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Inter-Agency Space Debris Coordination Committee

# IADC Report on the Status of the Space Debris Environment

Issued by IADC Working Group 2 / Steering Group

Working Group Internal Task 39.2

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# Revision History

| Issue | Date | Reason for Revision |
|---|---|---|
| 1 | Jan 2023 | First Release, reference epoch for the report is 31 Dec 2021 |
| 2 | Jan 2024 | Reference epoch for the report is 31 Dec 2022.<br><br>Additional sources for debris density profiles, number of fragmentation events per year, mission related objects released, long-term evolution of the environment.<br><br>New plots: debris density profiles for different epochs; number of fragments per fragmentation cause and event year. |

# List of Abbreviations

| Abbreviation | Description |
|---|---|
| ASI | Agenzia Spaziale Italiana (Italian Space Agency) |
| CNES | Centre National d'Etudes Spatiales |
| CNSA | China National Space Administration |
| CSA | Canadian Space Agency |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center) |
| ESA | European Space Agency |
| GEO | Geostationary Earth Orbit |
| IADC | Inter-Agency Space Debris Coordination Committee |
| ISRO | Indian Space Research Organisation |
| JAXA | Japan Aerospace Exploration Agency |
| KARI | Korea Aerospace Research Institute |
| LEO | Low Earth Orbit |
| MRO | Mission Related Object |
| NASA | National Aeronautics and Space Administration |
| ROSCOSMOS | Space State Corporation "Roscosmos" |
| SSAU | State Space Agency of Ukraine |
| UKSA | UK Space Agency |

## List of Definitions

| Term | Description |
|---|---|
| Catastrophic collision | Collision leading to the complete destruction of target and impactor |
| Constellation | Set of at least 20 individual satellites, released into orbit over more than two events and covering more than one year in time from first to last event, sharing the same objective as a combined system |
| Mission related object (MRO) | Space objects released as space debris which served a purpose for the functioning of a spacecraft or of a launch vehicle |
| Naturally compliant | Space objects that operate in an orbit such that they naturally re-enter within 25 years (i.e., without requiring any manoeuvre) |
| Spacecraft | Space object designed to perform a specific function in space excluding launch functionality. This includes operational satellites as well as calibration objects |
| Launch vehicle | Space object constructed for ascent to outer space, and for placing one or more objects in outer space. This includes the various orbital stages of launch vehicles, but not spacecraft which release smaller spacecraft themselves |
| (Launch vehicle) orbital stage | Any stage of a launch vehicle left in Earth orbit |

# 1 Executive summary

As space debris poses a problem for the near-Earth environment on a global scale, only globally supported solutions can be the answer. This creates the need for internationally accepted space debris mitigation measures. A major step in this direction was taken in 2002, when the *Inter-Agency Space Debris Coordination Committee* (IADC) published its *Space Debris Mitigation Guidelines*, which have been updated more recently in 2021 [1]. This document has since served as a baseline for non-binding policy documents, national legislation, and as a starting point for the derivation of technical standards.

## A need to assess the environment

To have an overview of the on-going global debris mitigation efforts and to raise awareness of space activities in general, the current document has been prepared. In particular, different figures are presented to capture the progress with respect to space debris mitigation objectives such as the minimization of the potential for on-orbit break-ups (Section 4.1), the limitation of space debris released during normal operations (Section 4.2), and the implementation of post-mission disposal strategies (Section 4.3). The main findings of the document are summarized here.

## Current status of the environment

Statistical models estimate more than 30.000 space debris objects larger than 10 cm in orbit and around 900.000 objects larger than 1 cm. The smaller fragments are considered to be large enough to be able render spacecraft inoperable or destroy sensitive spacecraft components, whereas larger fragments could cause spacecraft to completely fragment in case of collision – in particular in the Low Earth Orbit region – leading to the creation of hundreds to thousands of new fragments in orbit.

The space traffic in Low Earth Orbit has seen notable changes since 2015 principally as a result of the deployment of large constellations and a shift towards commercial operators. Launch traffic (Figure 4) is currently around ten times the level observed in the early 2000's. The increase in the number of launched satellites has also started to result in an increasing trend in the number of yearly re-entering spacecraft and orbital stages (Figure 8) with recently counts seeing more than 200 re-entries occurring per year.

With the deployment of large constellations the majority of the catalogued objects in some altitude bands are now manoeuvrable (Figure 9). This has started to have implications on the design and operational strategies for spacecraft in these orbits with spacecraft increasingly requiring coordination to perform collision avoidance.

Four fragmentation events were observed in the year covered by the present report (Table 1) and, on average over the last two decades, around 11 on-orbit fragmentations occurred every year (Figure 10). For what concerns the release of space debris objects during operations, the number of objects released by spacecraft has decreased significantly since the 1990s, whereas it remains relatively stable for orbital stages (Figure 12).

One of the core principles of the space debris mitigation guidelines is to remove objects from the LEO and GEO protected regions with a high success rate for those orbits where a natural disposal mechanism is absent [1]. Between 85% and 100% of all spacecraft reaching end-of-life during the last decade in the GEO protected region attempt to comply with space debris mitigation measures and between 60% and 90% do so successfully, with the compliance trend asymptotically increasing (Figure 14), with the exception of 2022 when a number of objects were disposed of below the GEO protected region.

Between 30% and 60% of the orbital stages delivering spacecraft in or near the GEO protected region during the last decade are in compliance with space debris mitigation measures, with the compliance trend increasing also in this case (Figure 16).

Between 45% and 90% of all spacecraft reaching end-of-life during the last decade (2013 – 2022) in the LEO protected region are in compliance with space debris mitigation measures, with the compliance trend increasing (Figure 17). However, this increase in absolute numbers is mainly due to the growth in the rate of spacecraft operating in naturally compliant orbits (as it can be derived from Figure 18). If those objects are discarded in the analysis, one can observe that until 2017 only between 10% and 40% of the spacecraft reaching end-of-life during the last decade are compliant with space debris mitigation measures, which is a very low compliance rate. After this, values reached higher relative compliance rates mainly due to the de-orbiting of one constellation and a low amount of satellites reaching end-of-life in a non-compliant orbit (Figure 19).

Between 70% and 90% of the orbital stages delivering spacecraft in the LEO protected region during the last decade are in compliance with space debris mitigation measures, with an increasing compliance trend (Figure 22) mainly due to an increasing number of spacecraft operating in naturally compliant orbital altitudes.

## Evolution of the environment

Whereas the trends in the compliance to space debris mitigation practices at a global level slowly increasing, it is of importance to note that the successful implementation is still at a too low level to ensure a sustainable environment in the long run. In particular, the extrapolation of the current levels in launch traffic, combined with continued fragmentations and limited post mission disposal success rate could lead to a rapid growth of the debris population, with an estimated number of objects larger than 10 cm more than doubling in less than 50 years (Figure 23). Even in case of no further launches into orbit, it is expected that collisions among the space debris objects already present will lead to a further growth in space debris population.

# 2 Introduction

More than 20 years have passed after the *IADC Space Debris Mitigation Guidelines* have been issued first in 2002. While mitigation measures have found broad consensus, today, it is of increasing importance to verify their effect in practice and to monitor their level of implementation. Therefore, the members of the IADC have decided on a collaborative effort in analysing and documenting the state of the environment in this comprehensive report and publish it in regular intervals for the awareness of space farers, decision takers and the interested public.

To this end, the information in this report is structured into three parts:

1. A presentation of the current state of the environment, as a result of measurement and modelling efforts and a presentation of the current launch. This also includes updates on the space traffic, which provides important indications for the future dynamics of the environment.
2. A presentation of latest debris generating events in combination with statistics on the conduct of apparent mitigation actions (like post mission disposal, mission related object release), relying on observation data accessible to IADC members.
3. An outlook on the evolution of the environment, projecting the consequences of the current behaviour and attempting to present an overall environment health status.

The IADC considers this information to be a solid reference for the state of the environment and as a tool to identify new traffic or environmental trend and to analyse the need for corrective and additional measures.

# 3 Current status

This section provides an estimate of the number of objects in classical Keplerian Earth bounded orbits at the reference epoch. The estimate is provided both in terms of object counts and models.

Launch statistics and in orbit release, are also reported, with a breakdown in top-level mission classification and mass range.

The reference epoch for the report is 31/12/2022.

## 3.1 Objects in the environment

According to space debris environment models, at the epoch of November 1st 2016, the estimated number of debris objects in orbit in the different size ranges is the following:

- 34,000 objects greater than 10 cm,
- 900,000 objects from 1 cm to 10 cm,
- 128 million objects from 1 mm to 1 cm.

The distribution of the number of objects as a function of their size is shown in Figure 1. The plot shows the number of objects larger than the threshold size indicated in x-axis. Different curves refer to different environment models, highlighting (with the shaded region) the current uncertainty associated with the modelling of small objects, especially below the 1 mm size range, because this size regime is only poorly covered by measurement data. More details on the comparison between environment models can be found in [2].

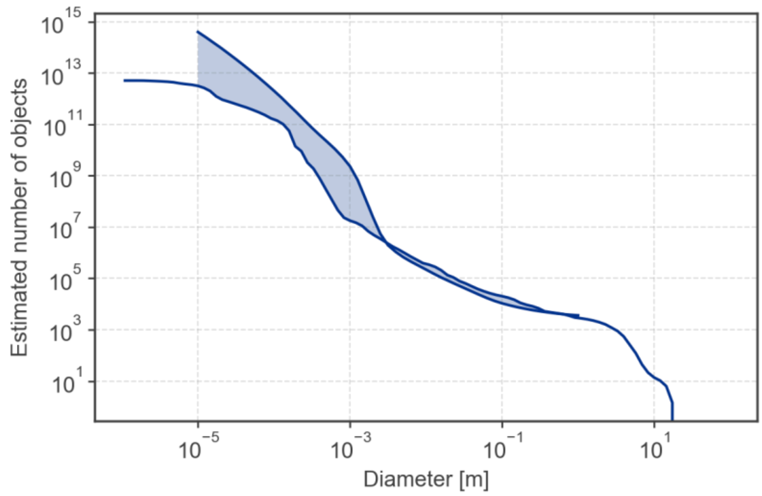


**Figure 1** Estimated number of objects as function of object size.

Figure 2 shows the density profiles with altitude corresponding to different minimum debris sizes (respectively 10 cm in dark blue, 1 cm in light blue, and 1 mm in green), considering only the LEO region. The logarithmic scale is used in the y-axis to consider the different orders of magnitude corresponding to the three populations. As for Figure 1, the shaded region indicates the difference between available environment models. Both Figure 1 and Figure 2 refer to the epoch of November 1st 2016.

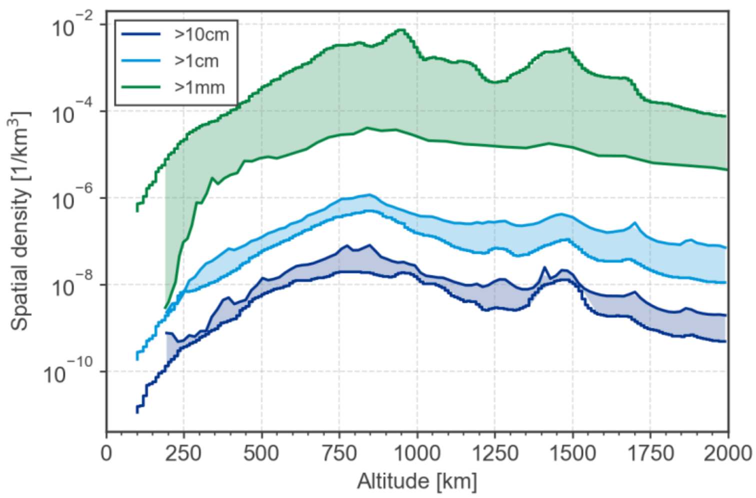


**Figure 2** Density profiles in LEO as a function of altitude for different size ranges

Figure 3 shows the results for different years, namely for the reference epoch in 2016 (in line with what is shown in Figure 2) and in 2022, which highlights the contribution coming from recent fragmentations (listed in Table 1).

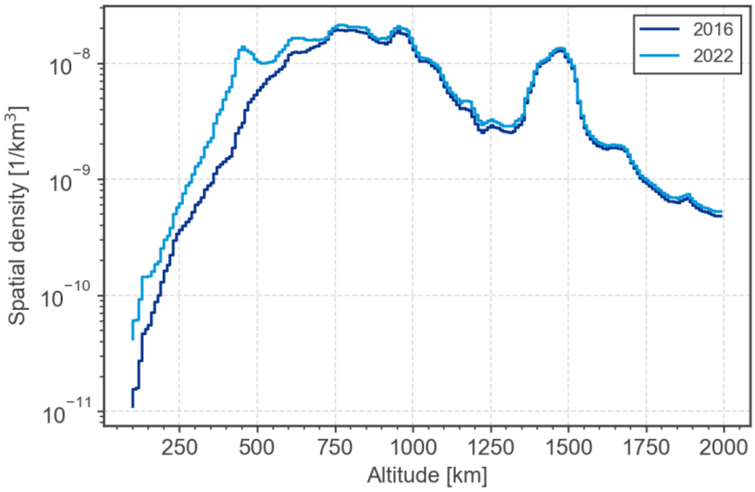


**Figure 3** Density profiles in LEO as a function of altitude for different epochs for the population larger than 10 cm.

## 3.2 Launch traffic

This section provides statistics on the number of spacecraft launched in the LEO (Figure 4 and Figure 5) and GEO region (Figure 6 and Figure 7) where the objects are categorised based on the altitude of the perigee ($h_p$). Two classifications are shown. In the first one, the launch traffic of spacecraft can be categorized in terms of the main funding source (Civil, Defence, Commercial, Amateur, where the Amateur category includes those spacecrafts associated with academic institutions when none of the other entities are the driving contributor). The second classification is based on the satellite dry mass.

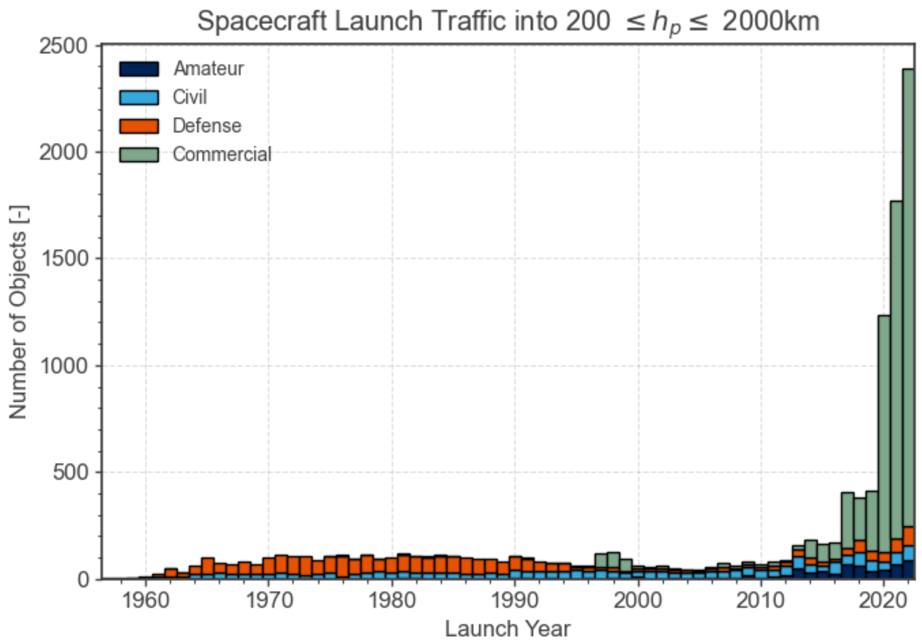


**Figure 4** Launch traffic into LEO by mission class.

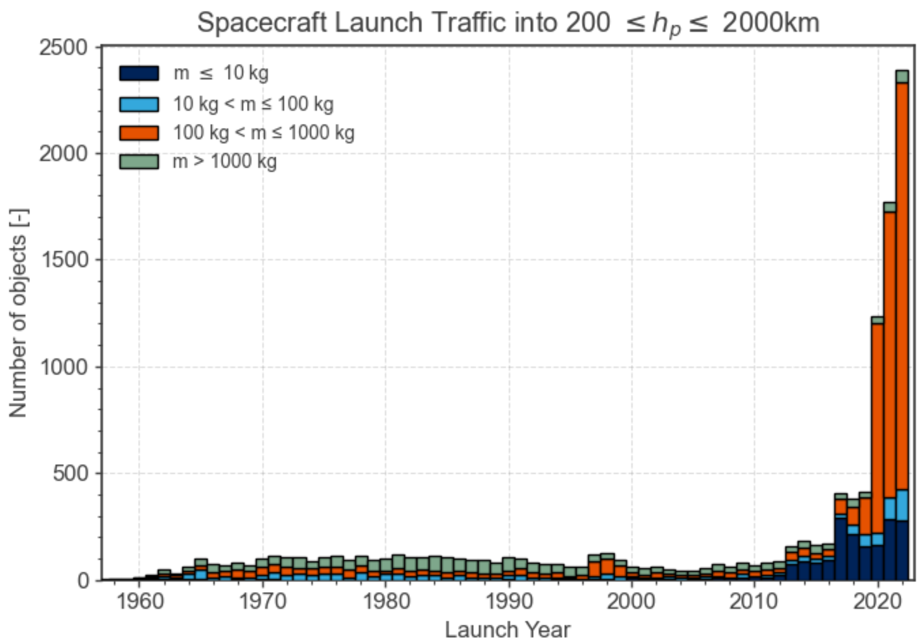


**Figure 5** Launch traffic into LEO by mass class.

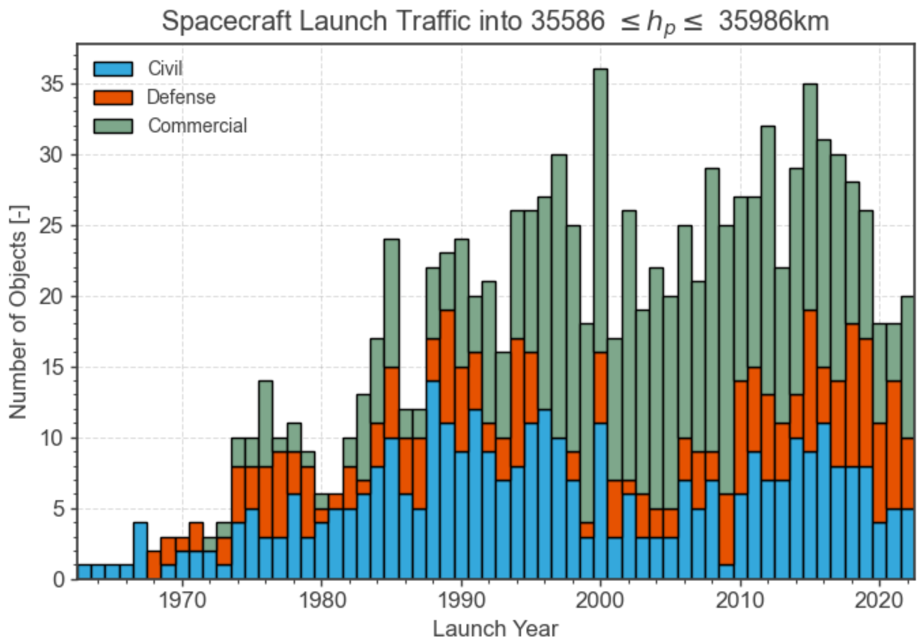


**Figure 6** Launch traffic into GEO by mission class.

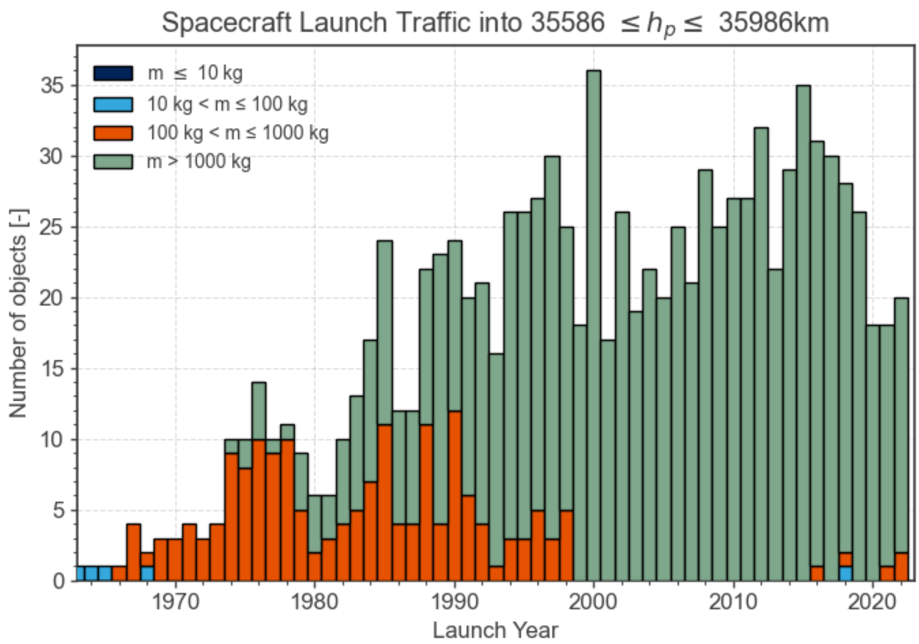


**Figure 7** Launch traffic into GEO by mass class.

## 3.3 Re-entries

Figure 8 shows the evolution in time of the number of re-entering objects each year by object type, excluding space objects related to human spaceflight. The numbers include both controlled and uncontrolled re-entries.

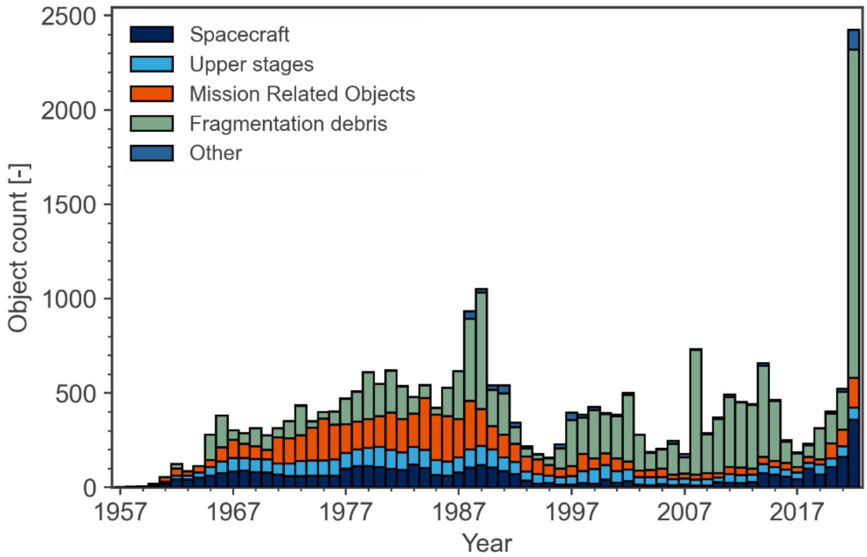


**Figure 8** Re-entries of catalogued objects by object type.

## 3.4 Manoeuvrable objects

Figure 9 shows the distribution of manoeuvrable spacecraft in LEO as a function of altitude together with the distribution of non-manoeuvrable objects. The manoeuvrability status is estimated based on space surveillance data, so only spacecraft exhibiting recurring manoeuvre capabilities are classified as manoeuvrable.

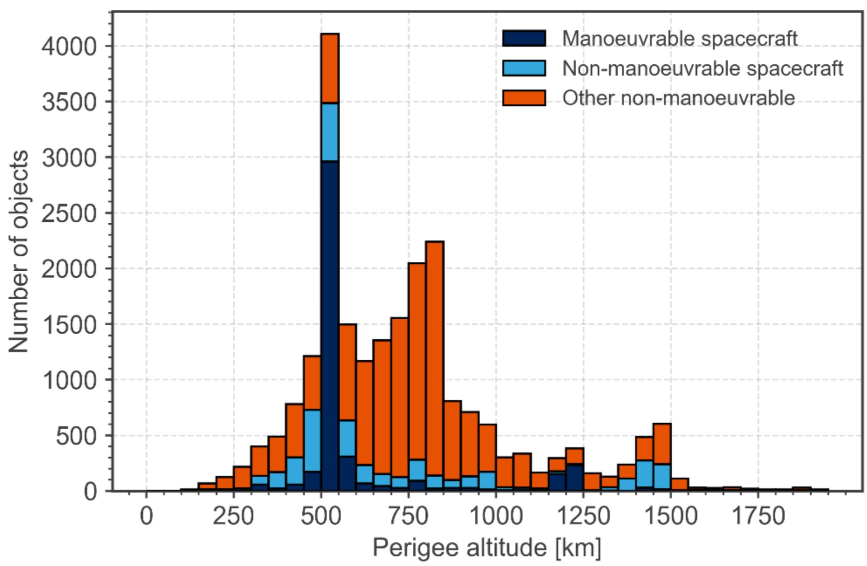


**Figure 9** Distribution of manoeuvrable and non-manoeuvrable objects in LEO as a function of altitude

# 4 Contributors to the space debris issues

## 4.1 Fragmentations

### 4.1.1 Fragmentations in period of analysis

Table 1 lists the fragmentations reported in the period of analysis (year 2022), with information on the event epoch and cause, together with the parent type and orbit. The table also reports the total number of catalogued debris objects: this indicates the total number of fragments associated to the break-up event, which may include objects that have already decayed at the time of compilation of the report. Much more debris, too small to be catalogued but that could still cause serious damage and threaten missions, is also generated from each breakup event. A range of values is provided for this entry when the sources available for this analysis present different values.

**Table 1:** Fragmentation Events in the period of analysis (year 2022).

| Event Epoch | Event cause | Total debris objects catalogued | Parent orbit | Parent type |
|---|---|---|---|---|
| **15 Apr 2022** | Propulsion | [3 – 16] | Other | Upper stage MRO |
| **03 Jul 2022** | Other | [23 – 37] | LEO | Upper stage MRO |
| **12 Nov 2022** | Propulsion | [369 – 533] | LEO | Upper stage |
| **17 Nov 2022** | Unknown | [31 – 50] | LEO | Upper stage MRO |

### 4.1.2 Historical fragmentations

Figure 10 shows the historical trend of the number of fragmentation events per year and Figure 11 shows the number of fragments generated by the events classified by the fragmentation cause. For these visualisations, the contributions from different sources were aggregated considering the highest number of fragmentation events per year and generated fragments per year reported by each source.

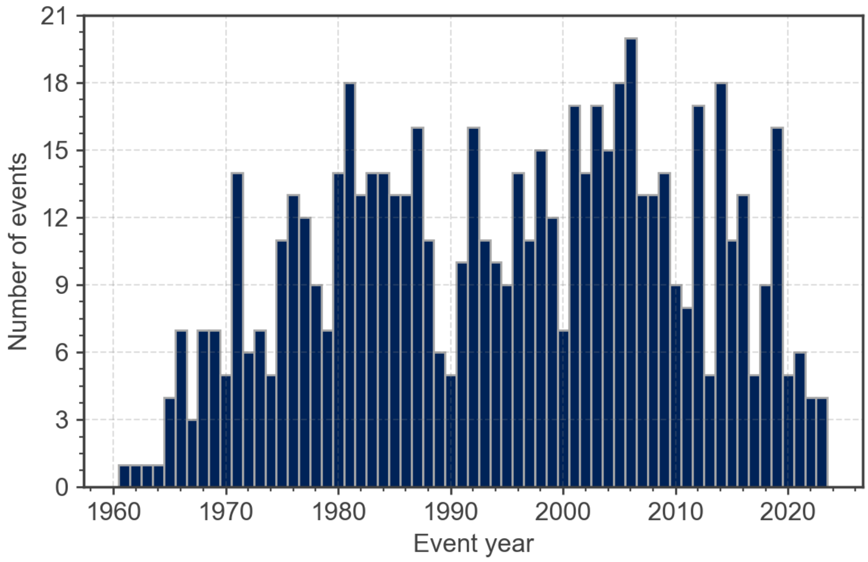


**Figure 10** Number of fragmentation events per event year.

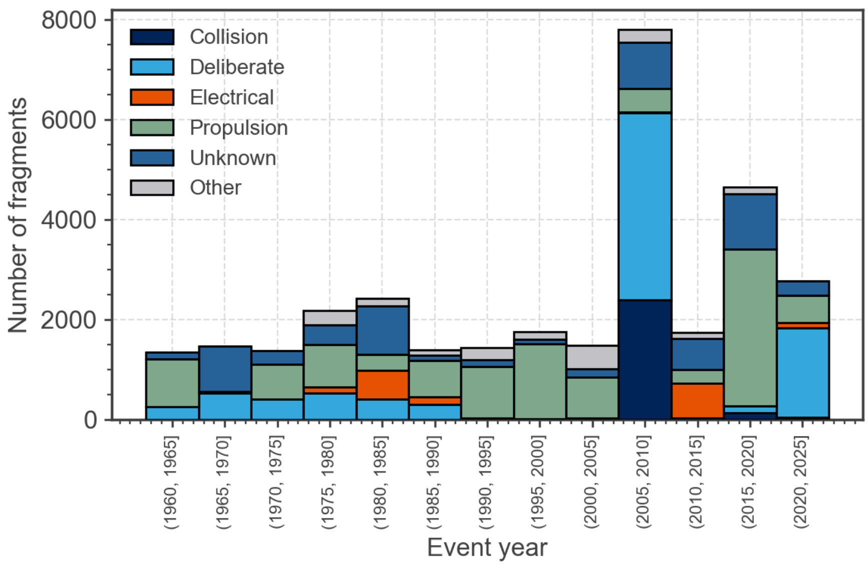


**Figure 11** Number of fragments per fragmentation cause and event year (5-year bin).

## 4.2 Mission Related Objects Release

Figure 12 shows the absolute number of released and catalogued mission related objects (MROs) by spacecraft and orbital stages: the shaded region indicates the difference between available catalogues. Figure 13 shows the yearly fraction of MRO release events over the total amount of spacecraft and orbital stages injected into the space environment during that year.

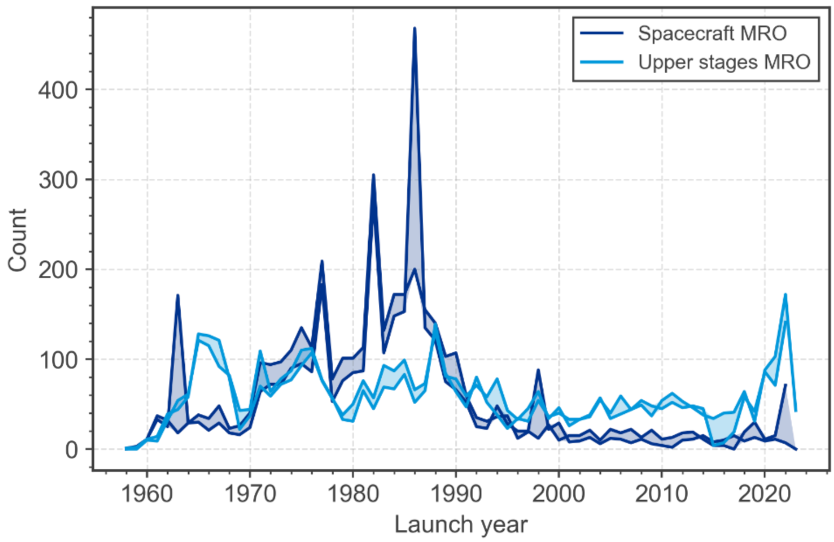


**Figure 12** Total number of catalogued mission related objects released.

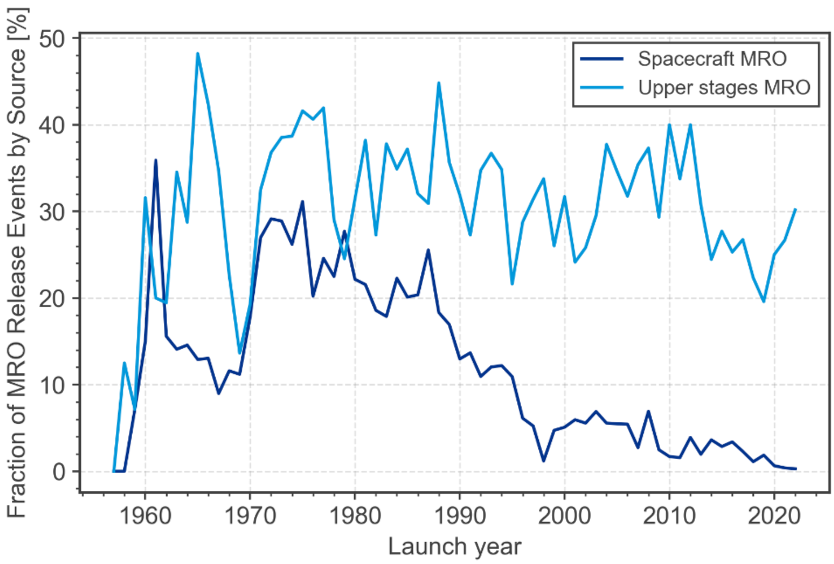


**Figure 13** Fraction of mission related objects releases per year with respect to the total amount of payloads and rocket bodies injected into the space environment during that year.

## 4.3 Disposal statistics

The analyses by different agencies are summarised showing the mean value of the analysed parameter (e.g., compliance rate, no attempt rate) for each year with a round marker, whereas the interval indicates the spread of minimum and maximum values recorded. Across different editions of this report, reclassification of past data can occur. A description of the compliance assessment methodology can be found in [3]. The data shown in the following sections includes the assessment of satellites that were launched before mitigation measures were introduced and, in general, recent improvements in reliability or increase in compliance are visible once that these new generations of spacecraft reach their end-of-life. For reference, the typical operational lifetime for satellites is around 15 years in GEO and 6 years in LEO (excluding satellites operating in naturally compliant orbits with the 25-year rule).

### 4.3.1 GEO

This section covers:

- Disposal of spacecraft operating in GEO (Figure 14, Figure 15),
- Disposal of launch vehicle orbital stages used for the insertion of spacecraft targeting GEO (Figure 16).

In particular, Figure 14 and Figure 16 show the rate of compliance, i.e., the number of spacecraft disposed of in a given year being compliant with the IADC Space Debris Mitigation Guidelines over the total number of spacecraft that reached end-of-life in that year. Figure 15 shows instead the rate of no disposal attempts for the analysed years.

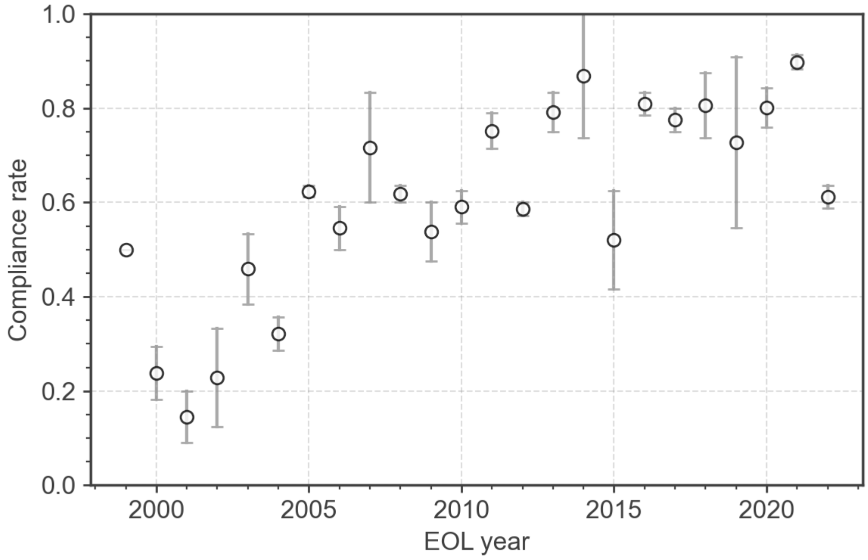


**Figure 14** General rate of successful disposal attempts for spacecraft in GEO as assessed by the contributing agencies.

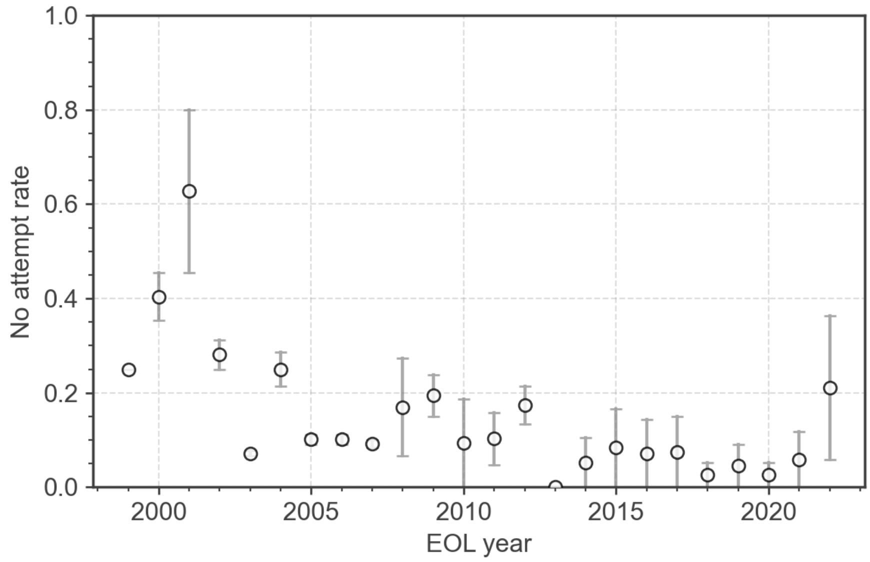


**Figure 15** General rate of no disposal attempts for spacecraft in GEO as assessed by the contributing agencies.

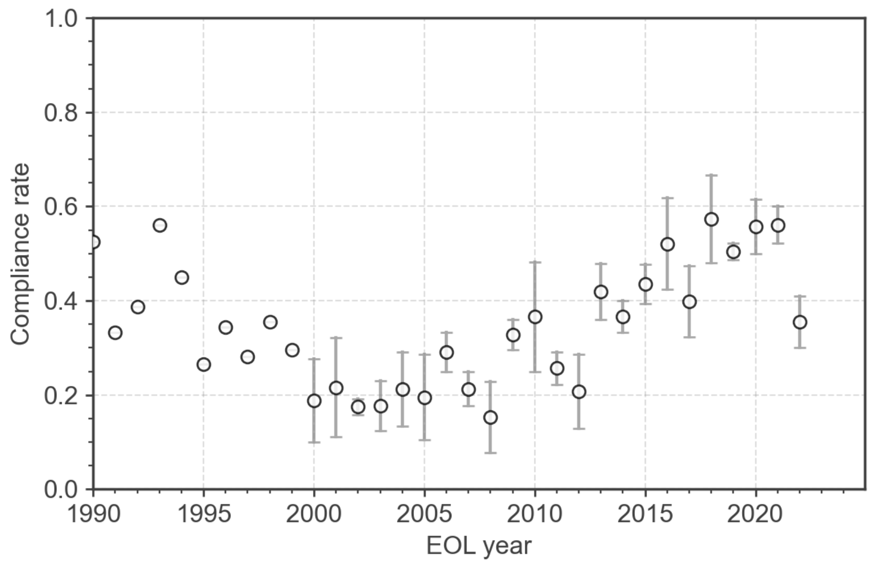


**Figure 16** General rate of compliant objects for orbital stages used to insert spacecraft in GEO as assessed by the contributing agencies.

### 4.3.2 LEO

This section covers:

- Disposal of spacecraft operating in LEO,
- Disposal of launch vehicle orbital stages in LEO,
- Disposal of spacecraft and launch vehicle orbital stages crossing LEO.

For the classification, above-LEO graveyard disposal is considered as non-compliant, in accordance with the IADC guidelines [1]. Human spaceflight related objects (including space tugs) are excluded from the analysis.

The notation *naturally compliant* is used to indicate orbital stages and spacecraft that operate in an orbit such that they naturally re-enter within 25 years (i.e., without requiring any manoeuvre).

Figure 17 shows the general rate of compliance for spacecraft in LEO, i.e., the sum of the number of naturally compliant objects and of the number of successful disposal attempts over the total number of spacecraft reaching end-of-life in a given year. Figure 18 shows instead the rate of compliance considering only non-naturally compliant satellites. The 90% level represents the minimum probability of success for disposal manoeuvres, as stated in the IADC guidelines [1]. In other words, spacecraft that need to manoeuvre in order to be compliant shall succeed with a probability of at least 90%. According to the data in Figure 18, the combined compliance rate for non-naturally compliant satellites that reached end-of-life from 2017 onwards is estimated to be 60%. Figure 19 shows the share of naturally compliant spacecraft over the total number of spacecraft reaching end-of-life in the year of analysis.

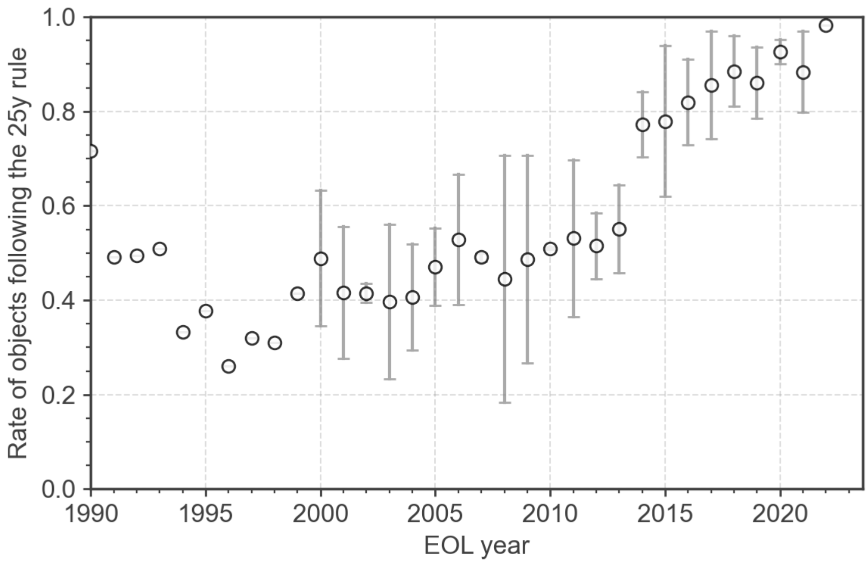


**Figure 17** General rate of compliant spacecraft in LEO as assessed by the contributing agencies. This includes naturally compliant objects and successful disposal attempts.
*Note:* because of the adopted methodologies, the value for the last year always needs re-confirmation in the report coming in the following year.

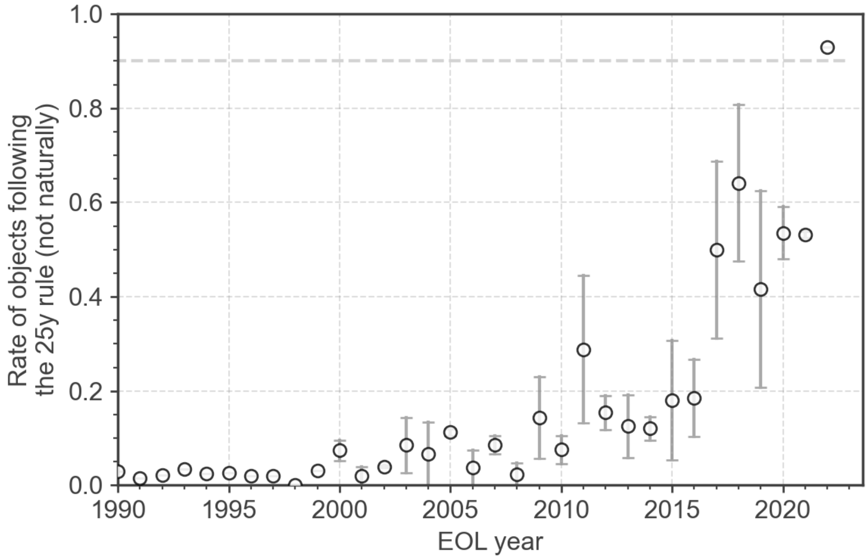


**Figure 18** General rate of compliant spacecraft in LEO considering only not naturally compliant objects as assessed by the contributing agencies. The dashed horizontal line at 90% represents the minimum probability of success for disposal manoeuvres, as stated in the IADC guidelines.
*Note:* because of the adopted methodologies, the value for the last year always needs re-confirmation in the report coming in the following year.

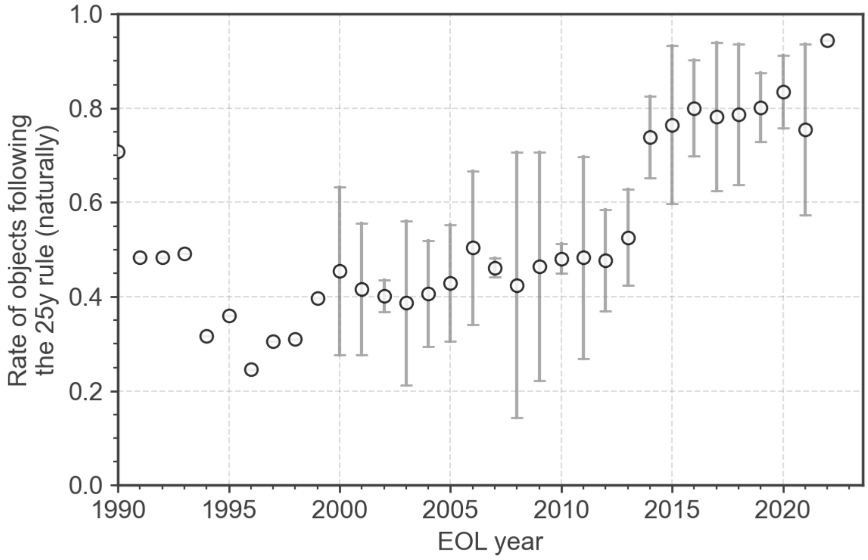


**Figure 19** General rate of naturally compliant spacecraft in LEO over total as assessed by the contributing agencies.
*Note:* because of the adopted methodologies, the value for the last year always needs re-confirmation in the report coming in the following year.

Figure 20 shows the general rate of compliance for spacecraft in LEO considering the classification in main funding source introduced in Section 3.2. Figure 21 shows the general rate of compliance for spacecraft in LEO considering whether they belong to a constellation (see List of Definitions).

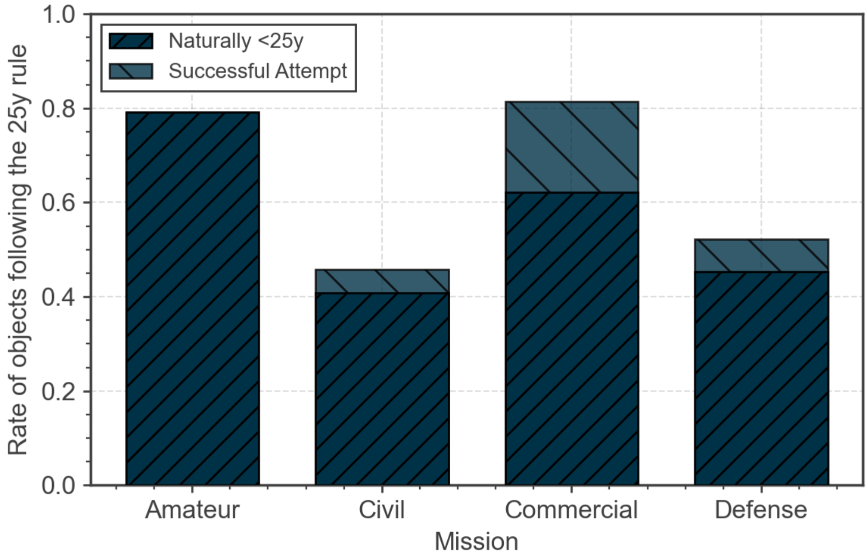


**Figure 20** General compliance rate for spacecraft in LEO by mission type as assessed by the contributing agencies.

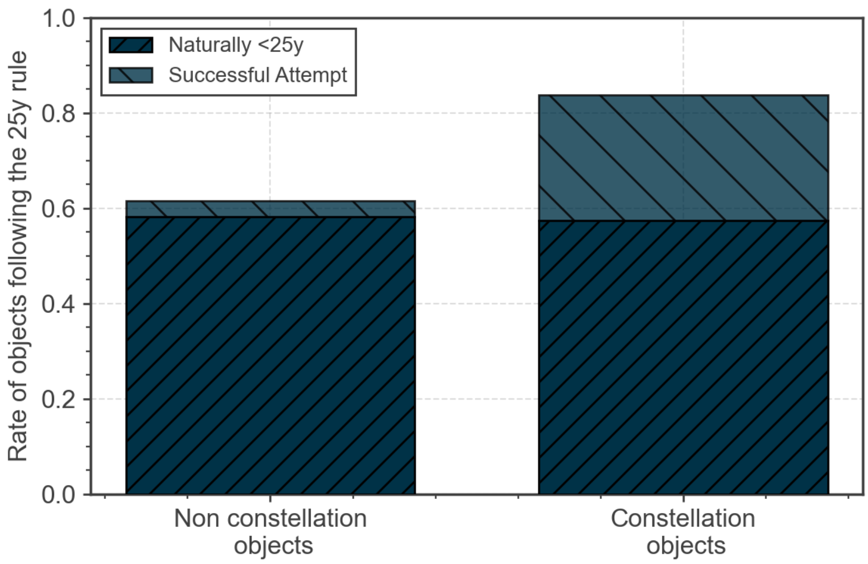


**Figure 21** General compliance rate for constellation and non-constellation objects as assessed by the contributing agencies.

Finally, Figure 22 shows the general rate of compliance for upper stages targeting or crossing LEO.

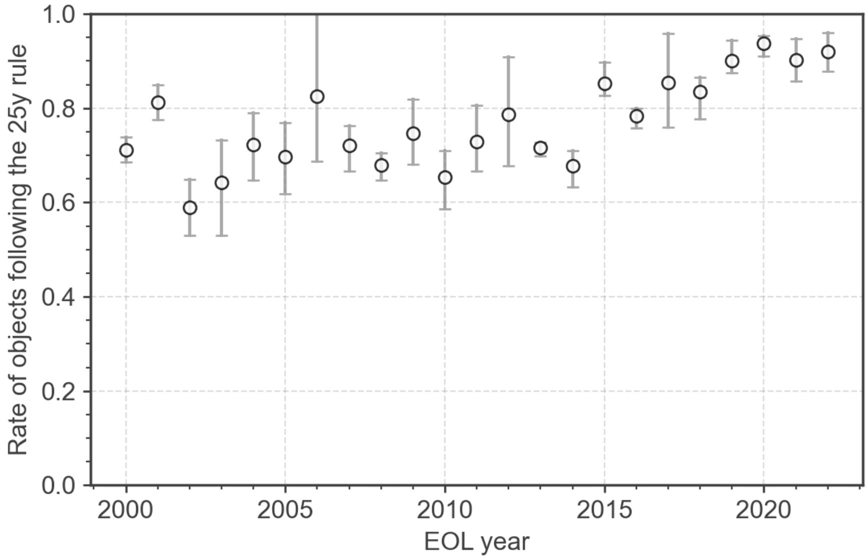


**Figure 22** General rate of compliant orbital stages in LEO as assessed by the contributing agencies. This includes naturally compliant objects and successful disposal attempts.

# 5 Environment Evolutions

The simulation of the future evolution of the debris population can be used to assess the efficacy of proposed mitigation actions and of current behaviours. In particular, two scenarios are presented in this section:

- A defined *extrapolation* of the current behaviour in terms of launch traffic, explosion rates, and disposal success rates.
- *No further launches* (NFL), where it is assumed that no launch takes place after the reference epoch.

The definition of trends in launch traffic, explosion rates, and disposal success rates is based on the data available to the contributing agencies and on the analysis contained in this report. The same inputs are used for each simulated scenario, whereas each agency uses its own model for the simulation of the long-term evolution of the environment over 200 years, performing at least 100 Monte Carlo runs per scenario. The parameters for the scenario definition are summarised below.

For both scenarios, the reference population used for the analysis is an extraction of the DISCOS population at the reference epoch (31/12/2022). For each object, physical characteristics such as mass, cross-sectional area, and orbital parameters are retrieved. For orbital stages and spacecraft, launch information is also stored. And for spacecraft specifically, it is also stored in which orbital region they are active and whether they belong to a constellation.

The yearly explosion rate is taken from the last decade statistics on non-system related fragmentations. In addition, for the *NFL* scenario, no explosion event is simulated after the first 18 years; this is motivated by the fact that it has been observed that 95% [4] of the non-system related fragmentation events occur within that time interval from launch.

For the *extrapolation* scenario, a launch traffic model is also needed as input for the simulations. This was obtained by repeating the launch traffic between 2017 and the reference epoch, discounting the contribution from constellations. For each of the constellations currently in orbit, a model of deployment and replenishment was defined using the publicly available data. A capability to successfully perform collision avoidance manoeuvres is assumed for as long as a spacecraft is active in the simulation.

A fixed operational lifetime of eight years is assumed for spacecraft not belonging to a constellation instead of the values derived in this report, in-line with current long-term space debris environment modelling practices. Specific values are used for spacecraft belonging to constellations, based on the available information on the current constellation designs where possible. Post-mission disposal success rates are derived from the observed values reported in Section 4.3, considering the performance for objects with end-of-life equal or later than 2017. A value of 90% is used for constellation objects, which is above the historically observed rates, but statistically valid rates could not yet be derived from the current active population. As such, it is set to the bare minimum identified in the IADC guidelines.

The evolution of the number of objects larger than 10 cm and the cumulative number of catastrophic collisions, i.e., collisions leading to the complete destruction of target and impactor, are shown in Figure 23 and Figure 24. The dark line represents the mean value over all the Monte Carlo runs and the light shaded region indicate the envelope of results (i.e. defined by the minimum and maximum case). This representation was selected to visualise the variability across the runs without introducing standard deviation bands as they may be not representative of the result distribution [5].

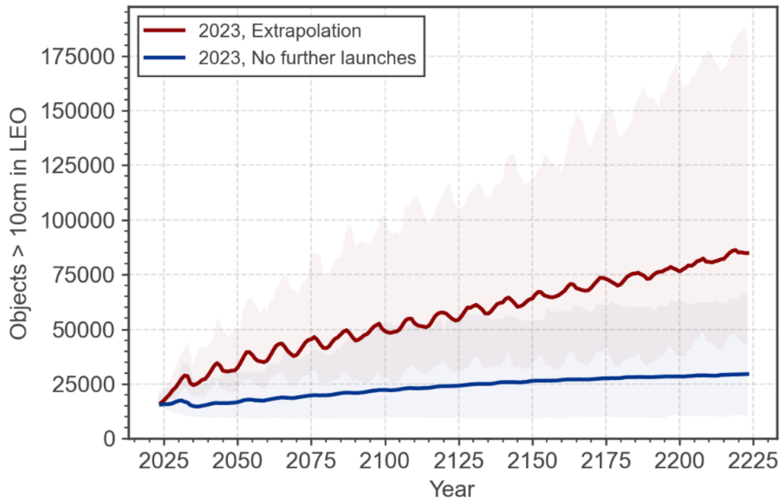


**Figure 23** Number of objects larger than 10cm in LEO in the simulated scenarios of long-term evolution of the environment.

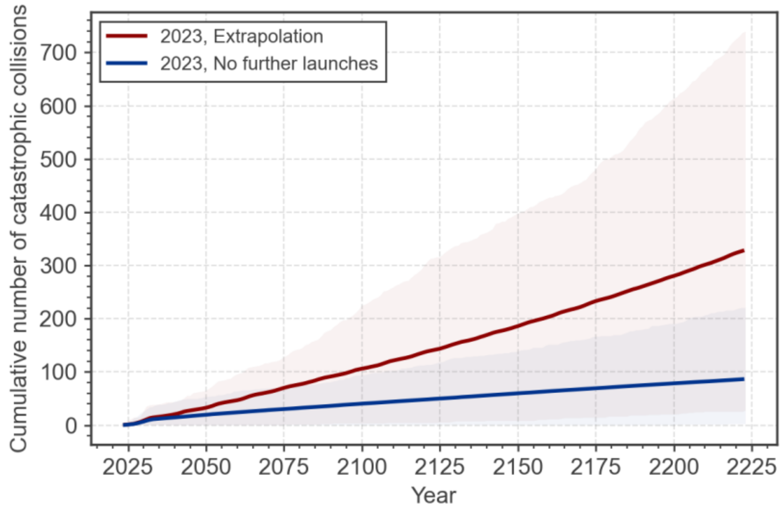


**Figure 24** Cumulative number of catastrophic collisions in LEO in the simulated scenarios of long-term evolution of the environment.

The results in Figure 23 and Figure 24 show a spread in the number of objects and collisions due not only to the intrinsic variability across different Monte Carlo runs (e.g. related to the conditions under which a collision will take place), but also due to the differences across the models available to the contributing agencies. For example, different models for the solar activity were used in the simulations and, already in the past, this was identified as a significant contribution to the variability of the results [6].

To compensate for this effect, a normalisation process was applied as follows:

- For each contributing agency, the mean curve in the *No further launches* scenario is computed (both for the number of objects and the cumulative number of catastrophic collisions);
- For each contributing agency, the individual outcome of the Monte Carlo runs in the *Extrapolation* scenario is normalised with the reference case at the point above;
- An overall mean is computed considering the normalised outcome from all simulations.

The results of this process for the number of objects and the number of catastrophic collisions are shown in Figure 25 and Figure 26, respectively. In spite of the variability of the results in Figure 23 and Figure 24, the normalised plots show a good level of consistency, with the *Extrapolation* scenario resulting in around three times more objects than the *No further launches* case, and almost 7.5 times more catastrophic collisions.

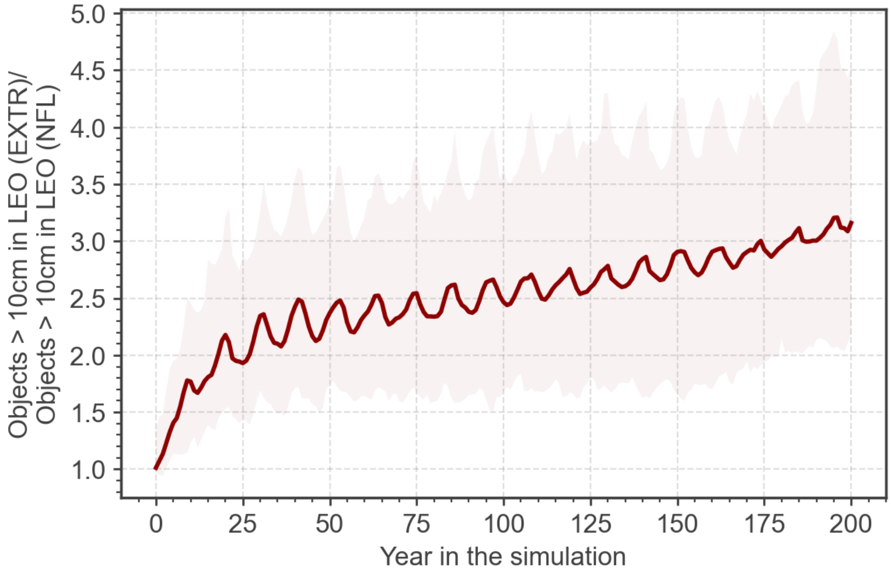


**Figure 25** Number of objects larger than 10cm in LEO in the simulated scenarios of long-term evolution of the environment.

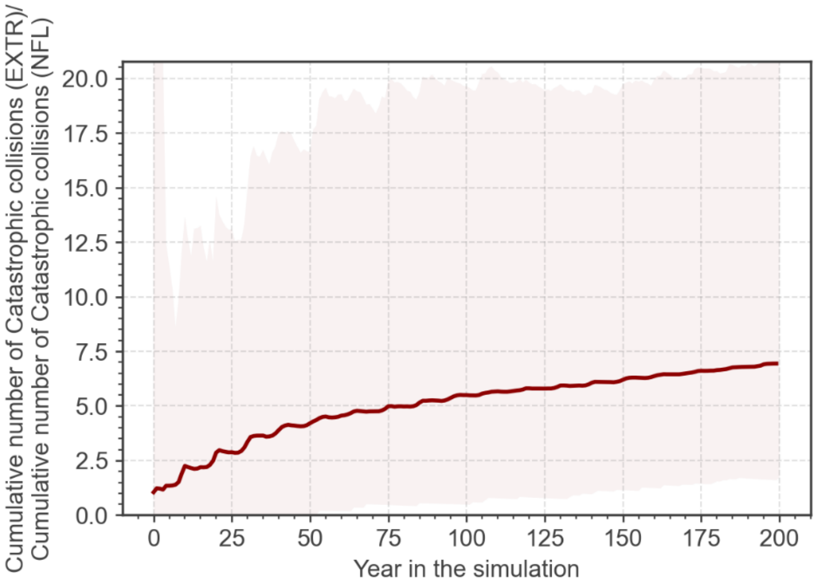


**Figure 26** Cumulative number of catastrophic collisions in LEO in the simulated scenarios of long-term evolution of the environment.

# 6 Sustainable space

The United Nations has previously defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Building upon this, the IADC is performing work to set metrics to define a sustainable space environment. It is hoped that future releases of this report will include the outcome of this work and this section will build upon this research by providing a quantitative interpretation of the space environment status and forecasts. Ahead of this and using the results provided in this report, the following observations can be made concerning the current and future state of the space environment:

- The most significant change in the launch traffic has been seen in LEO, principally from 2010, due to the deployment of large constellations and a shift towards commercial operators, as shown in Figure 4 and Figure 5;
- The widespread adoption of the COPUOS and IADC space debris mitigation guidelines and the IADC recommendations for large constellations of satellites continue to remain the most effective method to reduce the long-term environmental impacts of global space activity by slowing the rate of growth of the space debris population observed;
- With an increasing number of active satellites collision avoidance is also becoming increasingly important;
- Adoption of the IADC space debris mitigation guidelines is not yet at a level that is sufficient to induce substantial benefits or slowing of the population growth;
- With the current level of adoption of the IADC guidelines and recommendations, the extrapolation of current space launch activity could lead to the rapid growth of the orbital object population. The environmental evolution results in Section 5 identified that a doubling of the space debris population may occur in less than 50 years;
- Critically, in the case of no further launches into orbit, it is expected that collisions among space debris objects already present will lead to a further growth in space debris population;
- The IADC continues to encourage widespread adoption of the IADC guidelines and its recommendations. However, even with widespread adoption of these guidelines and recommendations, or even stricter behaviours, the consensus is that the environmental impacts cannot be removed completely and additional steps should to be taken, such as enabling the technology for active debris removal;
- Further research and discussions are encouraged within the global community to develop a consensus view on the definition of a sustainable space environment. The IADC will continue to perform research in this area and will provide regular releases of this environment report to support these discussions, including at the UN sessions.

# 7 Bibliography

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