# REORBITING STATISTICS OF GEOSTATIONARY OBJECTS IN THE YEARS 1997-2000

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## ABSTRACT

Based on orbital data in the DISCOS database the situation in the geostationary ring is analysed. From 878 known objects, 305 are controlled inside their longitude slots, 353 are drifting above, below or through GEO, and 125 are in a libration orbit (status of Jan. 2001). In the last four years (1997-2000) 58 spacecraft reached end-of-life. 20 of them were reorbited in compliance with the IADC recommendations, 16 were reorbited below this recommendation and 22 were abandoned without any end-of-life disposal manoeuvre.

## 1. INTRODUCTION

The geostationary ring is a valuable resource currently populated by some 300 operational satellites. Unlike in low Earth orbit there is no atmospheric drag which will remove abandoned objects over time. Therefore, it is the responsibility of the spacecraft operators to keep this unique orbital region clean. Already in 1977, Perek proposed that spacecraft should be systematically removed from GEO at end-of-mission [9]. In the same year INTELSAT sent for the first time in space history an aging satellite into a GEO graveyard orbit.

Since then a number of guidelines and recommendations for end-of-mission disposal by national and international institutions is following as described in [7] and [10]: In the early eighties, the US National Oceanic and Atmospheric Administration' disposal orbit guideline was 300 km above GEO. A recommendation by the United Kingdom in 1984 suggested that the disposal orbit should exceed 400 km above GEO [2].

Also during the 1980s, the International Telecommunications Union (ITU) began addressing the issue of end-of-mission disposal and super-synchronous graveyard orbits. Although ITU did not explicitly recommend a specific super-synchronous graveyard orbit, its definition of GSO "as a mean radius of 42164 $\pm$ 300 km and extending to 15 degrees north and south latitude" dictated a minimum perigee of the disposal orbit 300 km above GEO [6].

In 1995 the International Academy of Astronautics recommended to reorbit "geostationary satellites at end-of-life to disposal orbits with a minimum altitude increase 300-400 km above GEO depending on spacecraft characteristics" [4]. At the same time, space agencies like NASA, NASDA, RKA and ESA developed national guidelines. All recommended an altitude increase of more than 200 km above GEO. Finally in 1997, an international consensus was found within the Inter-Agency Space Debris Coordination Committee (IADC). The recommended altitude increase (in km) is given as

$$\Delta H = 235 + 1000 \cdot C_R \cdot A/m \qquad (1)$$

where $C_R$ is the solar radiation pressure coefficient (usually with a value between 1 and 2), $A$ is the average cross-sectional area and $m$ is the mass of the satellite [5].

In view of all these guidelines and recommendations one would expect that the geostationary ring is a well protected and unlittered space. However, as investigated by Johnson [7] only about one third of all satellites follow the internationally agreed recommendations. Two out of three satellites are reboosted into an orbit so low above GEO that they will sooner or later interfere with geostationary satellites or they are completely abandoned without any end-of-life disposal manoeuvre.

In this paper an updated survey of the situation in the geostationary ring is given. Following the statistics about the number of controlled and uncontrolled satellites the paper focuses on the reorbiting practices during the last four years (1997-2000).

## 2. ORBITAL DATA ANALYSIS

The basic source of information are the NASA Two-Line Elements (TLE). They are copied into ESA's DISCOS Database (Database and Information System Characterising Objects in Space) every day except Saturday and Sunday by ESOC's Mission Analysis Section. Usually one TLE per week and per object is stored. Geostationary objects are selected from the DISCOS Database according to the following criteria:

- eccentricity smaller than 0.1

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- mean motion between 0.9 and 1.1 revolution per sidereal day, corresponding approximatively to a radius of 42164 ± 2800 km
- inclination lower than 20 degrees

762 objects met these criteria as of 31 December 2000. Their orbital histories were analysed in order to classify them according to different categories. Six different types of categories are defined:

- C1: objects under longitude and inclination control (E-W as well as N-S control) - the longitude is nearly constant and the inclination is smaller than 0.3 degrees,
- C2: objects under longitude control (only E-W control) - the longitude is nearly constant but the inclination is higher than 0.3 degrees,
- D: objects in a drift orbit,
- L1: objects in a libration orbit around the Eastern stable point (longitude 75 degrees East),
- L2: objects in a libration orbit around the Western stable point (longitude 105 degrees West),
- L3: objects in a libration orbit around both stable points.

The algorithm to classify the objects is described in [8].

## 3. CURRENT SITUATION IN GEO

Next to these 762 objects, there are 116 more objects also known to be in this orbital region although no orbital elements are available in DISCOS. Thus, the total number of objects in the geostationary region is 878. They were classified as follows:

- 305 are controlled (186 under longitude and inclination control),
- 353 are in a drift orbit,
- 125 are in a libration orbit,
- 76 are uncontrolled with no orbital elements available,
- 19 could not be classified (5 of them were recently launched and are en route to their longitude slot; the other 14 either had a recent manoeuvre or there were too few orbital elements available).

In Fig. 1 the percentage of the various categories is illustrated. Please note, that the 119 controlled objects consist of the 79 objects in class C2 (only East-West station keeping) and 40 objects where no TLEs are available [1].

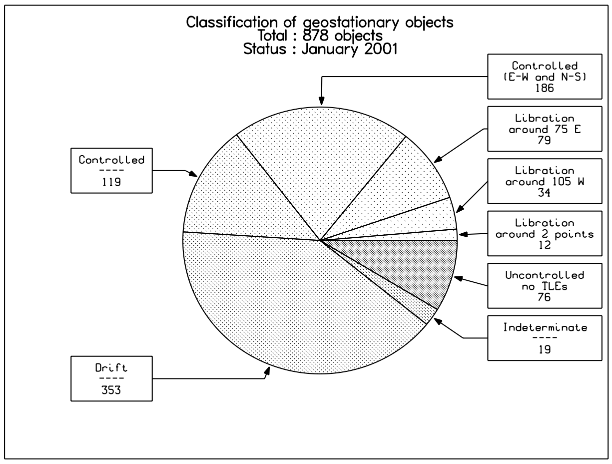


*Figure 1. Number of objects in each category.*

Fig. 2 shows the number of objects under control (bottom bars), in drift orbit or in libration orbit (top bars) according to the launch year. Most of the satellites launched before 1990 are meanwhile either in a drift orbit or in a libration orbit. Up to 10 objects were abandoned in such libration orbits every year.

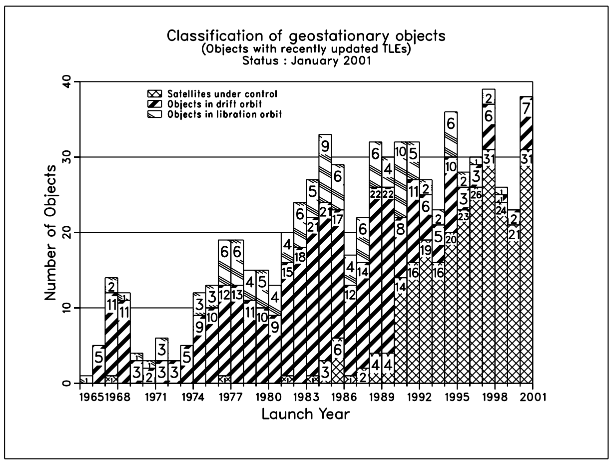


*Figure 2. Number of objects in each category according to the launch year.*

Fig. 3 shows the distribution of the longitude of the 265 satellites under control for which the orbital position is known. A concentration of satellites over Europe and also over the United States can be observed. Except for a small "hole" around 200° East, the congestion of the geostationary ring becomes evident.

Fig. 4 illustrates the distribution of the objects in drift orbit. Each vertical line represents one object. The horizontal axis gives the semi-major axis mean deviation from the geostationary altitude, which is inversely proportional to the mean drift rate of the object. The vertical axis gives the perigee and apogee mean deviation from the geostationary altitude. The altitude of the object varies between these two values. One can see that if the eccentricity is

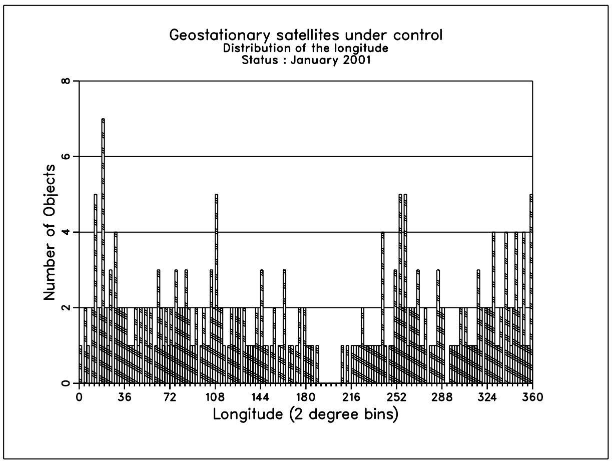


*Figure 3. Distribution of the longitude of the 265 satellites under control (with updated TLEs) in 2-degree bins.*

large, the object will go through the geostationary altitude.

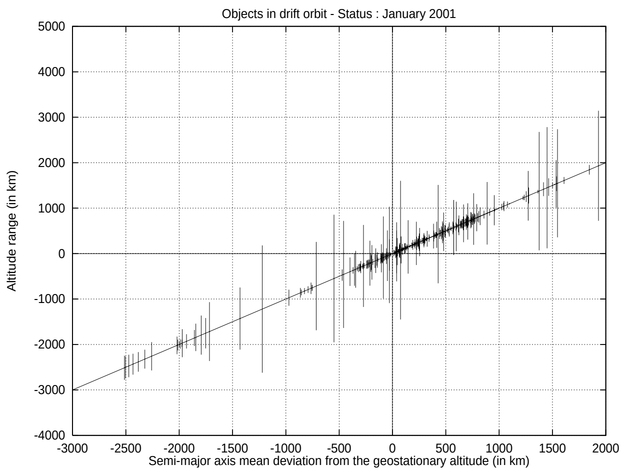


*Figure 4. Distribution and altitude range of the objects in drift orbit.*

Fig. 5 is a close-up of the previous figure showing the direct area around GEO. This area is important because, according to the IADC recommendations, a satellite should be reorbited at its end-of-life to a graveyard orbit with a perigee altitude which is about 300 km above the GEO ring [5]. All lines which are either totally or partly below the horizontal line at 300 km above GEO represent objects entering into the protected zone around GEO.

Fig. 6 shows the distribution of the perigee mean deviation from the geostationary altitude in 20-km bins. Most of the objects have their perigee between 0 and 500 km above GEO.

Fig. 7 illustrates the distribution of the objects in a libration orbit. For every interval of 5 degrees, the number of objects librating through this longitude interval is given. For instance, an object librating between 64° E and 86° E

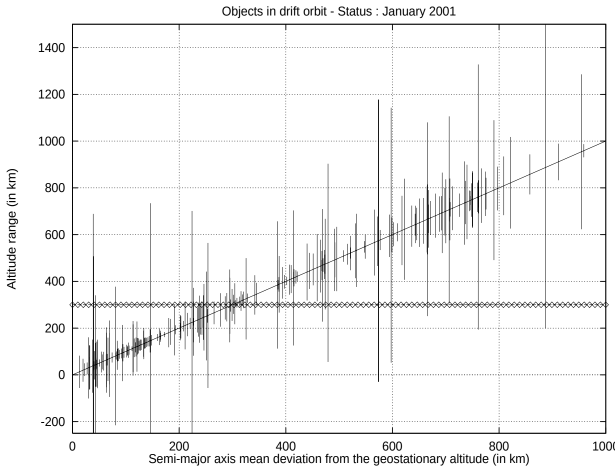


*Figure 5. Zoom in the distribution and altitude range of the objects in drift orbit.*

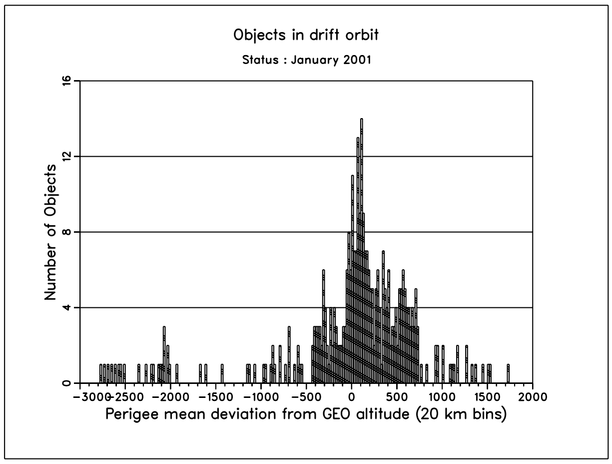


*Figure 6. Distribution of the perigee mean deviation from the geostationary altitude.*

is counted in the 5 intervals 62.5-67.5, 67.5-72.5, 72.5-77.5, 77.5-82.5 and 82.5-87.5.

For the same reason, all the objects classified as librating around the Eastern stable point or around the 2 stable points are counted in the interval 72.5-77.5, because they all go through the longitude 75° E. Thus, the number of objects at 75° E shown in this figure is equal to the sum of the objects in the L1 and L3 categories.

## 4. GEO REORBITING STATISTICS

Having analysed the current situation in GEO, it is certainly interesting to investigate how it has evolved over the last years. Therefore, the disposal practices which were applied to satellites at end-of-mission are analysed here. The time period covered are the four years from 1997 to 2000. The weekly Two-Line-Elements as stored in the DISCOS database were processed to detect the last orbit manoeuvre. This provided the date of the reorbiting

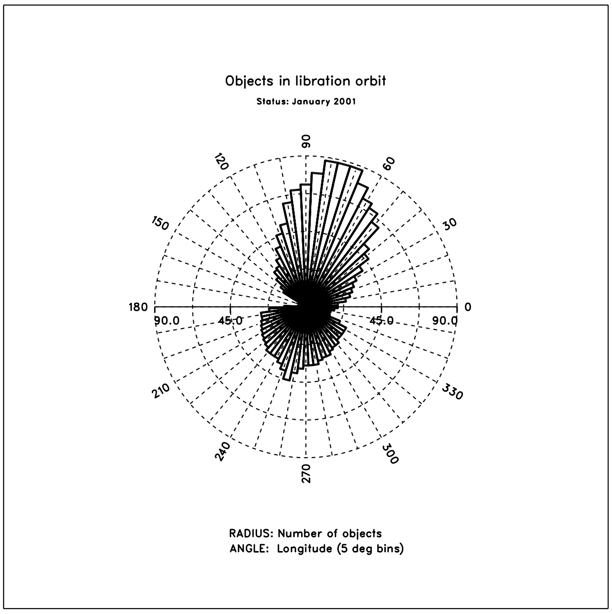


*Figure 7. Distribution of the objects in libration orbit in 5-deg bins of geographic longitude (objects with updated TLEs only, for full explanation see description in the text).*

manoeuvre if such a manoeuvre was performed. If a satellite was abandoned then the longitude history was analysed to determine the date when the satellite left its allocated orbital slot.

In total 58 satellites reached their end-of-life during the last four years. According to the orbital data in the DISCOS database, 22 of these (i.e. 38 %) were abandoned without any reorbiting manoeuvre. 15 were abandoned in the Eastern hemisphere (mainly Russian spacecraft) and are now librating around the Eastern libration point $L_1$ at 75° E over India. The libration period is between 2 years (Elektro 1) and nearly 5 years (Kosmos 2224). 5 were abandoned in the Western hemisphere (3 Russian and 2 US spacecraft) and are now librating around the Western libration point $L_2$ at 105° W. Two spacecraft were abandoned in orbits librating around $L_1$ and $L_2$ crossing nearly all longitudes during a libration period of nearly 10 years. Sometimes a failure was the reason that no end-of-life manoeuvre was performed like in the case of Telstar 401, but in most cases spacecraft owners operate their spacecraft as long as possible to maximise the results of their mission without considering the negative environmental effects.

16 GEO spacecraft (i.e. 27.5 %) performed an end-of-life manoeuvre where the perigee was not raised above GEO + 245 km, which is the approximate reorbiting altitude calculated with Eq. 1 for typical GEO spacecraft. Some spacecraft operators reserve only a minimum amount of propellant to free their own orbital slot. The reorbited satellites will then drift slightly above the geostationary ring in a region which is declared "protected" because it is the area where GEO satellites are drifting during station acquisition or during relocation manoeuvres.

Only 20 GEO spacecraft (i.e. 34.5 %) were reorbited in compliance with the IADC recommendations. 6 of them were Intelsat satellites, 4 Japanese, 4 Russian, 2 US American and 4 belonging to other countries, including one Eutelsat satellite.

The special case of Insat 2D (1997 027 B) was not included in the statistics of the 58 satellites reaching end-of life in the last 4 years, because due to serious power supply problems it apparently never became fully operational. At the end of 1997 only a few months after its launch it was manoeuvred into an orbit with a perigee 2620 km below and the apogee 180 km above GEO.

Table 1 summaries the reorbiting practices during the last four years. It should be noted that the relative low number of spacecraft reaching end-of-life in the year 2000 is due to the fact that satellites which started their reorbiting manoeuvres or were just abandoned at the end-of the year were not yet classified as having reached end-of-life. Therefore, the column showing the year 2000 will have to be updated at a later time.

*Table 1. Reorbiting practices from 1997 to 2000*

| | 1997 | 1998 | 1999 | 2000 | Total |
|---|---|---|---|---|---|
| Left around $L_1$ | 1 | 7 | 5 | 2 | 15 |
| Left around $L_2$ | 3 | 1 | 1 | - | 5 |
| Left around $L_1/L_2$ | 1 | - | - | 1 | 2 |
| Drift Orbit (too low perigee) | 5 | 6 | 2 | 3 | 16 |
| Drift Orbit (acc. IADC) | 7 | 7 | 4 | 2 | 20 |
| Total | 17 | 21 | 12 | 8 | 58 |

Table 2 shows the owners of the spacecraft which reached end-of-life. There are some general trends to be seen: Whereas some countries like Japan or organisations like Intelsat and Eutelsat tend to comply with the general reorbit recommendations, other nations like China, Russia and USA are more reluctant to take measures to preserve the geostationary ring.

Table 3 to 5 list the 58 spacecraft which reached end-of-life in the years 1997 to 2000 according to their "class": Abandoned, drifting too close to GEO, and properly re-orbited.

*Table 2. Reorbiting practices from 1997 to 2000 - distribution by country.*

| | China | Intelsat | Japan | Russia | USA | Other | Total |
|---|---|---|---|---|---|---|---|
| Left in libration orbit | 3 | - | - | 16 | 2 | 1 | 22 |
| Drift Orbit (too low perigee) | 1 | 1 | 2 | 1 | 7 | 4 | 16 |
| Drift Orbit (acc. IADC) | - | 6 | 4 | 4 | 2 | 4 | 20 |
| Total | 4 | 7 | 6 | 21 | 11 | 9 | 58 |

*Table 3. 22 Objects were abandoned in libration orbits around $L_1$, $L_2$ or both libration points.*

| COSPAR | Name | Year | Mode | Country |
|---|---|---|---|---|
| 1988 014 A | STTW-2 | 1997 | $L_1$ | China |
| 1989 101 A | Kosmos 2054 | 1997 | $L_2$ | Russia |
| 1990 016 A | Raduga 25 | 1997 | $L_2$ | Russia |
| 1993 077 A | Telstar 401 | 1997 | $L_2$ | USA |
| 1994 082 A | Luch 1 | 1997 | $L_1/L_2$ | Russia |
| 1994 069 A | Elektro 1 | 1998 | $L_1$ | Russia |
| 1998 025 A | Kosmos 2350 | 1998 | $L_1$ | Russia |
| 1997 070 A | Kupon 1 | 1998 | $L_1$ | Russia |
| 1989 081 A | Gorizont 19 | 1998 | $L_1$ | Russia |
| 1988 095 A | Raduga 22 | 1998 | $L_1$ | Russia |
| 1991 014 A | Raduga 27 | 1998 | $L_1$ | Russia |
| 1990 011 A | STTW-4 | 1998 | $L_1$ | China |
| 1987 100 A | Raduga 21 | 1998 | $L_2$ | Russia |
| 1990 051 A | Insat 1D | 1999 | $L_1$ | India |
| 1994 008 A | Raduga 1-3 | 1999 | $L_1$ | Russia |
| 1990 054 A | Gorizont 20 | 1999 | $L_1$ | Russia |
| 1992 088 A | Kosmos 2224 | 1999 | $L_1$ | Russia |
| 1997 041 A | Kosmos 2345 | 1999 | $L_1$ | Russia |
| 1987 022 A | GOES 7 | 1999 | $L_2$ | USA |
| 1990 102 A | Gorizont 22 | 2000 | $L_1$ | Russia |
| 1988 111 A | STTW-3 | 2000 | $L_1$ | China |
| 1990 094 A | Gorizont 21 | 2000 | $L_1/L_2$ | Russia |

*Table 4. 16 Objects were moved into orbits with a perigee too low to comply with the IADC recommendation.*

| COSPAR | Name | Year | Country |
|---|---|---|---|
| 1982 110 C | Anik C3 | 1997 | Canada |
| 1987 070 A | Kiku 5 | 1997 | Japan |
| 1986 026 A | GStar 2 | 1997 | USA |
| 1986 003 B | Satcom Ku1 | 1997 | USA |
| 1984 093 D | Telstar 3C | 1997 | USA |
| 1987 029 A | Agila 1 | 1998 | Philippines |
| 1989 052 A | Gorizont 18 | 1998 | Russia |
| 1981 119 A | Intelsat 503 | 1998 | |
| 1989 020 A | JC-Sat 1 | 1998 | Japan |
| 1988 109 A | Skynet 4B | 1998 | Great Britain |
| 1984 114 A | Spacenet 2 | 1998 | USA |
| 1985 048 D | Telstar 3D | 1999 | USA |
| 1989 062 A | TV-Sat 2 | 1999 | Germany |
| 1984 049 A | Star of China 5 | 2000 | China |
| 1988 018 A | Spacenet III R | 2000 | USA |
| 1988 081 B | SBS V | 2000 | USA |

## 5. CONCLUSIONS

Analysis of orbital data of 762 objects in or near the geostationary orbit revealed that 125 satellites were abandoned in the past and are now librating through all longitudes of the geostationary ring. 353 objects are drifting, mostly above GEO, but the majority of them cross GEO twice a day. These abandoned objects pose a collision risk to the active GEO spacecraft. Therefore the reorbiting of GEO spacecraft at end-of-life is recommended since over 20 years.

In 1997 the Inter-Agency Space Debris Coordination Committee issued a world-wide accepted recommendation to reorbit GEO spacecraft by at least 235 km plus a term depending on the spacecraft characteristics (see Eq. 1). However, this recommendation is only followed in one out of three cases. During the last four years, from 1997 to 2000, only 20 out of 58 spacecraft were properly reorbited. 16 were put in a disposal orbit with a perigee below the IADC recommended value. And 22 GEO spacecraft were completely abandoned without any end-of-life manoeuvre.

In order to preserve the unique resources which the geostationary orbit offers, a strict compliance with internationally agreed reorbiting procedures is required. As long as major space-faring nations like USA, Russia and China ignore these recommendations, the collision risk will steadily increase in the geostationary ring.


## 6. ACKNOWLEDGEMENTS

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*Table 5. 20 Objects were reorbited complying with the IADC recommendation.*

| COSPAR | Name | Year | Country |
|---|---|---|---|
| 1988 086 A | Sakura 3B | 1997 | Japan |
| 1982 106 A | DSCS 2-15 | 1997 | USA |
| 1988 108 A | Ekran 19 | 1997 | Russia |
| 1989 004 A | Gorizont 17 | 1997 | Russia |
| 1981 050 A | Intelsat 501 | 1997 | |
| 1976 017 A | Marisat 1 | 1997 | USA |
| 1989 048 A | Raduga 1-1 | 1997 | Russia |
| 1983 059 B | Anik C2 | 1998 | Argentina |
| 1990 077 A | Yuri 3A | 1998 | Japan |
| 1991 074 A | Gorizont 24 | 1998 | Russia |
| 1980 098 A | Intelsat 502 | 1998 | |
| 1983 047 A | Intelsat 506 | 1998 | |
| 1985 087 A | Intelsat 512 | 1998 | |
| 1989 027 A | Tele-X | 1998 | Sweden |
| 1990 063 A | TDF2 | 1999 | France |
| 1991 060 A | Yuri 3B | 1999 | Japan |
| 1982 097 A | Intelsat 505 | 1999 | |
| 1985 025 A | Intelsat 510 | 1999 | |
| 1988 063 B | Eutelsat I F-5 | 2000 | |
| 1989 070 A | Himawari-4 | 2000 | Japan |

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