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APPLICABLE TRACKING DATA ARCS FOR NORAD TLE ORBIT DETERMINATION OF THE KOMPSAT-1 SATELLITE USING GPS NAVIGATION SOLUTIONS

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ABSTRACT

NORAD Two Line Element (TLE) is very useful to simplify the ground station antenna pointing and mission operations. When a satellite operations facility has the capability to determine NORAD type TLE which is independent of NORAD, it is important to analyze the applicable tracking data arcs for obtaining the best possible orbit. The applicable tracking data arcs for NORAD independent TLE orbit determination of the KOMPSAT-1 using GPS navigation solutions was analyzed for the best possible orbit determination and propagation results. Data spans of the GPS navi gation solutions from 1 day to 5 days were used for TLE orbit determination and the results were used as initial orbit for SGP4 orbit propagation. The operational orbit determination results using KOMPSAT-1 Mission Analysis and Planning System (MAPS) were used as references for the comparisons. The best-matched orbit determination was obtained when 3 days of GPS navigation solutions were used. The resulting 4 days of orbit propagation results were within 2 km of the KOMPSAT-1 MAPS results.

Keywords: NORAD, TLE, orbit determination, GPS, navigation solution, KOMPSAT

1. INTRODUCTION

Worldwide Space Surveillance Network (SSN) of North American Aerospace Defense Command (NORAD) tracks about 8,500 space objects on Earth orbit. The SSN consists of three primary types of sensors such as conventional radars, phased-array radars, and an optical system known as the Ground-based Electro-Optical Deep Space Surveillance (Kelso 1997). NORAD generates a mean orbital elements set called Two Line Element (TLE) of the tracked space object. NORAD TLE has been widely used by the satellite operations community who don't have their own orbit determination system for satellite antenna pointing and mission planning. The orbital position and velocity of the space object can be propagated from the NORAD TLE using five general perturbation formulas such as SGP, SGP4, SGP8, SDP4, and SDP8 (Hoots & Roehrich 1980). However, the NORAD TLEs are generated with either SGP4 or SDP4 depending on the satellite orbital period. The SGP4 model is used for the near-Earth object of which orbital period is less than 225 minutes. Use of NORAD TLE simplifies the structure and operations of the satellite ground system. NORAD

TLE is updated once or twice a week but it depends on NORAD activities. The orbit propagation using an un-updated NORAD TLE causes orbit position errors in satellite operations.

The TLE independent from NORAD can be generated in two different ways. One is direct TLE Orbit Determination (OD), which employs NORAD like method to determine the TLE using satellite tracking data. The other is indirect TLE generation by converting the osculating orbital elements, which are the results of the ordinary OD system (Lee 2002, Lee & Park 2003). German Space Operations Center (GSOC) simplified the operations of the small satellite mission with self-developed TLE OD system using GPS navigation solutions (Jochim et al. 1996). In Korea, a batch weighted least square TLE OD system with SGP4 model using GPS navigation solutions was developed for the KOMPSAT-1 mission operations (Cho et al. 2002). However, the TLE OD system has not yet been applied to the normal KOMPSAT-1 satellite operations. In the mean time, normal operations of the KOMPSAT-1 has been conducted with the osculating orbital elements, which are the results of the Operational Orbit Determination (OOD) function in the Mission Analysis and Planning System (MAPS) (Lee et al. 2003). The OOD in MAPS uses a batch-type minimum variance estimator for processing a batch of 32-second interval GPS navigation solutions from Viceroy C/A code GPS receiver on-board the KOMPSAT-1.

In order to apply the result from NORAD independent TLE OD to the KOMPSAT-1 operations, the accuracy of the TLE orbit determination and propagation should be analyzed for various tracking data arcs. In this paper, applicable tracking data arcs of the GPS navigation solutions for achieving more accurate TLE in the TLE orbit determination were analyzed. KOMPSAT-1 GPS navigation solutions with various time spans from one day to five days were applied to the TLE orbit determination. The TLE orbit determination results were propagated for four days using SGP4 model and then compared with the MAPS OOD results.

2. TLE ORBIT DETERMINATION

The KOMPSAT-1 TLE Orbit Determination (OD) was carried out by using GPS navigation solutions with 32-second interval from Dec. 2, 2003 to Dec. 15, 2003. No orbit maneuvers were conducted during the period. At that time, the satellite was in a sun-synchronous orbit i.e., mean altitude of 667 km, mean inclination of 98.068 degrees, and the local time of ascending node of 10:52:11. Five cases of ODs were performed every day according to the GPS navigation solution data arcs from 1 day to 5 days. Epoch of the OD was the same as the first data in the GPS navigation solutions. The TLEs for the SGP4 model including mean motion and B^* values were estimated in the TLE OD processes.

Figure 1 shows a variation of the TLE mean motion in the ODs. The TLE mean motion is directly related to the semi-major axis in the Keplerian orbital elements. Daily mean motions of the TLE ODs using 1-day arcs are very changeable. Moreover, the OD generated a wrong mean motion in Dec. 8, 2003. The variations of the mean motions are stabilized when the OD used more than 3-day arc data. The mean motion values from NORAD on Dec. 3 and Dec. 12 are also presented in Figure 1. The mean motion for Dec. 3 from NORAD is quite different from the OD results in this paper. Only two NORAD TLEs can be archived during the period and it is quite normal for NORAD TLE dependent satellite operations.

Figure 2 presents a variation of B^* values which are related to the atmospheric drag coefficient. The B^* values from 1-day arcs OD shows very much daily variations. The B^* values are still unstable for the 2-day arcs OD. When using more than 3-day arcs data, the more data arcs were used in the orbit determinations, the more B^* values were stabilized. Figure 2 also shows the difference of the B^* values between NORAD and TLE OD. The mean motion and B^* values in NORAD TLEs

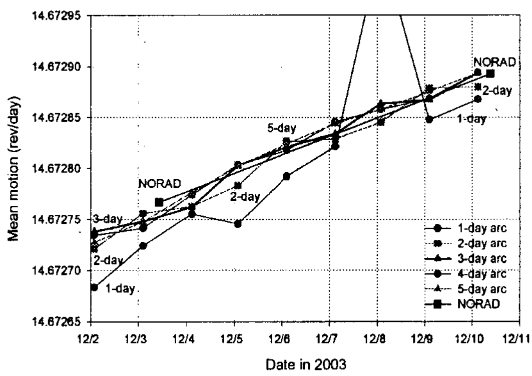

Figure 1. Variation of the mean motion by TLE ODs using different tracking data arcs.

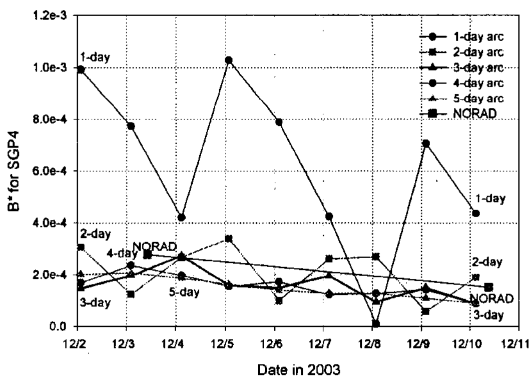

Figure 2. Variation of the B* by TLE ODs using different tracking data arcs.

are compared because the two parameters are the most significant values in NORAD TLE orbit determination and SGP4 orbit propagation.

3. SGP4 ORBIT PROPAGATION

In order to analyze the TLE Orbit Determination (OD) accuracy according to the tracking data arcs, the TLE ODs using GPS navigation solutions for 1-day to 5-day tracking arcs were performed and then the orbit propagation using SGP4 model were carried out. Table 1 shows the orbit epoch and used data arcs for five cases of TLE orbit determination. The orbit propagations were performed for 4 days from Dec. 8, 2003 using five orbital epochs in Table 1. The more tracking data arcs were used, the longer orbit prediction from epoch should be carried out. It was due to the different epoch time for the different tracking data arcs. In case 1, TLE OD was performed using 1-day tracking data arcs on Dec. 7, and the orbit propagation was carried out from Dec. 7 to Dec. 12. Whereas in case

Table 1. Case of the TLE orbit determination.

Case	Data Arc	Orbit Epoch (UTC)
Case 1	1-day data	2003/12/07 02:47:25
Case 2	2-day data	2003/12/06 02:13:17
Case 3	3-day data	2003/12/05 01:39:09
Case 4	4-day data	2003/12/04 02:45:17
Case 5	5-day data	2003/12/03 02:12:45

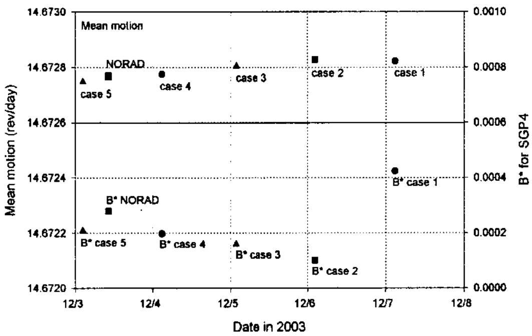

Figure 3. Mean motion and B* for five cases and a NORAD.

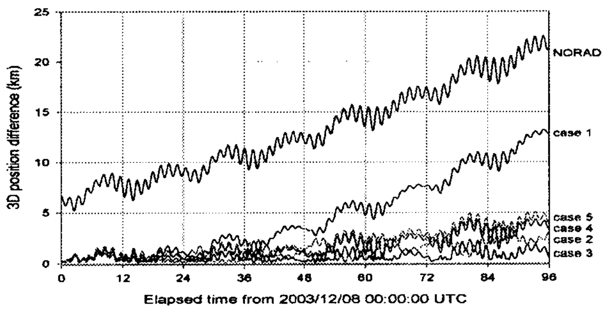

Figure 4. Position difference of NORAD and five cases from MAPS.

5, tracking data arcs for 5 days from Dec. 3 to Dec. 7 were used in TLE OD and orbit propagation for 9 days was performed from Dec. 3 to Dec. 12.

To generate a reference orbit, KOMPSAT-1 MAPS OOD was carried out using GPS navigation solutions for 4 days from 2003/12/08 00:00:00 to 2003/12/12 00:00:00. The position differences of the KOMPSAT-1 using three-day orbit overlaps were estimated as along-track 4.6 m, cross-track 1.3 m, and radial 0.4 m RMS (Lee et al. 2005). In order to find the applicable tracking data arc, the TLE OD and the resultant SGP4 orbit prediction for each case was performed and compared with

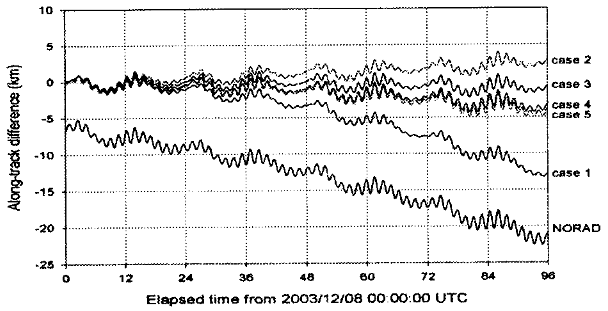

Figure 5. Along-track differences in five cases and NORAD.

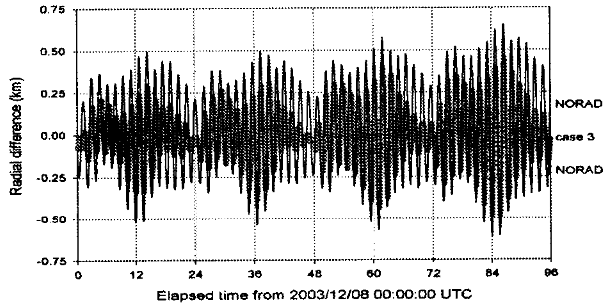

Figure 6. Radial differences in case 3 and NORAD.

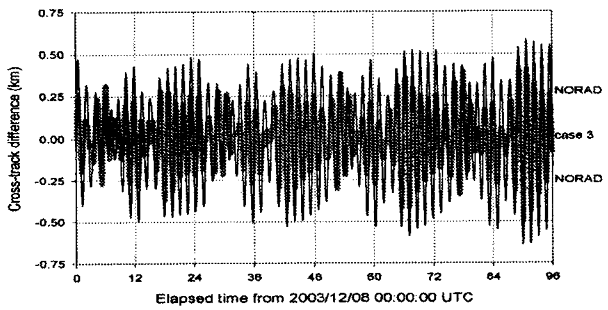

Figure 7. Cross-track differences in case 3 and NORAD.

the MAPS OOD. SGP4 orbit prediction using TLE started at epoch of the each case with 60 seconds time step from 2003/12/08 00:00:00 to 2003/12/12 00:00:00.

Figure 3 shows the mean motion and B* value at epoch for five cases. The figure also presents the mean motion and B* values from NORAD. The NORAD TLE was also propagated using SGP4 for comparison.

Figure 4 shows the position differences of the orbit prediction from NORAD TLE and five cases

TLE ODs. MAPS OOD using 4 days of GPS navigation solutions were used as a reference orbit. The orbit prediction using NORAD TLE starts from about 6 km in position differences and more than 22 km differences after 4 days. TLE orbit determination using 1-day data and SGP4 prediction in case 1 shows 13 km position differences after 4 days. In case 3, which uses 3-day data, the smallest differences of 2 km show after 7 days of orbit propagation from orbit epoch of 2003/12/05 01:39:09. The position differences show increasing pattern when using more data as in case 4 and case 5. These results show that the TLE OD using 3 days of GPS navigation solution gives the best orbit determination and propagation result. The satellite operations using SGP4 orbit prediction for 4 days can be achieved within about 2 km of position accuracy.

Figure 5 presents that the greater part of position difference in orbit determination and prediction are in the along-track direction. The difference in case 3 shows the smallest in six curves.

Figures 6 and 7 present the position differences in radial direction and cross-track direction, respectively. Two position differences in NORAD and in case 3 are shown in the figures. The position difference in NORAD is the biggest one in six cases, and the position difference in case 3 is the smallest one. The radial and cross-track differences show a sinusoidal behavior in maximum amplitude of 600 m and the differences are small compare to the along-track difference. The along-track difference is mainly due to the mean motion and B^* values in TLE orbit determination.

5. CONCLUSIONS

NORAD independent TLE orbit determination of the KOMPSAT-1 using GPS navigation solutions was performed to find the applicable tracking data arcs for obtaining the best possible orbit determination and propagation result. Tracking data spans of the GPS navigation solutions from 1 day to 5 days were used for TLE orbit determination. The SGP 4 orbit propagation was performed using orbit determination results as initial input data. The operational orbit determination results using KOMPSAT-1 Mission Analysis and Planning System (MAPS) were used for comparison. The best-matched orbit determination was obtained when GPS navigation solutions for 3 days were used and then the orbit prediction results for 4 days were within 2 km of the KOMPSAT-1 MAPS operational orbit determination results.

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