OBSERVATION OF SPACE DEBRIS BY THE KAMISAIBARA RADAR SYSTEM

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ABSTRACT

Japan's first experimental radar system for space debris observation was built in March 2004 and equipped in Kamisaibara Space Guard Center (KSGC), which is located in Okayama Prefecture, the west part of Japan. This radar system was built by Japan Space Forum (JSF) in collaboration with Japan Aerospace Exploration Agency (JAXA). JXAX developed their debris data processing capability in Tsukuba Space Center and necessary data interface terminal in KSGC.

Since April 2004, JAXA, as a user of KSGC, has been low-Earth orbital debris observation data through this system. Regarding the first year as the preliminary operation phase, JAXA has implemented a pilot experiment to evaluate the performance of their orbit determination capability. In the first half of the year, we observed 25 catalogued space objects, then 152 space objects were catalogued for the second half year.

This paper reports the summery of this one-year preliminary accuracy of the orbit determination and our future plan for the coming next few years.

1. INTRODUCTION

Since "Sputnik 1" was launched in 1957, human beings have launched more than 5000 satellites. About 3000 out of 5000 have already finished their missions or reached to the satellite life, and lost their control. But they are still keeping rotating around the Earth. If we count the objects about 10cm in size or more, for example, fragments of Rockets and satellites, or artificial objects which are separated during the launch, about 10,000 space debris are considered to be drifting around the Earth. Although some of them are burned out and vanished while they are passing through the atmosphere during their reentry, they are counted only at about few dozens of space debris in one year. And at the same time, because of the breakup of space debris, the number of space debris is getting larger and larger every year.

Under these circumstances we are enlarging our field every day, we can see it clearly that we are in dare need of understanding the distribution of space debris around the Earth, and it has been getting necessary to observe space debris ourselves and understand the distribution of space debris caused by Japanese satellites and rocket bodies. As of Feb. 28, 2005, referring the database of Orbital Information Group (OIG) at NASA/GSFC, there seems to be about 140 space debris which belongs to Japan. Considering these circumstance, Japan has started to observe these space debris, using our own telescopes and radar in recent years.

1.1. Observation of Space Debris in Japan

The observation of space debris is implemented by USA, Russia and etc. so far. In Japan, Japan Aerospace Exploration Agency (JAXA) has started to build their own catalogue of space debris, observed by telescopes since 2000 and by radar since 2004.

About the observation by telescopes, our group uses the telescope-data of the Bisei Spaceguard Center (BSGC) in Okayama prefecture, which is located in the west part of Japan, based upon our observation requirements, with 1m and 50cm telescopes mostly.

About the observation by radar, the first radar observation for space debris exclusive use has started its operation in April, 2004. The radar is located in KSGC and Tsukuba Space Center (TKSC) space debris processing capability is communicating with KSGC for requirements transmission, and observation data receiving.

We'll describe the outline of the radar and the report of the first-one-year observation fully in the following sections.

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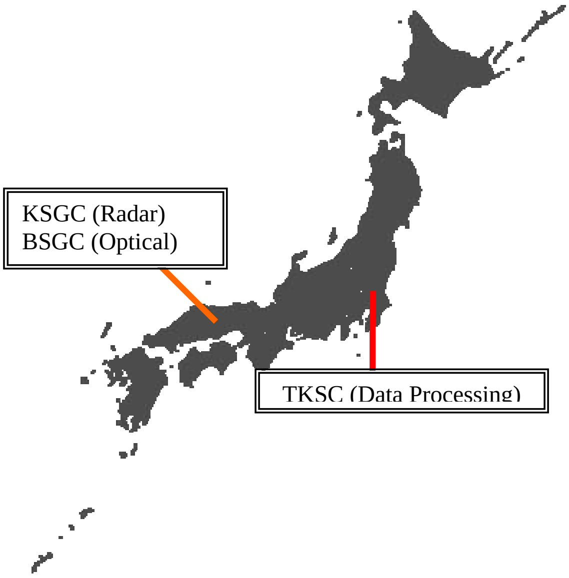

Figure 1. The locations of KSGC, BSGC and TKSC

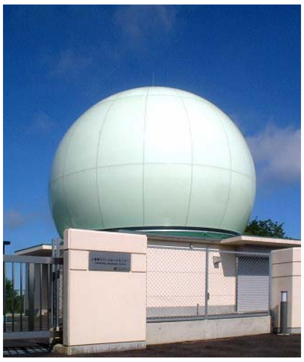

Figure 2. Radome at KSGC

Figure 3. KSGC Radar

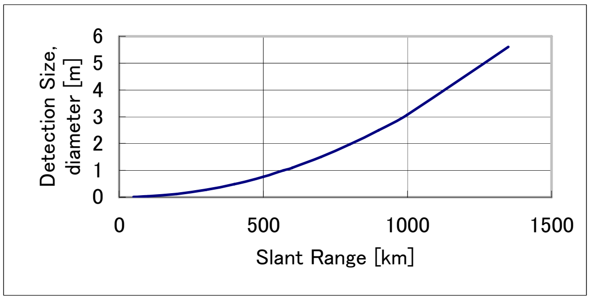

Figure 4. Detectable targets in size against slant range

2. CAPABILITY AND FUNCTION

2.1 The Radar System (KSGC)

2.1.1 The Function Capability

This radar adapts the flat Active Phased Array (APA) as a pilot system, and its appearance is as the following. Fig. 2 is the exterior of the building which has the radar inside. The building itself is a square 10m on a side and its height is 4m, and the radome is 3/4 spherical. Fig. 3 is the radar itself. The KSGC radar is 3m x 3m in size. It has 1395 transceiver modules (TRM) and transmits 70kW as a peak level. Considering the skyline of KSGC site, the elevation of KSGC radar is fixed at 45 degrees and this radar can observe from 15 to 75 degrees by electrical scanning. Regarding the azimuth scanning area, we set true north of KSGC as 0 degree, then this radar can rotate 270 degrees to both east and west side mechanically, and in addition to it, it can also scan ±45 degrees electrically.

As for the method to track space debris, two modes are possessed; one to track them by using their initial orbital prediction to all the observed passes and another to track by self-velocity prediction system. The KSGC radar is able to track up to ten space debris at the same time.

2.1.2 Detection Capability

It has the capability to detect 1m-across sphere at the slant-range of 577km, and their detection limit is 1350km. Fig. 4 shows detectable target size by slant range of the radar system.

2.2 Orbit Determination and Prediction Capability (TKSC)

The orbit determination and prediction capability at TKSC has two characters mainly, as following.

- Automatic orbit determination capability for multiple tracking by KSGC
- The best suitable observational requirements generation to KSGC

About the orbit determination, automatic processing by using data of the three passes observed during five days in typical and multiple debris orbits can be determined.

About the observational requirements, the requirements represent the use requirements for individual debris target based on the KSGC radar system capability and condition such as azimuth rotation, beam direction control.

The Plane Position Indicator (PPI) provides integrated operation and orbit determination status monitor in real-time at TKSC. Fig. 5 shows the screen image of the PPI; each line represents each trajectory of one space debris and drawn by each different color.

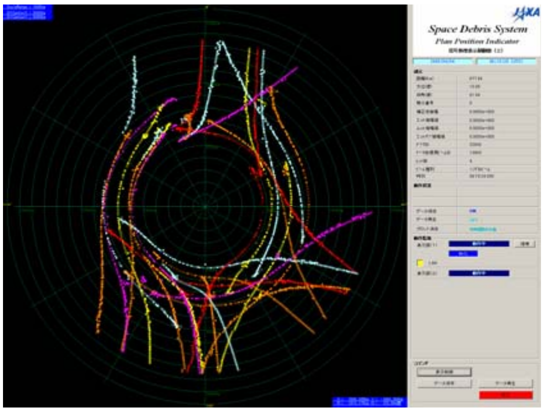

Figure 5. Plan Position Indicator

In addition to that, the Real-Time Trajectory Estimation Program for Space Debris (REPS) has also been adopted in TKSC since January, 2005. Although it is still in an early phase of development, we implemented its operation experimentally. We are planning to run the real-time reentry prediction against last-hour space debris with this system. Fig. 6 is showing an example of the screen image of the REPS, and Fig. 7 represents the screen image of the reentry prediction supported by REPS. We can see the errors compared with the predicted orbit in real-time.

3. OPERATION RESULT IN FY2004

3.1 Distribution of Space Debris Observable at KSGC

Considering the detectable distance, beam scanning area and the position of KSGC, 322 known space debris are observable in full time and 233 known space debris are observable only when they pass through near the perigee. Therefore there are, in total, 555 known space debris in the area we will be able to observe constantly. (These numbers is referred to OIG database at NASA/GSFC on Feb. 23, 2005.) Fig. 8 shows the known space debris of these 322, 555 and all the other space debris.

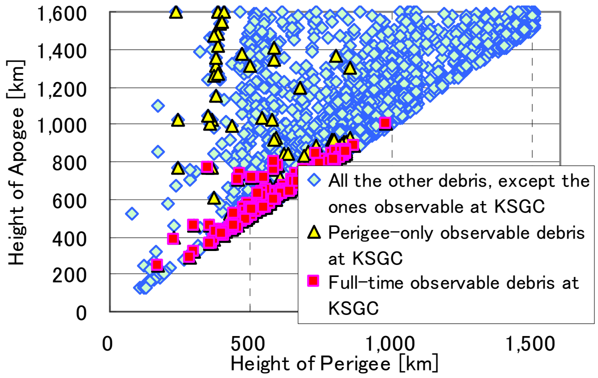

Figure 8. Distribution of space debris observable at KSGC

3.2 Observation Result

3.2.1 Number of Cataloged Objects

At the beginning of the observation in April, 2004, we set our observation as a test and observed rather large objects as the Engineering Test Satellite VII (ETS-VII) et al, and tried to figure out how long we can reach, how small we can detect, how accurate we can observe and how well we can track more. After this test observation we increased the number of space debris to try to observe; 20 objects in July, 100 in December, 200 in January and 300 in March. As the result, we could capture and moved on to track more than half of the space debris we tried to observe. As of Mar. 31, 2005, 152 objects out of 300, we observed, are catalogued so far. Fig. 9 is a graph to show the number of space debris we catalogued and observed, comparing to the total number of space debris, based on the OIG database on Mar. 31 2005.

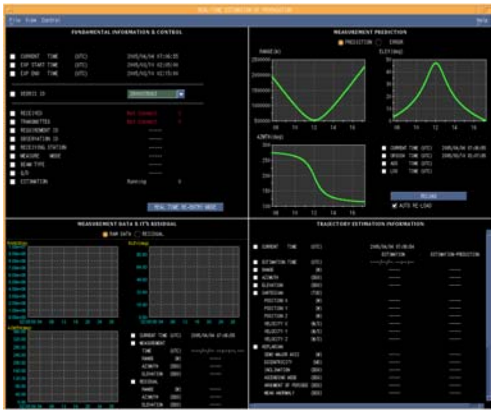

Figure 6. Screen image of REPS

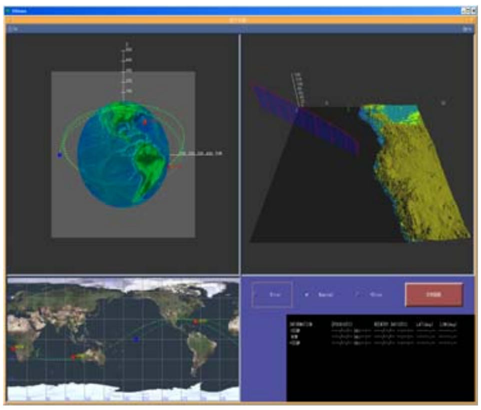

Figure 7. Screen image of the reentry prediction

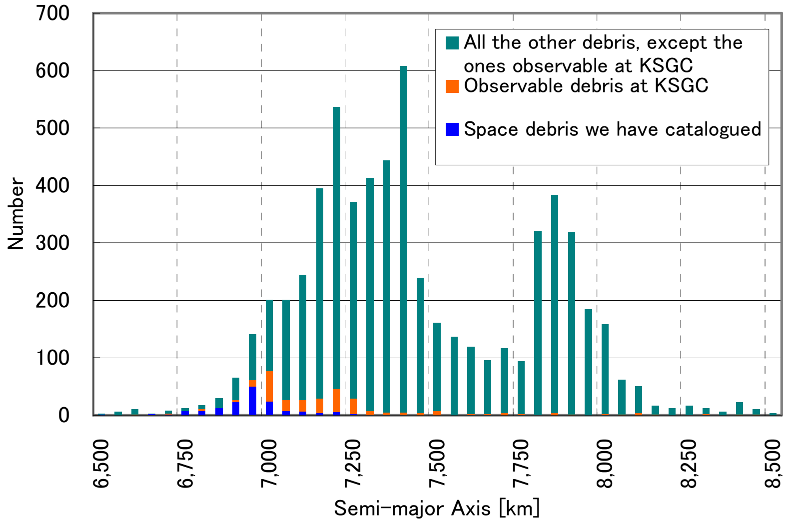

Figure 9. Number of catalogued space debris (a < 8,500 [km])

3.2.2 Accuracy of Orbital Determination

To evaluate the accuracy of the orbital determination, we compared the orbital elements which are determined by the data taken one day before and on that day, by propagating the one-day-before data for one day to on that day, so that they should be on the same epoch each other. Therefore, we took all the catalogued data at KSGC and evaluated their accuracy. And the result was that we had errors in semi-major axis: $\Delta a \cong 22.0[m]$, in position: $\Delta R \cong 5.57[km]$ and in inclination: $\Delta i \cong 0.00852[\deg]$. If we take only one space debris; the Engineering Test Satellite VII (ETS-VII) which was ended its operation in 2002, for an example, to compared with the evaluation by all the data, as we showed as the above, we had errors in semi-major axis: $\Delta a \cong 8.35[m]$, in position: $\Delta R \cong 2.26[km]$ and in inclination: $\Delta i \cong 0.00380[\deg]$. Fig. 10 represents the errors of the orbital determination in its semi-major axis.

As the above, we can say that our data is satisfactory from the viewpoint that we can ensure the recursive observation against low orbital space debris, even allowing for the ambiguity of 25m caused by signal procession, noises of data and the constraints of the jump of RCS values caused since the attitude of space debris change all the time.

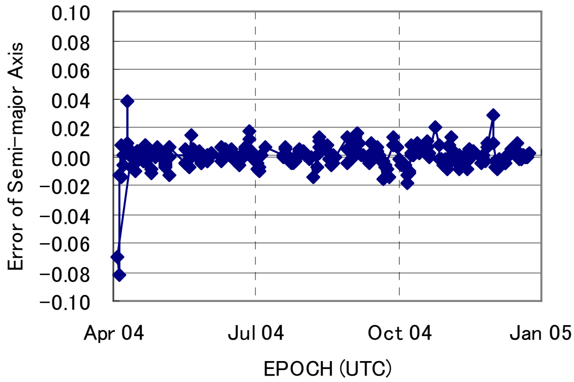

Figure 10. Δa of ETS-VII orbit determination

3.2.3 The Reentry Prediction

In regard to the space debris which are tend to be re-entered in the near future, we track the target, determine its orbit and predict the time of re-entry, as needed. As a first try against the re-entering space debris, we tried to get data of COSMOS 2332, which was chosen as the object for the IADC re-entry campaign this February. As shown in Fig. 11, we began observing COSMOS 2332 at around the middle of December in 2004. Although we couldn't receive good data for the last 3 weeks or so, we could confirmed that the accuracy of orbit determination was improving as the number of data is storing in our database.

In the future, we are planning to track more space debris which are about to re-enter and to asses our new system, REPS, just mounted this January, 2005.

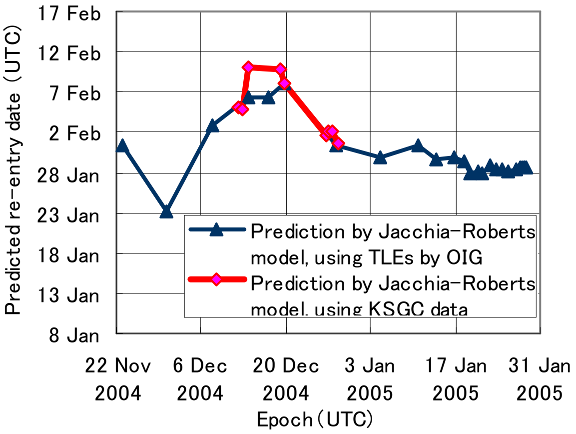

Figure 11. The comparison of the date between the data predicted by using TLEs at OIG and our KSGC data

4. PLAN FOR THE FUTURE OPERATION

As a planning for the next few years, we put the central aim to observe all the 322 space debris or more, which should be observable at KSGC in full time by their orbits. And for this aim, we are attempting to improve the detection capability and observe space debris as much as possible with this radar.

- To obtain more capability, we try to asses the system for capturing and tracking space debris, and to improve our signal processing.
- We evaluate the variation to RCS, caused by the spinning of space debris, and turn it to practical use by estimating the best suited value of RCS.

5. CONCLUSION

The first-one year had passed since our radar at KSGC was operated. In its process, we catalogued 152 low orbital space debris and we could obtain the prospect to the cooperation between the radar observation and the re-entry prediction. On the other hand, we have some jumps or lack of the data, considered to be originated to the spinning motion of space debris. Therefore, it will be necessary to give feedback to our observation by evaluating our observed data.

6. REFERENCE

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