IAC-10-A6.4.1

MEDIUM EARTH ORBITS: IS THERE A NEED FOR A THIRD PROTECTED REGION?

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The Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations have adopted the concept of near-Earth regions which should be afforded protection from the accumulation of orbital debris. These regions are low Earth orbit (LEO), which extends up to 2000 km altitude, and geosynchronous orbit (GEO), which includes the volume of space encompassed by 35,786 km +/- 200 km in altitude and +/- 15 degrees in latitude. The region between LEO and GEO is commonly referred to as Medium Earth Orbit (MEO). Although historically a small minority of spacecraft have operated in MEO, the number of such satellites residing in or routinely transiting the zone is increasing. The question thus arises: should MEO be considered an orbital debris protected region? This paper contrasts MEO with LEO and GEO, both physically and pragmatically. Characteristics of space systems now utilizing MEO, as well as those anticipated to join them in the near future, are reviewed. Potential orbital debris mitigation guidelines for MEO space vehicles are highlighted, and the challenges of spacecraft and launch vehicle stage disposal are recognized. Note is also made of the principal tenets of the United Nations Outer Space Treaty and of recent trends toward *de facto* partitioning of MEO. Finally, the efficacy and practicality of establishing MEO as a new protected region with regard to orbital debris is addressed.

I. DEFINITIONS OF NEAR-EARTH REGIONS

The international lexicon associated with near-Earth satellite orbits has evolved during the more than half century of space activities. Early on, the U.S. Space Surveillance Network (SSN) adopted a simple bifurcation of near-Earth space based upon astrodynamic considerations in the propagation of satellite orbits. Orbits were classified as "near-Earth" or "deep space". The former was defined as those orbits with orbital periods of less than 225 minutes (equivalent to a circular orbit height of 5876 km above the surface of the Earth), while the latter indicated that the orbital periods were equal to or greater than 225 minutes.[1] In time these orbital regimes were often commonly referred to as low Earth orbits (LEO) and high Earth orbits (HEO).[2-3] The HEO region included the unique geosynchronous orbits (GEO) with an orbital period of approximately 1436 minutes at a mean altitude of 35,786 km.

By the 1990's various definitions for LEO were in use world-wide. With the formation of the Inter-Agency Space Debris Coordination Committee (IADC) in 1993 and the adoption of space debris as an agenda item for the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in 1994, the need arose for an internationally accepted set of definitions for the volume of space in the immediate vicinity of the Earth. Today, those regions are known as

Low Earth Orbit (LEO) region:	the region of space up to an altitude of 2000 km (equivalent circular orbital period of approximately 127 minutes)
Medium Earth Orbit (MEO) region:	the region of space from 2000 km to 35,586 km
Geosynchronous Orbit (GEO) region:	the region of space from 35,586 km to 35,986 km (GEO +/- 200 km).

Since most Earth satellites are in non-circular orbits, the populations of these regions are normally described in one of two ways: the number of objects with orbital periods covered by the region's altitude limits and the number of objects residing in or passing through a given region. The total number of cataloged objects in Earth orbit on 1 July

2010 was approximately 15,500. Of these 78% had orbital periods of less than 127 minutes, 5% had orbital periods associated with the GEO region (1426-1446 minutes), and 15% had orbital periods between 127 and 1426 minutes. On the other hand, 88% of all cataloged objects either resided within or passed through LEO. The corresponding percentages for MEO and GEO were 18% and 9%, respectively. Less than 4% of the cataloged population (i.e., less than 600 objects) resides completely within the MEO region.

The volumes of space encompassed by these three regions differ significantly with the MEO region containing 34 times the volume of the GEO region, which in turn is seven times greater than the LEO region. Taking into account the number of objects which reside in and pass through the various regions, spatial densities can be derived as a function of altitude (Figure 1). The MEO region spatial densities are less than those in either the LEO or GEO regions.

II. OPERATIONS IN THE MEO REGION

The first U.S. satellite, Explorer 1, was placed in an elliptical orbit with an apogee greater than 2500 km, making it the first man-made satellite to reach and to operate in the MEO region. The first space system to be deployed wholly within the MEO region was the U.S. Missile Defense Alarm System (MIDAS). During 1961-1966 eight MIDAS spacecraft were inserted into orbits near 3500 km. The mission of MIDAS was later assumed by a geosynchronous satellite network.

Historically, a significant number of MEO residents have been in highly elliptical orbits which spend the majority of each revolution in the region. One well known class of such spacecraft is the Russian Molniya satellites with initial perigees in the LEO region (typically 450-600 km) and with apogees near 40,000 km. About half of their communications relay operations occur while the satellites are in the MEO region, the rest at higher altitudes. A separate network of Russian missile launch detection satellites employs very similar, highly elliptical orbits. During the past twenty years, the use of highly elliptical orbits for both communications and missile detection has decreased significantly.

The MEO region is best known today for global navigation satellite networks. After the testing of two experimental navigation satellites in the MEO region during 1974-1977, the U.S. began deployment in early 1978 of its Global Positioning System (GPS), whose individual satellites are known as Navstar. Now utilizing a nominal constellation of 24 operational spacecraft in approximately circular orbits at a mean altitude near 20,300 km with an inclination of 55 degrees, GPS broadcast signals have become indispensible for both civilian and military applications. In May 2010 the 59th Navstar satellite was inserted into the GPS orbital regime.

The maiden flight of the then Soviet (now Russian) counterpart to GPS occurred in 1982. Known as the Global Navigation Satellite System (GLONASS), the network is designed to accommodate 24 operational spacecraft in nearly circular orbits near a mean altitude of 19,100 km at an inclination of 65 degrees. Normally launched three-at-a-time, by March 2010 a total of 115 GLONASS satellites had reached the vicinity of the constellation altitude.

China's response to GPS and GLONASS will be a diverse network of Beidou (meaning compass) satellites. The majority of the satellites (27) will be placed in the MEO regime at a mean altitude of 21,500 km with an inclination of 56 degrees. Eight additional satellites will be deployed in geosynchronous orbits: five in geostationary orbits and three in inclined geosynchronous orbits. The first (and to-date only) Beidou satellite in the MEO region was launched in 2007.

For many years, the European Space Agency (ESA) has been planning its own network of navigation satellites in the MEO region. The Galileo constellation will be stationed in orbits at a mean altitude of 23,200 km with an inclination of 56 degrees. Two test satellites called GIOVE (Galileo In-Orbit Validation Element) were launched in 2005 and 2008, respectively.

If fully deployed, altogether these four navigation systems will account for 105 operational spacecraft plus spares. Table 1 summarizes the orbital characteristics of the four systems and indicates the number of satellites launched during the past decade (2000-2009).

Unlike their navigation cousins, communications satellites have yet to establish an enduring presence in circular orbits in the MEO region. The first such use was during the 1960's, when 27 satellites of the Initial Defense Communication Satellite Program (IDCSP) were inserted into the upper portion of the MEO region near 34,000 km altitude. In the 1990's development began for the establishment of the ICO (Intermediate Circular Orbit) communications network. Envisioned as a collection of 10 operational satellites operating in orbits at an altitude of 10,400 km and an inclination of 45 degrees, the network has encountered both technical and legal difficulties. The inaugural satellite was lost in a launch accident in the year 2000, followed by a successful mission in 2001. No subsequent launches into the MEO region have occurred, although several satellites remain in various stages of construction.

Perhaps the most controversial use of the MEO region came under Project West Ford in 1963. In an experiment to test the ability of creating a simple, long-distance communications network, nearly 500 million, 2-cm long dipoles (so-called Westford Needles) were to be deployed at an altitude of 3650 km. Due to solar radiation pressure, the orbital lifetimes of the dipoles were expected to be less than three years. One mission was at least partially successful with an estimated 25-40 % of the dipoles being properly deployed.[4] However, anomalous conditions are believed to have led to a breakup of the dipole packages, resulting in the creation of larger, long-lived orbital debris. The debris were still highly susceptible to solar radiation effects, which caused the orbits to periodically increase and then decrease in eccentricity. When extreme eccentricities drive the perigees deep into the LEO region, atmospheric drag can lead to reentry (Figure 2). A total of 147 Westford Needle debris clumps have been officially cataloged by the U.S. SSN, although two-thirds (98) have fallen out of orbit.

The MEO region has also received numerous other satellites, although normally in small numbers for a variety of applications and scientific missions. Two LAGEOS geodetic satellites were deployed in orbits between 5600 and 6000 km in 1976 and 1992, respectively. On two separate occasions in 1989 an Etalon geodetic satellite accompanied a pair of navigation satellites into the GLONASS orbital regime. During the period 2000-2009 on average only about two spacecraft were launched annually into elliptical orbits which passed through the MEO region each revolution of the Earth.

Finally, missions to the GEO region often leave launch vehicle upper stages and their components (*e.g*., separated propellant tanks) in geosynchronous transfer orbits (GTOs), which spend nearly all their time in the MEO region, typically with perigees in the LEO region and apogees near GEO. Depending upon their initial perigees and solar-lunar gravitational perturbations, the orbits of some of these derelict stages can be short-live, while others can be very long-lived.

III. PROTECTED REGIONS

Following the 1999 release of the *Technical Report on Space Debris*[2] by the Scientific and Technical Subcommittee of UN COPUOS, the IADC undertook a new action item to develop an international set of space debris mitigation guidelines. Completed in October 2002, the *IADC Space Debris Mitigation Guidelines* designated two protected regions in near-Earth space: the LEO and GEO regions. Figure 3 illustrates the general character of these two regions, although the regions and the Earth are not shown to scale. Note that the GEO protected region is only a small portion of the GEO region, as defined previously, since the protected region only includes the region between 15 degrees north latitude and 15 degrees south latitude.

Regarding these protected regions, the IADC document states that

> "any activity that takes place in outer space should be performed while recognizing the unique nature of the following regions, A and B, of outer space, to ensure their future safe and sustainable use. These regions should be protected regions with regard to the generation of space debris."[5]

In addition to their "unique" status, these two regions also have hosted the vast majority of all operational spacecraft, hence underscoring their preservation as a benefit to all mankind for generations to come.

One of the topics addressed by the *IADC Space Debris Mitigation Guidelines* is post-mission disposal. In order to reduce the creation of new debris in the protected regions from accidental collisions, recommendations were established to prevent the long-term stays of non-operational spacecraft and launch vehicle stages in the LEO and GEO regions. The recommendation for the LEO region included not only those vehicles within the LEO region, but also those vehicles which transited the region on a routine basis, *i.e*., those in elliptical orbits. In short, the IADC guidelines strongly suggested that LEO space structures be moved to lower orbits to accelerate orbital decay and that GEO space structures be maneuvered to long-term disposal orbits sufficiently far above the GEO region.

The regions of space between the LEO and GEO regions, *i.e*., the MEO region, and above the GEO region were consciously not designated as protected regions. However, the IADC guidelines did acknowledge their existence and offered the following recommendation:

> "Spacecraft or orbital stages that are terminating their operational phases in other orbital regions should be maneuvered to reduce their orbital lifetime, commensurate with LEO lifetime limitations, or relocated if they cause interference with highly utilized orbit regions."[6]

More recently, in accordance with a new 2010 agenda item on long-term sustainability of outer space activities, the Scientific and Technical Subcommittee of UN COPUOS acknowledged the special value of the LEO and GEO regions but did not assert an equal level of importance to the MEO region.[7]

IV. THE DISPOSAL OF SATELLITES IN THE MEO REGION

As noted above, a principal characteristic of a protected region is a desire to limit the long-term presence of spacecraft and orbital stages in the regime. However, the removal of a spacecraft or orbital stage from an orbit completely within the MEO region to one which does not interfere with the LEO and GEO regions is normally not practical due to energy requirements. For satellites in highly elliptical orbits with perigees passing through the LEO region, the guidelines for the LEO region already seek to limit the duration of their time in space. Likewise, some recommendations for the GEO region, *e.g*., those of NASA, also call for limiting the presence of objects in highly elliptical orbits, especially GTOs, which pass through the GEO region.

Since the first group of 10 GPS satellites (Block I, 1978-1985), GPS disposal maneuvers have normally lifted the spacecraft to slightly higher altitudes. GLONASS satellites are typically abandoned in place. This policy, coupled with the relatively short operational lifetimes of GLONASS satellites, has led to the sharp increase in spatial density at the GLONASS altitude (Figure 1). The first GIOVE satellite was moved to a slightly higher (~80 km) orbit after its primary mission was completed. The one and only Beidou satellite has not yet maneuvered from its initial operational orbit. Figure 4 indicates the orbits for each of the satellites from these four classes, as of July 2010.

As noted in the previous paragraph, the absence of disposal maneuvers for old GLONASS spacecraft (as well as their upper stages; see below) has led to a sharp increase in spatial density in the GLONASS operational regime. Nearly 140 large derelict objects now mingle with less than two dozen operational spacecraft. A collision among these objects could lead to the fratricide of an operational GLONASS satellite and would likely distribute large numbers of hazardous debris throughout the MEO navigational zone, posing increased risks to the spacecraft of other nations as well as additional GLONASS satellites.

Although currently the primary overlap among the navigation constellations is between non-operational GPS satellites and the single Beidou satellite, such will not be the case in the future. Satellites in the mid-MEO region can be particularly susceptible to unwanted orbital perturbations. The major effect is a gradual variation in the eccentricity of the orbit, which can lead to a gradual decrease in perigee.

For example, the last maneuver of the Navstar 6 satellite in 1991 left the vehicle in a slightly eccentric orbit with a perigee of 19,430 km, *i.e*., above the GLONASS constellation. However, by mid-2010 the perigee had naturally fallen nearly 600 km to 18,840 km (now below the constellation), while its apogee had risen an equivalent distance. Consequently, the spacecraft now passes through the GLONASS altitude regime each day (Figure 5). On the other hand, more than 1400 other resident space objects in elliptical orbits not related to GPS also pass through the GLONASS constellation each day, posing much greater risks of collision.

Another issue is the disposal of orbital stages which deploy the four navigation satellite systems. Until the latest GPS satellite (launched in May 2010), all GPS satellites inserted themselves into operational orbits from highly elliptical transfer orbits; hence, no stages were left permanently near the GPS altitude regime. Launch vehicle stages left in these transfer orbits have typically been short lived. However, beginning in 2010 GPS satellites will be deployed with the help of larger launch vehicles, whose stages will be left in orbits above the GPS constellation in the general vicinity of decommissioned GPS spacecraft.

For GLONASS missions, the final stage of the Proton launch vehicle is left in the heart of the constellation, where each poses future collision hazards. Like GLONASS, the two GIOVE missions left launch vehicle orbital stages near, but slightly above, their operational orbits. Following the single Beidou mission, the launch vehicle upper stage remained in a highly elliptical transfer orbit with an apogee near the Beidou operational regime.

V. WHAT SHOULD BE THE STATUS OF THE MEO REGION?

The MEO region is significantly unlike either the LEO or GEO protected regions both in volume and in value. The volume of the MEO region is 150 times that of the LEO and GEO protected regions combined. Not surprisingly, then, the MEO region exhibits the least risk of hazardous collisions in comparison with the LEO and GEO regions (Figure 1). Whereas approximately 1400 cataloged objects pose routine collision hazards with the GLONASS constellation, nearly 5000 cataloged objects potentially threaten ESA's ENVISAT spacecraft in the LEO region at an altitude of 785 km.

The MEO region also offers neither the advantage of lower launch costs, an essentially radiation-safe zone for human spaceflight, or high resolution for Earth observation as does the LEO region nor the unique aspect of fixed positions in the GEO region. Consequently, only about 5% of all operational satellites are found totally within the MEO region. One could conclude, therefore, that the MEO region does not possess a "unique nature" under the *IADC Space Debris Mitigation Guidelines*.

To date the principal concern about operations within the MEO region has been focused on physical or signals interference among the four navigation systems described previously. Proposals have even been made to allocate specific altitude zones to each of these national systems, as well as perhaps to their decommissioned satellites. Such demarcations would be in potential violation of Article II of the United Nations Outer Space Treaty which states that "Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[8]

In the LEO region hundreds of operational spacecraft successfully co-exist, often in very similar or intersecting orbits. No one nation or organization has exclusive or even principal rights to a particular orbital regime. In both the LEO and GEO regions, operators of satellites in close proximity to one another have been encouraged to coordinate activities or procedures which might lead to adverse effects. The MEO region should be handled no differently.

A background document for the new UN agenda item on long-term sustainability of activities in outer space already offers one preliminary recommendation for MEO region operations:

> "The operators of satellites in Medium Earth Orbits (MEO) should define in common the best end of life option for the satellites and upper stages in this region. The long term stability of MEO end-of-life disposal should be analyzed in order to avoid satellites or the upper stages of one operator interfering with the operational satellites of the other operators."[9]

This recommendation can be achieved with a minimum of effort, including the use of disposal orbits with very low initial eccentricity, without the formality of a designated MEO protected region. Even the eventual traverse of derelict spacecraft and stages through operational orbital regimes in the MEO region is fundamentally no different than experienced in the LEO region due to atmospheric drag effects.

It should further be noted that the general MEO navigation satellite zone represents less than 5000 km of the more than 33,000 km high region and less than 16% of the total volume of the entire MEO region. Therefore, designating the entire MEO region as a protected region seems ill-justified.

In part due to the vastness of the MEO region and to its relatively low utilization, the 1995 NASA orbital debris mitigation guidelines and the 2001 *U.S. Government Orbital Debris Mitigation Standard Practices* recognized the MEO region as a potential disposal zone, particularly for satellites operating in the high LEO region (*i.e*., 1400-2000 km) where less energy is needed to raise an orbit above LEO than to lower it into a 25-year-or-less terminal orbit.[10-11] However, an exception was made to avoid disposing of space structures near the GPS constellation altitude of 20,200 km.

In practice, the MEO region is rarely used as a satellite disposal zone. A few Globalstar spacecraft have maneuvered from their 1415 km altitude operational perches to disposal orbits in the MEO region, while others have moved up to orbits just below the MEO region. To avoid the risk of human casualties resulting from uncontrolled reentries and to avoid prolonged stays in the LEO region, the GTO perigees of some U.S. Delta IV upper stages are designed to be in the MEO region rather than the LEO region, *e.g*., the U.S. GOES 14 and 15 missions.

Finally, on average the consequences of satellite fragmentations in the MEO region are likely to be less severe than similar fragmentations in the LEO or GEO regions due to the existing lower levels of background spatial densities. Hence, future collisions between large fragmentation debris and other intact objects are less probable in the MEO region than if the same breakup occurred in the LEO or GEO protected regions.

CONCLUSION

Spacecraft and launch vehicle designers and operators should comply with national and international requirements and guidelines designed to mitigate or to eliminate the creation of new debris in Earth orbit, regardless of the altitude regime. Today the LEO and GEO protected regions do indeed represent volumes of near-Earth space which should be afforded special status. The establishment of a MEO protected region is currently both unjustified and unnecessary. However, owners and operators of satellites in the MEO region should be encouraged to work bilaterally and multilaterally to avoid potential interference and the creation of unnecessary debris and to coordinate the disposal of space assets which no longer serve a useful purpose.

DISCLAIMER

The opinions in this paper are those solely of the author and do not represent official NASA positions or policy.

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9. *Long-term sustainability of outer space activities, Preliminary reflections,* A/AC.105/C.1/2010/CRP.3, Recommendation C1, Scientific and Technical Subcommittee, Committee on the Peaceful Uses of Outer Space, United Nations, 8 February 2010.

10. *Guidelines and Assessment Procedures for Limiting Orbital Debris,* NASA Safety Standard 1740.14, Chapter 6, August 1995,

11. *U.S. Government Orbital Debris Mitigation Standard Practices*, Section 4, February 2001.

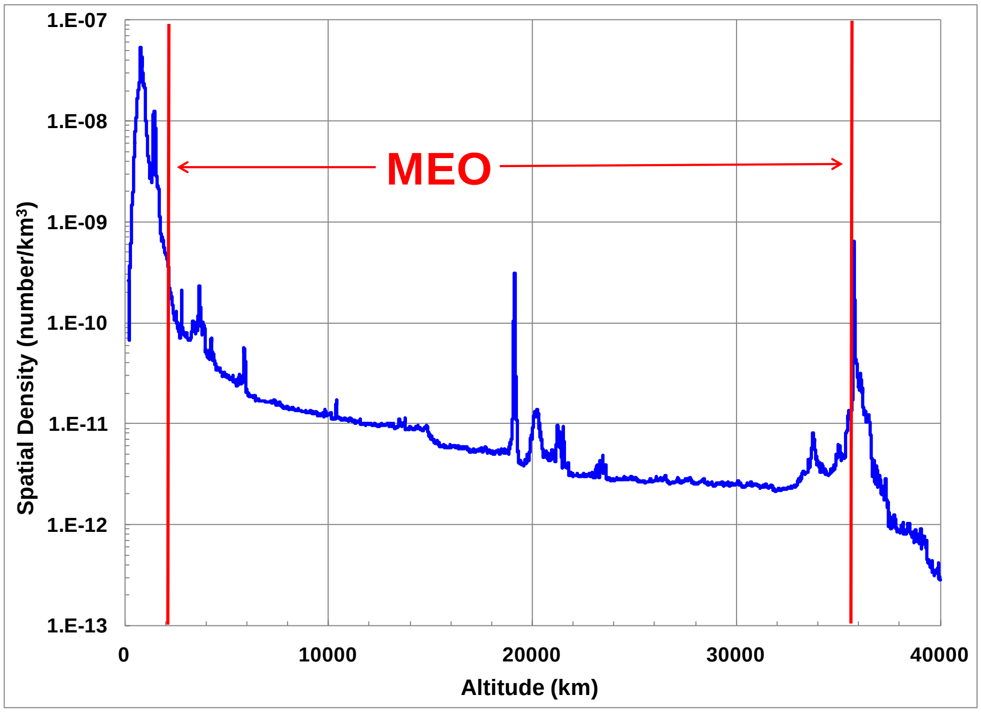

Figure 1. Spatial densities in the MEO regions are less than those in LEO or GEO.

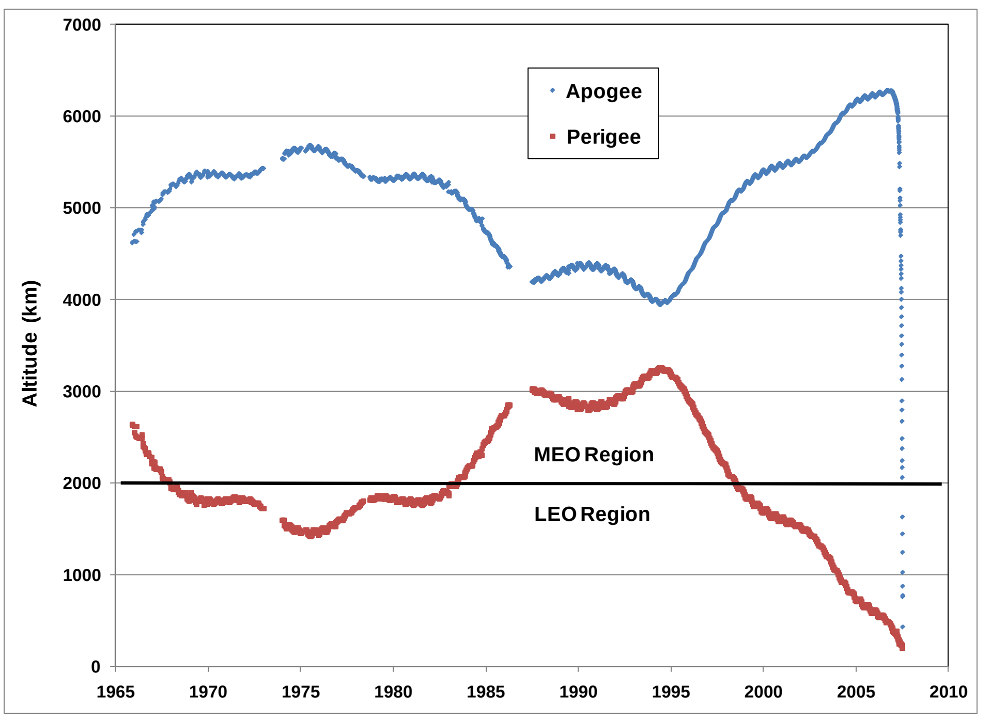

Figure 2. Orbital evolution of one debris (U.S. Satellite Number 2360) from the Project West Ford experiment.

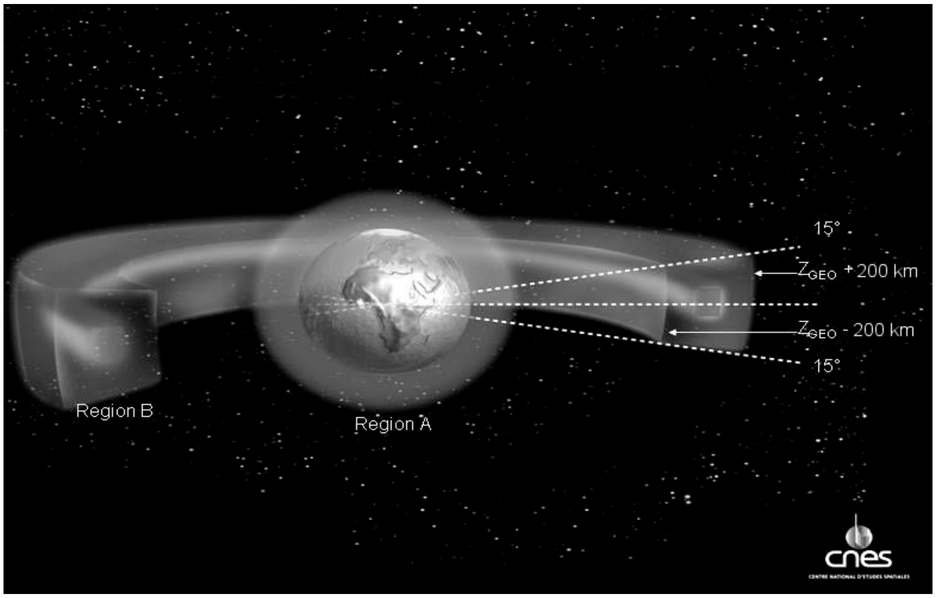

Figure 3. Protected Regions A and B, as defined by the Inter-Agency Space Debris Coordination Committee (IADC) and adopted by the United Nations. The regions are not to scale. (Source: *Support to the IADC Space Debris Mitigation Guidelines*, October 2004)

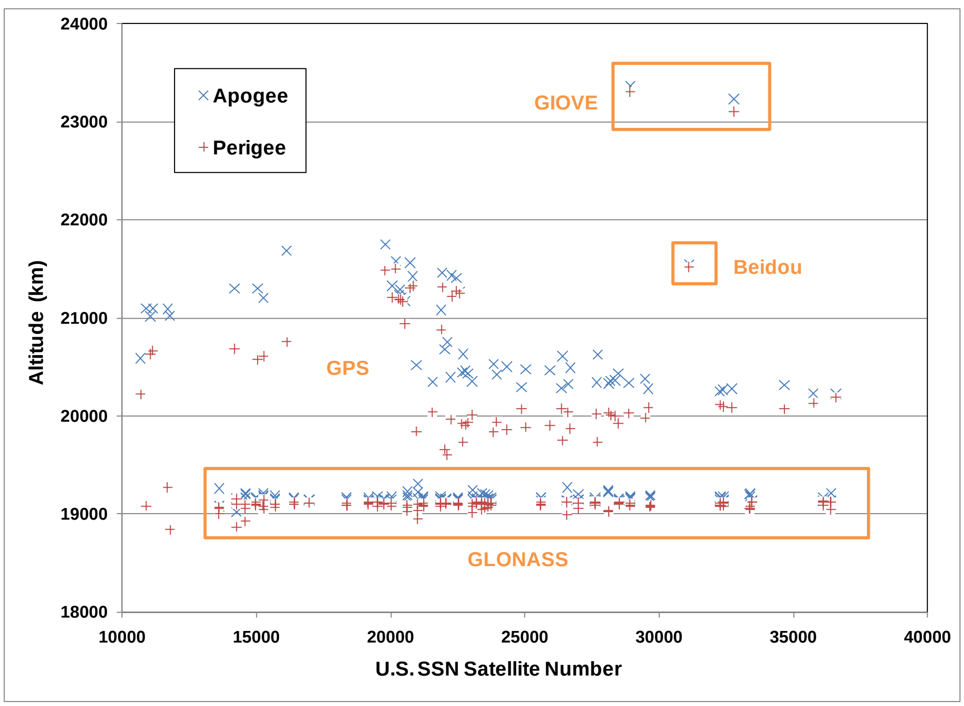

Figure 4. Orbital extremes of the Beidou, GIOVE, GLONASS, and GPS (not enclosed) operational and non-operational spacecraft as of July 2010.

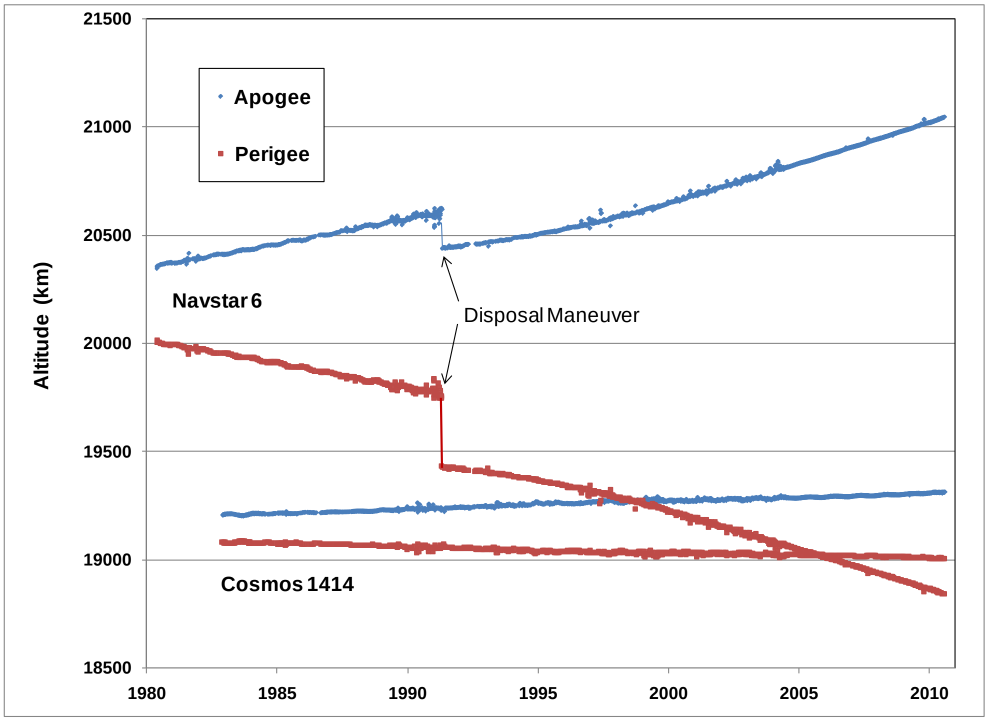

Figure 5. Examples of orbital perturbations for satellites of the GPS constellation (Navstar 6) and the GLONASS constellation (Cosmos 1414).

Table 1. Navigation satellite networks operational or planned for the MEO region.

Space System	Mean Altitude (km)	Inclination (deg)	Nominal Operational Spacecraft	Spacecraft Launched during 2000-2009
GLONASS	19,100	65	24	36
GPS	20,200	55	24	18
Beidou/Compass	21,500	56	27	1
Galileo/GIOVE	23,200	56	30	2