

GEO Disposal Orbit Eccentricity

IADC Action Item 22.1

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IADC WG-4 – ASI (ISTI/CNR)
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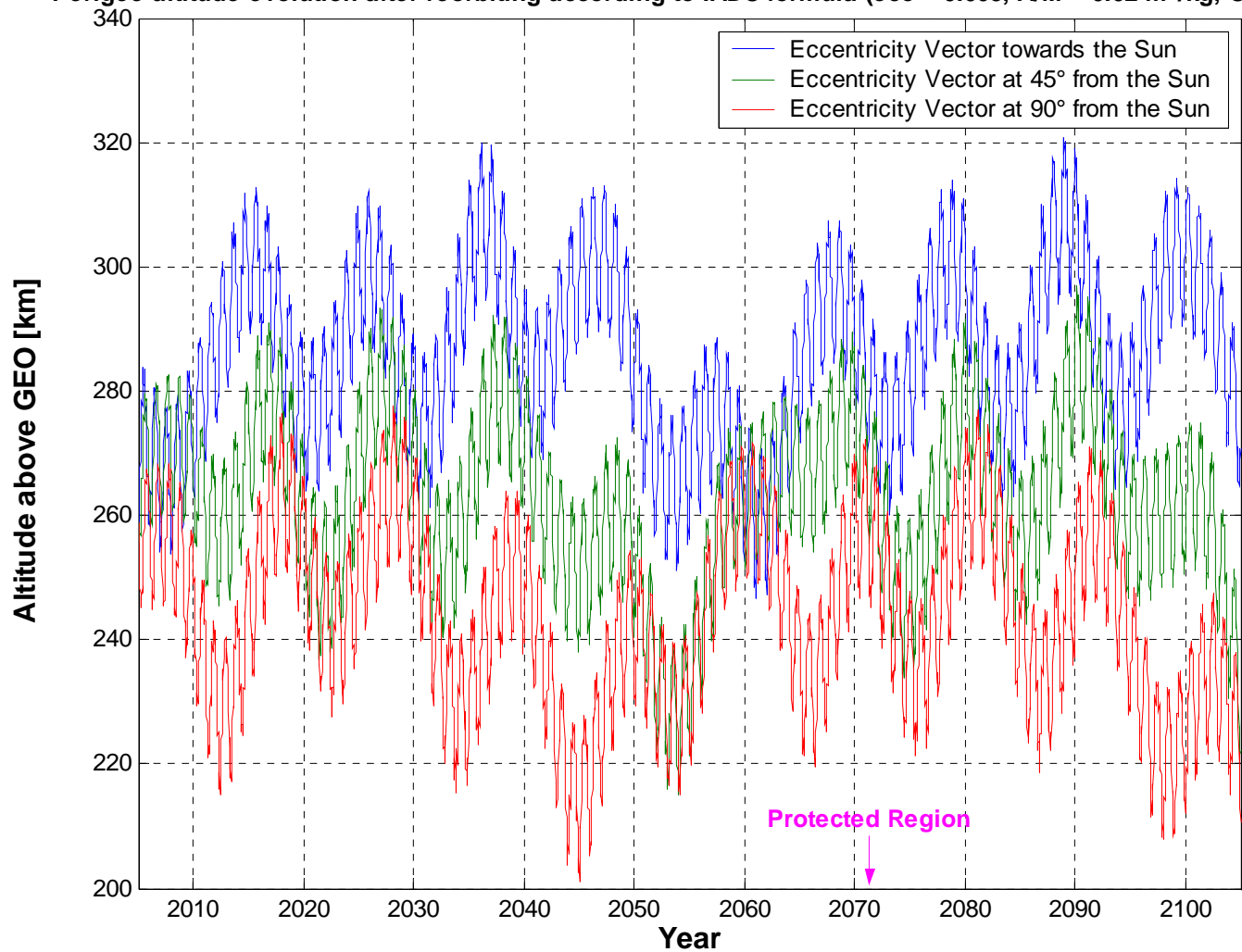
Propagation Model and Options

- Semi-analytical long-term orbit predictor (variation of parameters, mean anomaly removed before numerical integration)
- Terms with mean anomaly retained in resonant tesseral harmonics
- Geopotential harmonics up to the 8th order and degree, only resonant tesserals included in the computation
- Luni-solar attraction
- Solar radiation pressure with eclipses

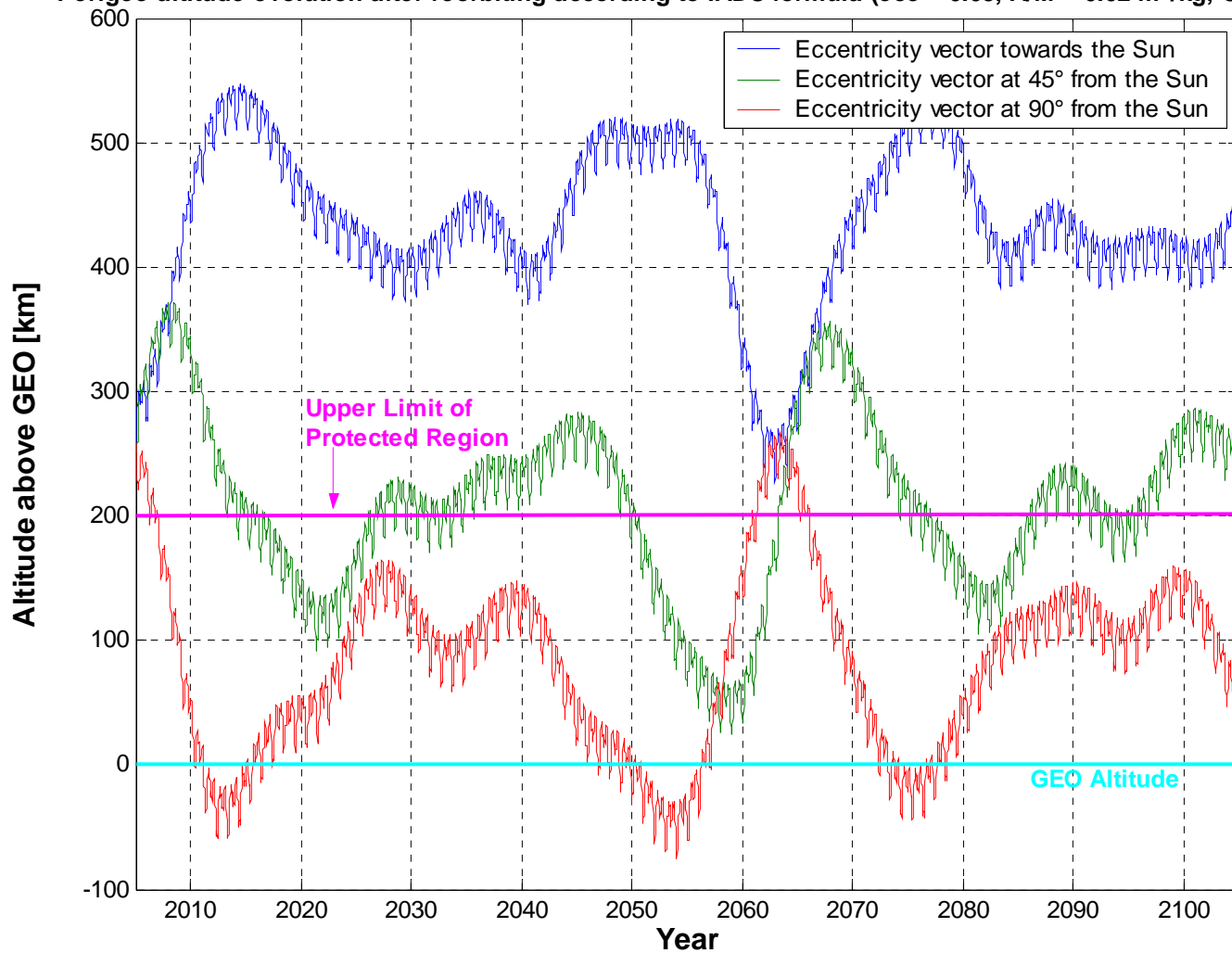
IADC AI 22.1 (GEO Disposal Orbit Eccentricity) Study Parameters

Initial angle between Sun and perigee direction	0 deg, +45 deg, +90 deg
Initial eccentricity	0.005, 0.05, 0.1
Initial inclination	0.1 deg
Initial right ascension of ascending node	90 deg
Initial mean anomaly	0 deg
Initial perigee altitude above GEO	ΔH , $2 \times \Delta H$, $3 \times \Delta H$
Spacecraft area-to-mass ratio	$0.02 \text{ m}^2/\text{kg}$
Spacecraft radiation pressure coefficient (C_r)	1.2
ΔH , $2 \times \Delta H$, $3 \times \Delta H$	259 km, 518 km, 777 km
Initial argument of perigee: 0 deg w.r.t. the Sun	191.6 deg
Initial argument of perigee: +45 deg w.r.t. the Sun	236.6 deg
Initial argument of perigee: +90 deg w.r.t. the Sun	281.6 deg
Reference epoch for the propagations	1 January 2005, 00:00 UTC
Propagation time span	100 years

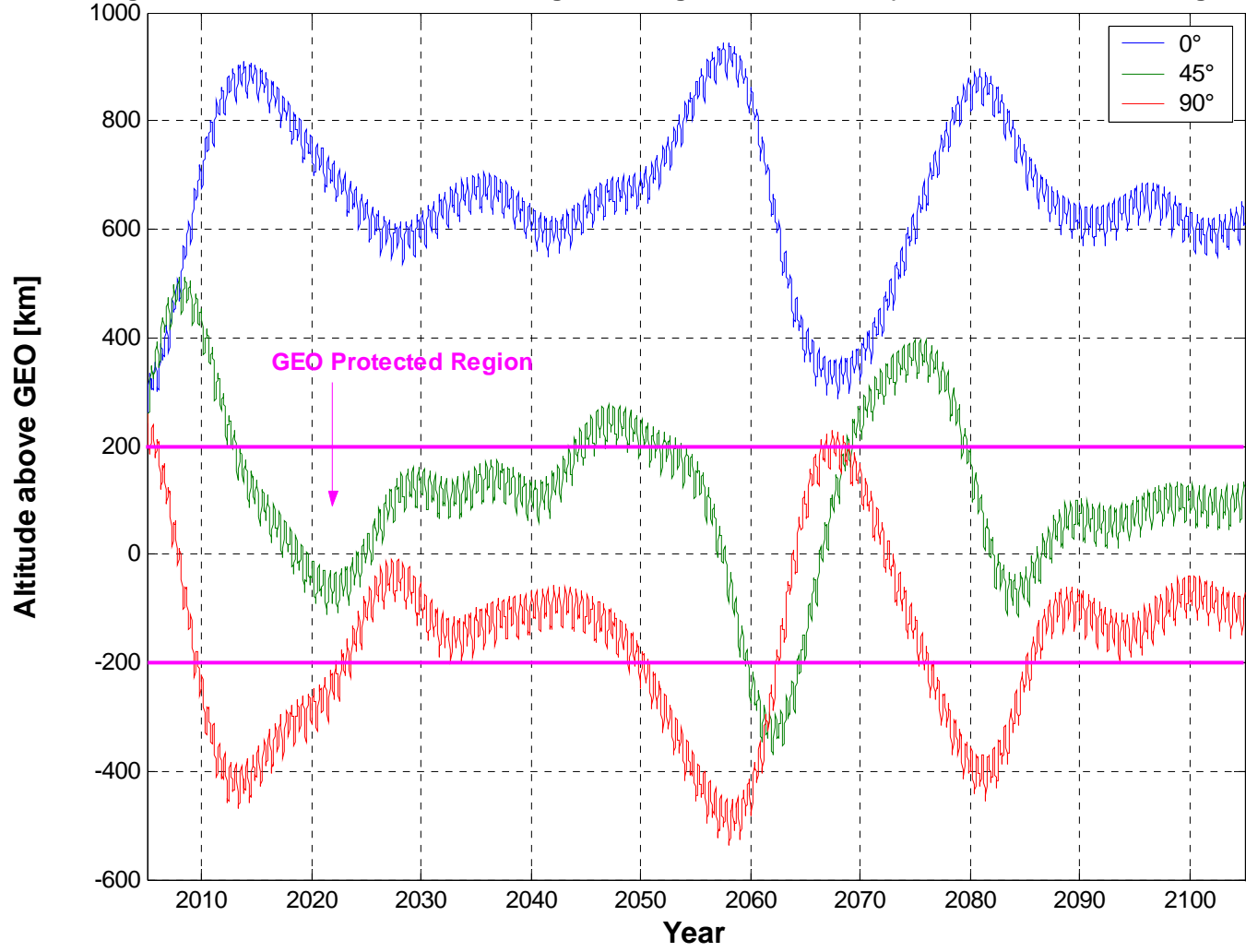
Perigee altitude evolution after reorbiting according to IADC formula ($\text{ecc} = 0.005$, $A/M = 0.02 \text{ m}^2/\text{kg}$, $\text{Cr} = 1.2$)



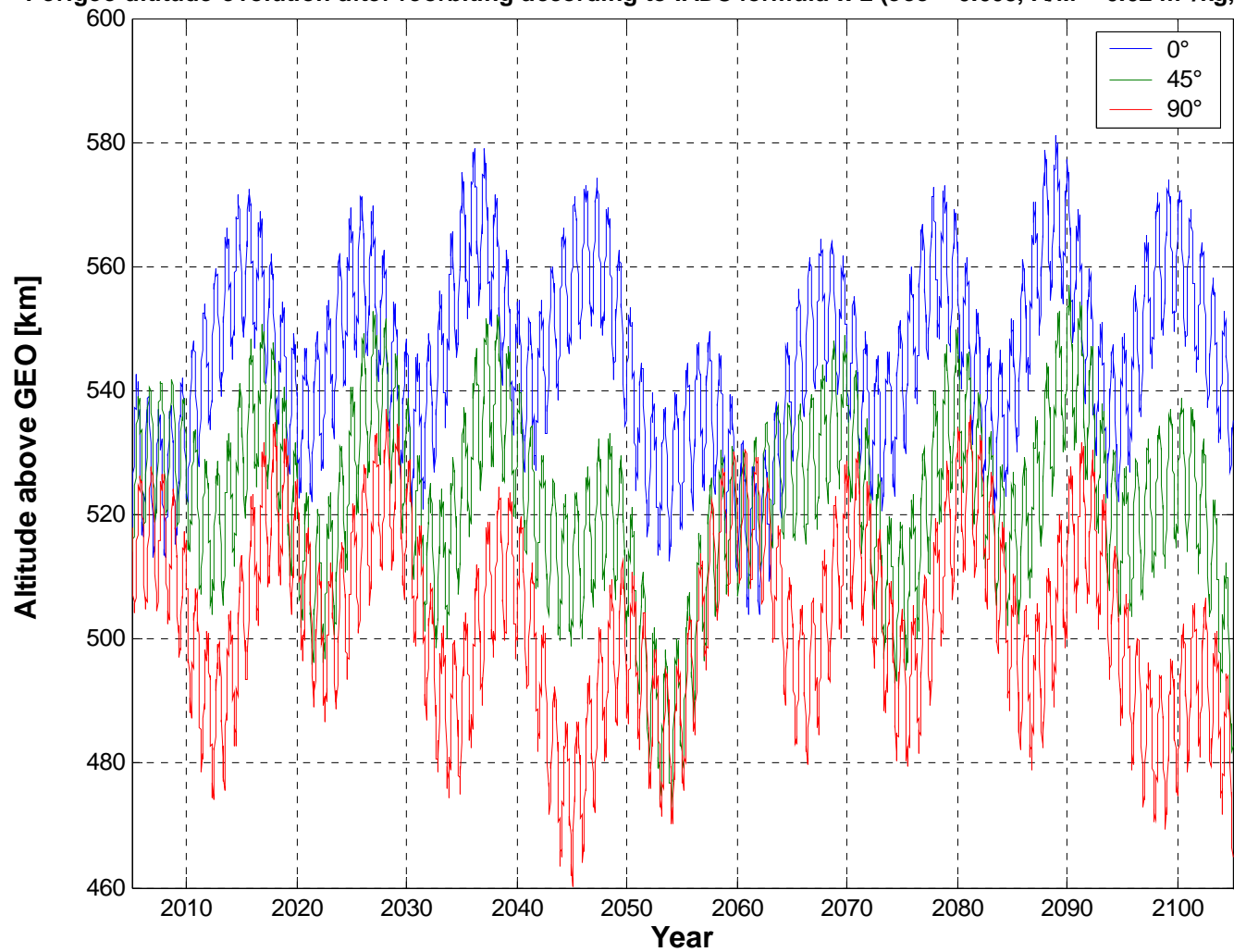
Perigee altitude evolution after reorbiting according to IADC formula (ecc = 0.05, A/M = 0.02 m²/kg, Cr = 1.2)



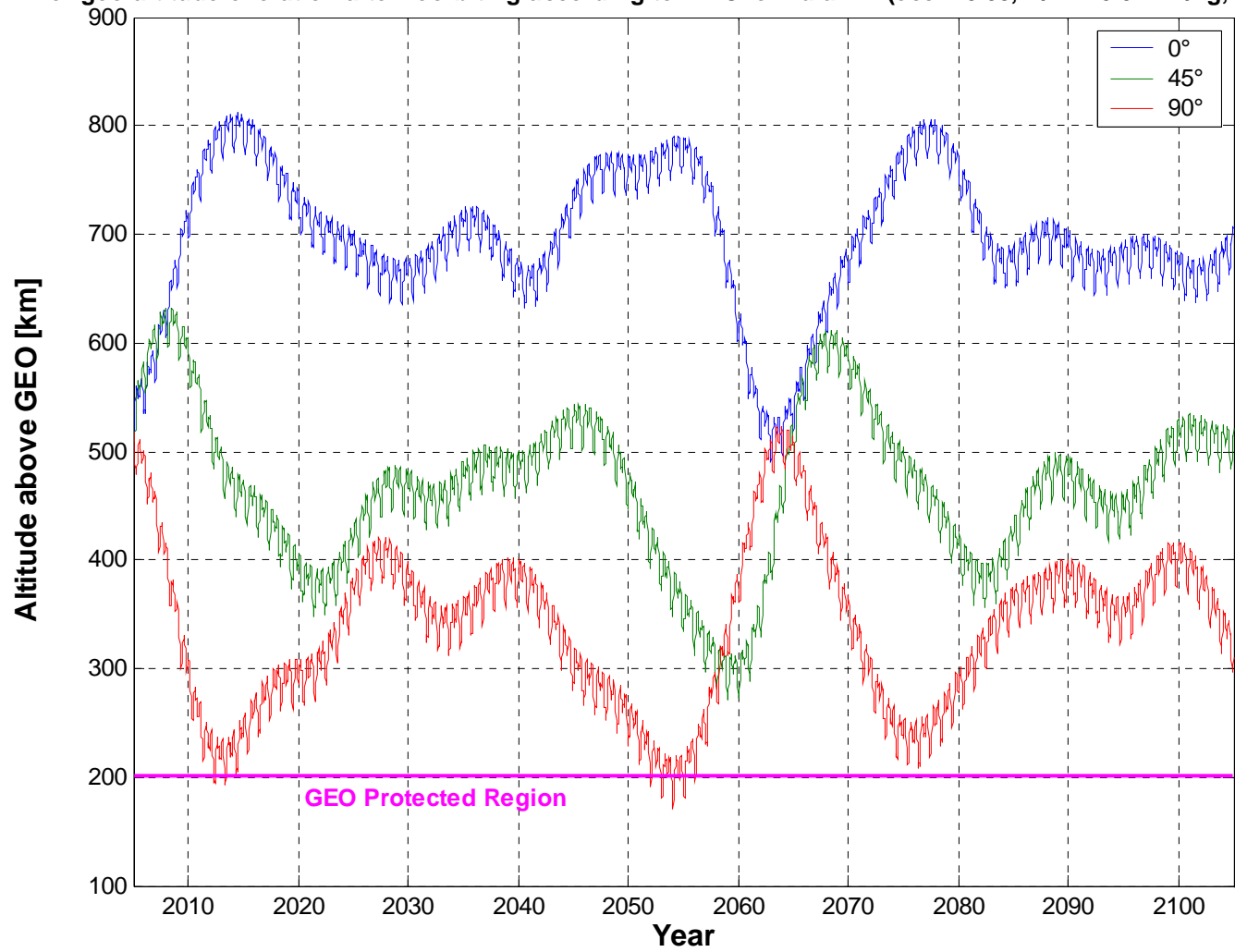
Perigee altitude evolution after reorbiting according to IADC formula (ecc = 0.1, A/M = 0.02 m²/kg, Cr = 1.2)



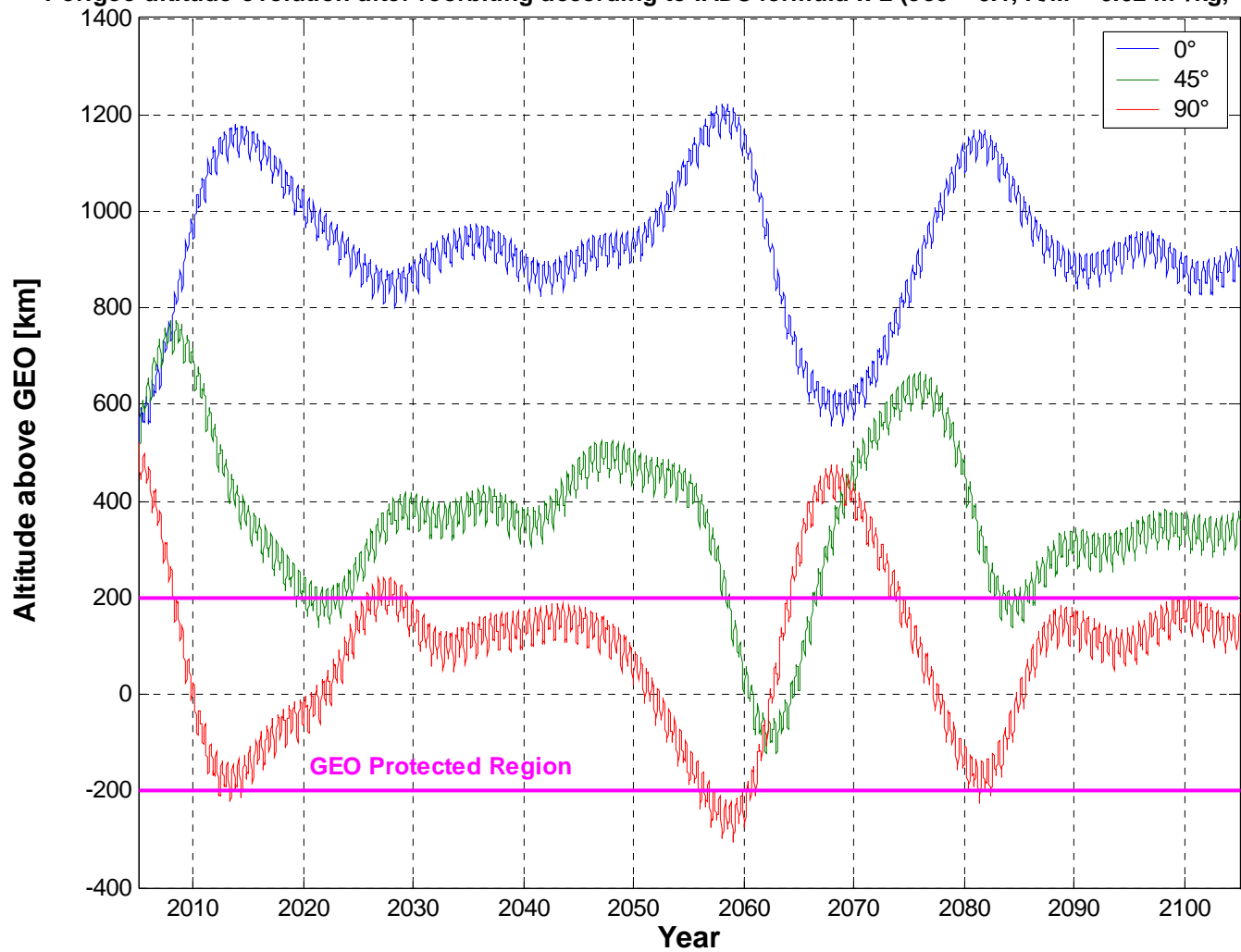
Perigee altitude evolution after reorbiting according to IADC formula x 2 (ecc = 0.005, A/M = 0.02 m²/kg, Cr = 1.2)



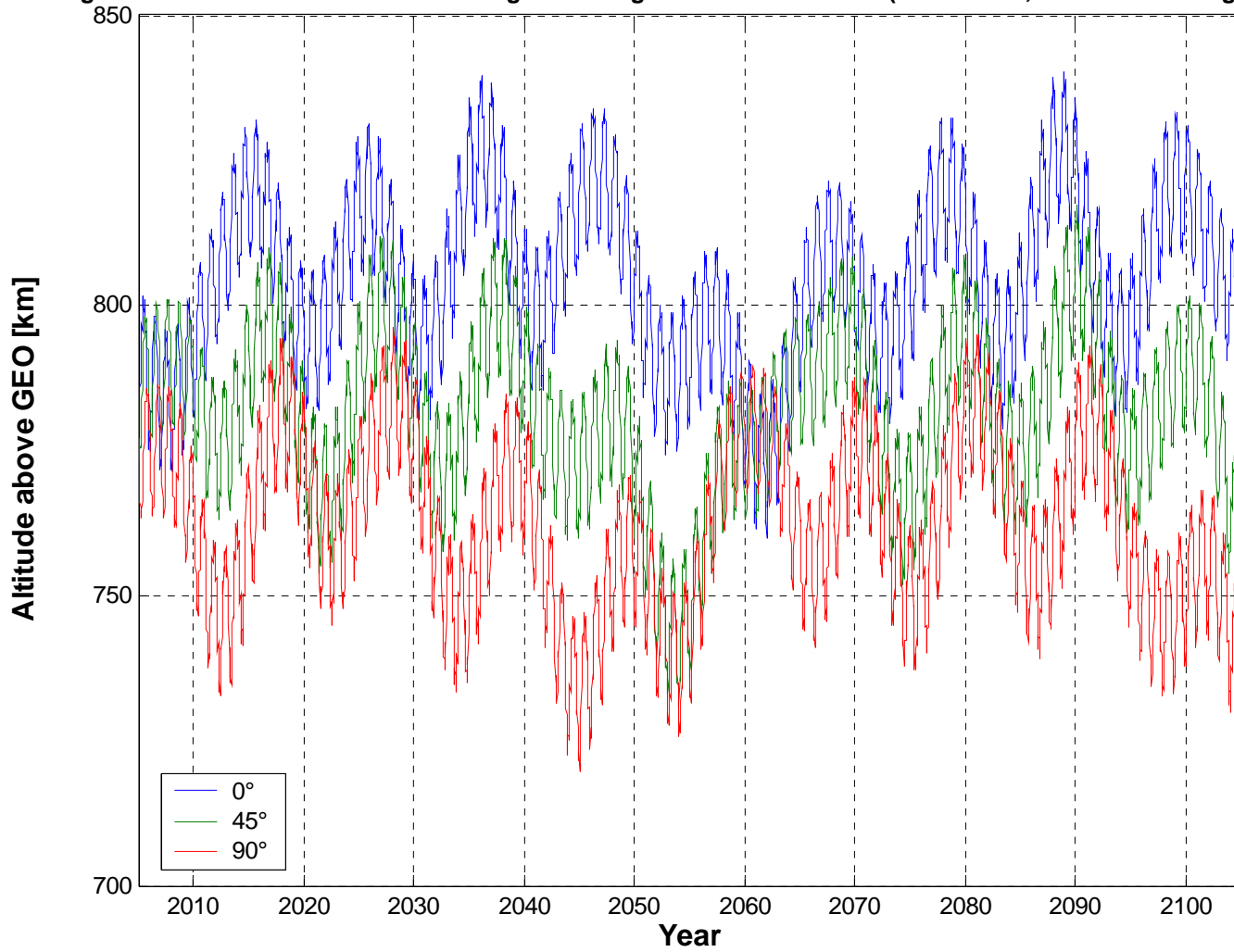
Perigee altitude evolution after reorbiting according to IADC formula x 2 (ecc = 0.05, A/M = 0.02 m²/kg, Cr = 1.2)



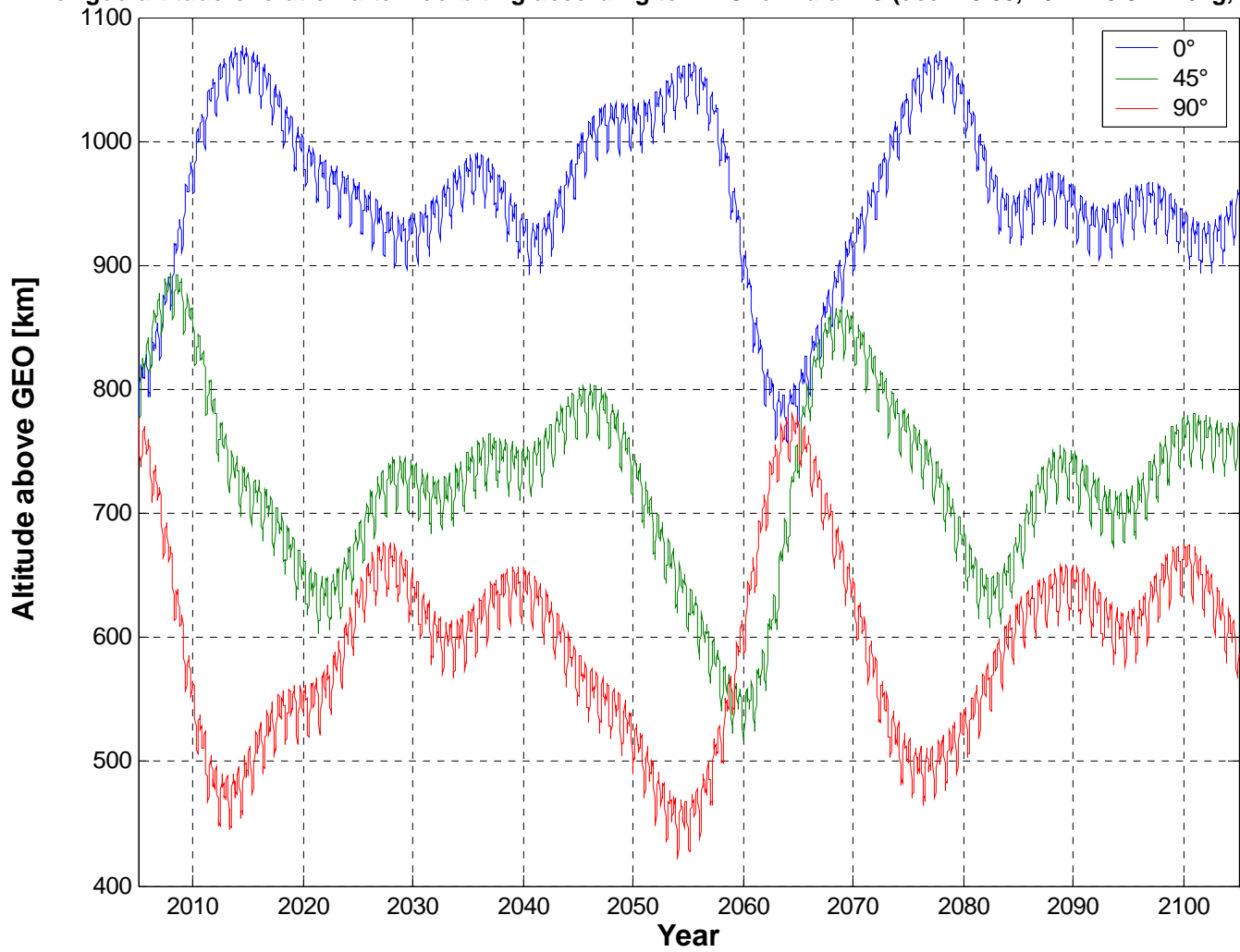
Perigee altitude evolution after reorbiting according to IADC formula x 2 (ecc = 0.1, A/M = 0.02 m²/kg, Cr = 1.2)



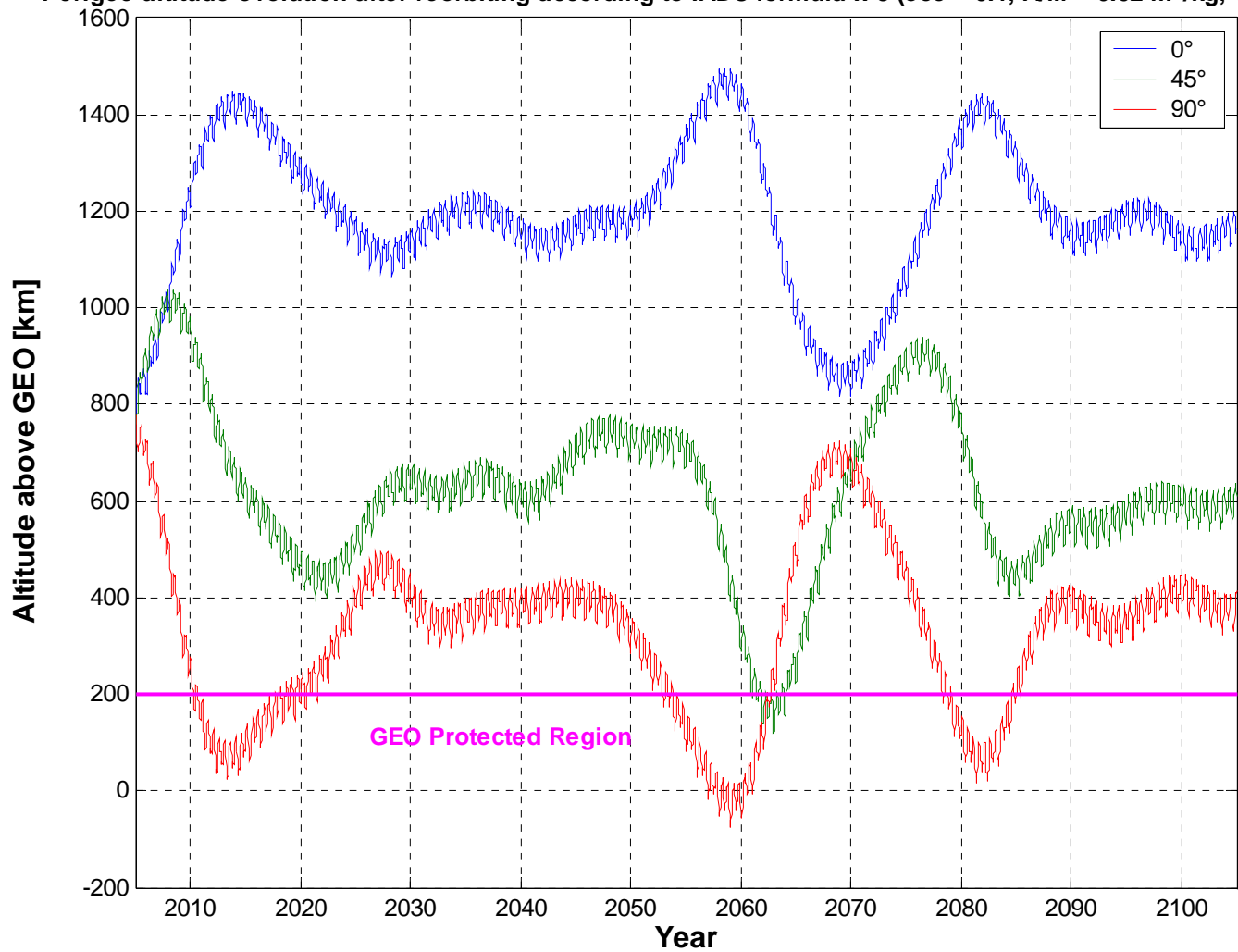
Perigee altitude evolution after reorbiting according to IADC formula x 3 (ecc = 0.005, A/M = 0.02 m²/kg, Cr = 1.2)



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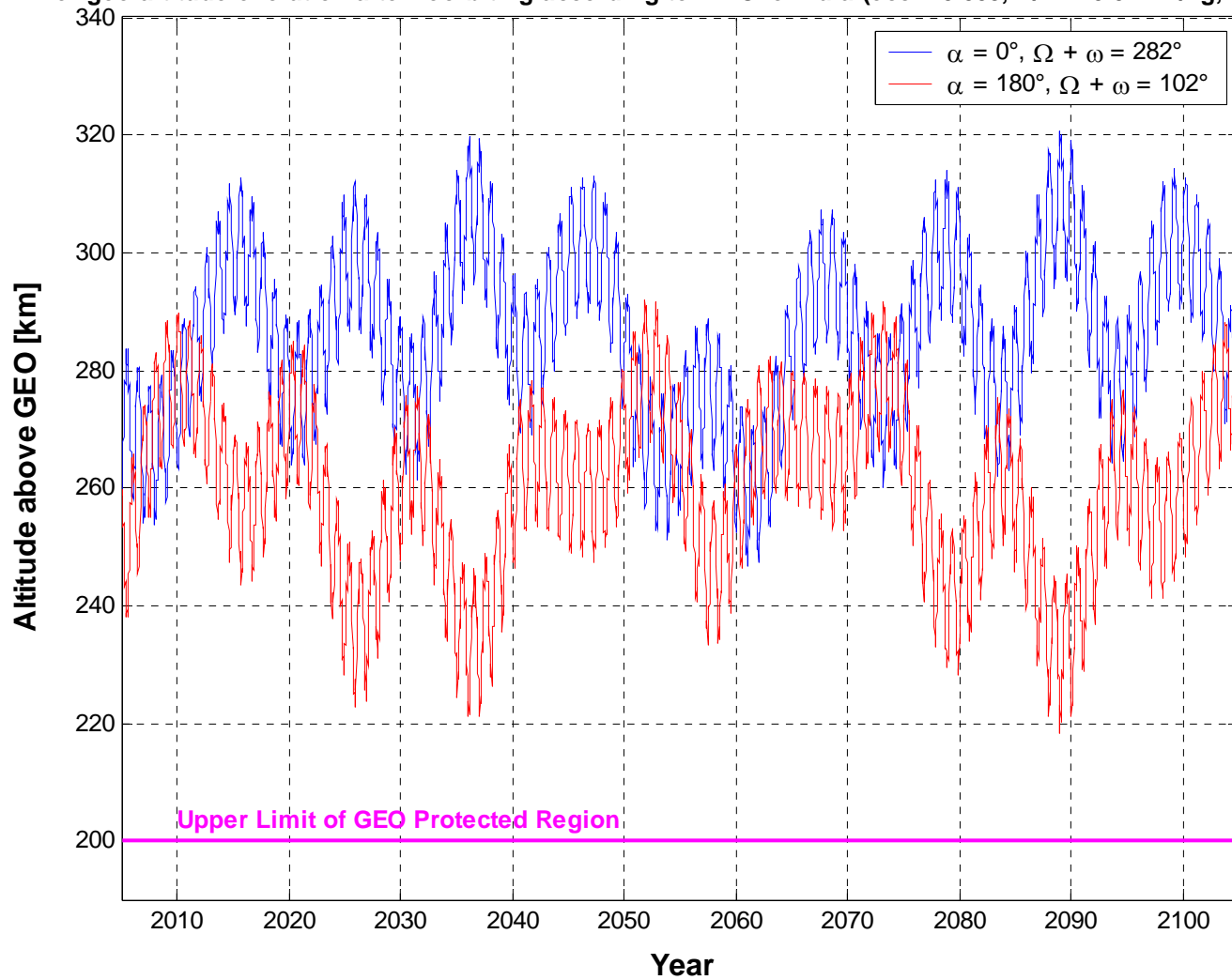
Perigee altitude evolution after reorbiting according to IADC formula x 3 (ecc = 0.1, A/M = 0.02 m²/kg, Cr = 1.2)



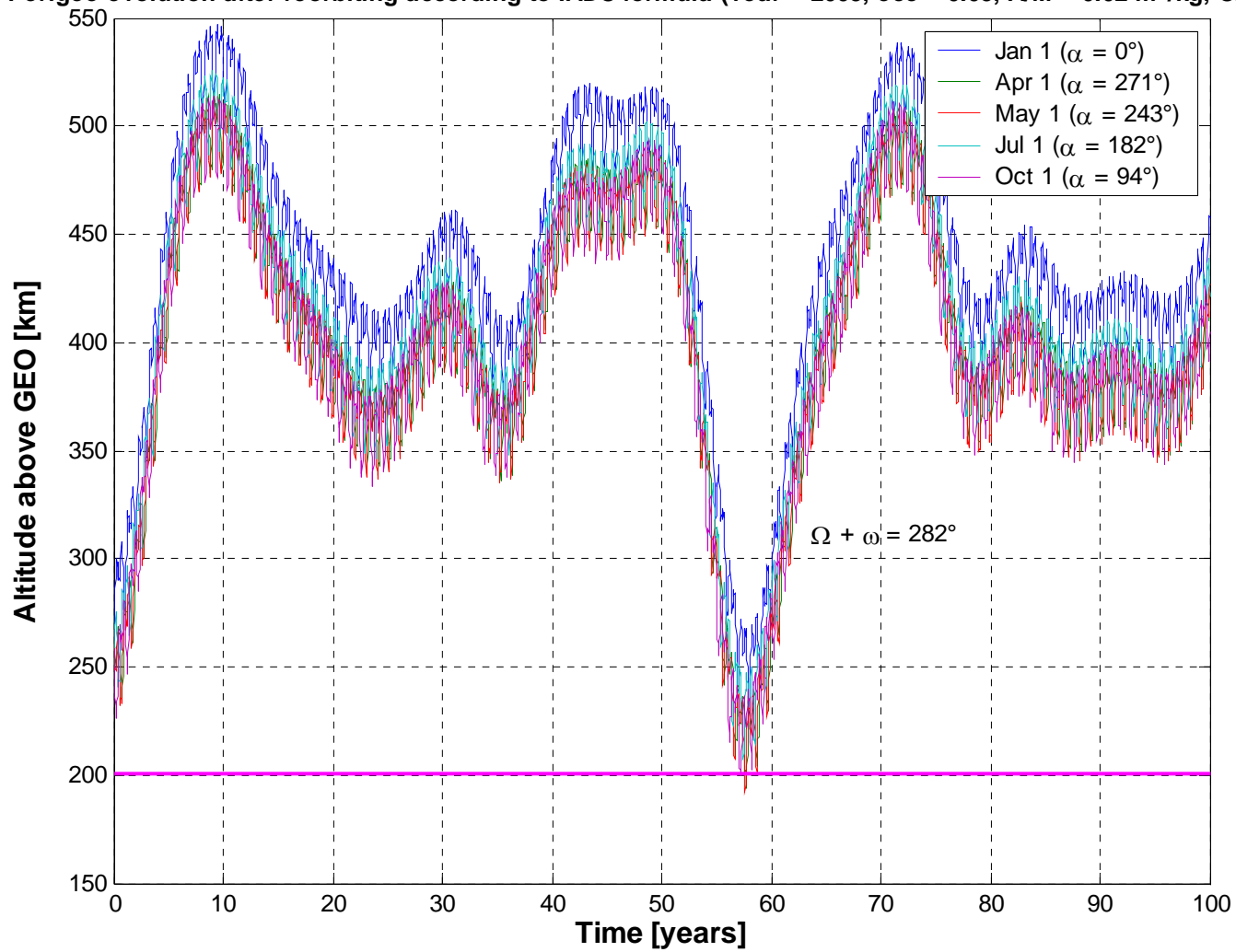
Preliminary Conclusions

- The study initial conditions (in particular $\Omega + \omega$) were too specific to reach general conclusions
- In reality the perigee evolution is strongly affected by the initial conditions (e.g. eccentricity, $\Omega + \omega$, etc...) and by the relative perturbing force of solar radiation pressure compared to luni-solar perturbations
- Additional simulations were carried out to investigate the perigee evolution as a function of eccentricity, $\Omega + \omega$ and angular separation between the perigee direction and the sun (α)
- Re-orbiting according to IADC formula
- The other relevant simulation parameters were the same used in the previous study cases

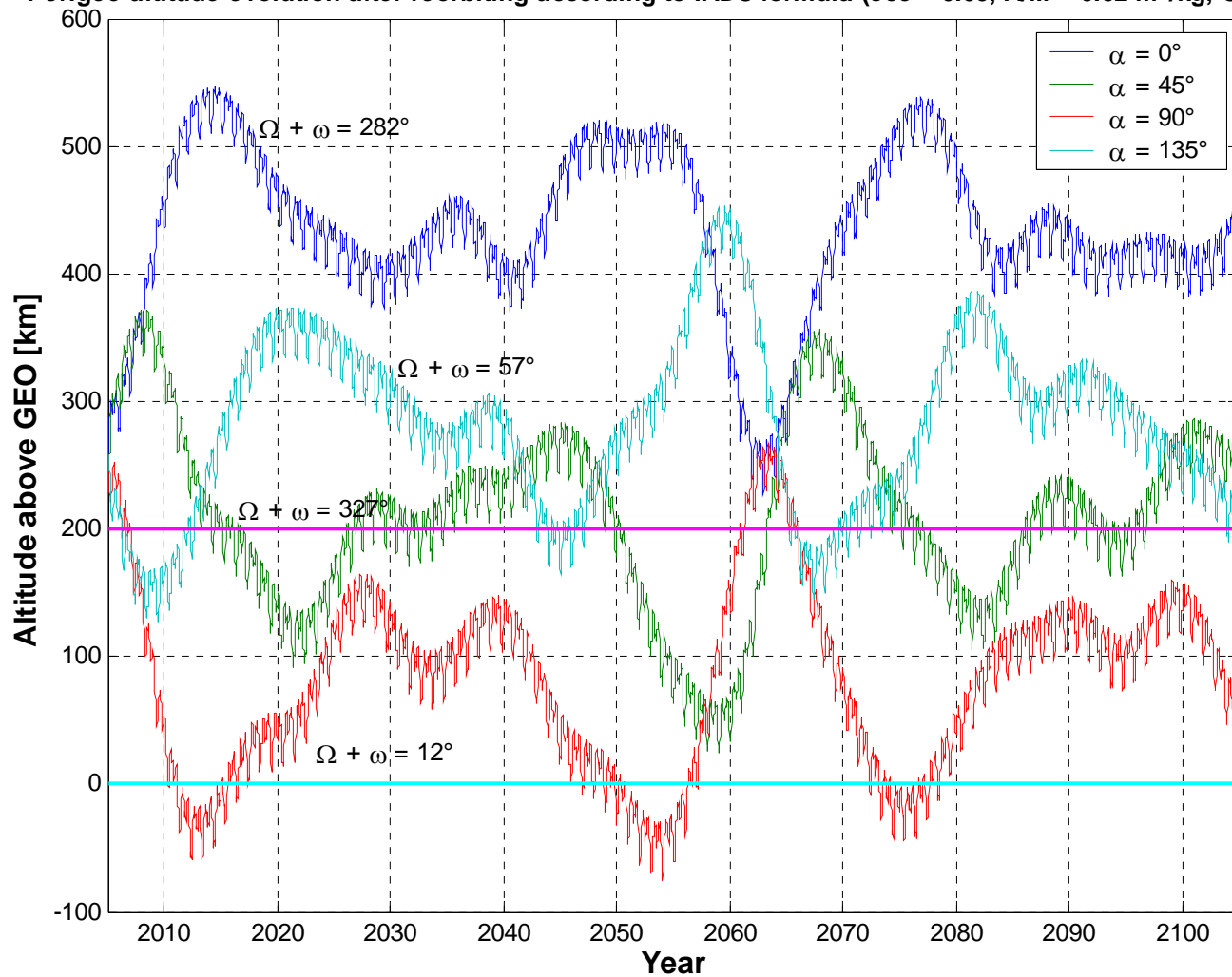
Perigee altitude evolution after reorbiting according to IADC formula (ecc = 0.005, A/M = 0.02 m²/kg, Cr =1.2)



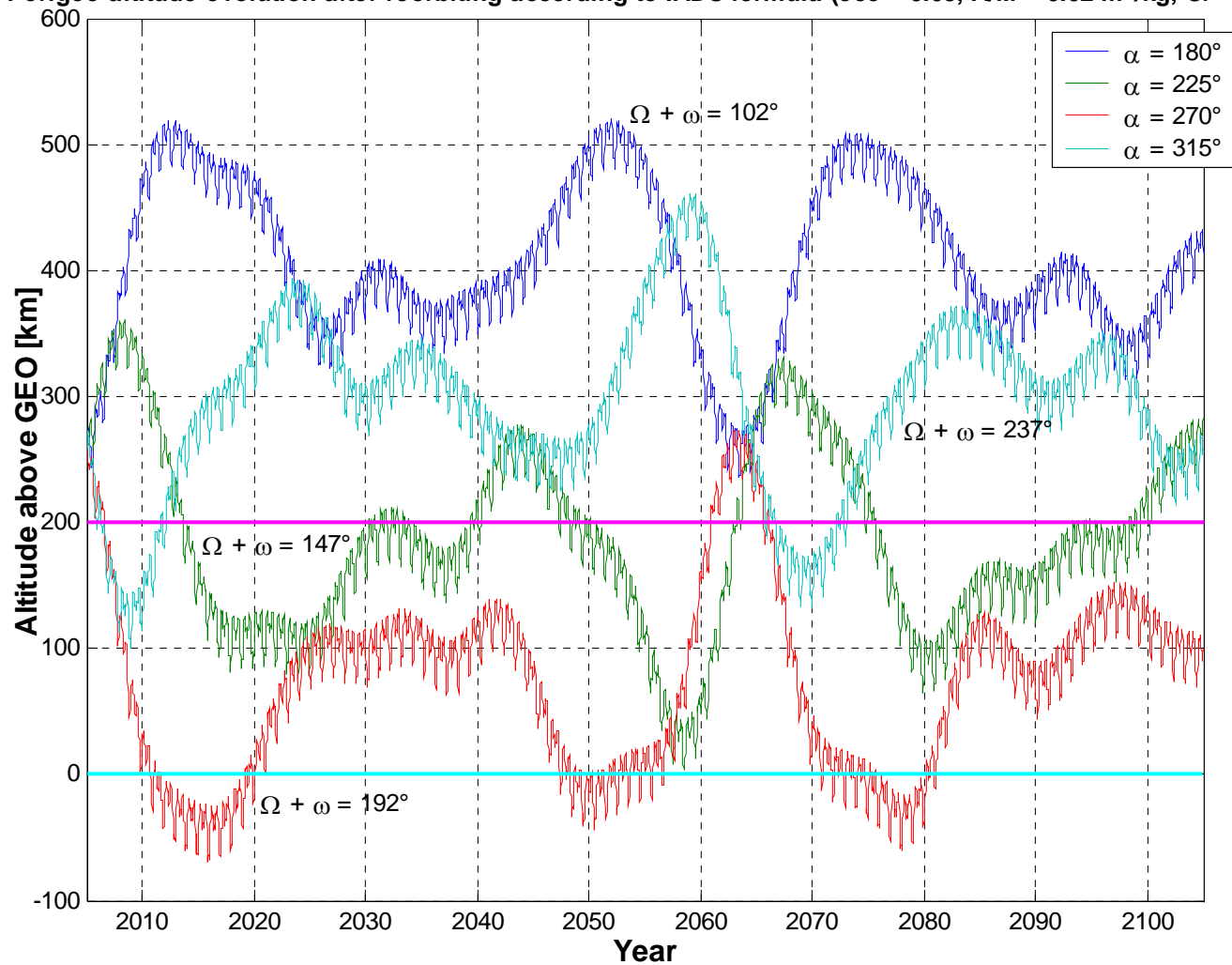
Perigee evolution after reorbiting according to IADC formula (Year = 2005, ecc = 0.05, A/M = 0.02 m²/kg, Cr = 1.2)



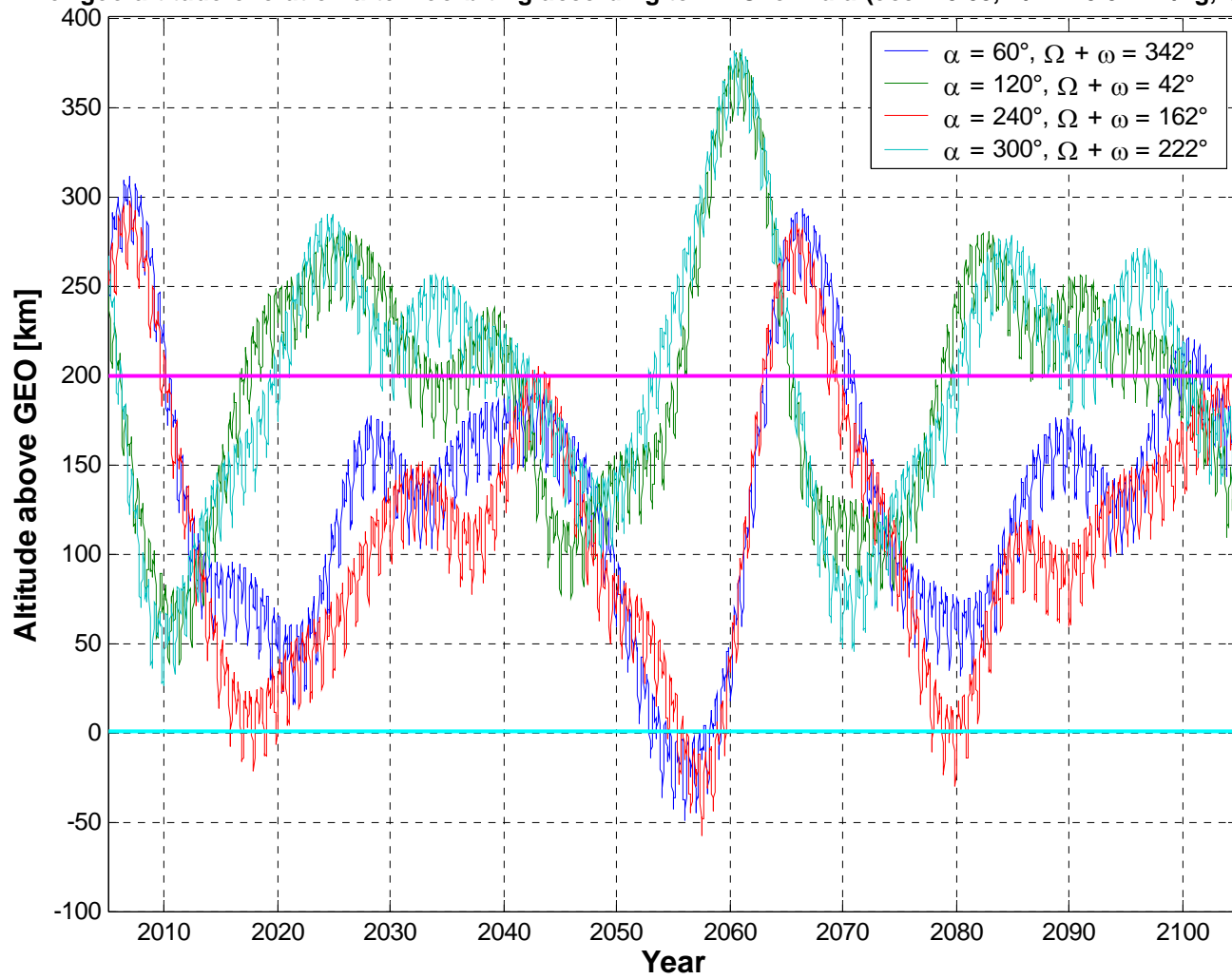
Perigee altitude evolution after reorbiting according to IADC formula (ecc = 0.05, A/M = 0.02 m²/kg, Cr = 1.2)



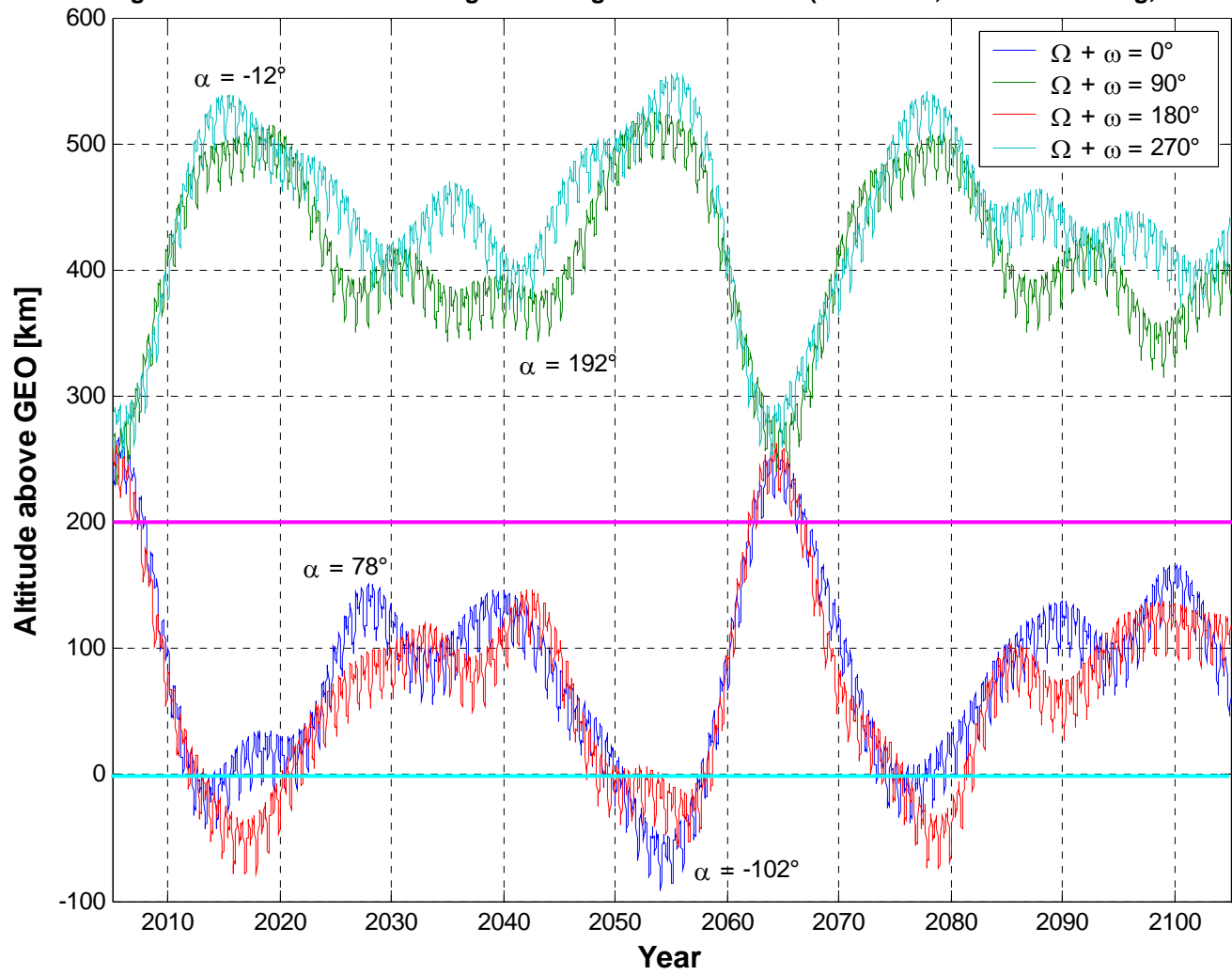
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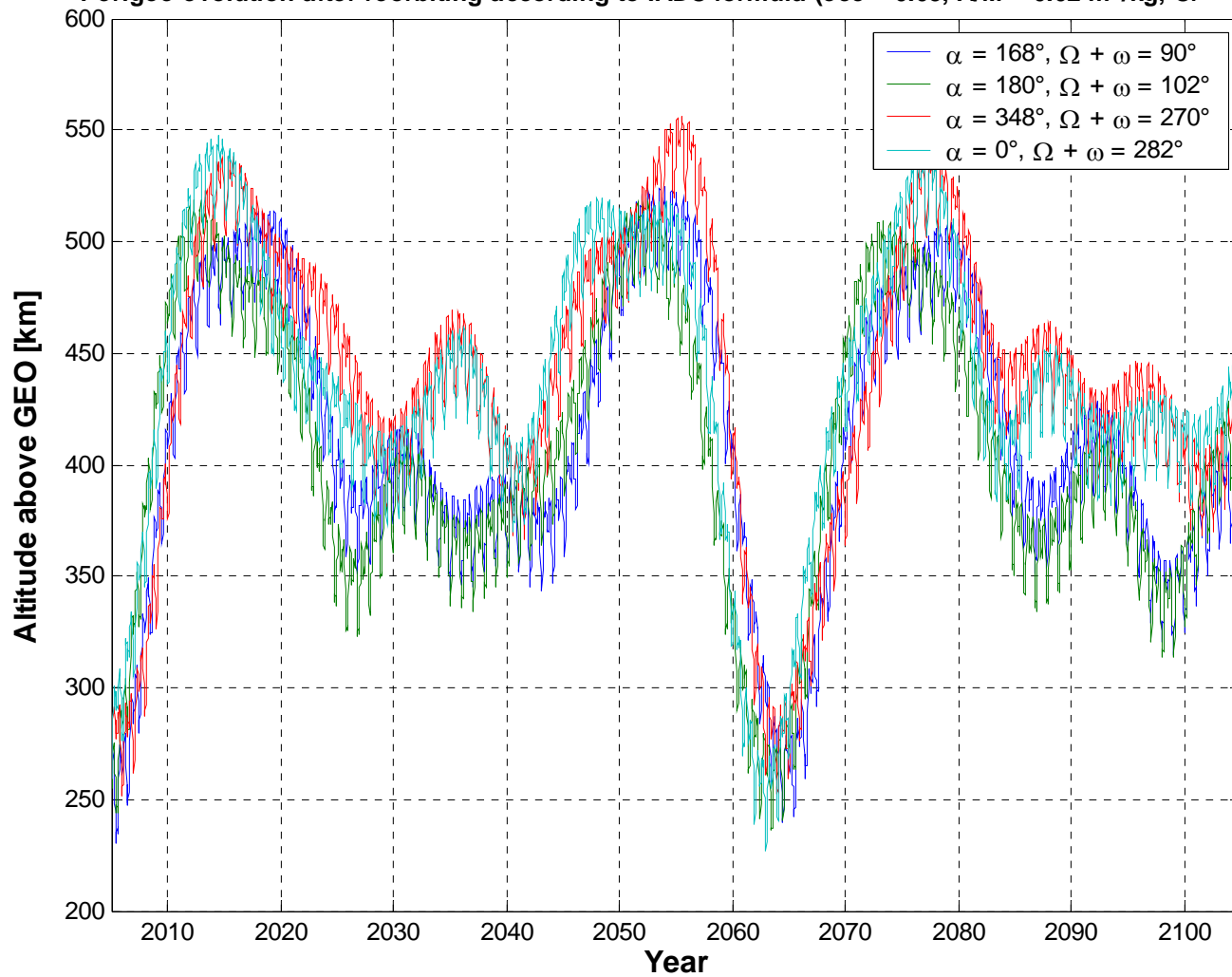
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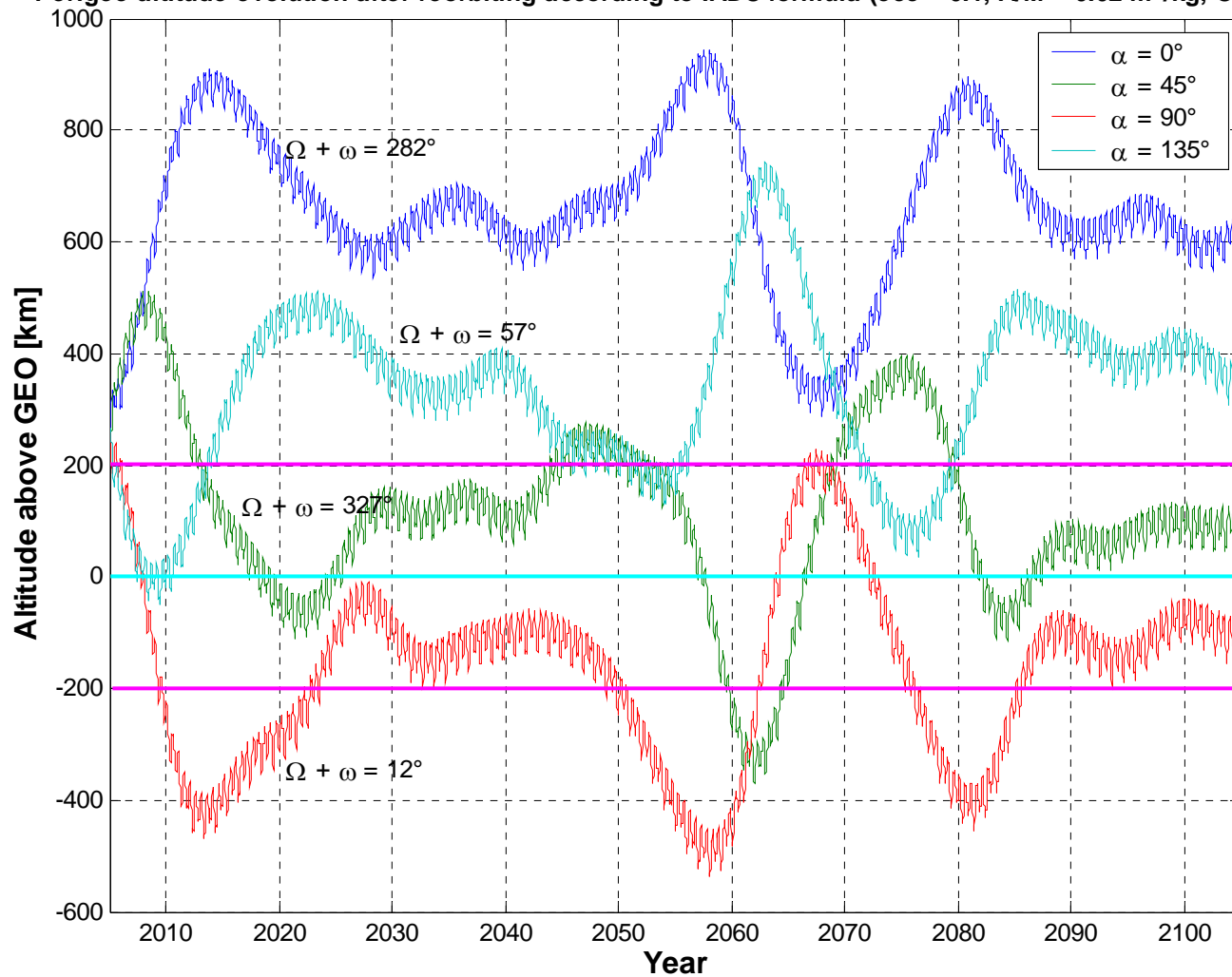
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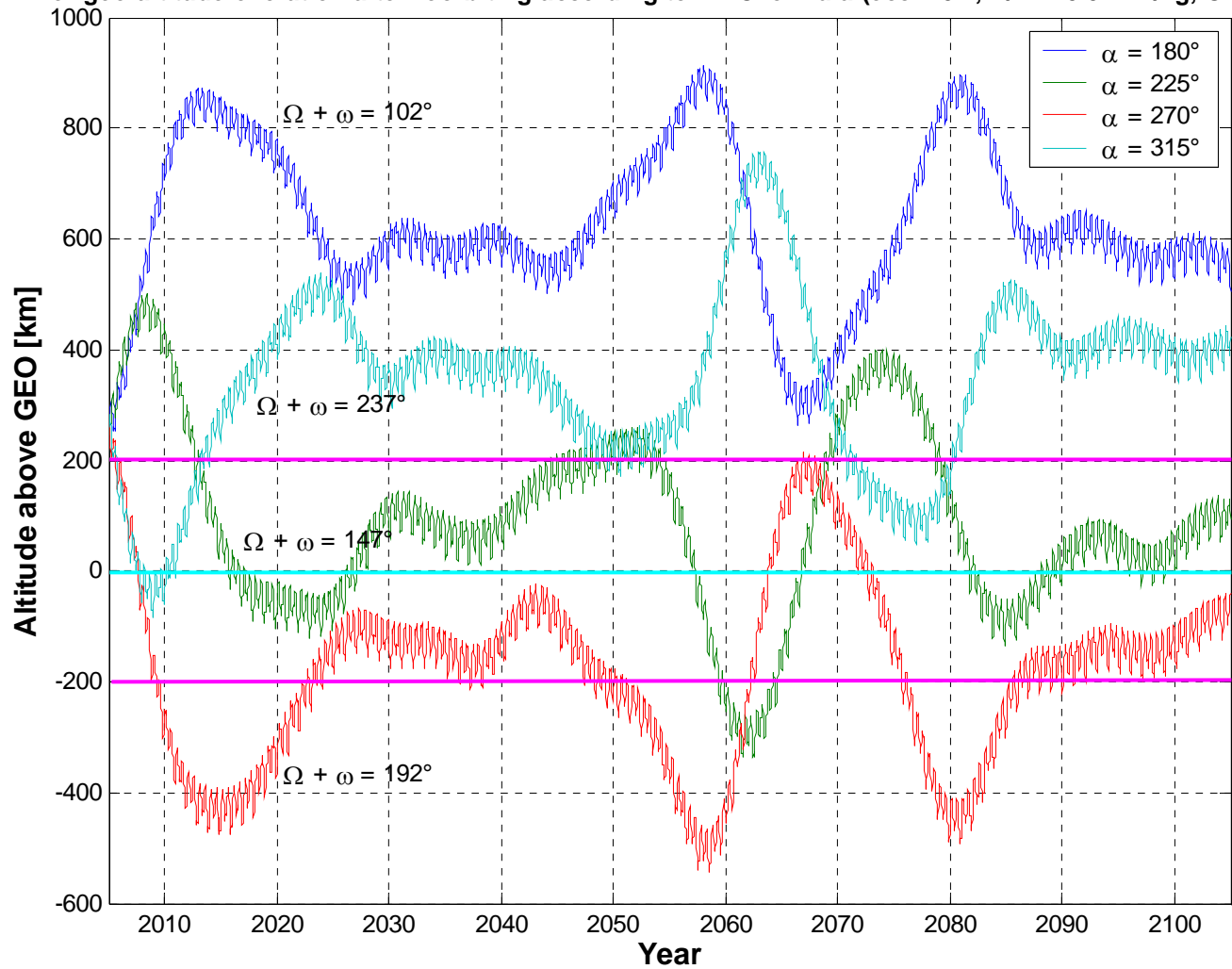
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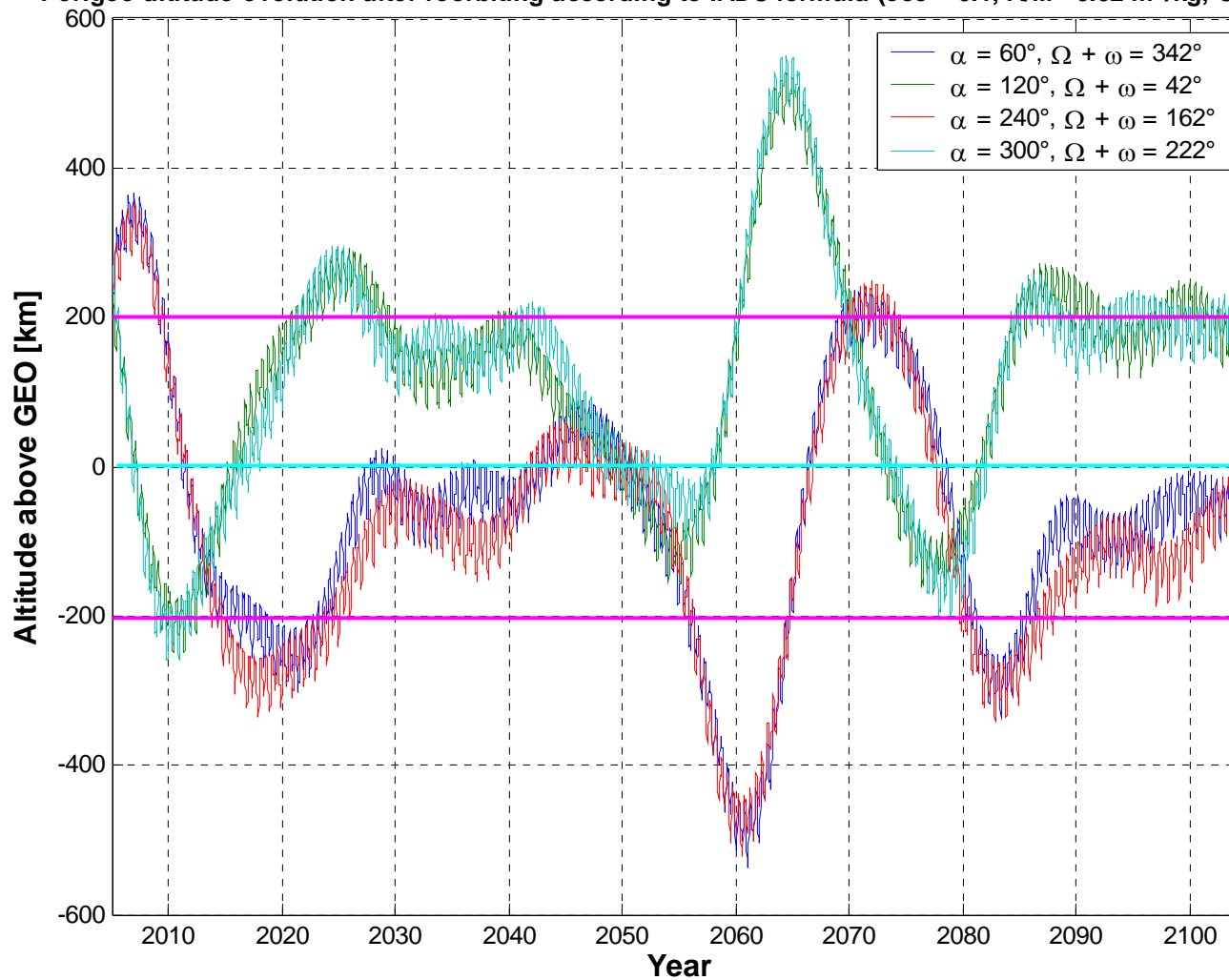
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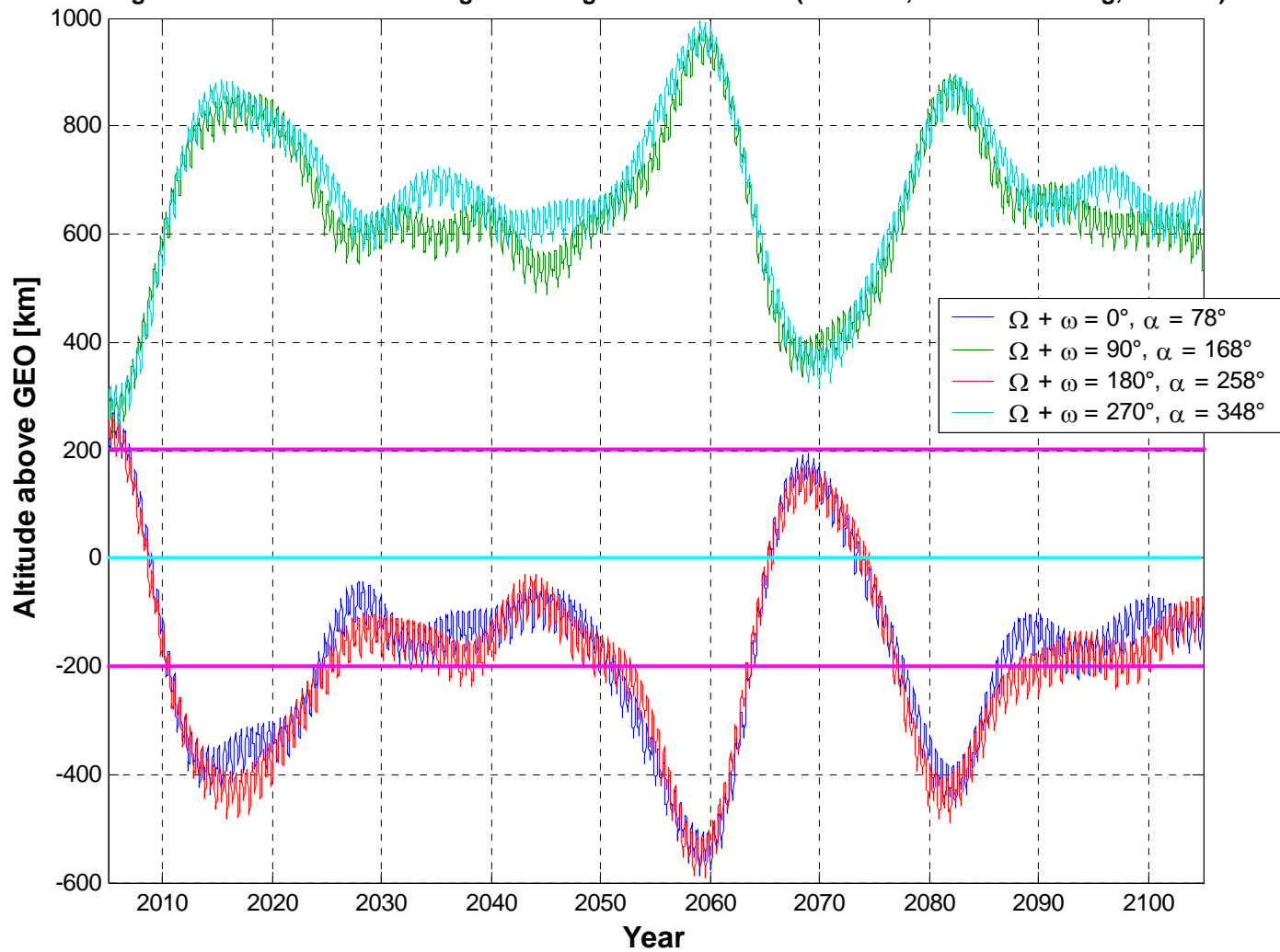
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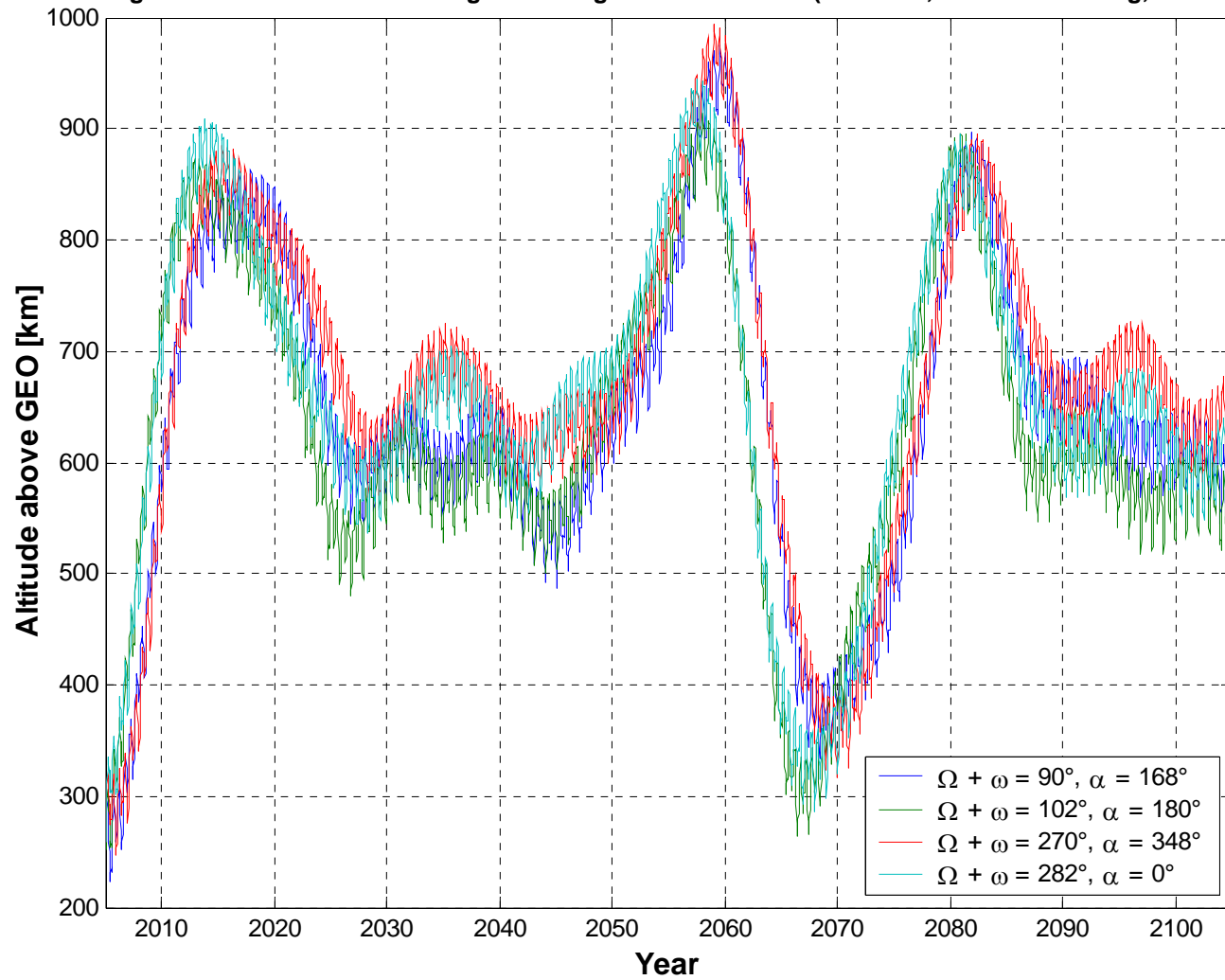
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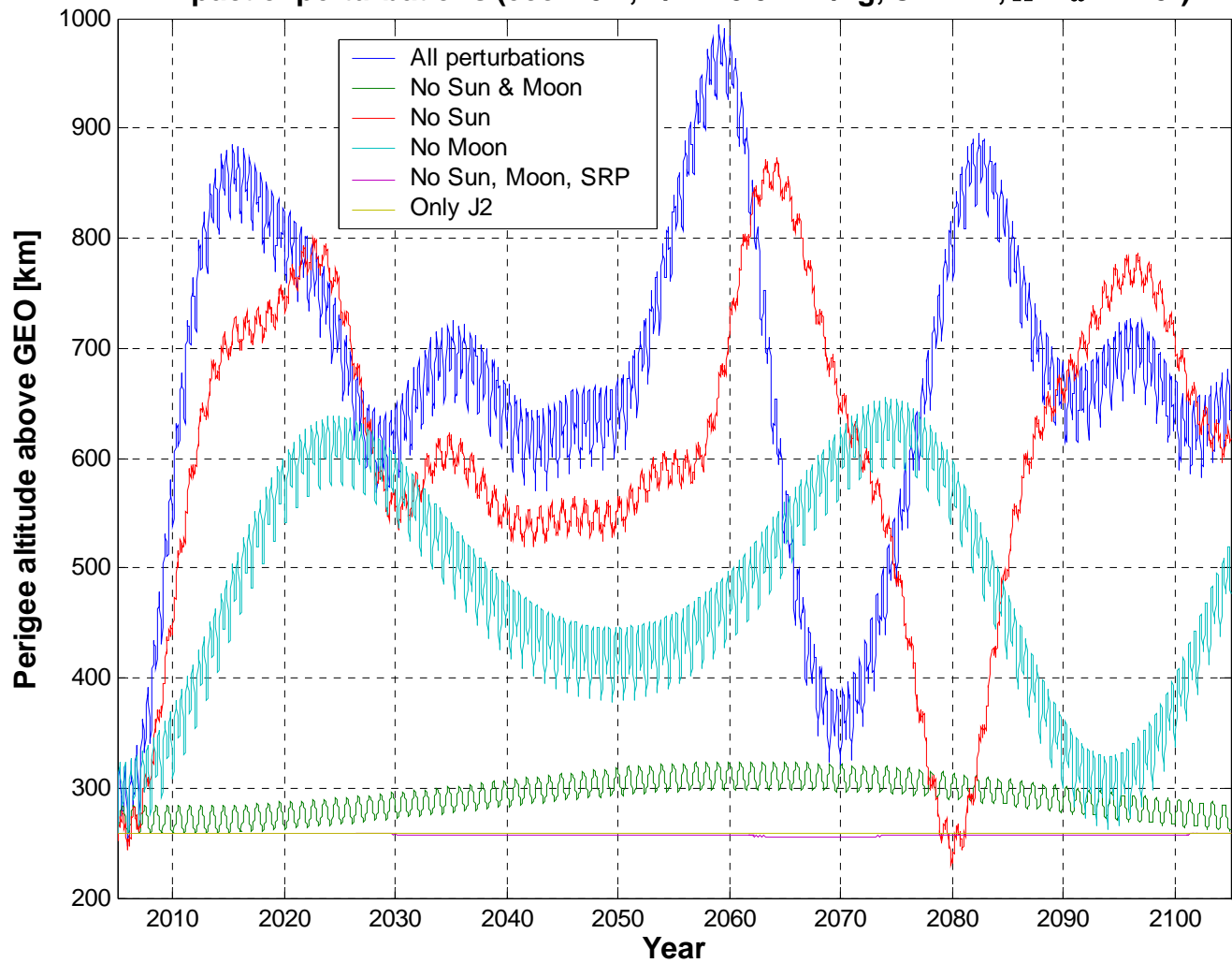
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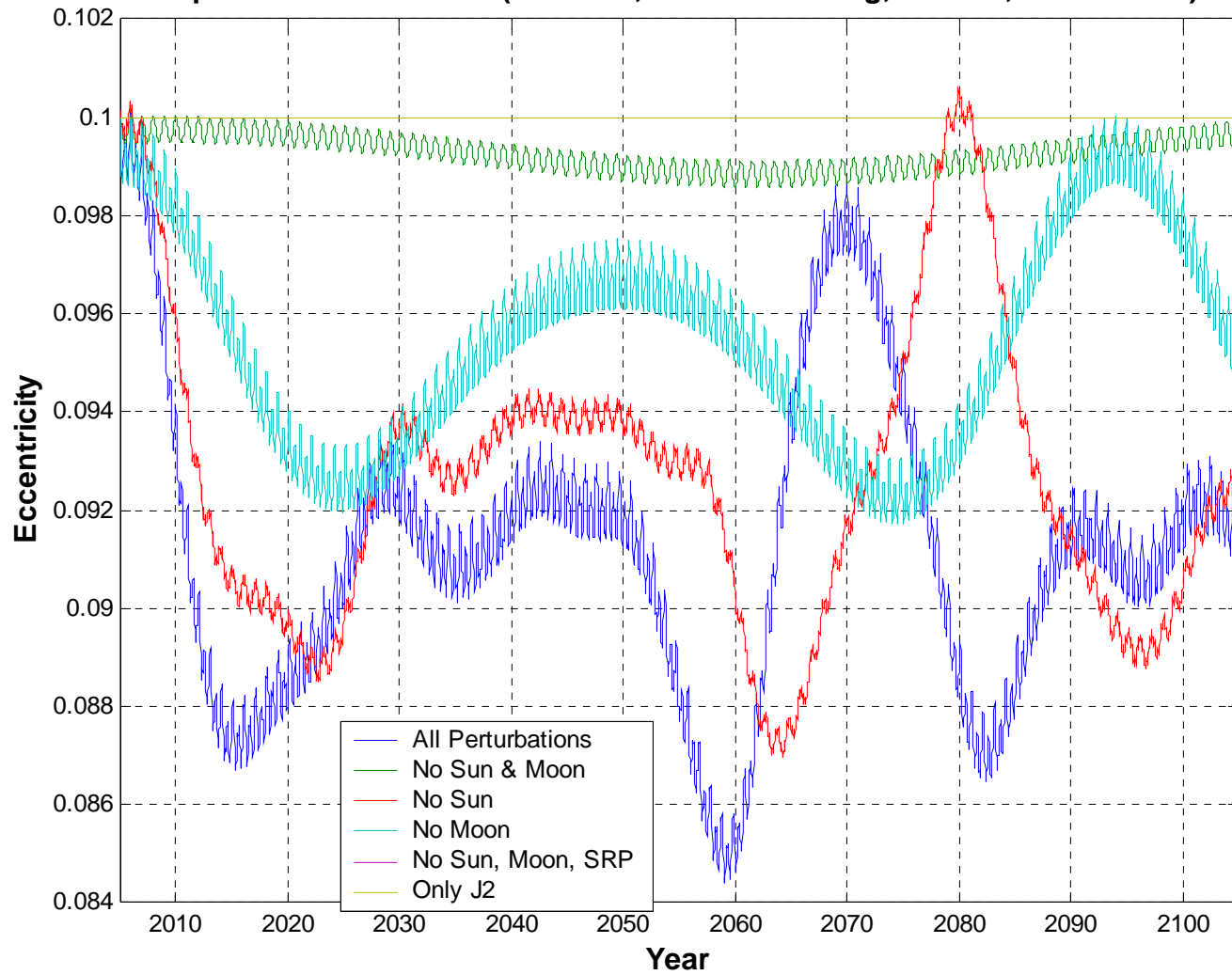
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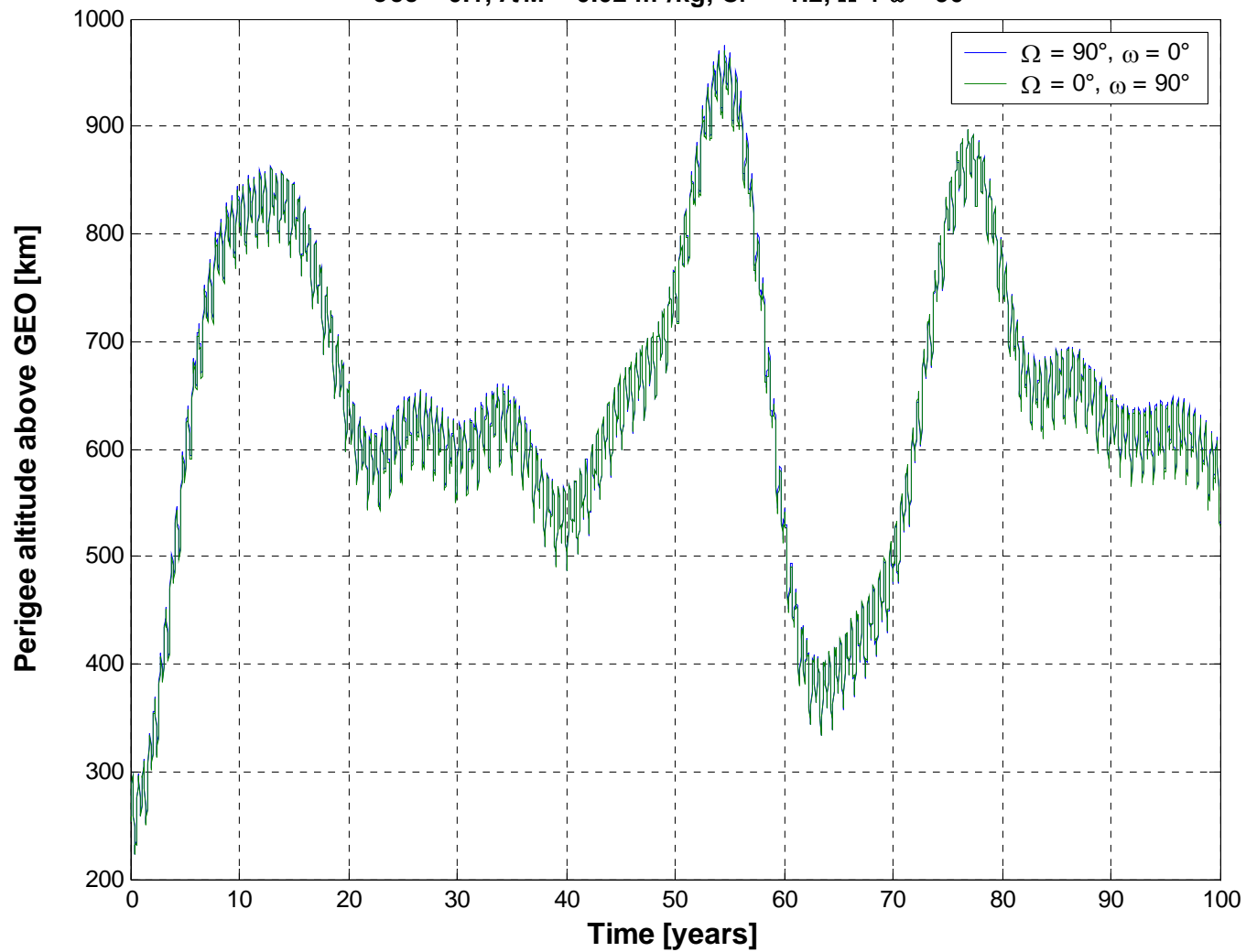
Impact of perturbations (ecc = 0.1, A/M = 0.02 m²/kg, Cr = 1.2, $\Omega + \omega = 270^\circ$)



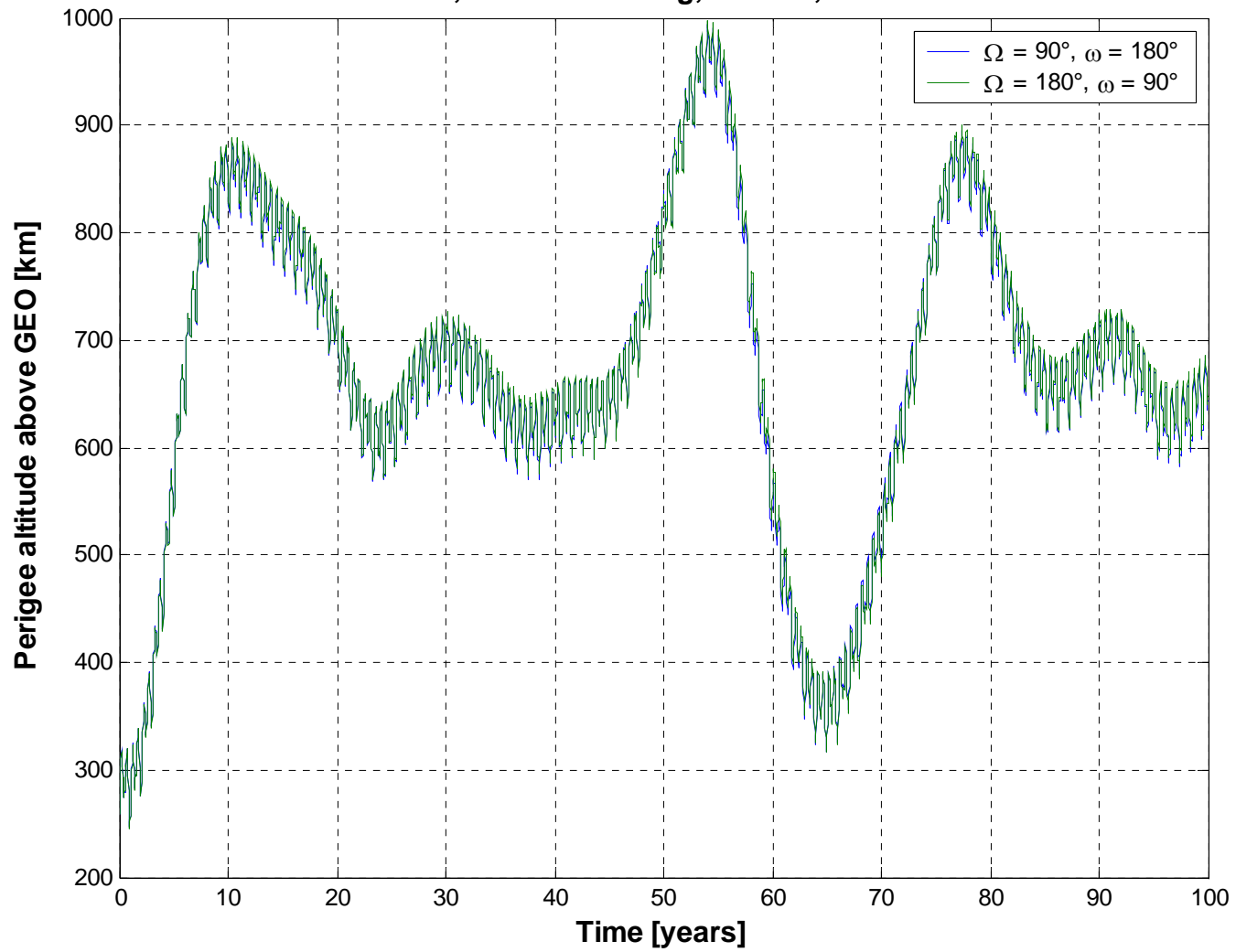
Impact of Perturbations (ecc = 0.1, A/M = 0.02 m²/kg, Cr = 1.2, $\Omega + \omega = 270^\circ$)



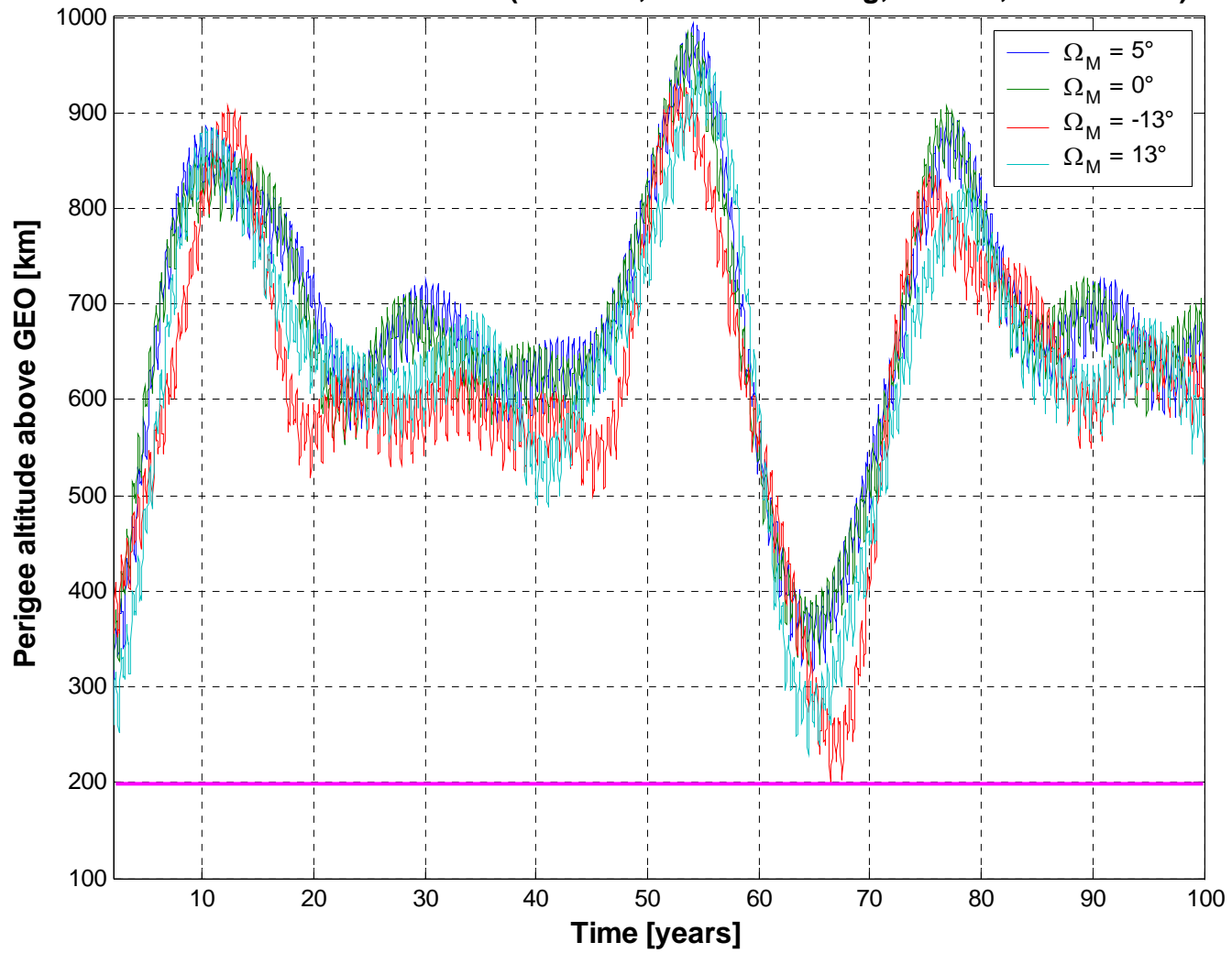
$\text{ecc} = 0.1, A/M = 0.02 \text{ m}^2/\text{kg}, Cr = 1.2, \Omega + \omega = 90^\circ$



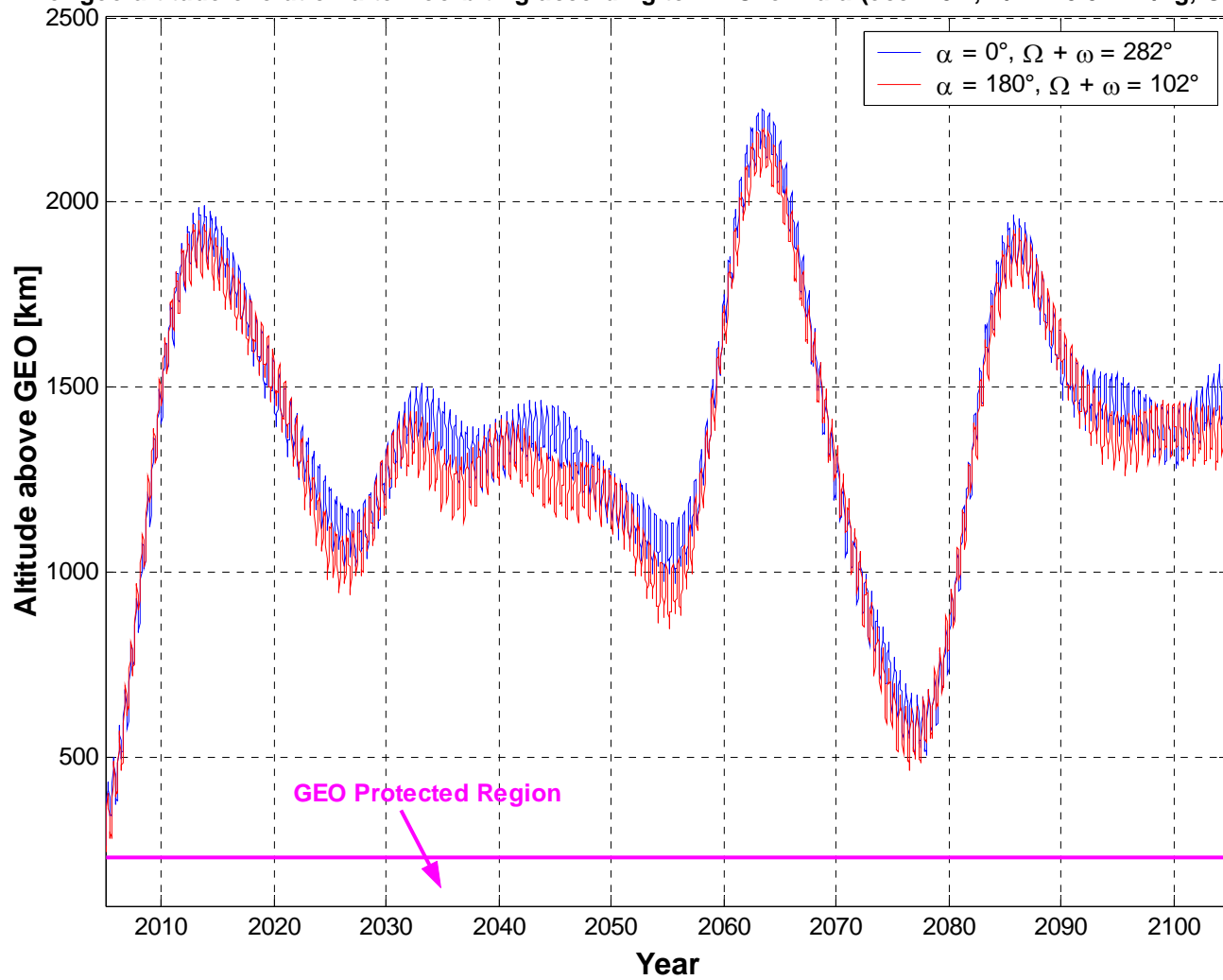
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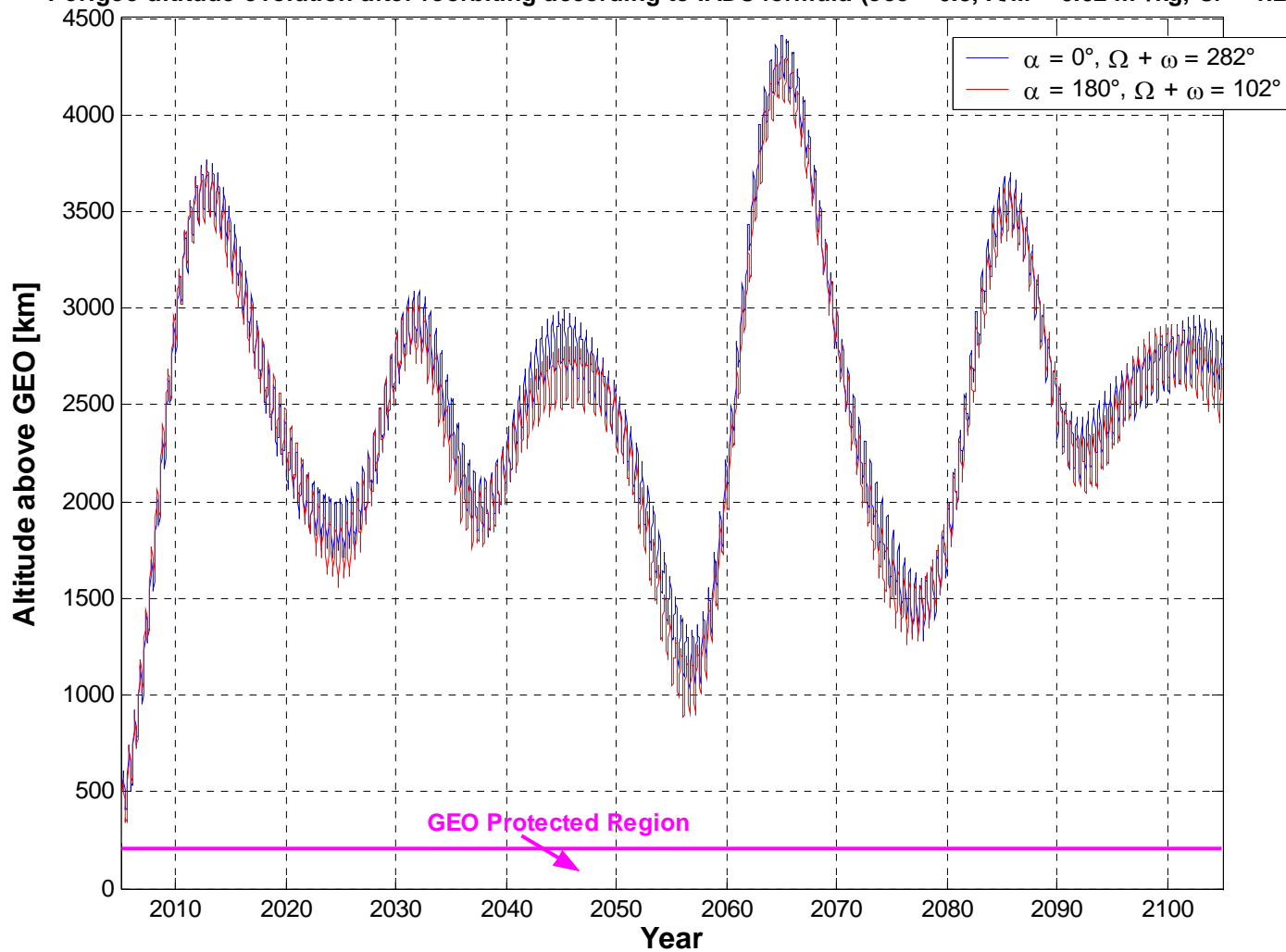
Effect of initial Moon RAAN (ecc = 0.1, $A/M = 0.02 \text{ m}^2/\text{kg}$, $Cr = 1.2$, $\Omega + \omega = 270^\circ$)



Perigee altitude evolution after reorbiting according to IADC formula (ecc = 0.2, A/M = 0.02 m²/kg, Cr = 1.2)



Perigee altitude evolution after reorbiting according to IADC formula (ecc = 0.3, A/M = 0.02 m²/kg, Cr = 1.2)



Conclusions

- The IADC formula can prevent the long-term crossing of the GEO protected region only by constraining the initial eccentricity vector
- An unconstrained argument of perigee translates into a maximum acceptable eccentricity of 0.005
- Eccentricities as large as 0.3 (or more) are acceptable with an appropriate perigee pointing driven by luni-solar perturbations ($\Omega + \omega \cong 90^\circ$ or 270°)
- The details depend on initial conditions, Sun RA, Moon RAAN and $C_R A/M$
- Increasing the re-orbiting altitude is not a viable alternative
- For small eccentricities, the choice of a sun-pointing perigee may result into a lower altitude increase, with respect to the IADC formula, able to preserve the GEO protected region with a ΔV or propellant saving by $\sim 15\%$

Proposals: Option 1

- Remove the IADC formula from the Mitigation Guidelines
- Add the prescription of an end-of-life re-orbiting able to guarantee the long-term clearance of the GEO protected region
- Advantage: Maximum flexibility for satellite operators
- Re-orbiting planning optimized as a function of satellite operations, health and control strategy (e.g. sun-pointing perigee?), propulsion system, accuracy of residual propellant estimate, passivation requirement, initial conditions, season, Moon RAAN, $C_R A/M$
- Present some examples of practical implementation in the Mitigation Support Document

Proposals: Option 2

- Retain the IADC formula in the Mitigation Guidelines
- Add a statement concerning the eccentricity vector constraints
- Eccentricity < 0.005 without control of argument of perigee
- Eccentricity $< \text{TBD}$ value if $\Omega + \omega \cong 90^\circ$ or 270° (in June or December for sun-pointing perigee)
- Precise constraints depend on initial conditions, Sun RA, Moon RAAN and $C_R A/M$
- Discuss the details in the Support Document
- Drawback: Better solutions exist in terms of ΔV

Open Issues

- Following the Mitigation Guidelines (Section 5.3.1): «The propulsion system for a GEO spacecraft should be designed not to be separated from the spacecraft. In the case that there are unavoidable reasons that require separation, the propulsion system should be designed to be left in an orbit that is, and will remain, outside of the protected geosynchronous region. Regardless of whether it is separated or not, a propulsion system should be designed for passivation.»
- The release of high A/M objects in GEO or in the graveyard orbit is not directly addressed
- It is implicitly and generically included in the provisions of Sections 5.1 and 5.2: Is it sufficient ?
- Passivation vs. eccentricity vector control: prioritization if operational conflict arises ?