LONG-TERM EVOLUTION OF RETIRED GEOSTATIONARY SATELLITES

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ABSTRACT

The Inter-Agency Space Debris Coordination Committee (IADC) published in 1997 a recommendation to reorbit GEO satellites after the end of their mission into a graveyard orbit about 250 to 300 km above the geostationary altitude. It was also debated whether the final eccentricity should be minimized (to minimize the temporal decrease in the perigee altitude) or even maximized (to spread as much as possible the satellites over the graveyard region). Lately the importance of the argument of perigee was recognized, but still no consensus on the optimum final eccentricity vector is reached.

In this paper, the orbital evolution of the GEO spacecraft, which were reorbited below 300 km in the years 2003, 2004 and 2005, is studied. Two-Line Element data is used to fit the area-to-mass ratio of the satellites. The results are used to propagate the spacecraft 200 years into the future. The effects of the luni-solar perturbations, the solar radiation pressure and the non-sphericity of the Earth will be analyzed. Special attention will be given to the evolution of the eccentricity for which an oscillation period of about 10.5 years is observed.

1. INTRODUCTION

The increasing number of satellites in the geostationary orbit together with the limitations of this valuable and unique ring require the removal of retired satellites from this orbit. This orbit is currently populated by more than 300 operational satellites and it has a total population of 1036 objects as it was presented by Jehn, Agapov and Hernandez (2005).

Due to the absence of atmospheric drag the retired satellites stay in their orbit for a long period of time. Therefore maneuvers are necessary to remove these satellites from the orbit as it was proposed already by Perek (1977). Meanwhile also national and international agencies have recommended sending the retired satellites to a graveyard orbit as mentioned by Johnson (1999) and UNCOPUOS (1999).

Several different distances above GEO were recommended for the graveyard orbit: NOAA (300 km), Roth (400-500 km) (1983) and United Kingdom (more than 400 km) (CCIR, 1984).

Jehn, Agapov and Hernandez (2005) presented the deviation of the satellites from GEO and it shows that retired satellites should be sent to a graveyard orbit with enough distance to avoid collisions between reorbited objects with the active satellites.

However, the Inter-Agency Space Debris Coordination Committee (IADC) defined GEO region as (2002):
"A segment of the spherical shell defined by the following:

$$Z_{GEO} - 200 \text{ km} \leq \text{altitude} \leq Z_{GEO} + 200 \text{ km}$$
$$-15 \text{ degrees} \leq \text{latitude} \leq +15 \text{ degrees}"$$

with geostationary altitude (Z_{GEO}) equal to 35 786 km.

IADC also published a recommendation to reorbit GEO satellites after the end of their mission into a graveyard orbit about 250 to 300 km above the geostationary altitude (1997). This decreases the risk of collision of retired satellites with active objects in GEO, although, long-term evolution of the graveyard orbit due to perturbations is not considered. Different perturbation sources can affect these orbits in long term. These sources are: geopotential, luni-solar gravitational attractions, solar radiation pressure, potential collisions with micrometeoroids, solar wind, etc.

In this paper a 200-year propagation of orbital elements of some of the satellites retired during 2003 - 2005 is given.

2. PERTURBATIONS IN THE GEOSTATIONARY ORBIT

Satellites in GEO (and in its vicinity) are subject to perturbing forces as described below:

2.1. Third-Body Perturbations

The gravitational forces of the Sun and the Moon cause periodic variations in all of the orbital elements, but only the longitude of the ascending node, argument of perigee, and mean anomaly experience secular variations. These secular variations arise from a gyroscopic precession of the orbit about the ecliptic pole. The secular variation in mean anomaly is much smaller than the mean motion and has little effect on the orbit; however the secular variations in longitude of the ascending node and argument of perigee are important, especially for high-altitude orbits.

2.2. Perturbations due to a Non-Spherical Earth

When developing the two-body equations of motion, it was assumed that the Earth was a spherically symmetrical, homogeneous mass. In fact, the Earth is neither homogeneous nor spherical. The most dominant features are a bulge at the equator, a slight pear shape, and flattening at the poles. For a potential function of the Earth, we can find a satellite's acceleration by taking the gradient of the potential function. The most widely used form of the geopotential function depends on latitude and geopotential coefficients, J_n, called the zonal coefficients. The potential generated by the non-spherical Earth causes periodic variations in all the orbital elements. The dominant effects, however, are secular variations in longitude of the ascending node and argument of perigee because of the Earth's oblateness, represented by the J_2 term in the geopotential expansion. For satellites in GEO and below, the J_2 perturbations dominate; for satellites above GEO the Sun and Moon perturbations dominate.

2.3. Perturbations from Solar Radiation Pressure

Solar radiation pressure causes periodic variations in all of the orbital elements. The eccentricity is affected most. Perigee and apogee vary annually approximately by 1500 times the area-to-mass ratio given in square meter per kg. For a typical satellite this is about 15 to 30 km.

3. LONG-TERM EVOLUTION OF RETIRED SATELLITES

29 satellites were reorbited during 2003 and 2004. Only 13 of these satellites fulfilled the requirements from IADC (IADC, 2002) and were reorbited into a proper graveyard orbit. 12 spacecrafts were reorbited to an altitude below the recommended value and 4 spacecraft were abandoned completely. In this paper the orbits of 11 retired satellites (Tab. 1) are propagated 200 years into future. The propagator which is used is LEGO (Long term Evolution of Geostationary and near-geostationary Orbits) developed by Van Der Ha (1980). This propagator implements the effects of the luni-solar perturbations, the solar radiation pressure and the non-sphericity of the Earth.

Table 1. Retired satellites which are analyzed in this paper

COSPAR ID	Name	Retirement year	Km above GEO[1]
89067A	Sirius 1	2003	285 x 330
90030A	Asiasat 1	2003	279 x 303
90074A	Thor I	2003	284 x 317
90079B	Eutelsat II-F1	2003	236 x 288
92060A	Hispasat 1A	2003	249 x 291
85109B	Morelos 2	2004	181 x 220
86026B	Brazilsat 2	2004	168 x 188
92021A	Telecom 2B	2004	194 x 224
93048B	Insat IIB	2004	9 x 161
97078A	Galaxy 8-i	2004	144 x 178
91083A	Eutelsat II F-3	2005	270 x 287

[1] In Dec 2004 according to Serraller and Jehn (2005)

Fig. 1 presents perigee and apogee evolution of the retired satellites listed in Table 1. It can be seen that Hispasat 1 A and Eutelsat II-F-1 stay always more than 200 km above GEO in spite of their rather low initial perigee. They can therefore be considered as reorbited fulfilling the IADC guidelines.

Fig. 1 also shows a periodic variation of the eccentricities. In all 11 cases a period of about 10.5 years can be observed. The Sun and Moon perturbations which are the main forces to cause this oscillation would produce a period of 8 to 9 years but combined with the most dominant terms in the geo-potential, the eccentricity reaches a maximum every 10.5 years.

In a truly geostationary orbit, the inclination and eccentricity are equal to zero and right ascension of the ascending node and argument of perigee are undefined. For a retired satellite when the orbit is affected by perturbations there are small changes in right ascension of the ascending node and argument of perigee and two different vectors can be used to show orbital properties. These two vectors are inclination vector and the eccentricity vector [e*cos(ω), e*sin(ω)]. Fig. 2 shows the eccentricity vector evolution of some of the retired satellites in 2003 (from Sep. 2003 to Dec. 2004). It can be seen that the eccentricity vector performs a full circle in one year. It can also be seen that the Two-Line-Element data is quite "jumpy", meaning that one should not rely too much on individual TLEs, but rather look at a whole set, to average out the outliers.

To reduce the risk of entering of reorbited objects into GEO it is efficient to try to reduce eccentricity changes of the object. This can be done by a so-called "Sun-pointed eccentricity vector".

The reason why the eccentricity vector should be Sun-pointed is the solar radiation pressure. Solar radiation's effects are dependent on epoch, area-to-mass ratio of the perturbed object, its distance from the Sun and initial orbit shape, i.e. eccentricity vector.

4. CONCLUSIONS

The orbital analysis of retired GEO spacecraft has shown that satellites can be placed between 250 and 300 km above GEO without them entering into the protected 200-km zone over long periods of time (200 years and probably much more). However, an initially Sun-pointing eccentricity vector is recommended. To be on the safe side (and consuming all the remaining fuel) some operators (8 out of 29) have reorbited their spacecraft more than 300 km above GEO. 5 spacecrafts were reorbited with the perigee altitude between 250 and 300 km above GEO. They will stay permanently 200 km above GEO. Unfortunately 16 out of the 29 spacecraft that reached end-of-life in 2003 and 2004 did not comply with the recommended reorbiting practice. In order to preserve the unique resource of the geostationary ring, a more rigorous implementation of the IADC guidelines is indispensable.

5. ACKNOWLEDGEMENTS

The authors thank Prof. Tetsuichi Ito at ISU for his advice, Eduardo Bellido for providing information on Eutelsat spacecraft and Nikola Pavkovic for his help with the installation of the LEGO software.

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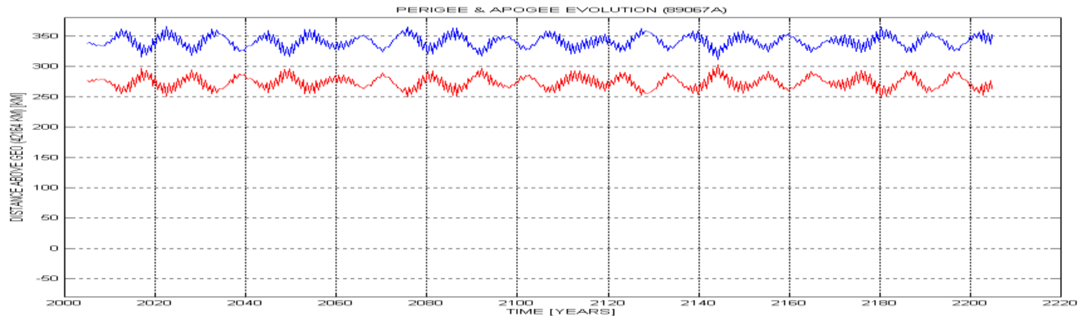
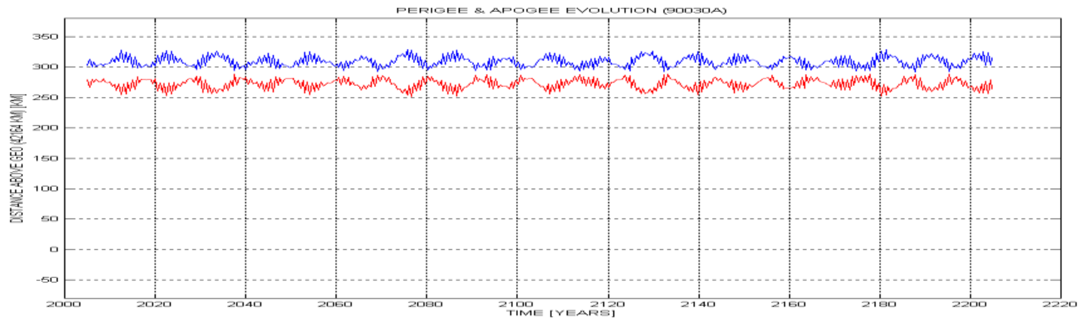
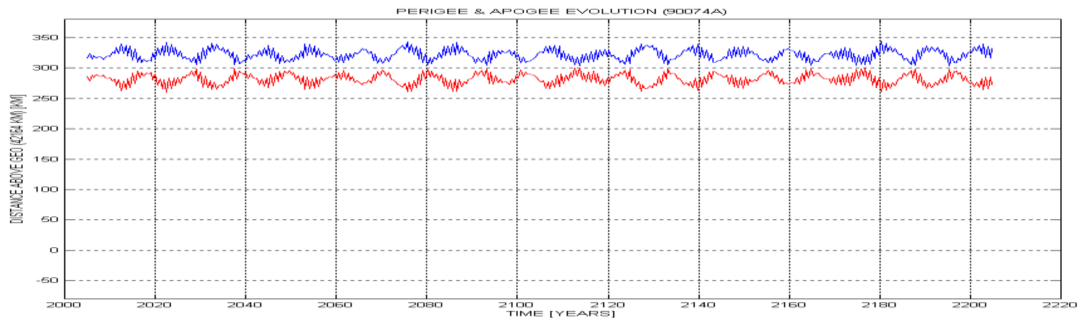
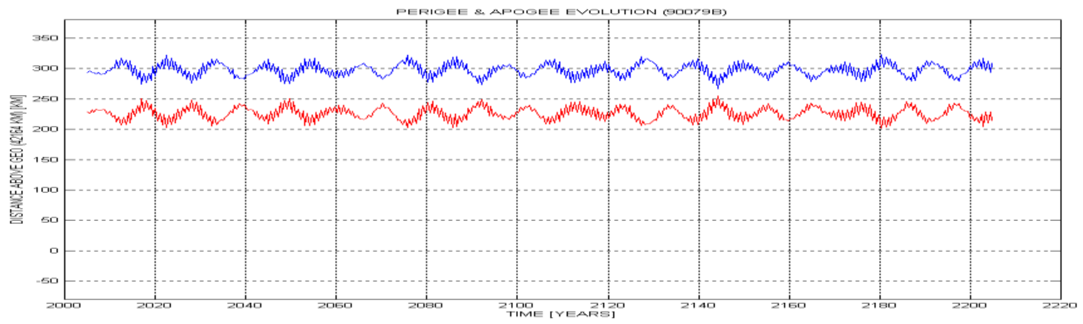
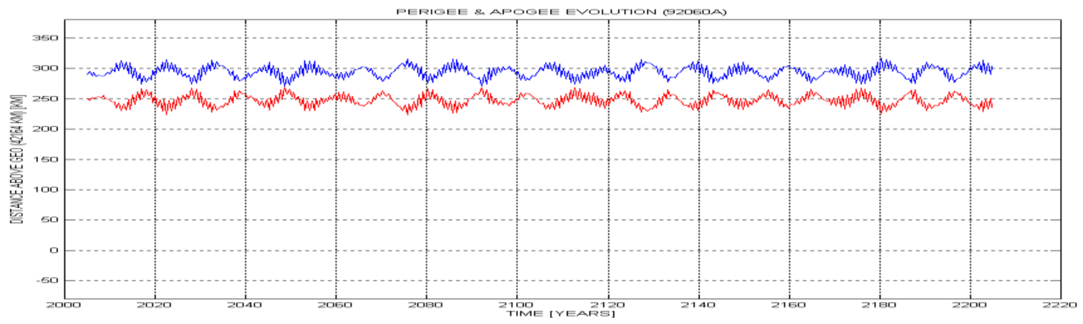
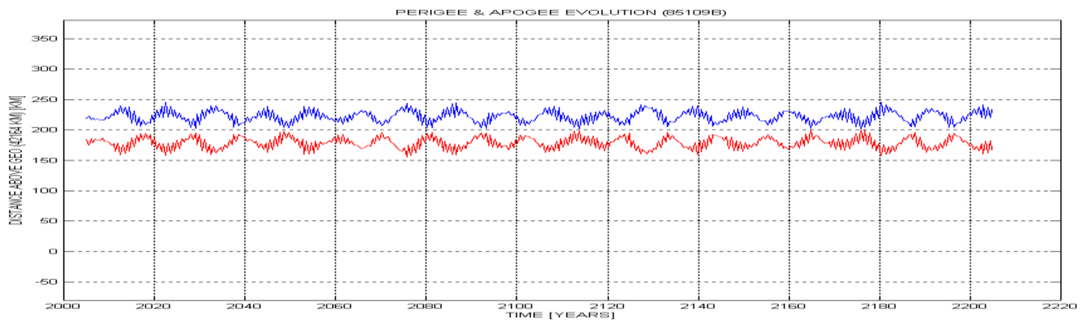
	89067A
	90030A
	90074A
	90079B
	92060A



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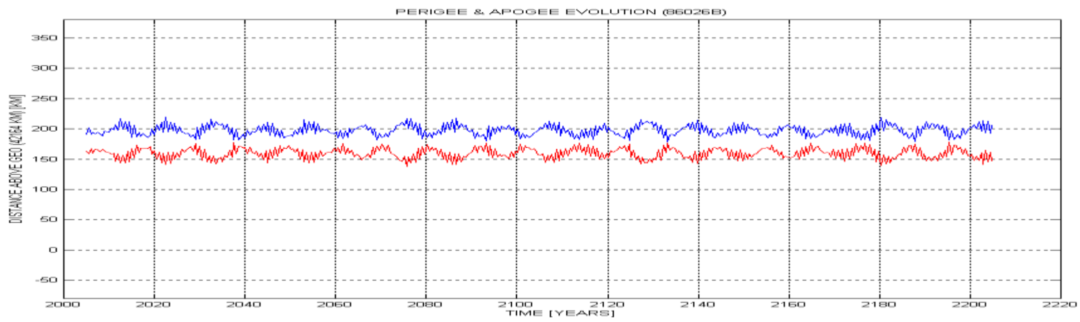

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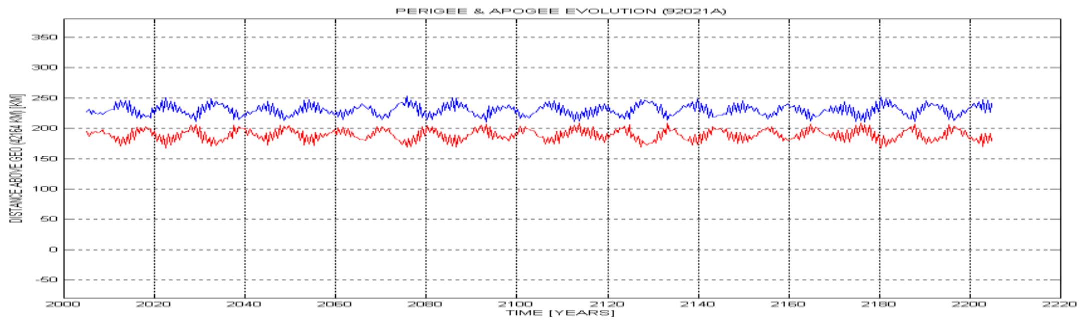

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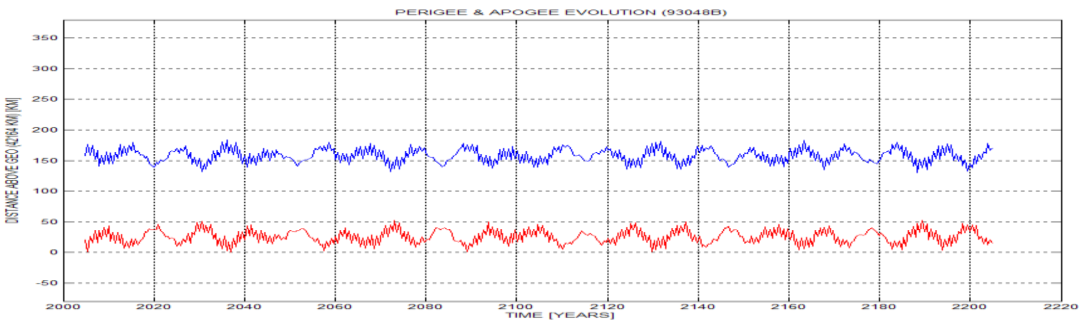

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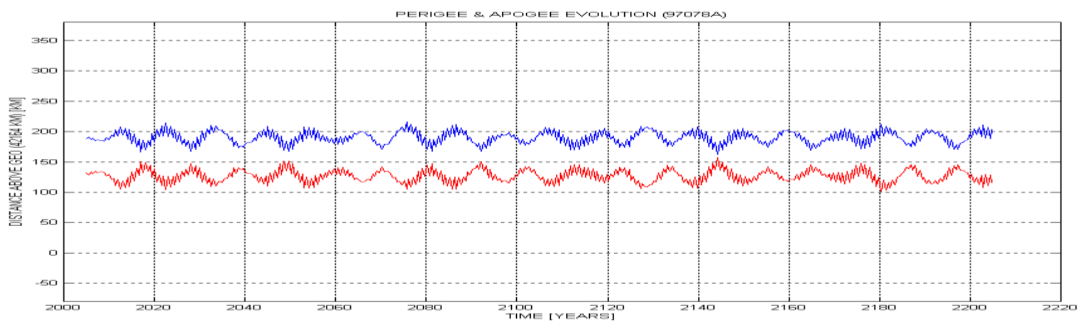

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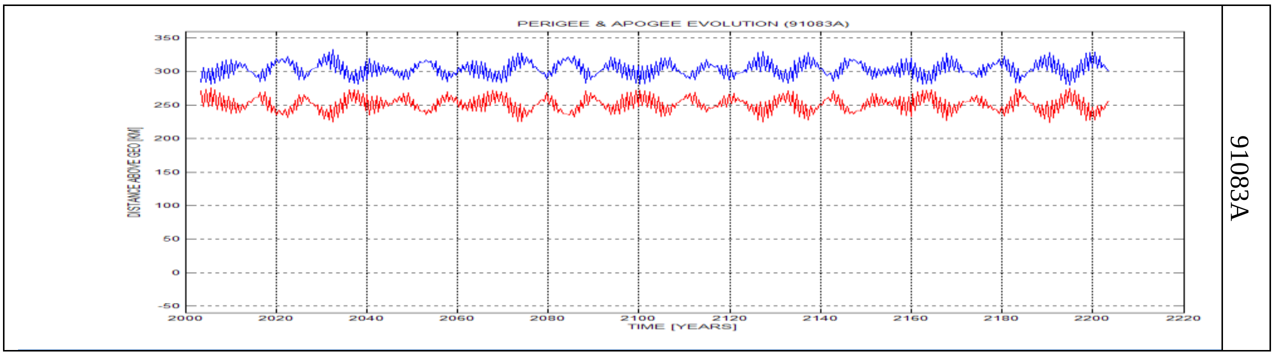

Figure 1. Long-term evolution of perigee and apogee of the retired satellites listed in Table 1. The area-to-mass ratios of the objects were set to 0.01 m^2/kg except for 91083A where a value of 0.0145 was used.

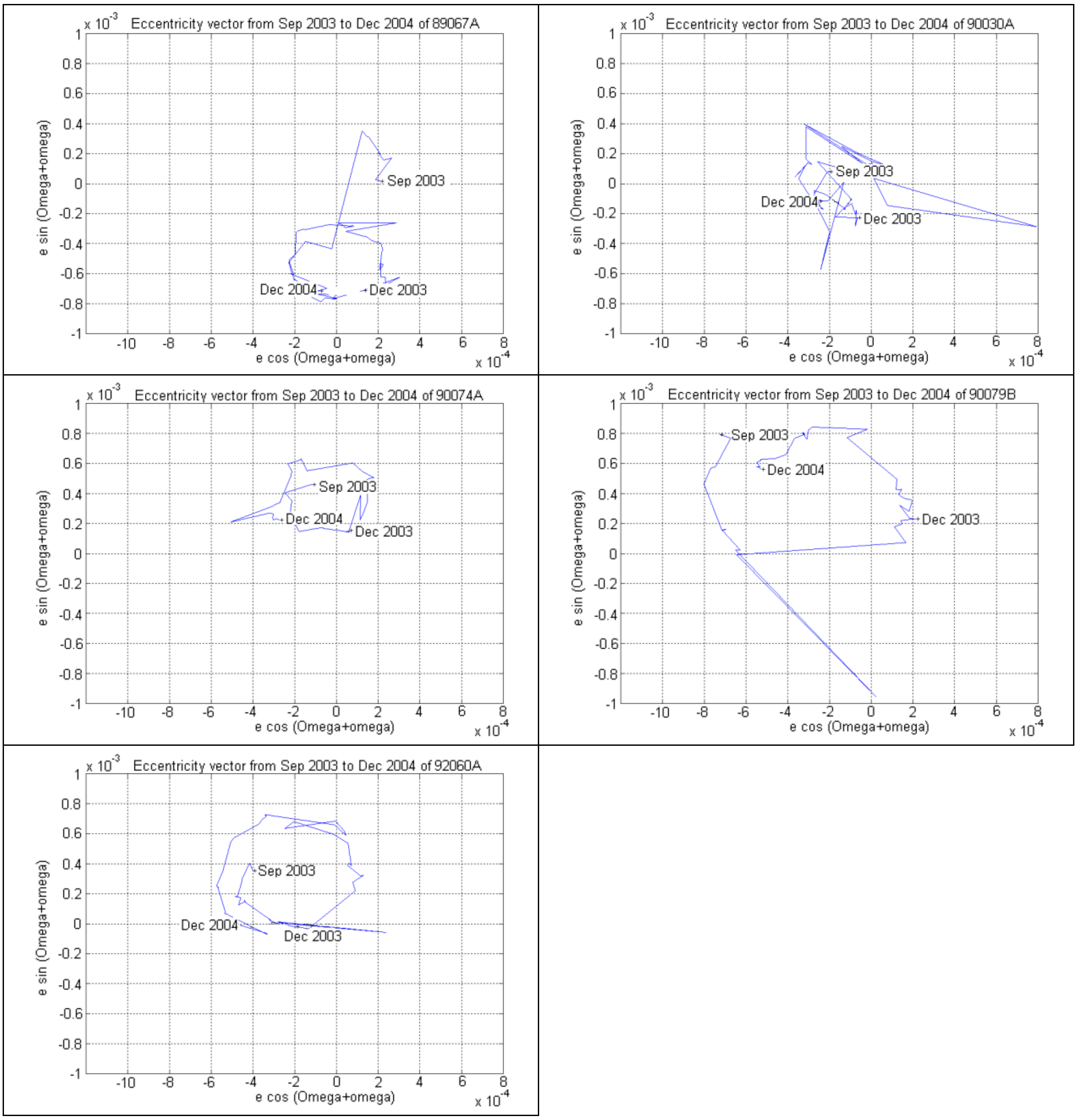

Figure 2. Evolution of Two-Line-Element eccentricity vector of the 5 satellites which where reorbited in 2003 between 250 and 300 km above GEO.