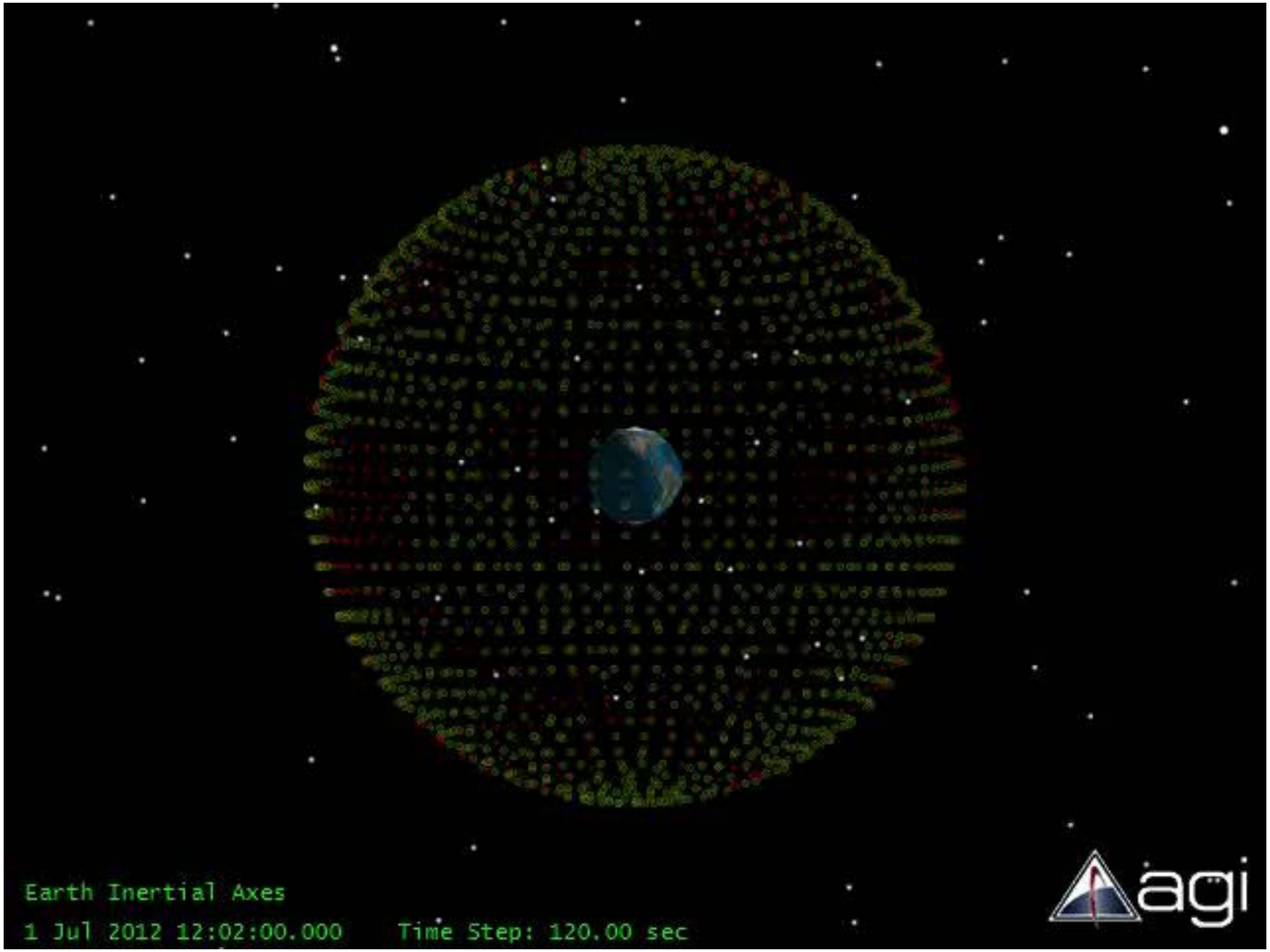
Four-Fold GPS Coverage at GEO Altitude



Four-Fold GPS + Galileo Coverage at GEO Altitude



Four-Fold Coverage of All GNSS Constellations at GEO Altitude



Four-Fold Coverage of All GNSS Constellations at 70,000 km Altitude