16th Meeting of the International Committee on Global Navigation Satellite Systems

Update of Study on Disposal Options of BDS EOL Satellites

Zhou Jing, Yang Hui
China Academy of Space Technology
12 Oct 2022

CONTENTS

01

GNSS Space Debris Status Update and International Guidelines

GNSS Space Debris Status Update and International Guidelines

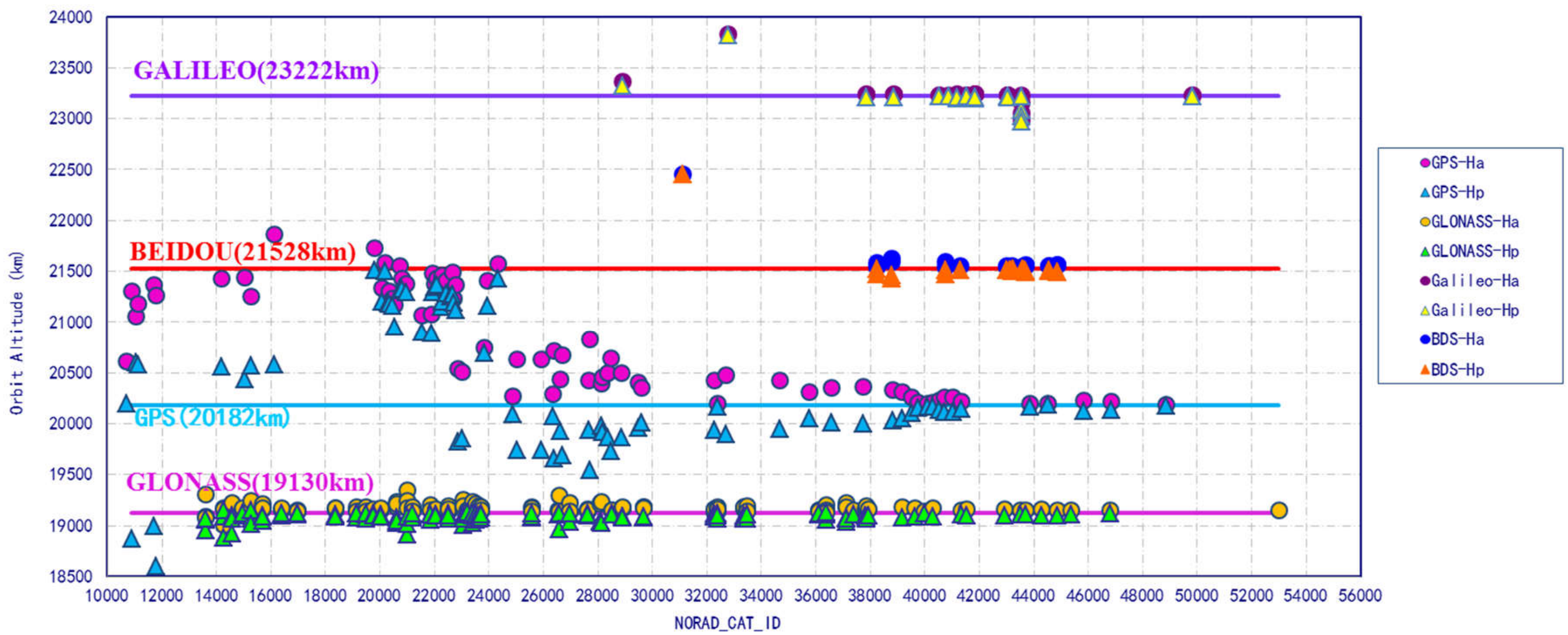
I. GNSS/RNSS Satellites in Orbit Update

Constellation	Nation/Region	Number of SVs *			
		GEO	IGSO	MEO	Total
GPS	USA	0	0	80	80
GLONASS	Russia	0	0	141	141
Galileo	Europe	0	0	30	30
BDS	China	15	12	32	59
QZSS	Japan	1	4	0	5
NAVIC	India	3	6	0	9

Data collected from www.space-track.org by Sep 16th 2022

GNSS Space Debris Status Update and International Guidelines

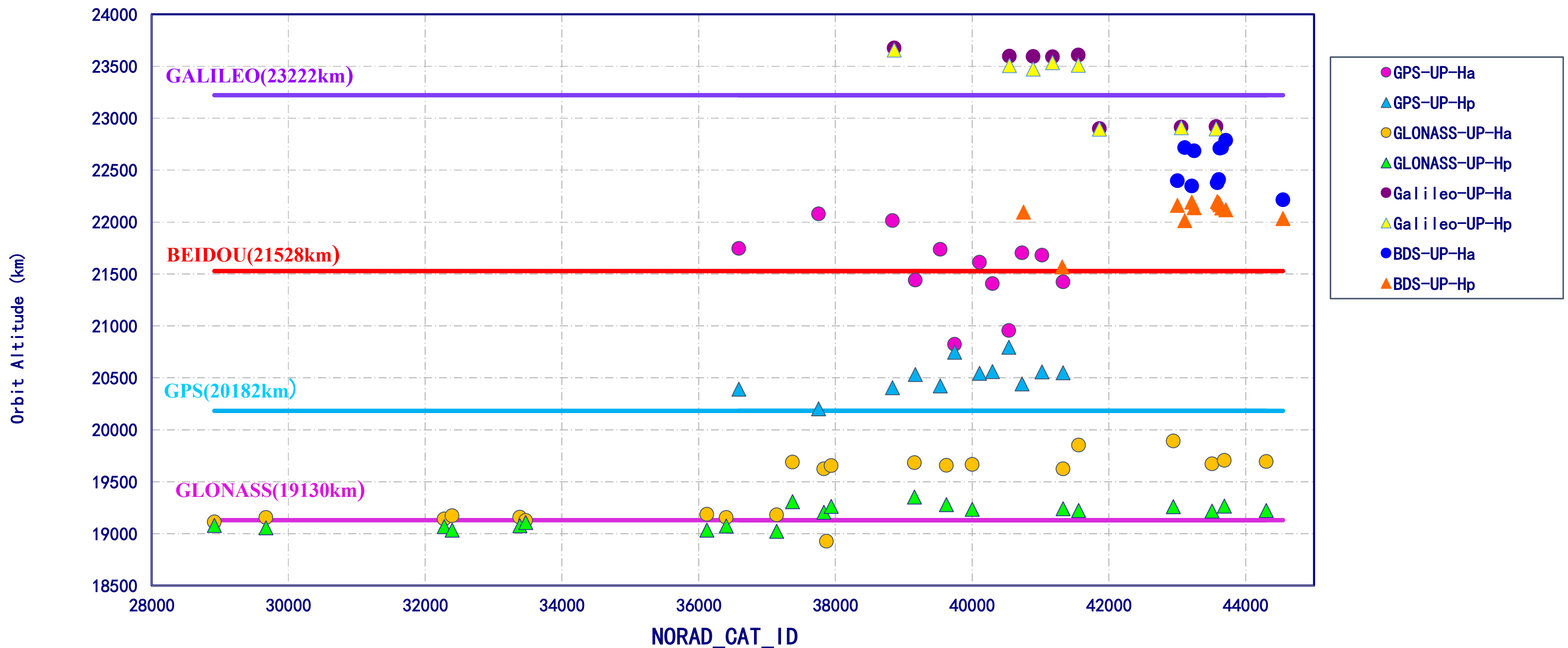
II. GNSS Satellites Orbit Altitude Update



Data collected from www.space-track.org by Sep 16th 2022

GNSS Space Debris Status Update and International Guidelines

III. GNSS Upper-stage Orbit Altitude Update



Data collected from www.space-track.org by Sep 16th 2022

GNSS Space Debris Status Update and International Guidelines

IV. MEO Disposal Requirements of IADC

Disposal Action	MEO Navigation Satellite Orbit
25-year decay	Not recommended due to large ΔV required
Disposal orbit	TBC: 1.Minimum long term perigee of 2000km,apogee below MEO 2.Perigee 500km above MEO or nearby operational region and e≤0.003; RAAN and argument of perigee selected for stability
Direct Reentry	Not recommended due to large ΔV required

Requirements from IADC-04-06'Support to the IADC Space Debris Guidelines' in Dec 2019

02 Long-term Evolution of BDS Satellites with Different Disposal Options

Long-term Evolution of BDS Satellites with Different Disposal Options

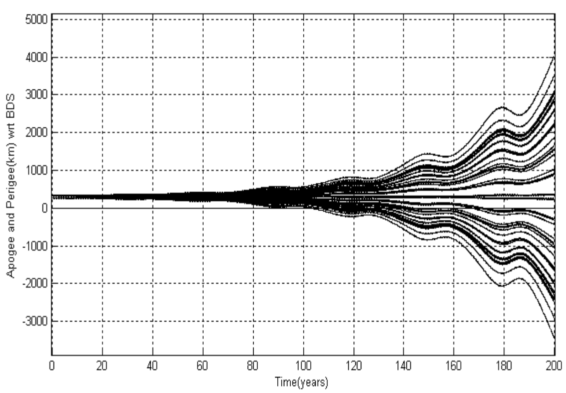
I. Disposal Safety Restrictions for BDS satellites

- Based on research of NASA and other organizations, disposal for BDS EOL satellites should ensure low collision risk with operational orbit and nearby constellations within 200 years.
- Considering propellant limitation, the current BDS EOL satellites will manoeuver to disposal orbit instead of decay or direct reentry.
- Considering isolation from nearby satellite orbits, the increase in altitude of BDS EOL satellites should be more than 300km.
- The variation of altitude after disposal should be minimized over 200 years, or the disposal orbit should decay as early as possible.

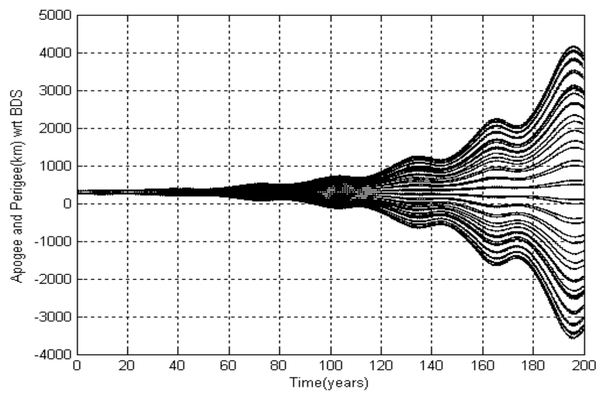
Long-term Evolution of BDS Satellites with Different Disposal Options

II. Evolution of BDS MEO Satellites

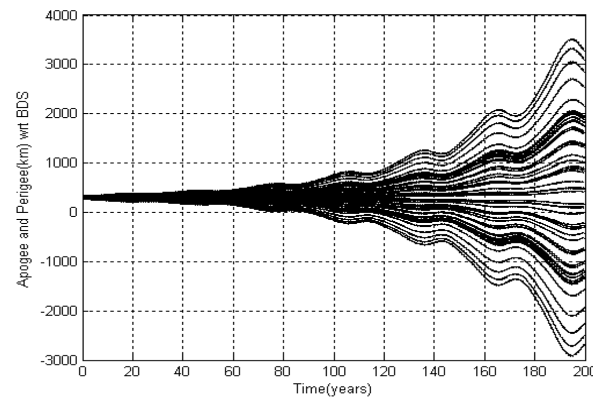
- Minimum eccentricity growth strategy (stable disposal strategy): ω_0=190/320/240 deg, the disposal orbit is very stable (e_{max}=0.006 and perigee remains above BDS constellation within 200 years)
- High eccentricity growth strategy (unstable disposal strategy): ω_0=290/70/350 deg, the disposal orbit eccentricity grows significantly (e_{max}=0.016 and perigee crosses the BDS constellation but does not reach GEO within 200 years)



Ω=30°,e=0.001,ω=0~360



Ω=150°,e=0.001,ω=0~360°

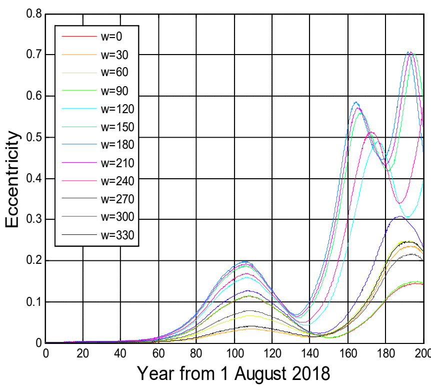


Ω=270°,e=0.001,ω=0~360°

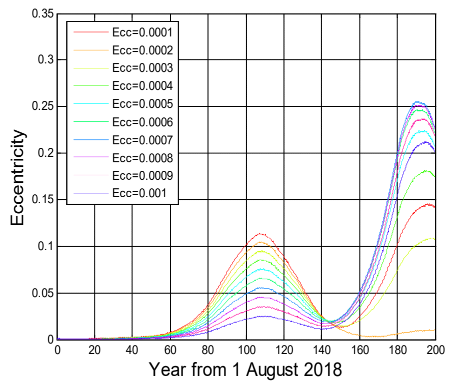
Long-term Evolution of BDS Satellites with Different Disposal Options

III. Evolution of BDS IGSO Satellites

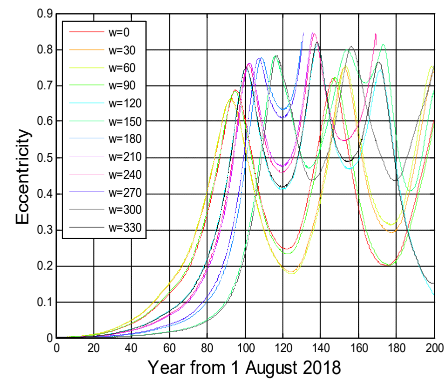
- Minimum eccentricity growth strategy: ω_0=0/0/120deg, the disposal orbit is very stable (emax=0.72 and perigee reaches GEO or MEO within 200 years)
- High eccentricity growth strategy: ω_0=180/270/270deg, the disposal orbit eccentricity grows significantly (emax=0.82 and perigee reaches MEO or has a reentry within 200 years)



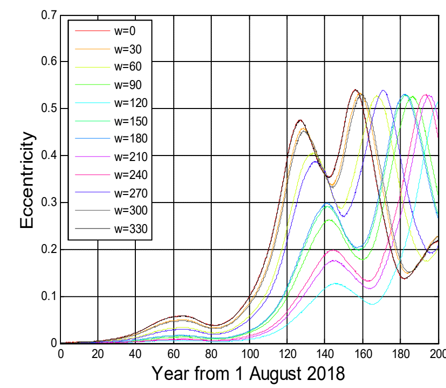
Ω=70°,e=0.001,ω=0~360



Ω=70°, ω=0 ,e=0.0001~0.001



Ω=190°,e=0.001,ω=0~360°



Ω=310°,e=0.001,ω=0~360°

Long-term Evolution of BDS Satellites with Different Disposal Options

IV. Recommendations for BDS Disposal Orbit Elements

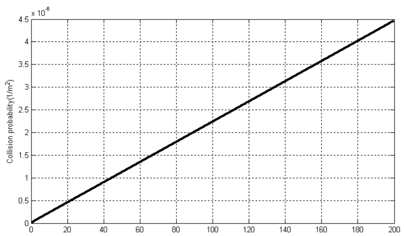
ORBIT	RAAN	Increase in orbit altitude/km	Eccentricity	Stable disposal strategy		Unstable disposal strategy	
				ω_0 / deg	Max Eccentricity in 200 years	ω_0 / deg	Max Eccentricity in 200 years
MEO	30	300	0.001	190	0.002	290	0.16
	150	300	0.001	320	0.006	70	0.14
	270	300	0.001	240	0.004	350	0.11
IGSO	70	300	0.0002	0	0.01	180	0.71
	190	300	0.001	0	0.72	270	0.82(decay in 130 years)
	310	300	0.001	120	0.52	270	0.55

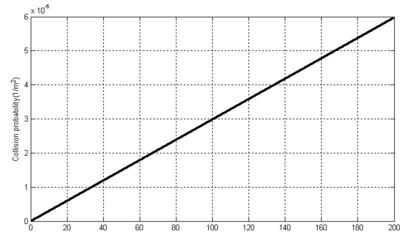
03

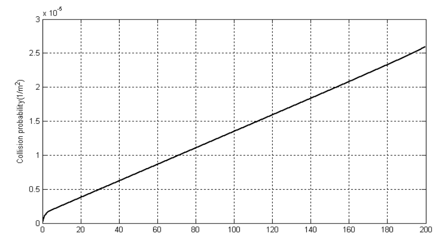
Long-term Collision Probability of BDS Satellites

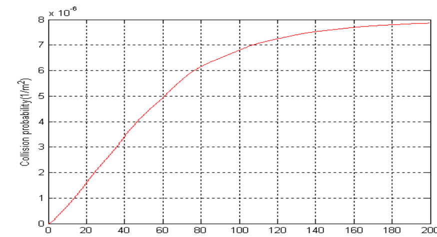
Long-term Collision Probability of BDS Satellites

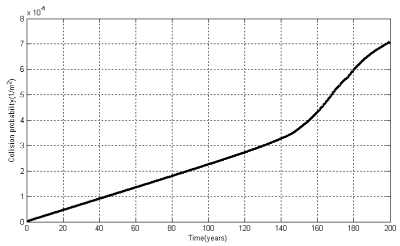
I. Collision Probability posed to GPS, Galileo and BDS and graveyard orbit

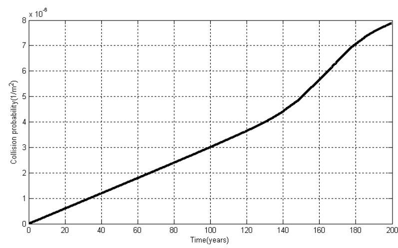

Collision probability posed to GPS by BDS with stable disposal orbit

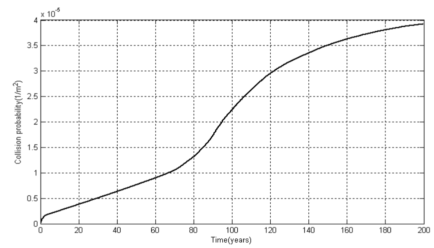

Collision probability posed to Galileo by BDS with stable disposal orbit

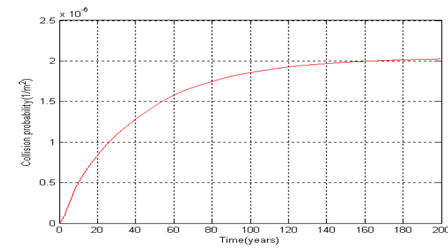

Collision probability posed to BDS constellation by the stable disposal orbit


Collision probability posed to the graveyard by BDS with stable disposal orbit


Collision probability posed to GPS by BDS with unstable disposal orbit


Collision probability posed to Galileo by BDS with unstable disposal orbit

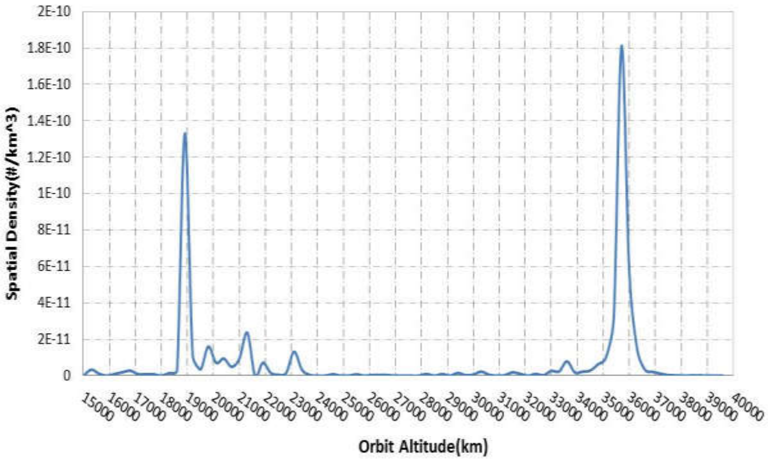

Collision probability posed to BDS by unstable disposal orbit


Collision probability posed to the graveyard by BDS with unstable disposal orbit

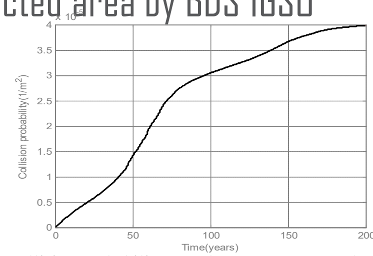
- The collision probability posed to operational orbit or graveyard orbit by BDS MEO Satellites is of a 10^{-5} ~10^{-6} order of magnitude.
- The unstable disposal strategy results in a lower collision probability (2×10^{-6}) to the BDS graveyard orbit than the stable disposal strategy (8×10^{-6}).
- The stable disposal strategy results in a lower collision probability (6×10^{-6}) to the nominal constellations of BDS, GPS and Galileo than the unstable disposal strategy (8×10^{-6}).
- As for BDS MEO EOL satellites, the stable disposal strategy would be proposed.

Long-term Collision Probability of BDS Satellites

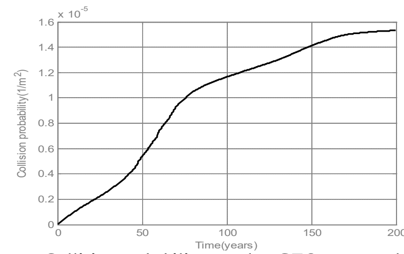
II. Collision Probability posed to the GEO Protected area by BDS IGSO



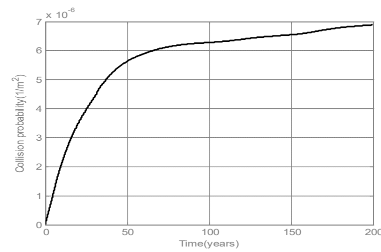
Spatial density of current space debris



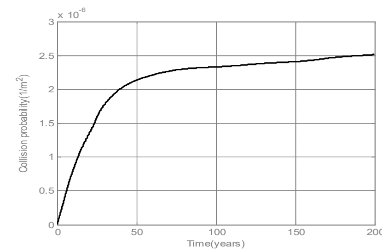
Collision probability posed to GEO protected area by BDS with stable disposal orbit



Collision probability posed to GEO graveyard by BDS with stable disposal orbit



Collision probability posed to GEO protected area by BDS with unstable disposal orbit



Collision probability posed to GEO graveyard by BDS with unstable disposal orbit

- The collision probability posed to operational orbit or graveyard orbit by BDS IGSO Satellites is of a 10^{-5} ~10^{-6} order of magnitude.
- The unstable disposal strategy results in a lower collision probability (7×10^{-6}) to the GEO graveyard orbit than the stable disposal strategy (4×10^{-5}).
- The unstable disposal strategy results in a lower collision probability (2.5×10^{-6}) to the GEO protected area than the stable disposal strategy (1.5×10^{-6}).
- As for BDS IGSO EOL satellites, the unstable disposal strategy would be proposed.

Long-term Collision Probability of BDS Satellites

III. Comparison of the Collision Probability

- The collision probability posed to operational orbit or graveyard orbit is of a 10^{-5} ~10^{-6} order of magnitude, which is less than the 0.001 threshold for LEO crossing objects.
- The unstable disposal strategy results in a lower collision probability to the BDS graveyard orbit than the stable disposal strategy.
- The stable disposal strategy results in a lower collision probability to the nominal constellations of BDS, GPS and Galileo than the unstable disposal strategy.
- As for BDS MEO EOL satellites, the stable disposal strategy would be proposed.
- As for BDS IGSO EOL satellites, the unstable disposal strategy would be proposed.

Conclusions and Recommendations

04

Conclusions and Recommendations

- There are no final guidelines for MEO/IGSO satellites post-mission disposal from international organizations (IADC), while post-mission disposal strategy and safety restrictions of GNSS EOL satellites are not exactly the same.
- Due to propellant limitation, the option of disposal orbit will be adopted by BDS EOL satellites instead of decay or direct reentry. The analysis showed that the collision probability posed to operational orbit or graveyard orbit by BDS MEO&IGSO EOL satellites within 200 yeas is of a 10^{-5} ~10^{-6} order of magnitude for both stable and unstable disposal strategy.
- The collision risk will increase as there are more GNSS/RNSS satellites deployed in the future. As a result, ICG members should continue to pay more attention to the safety of MEO and IGSO space debris.
- System providers should try to establish the GNSS/RNSS space debris guidelines together with IADC and continue to exchange information on their GNSS/RNSS satellites post-mission disposal plans and implements in WG-S.

Content of IADC report

I. In 2020, the IADC submitted a report named ‘Benefits and Risks Associated with MEO Disposal Options’ to ICG. This report introduced the evaluation of available disposal options for MEO operators and provided conclusions for the four kinds of disposal strategies including passivation in the operational orbit, manoeuver to stable disposal orbit, unstable disposal orbits and directed de-orbit.

II. The conclusions of the report are as follows:

- To assure long-term sustainability for the MEO operations, passivation combined with moving a space object away from operational missions is needed.
- Effective disposal includes avoiding the creation of orbital regions with a high density of disposed objects.
- Stable disposal orbits can minimize the collision risk and interference with active MEO constellations.
- Unstable disposal orbits increase the overall sustainability of MEO operations, but crossing with the other protected regions needs to be minimized and the risk on re-entering accounted for.
- Besides the passivation measure, disposal strategy or planned de-orbit should be planned as part of the mission design.

Feedback on IADC report

I. The long-term collision risk of the available disposal options for BDS EOL satellites has been studied and the conclusions of BDS study complies with that of IADC report. Furthermore, the stable disposal strategy would be proposed for BDS MEO satellites and the unstable disposal strategy would be proposed for BDS IGSO satellites.

II. Recommendations for IADC report

- Based on the current analysis, the orbital lifetime of stable and unstable disposal orbit may be much longer than 25 years, which is the lifetime limitation for MEO objects from IADC. It is recommended that the orbital lifetime of MEO disposal orbit need to be expanded.
- Due to the limitation of propellant and lack of low-thrust electrical propulsion system, it may be unrealistic for the on-orbit MEO objects to have a directed de-orbit. As a result, the directed de-orbit has not been included in the current disposal options for BDS EOL satellites.n The research on directed de-orbit option with low thrust propulsion system will be the next step.
- As the disposal strategy, capability of collision risk prediction and long-term evolution of each GNSS system may be different, it is necessary for GNSS system providers to pay attention to the collision risk and carry out regular communication and coordination with IADC and ICG.

Action item: MEO/IGSO Satellite Disposal Status and Plan

According to the feedback of provider on IADC report, a form template (first draft below) of "MEO and IGSO Satellite Disposal Status and Plan" is proposed to be formed, and it is recommended that all systems complete the table filling.

GNSS /RNSS Providers	Orbit type	Current Disposal Options					Planned Disposal Options					Description for disposal options	Remarks
		passivation in the operational orbit	manoeuver to stable disposal orbit	manoeuver to unstable disposal orbit	directed de-orbit	other option	passivation in the operational orbit	manoeuver to stable disposal orbit	manoeuver to unstable disposal orbit	directed de-orbit	other option		
GPS	MEO	○	○	○	○	○	○	○	○	○	○		
GLONASS	MEO	○	○	○	○	○	○	○	○	○	○		
	IGSO (as planned)	○	○	○	○	○	○	○	○	○	○		
BDS	MEO	○	○	○	○	○	○	○	○	○	○		
	GEO	○	○	○	○	○	○	○	○	○	○		
	IGSO	○	○	○	○	○	○	○	○	○	○		
Galileo	MEO	○	○	○	○	○	○	○	○	○	○		
Navic	GEO	○	○	○	○	○	○	○	○	○	○		
	IGSO	○	○	○	○	○	○	○	○	○	○		
QZSS	GEO	○	○	○	○	○	○	○	○	○	○		
	IGSO	○	○	○	○	○	○	○	○	○	○		
…													

Thank you!