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Orbit determination and analysis for STSAT-2C

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Abstract. *The Korea's first satellite laser ranging (SLR) satellite, Science and Technology SATellite (STSAT)-2C was launched on January 30, 2013 by Korea Space Launch Vehicle (KSLV)-1. SLR tracking for STSAT-2C was started on March 29, 2013. However, there are very few SLR measurements because the accuracy of predicted orbit by consolidated prediction format (CPF) is low. It becomes trouble both tracking and orbit determination (OD) for STSAT-2C. In this study, OD using SLR measurements for STSAT-2C is performed. For OD, NASA/GSFC GEODYN II software is used and various estimation strategies are applied. The estimation periods of atmospheric drag coefficients and empirical acceleration parameters and arc length are changed. For orbit quality assessment, post-fit residuals of OD process and orbit overlaps of arcs are analyzed. Additionally, the differences between estimated orbit and CPFs are presented for reliability check. Finally, the results of this study can be utilized for making enhanced CPFs in order to support more tracking and precise orbits for STSAT-2C.*

Introduction

The Science and Technology SATellite (STSAT)-2C is the Korea's first satellite laser ranging (SLR) satellite. It was launched by Korea Space Launch Vehicle (KSLV)-1 on January 30, 2013. The primary mission of STSAT-2C is to develop spacecraft and test launch vehicle. The specification of STSAT-2C is displayed at Table 1. STSAT-2C has elliptical orbit which altitude is 300 km at perigee and 1,500 km at apogee. Figure 1 shows the shape of STSAT-2C. The primary SLR application is precise orbit determination. International Laser Ranging Service (ILRS) supports STSAT-2C by global SLR tracking. First tracking was done successfully on March 29, 2013. Currently in October 2013, 12 stations are tracking STSAT-2C by SLR. Changchun, Grasse, Graz, Greenbelt, Herstmonceux, Katzively, Kiev, Matera, Monument Peak, Mount Stromlo, Simeiz and Yarragadee uploaded consolidated laser ranging data format (CRD) normal point (NP) data to ILRS data center. Tracking status at the end of October is summarized in Table 2. For SLR tracking, consolidated prediction format (CPF) information are required. CPFs have orbit information to find satellites for SLR tracking. ILRS prediction centers normally provide CPFs. For STSAT-2C, KAI (Korea Advanced Institute of Science and Technology) provides CPFs now and SGF (NERC Space Geodesy Facility) made CPFs from August 30 through September 25, 2013. However, the CPFs of STSAT-2C, which are predicted based on S-band tracking data only, have low accuracy, and therefore STSAT-2C has bad observability for SLR tracking. Figure 2 shows the tracking history of STSAT-2C. In this figure, we can see that the distribution of SLR measurements is very sparse. Moreover, it can be a poor condition for orbit determination (OD), which is sparse and insufficient measurements. Hence more accurate orbit acquisition for STSAT-2C is getting more difficult. In this study, we try to perform the OD using SLR for STSAT-2C to make enhanced orbit. For orbit quality assessment, post-fit residuals and orbit overlaps are analyzed. The differences between estimated orbit in this study and current CPFs are also investigated for reliability confirmation.

Table 1. Mission parameters of STSAT-2C

Parameter	Value
Sponsor	MEST, KAIST
Primary applications	Spacecraft development
Primary SLR applications	Precise orbit determination
COSPAR ID	1300310
Launch date	January 30, 2013
Reflector	9 corner cubes
Orbit	Elliptical
Inclination (deg)	80
Eccentricity	0.082
Perigee (km)	300
Apogee (km)	1500
Weight (kg)	100

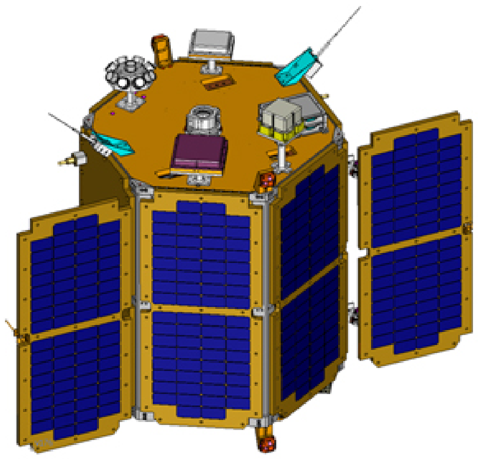

Figure 1. STSAT-2C satellite (http://ilrs.gsfc.nasa.gov/missions).

Table 2. Current ILRS tracking statistics of STSAT-2C (2013/10)

Station Name	Station	Start Date	End Date	No. Pass	No. NP
Changchun	7237	03/29 12:24:55	10/02 12:18:33	7	31
Grasse	7845	09/03 22:26:07	09/03 22:26:07	1	14
Graz	7839	04/25 00:52:24	08/30 21:00:56	17	246
Greenbelt	7105	04/10 09:33:33	09/18 00:14:12	14	229
Herstmonceux	7840	04/01 21:05:26	09/07 21:59:02	10	100
Katzively	1893	04/19 01:01:02	09/12 19:42:12	10	89
Kiev	1824	04/01 17:37:58	04/16 00:58:41	2	10
Matera	7941	09/27 17:56:31	09/27 17:56:31	1	10
Monument Peak	7110	04/11 02:12:54	04/11 02:12:54	1	13
Mount Stromlo	7825	07/08 09:20:09	09/27 08:57:07	3	11
Simeiz	1873	05/08 00:57:46	09/13 19:34:57	8	118
Yarragadee	7090	04/01 12:10:50	10/26 20:02:08	24	255

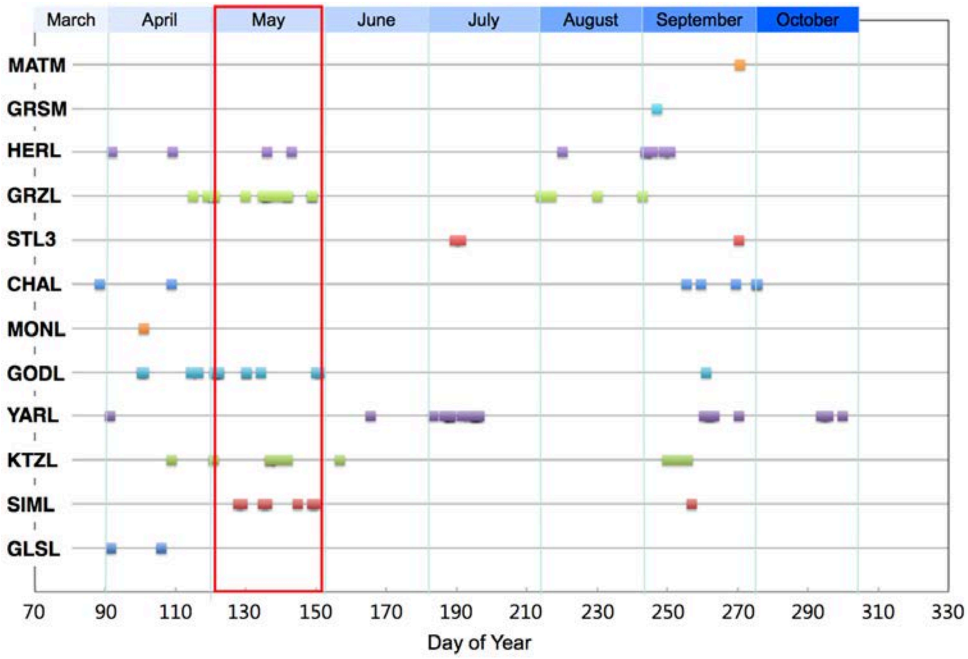

Figure 2. Tracking history of STSAT-2C measurements.

Orbit determination using SLR

In this section, the configurations of OD for STSAT-2C are summarized. For OD, NASA/GSFC GEODYN II software are used (Pavlis et al. 1998). Table 3 shows details of models and parameters for OD. We select SLR observations of May for OD because May and September have relatively abundant measurements as shown in Figure 2. Finally, we select arcs which have two passes per day at least. Table 4 shows the finally selected arcs for OD. 325 NPs by 5 ILRS stations are used. For estimation of drag coefficients and empirical acceleration coefficients, various estimation frequencies are tried and optimal frequencies are determined. Finally, we selected optimal frequencies for drag and empirical acceleration coefficients estimation as 8 hours and one day, respectively. No editing strategy, which means all measurements are used, are applied. Observation weighting of each station is determined as performance of station. Measurement bias of each station is estimated by pass.

Table 3. Dynamic and measurement models for STSAT-2C orbit determination

Model	Description	References
Earth gravity	JCET_RL04 180X180	Jeon et al. (2011)
Planetary ephemeris	JPL DE-1403	Standish et al. (1995)
Atmospheric density	MSIS-86	Hedin (1991)
Station coordinates	ITRF2005 SLR rescaled	Altamimi et al. (2007)
Precession/nutation	IAU2000	Mathews et al. (2002)
Tropospheric refraction	Mendes and Pavlis	Mendes et al. (2002) Mendes & Pavlis (2004)
Earth tide	IERS convention 2003	McCarthy & Petit (2004)
Ocean tide	GOT00.2	Ray (1999)
Solar Radiation	Cannonball(C_R=1.13)	

Table 4. The summary of selected STSAT-2C arcs

Arc	Start Time	End Time	No. NP	Arc Length	Station
1	05/01 00:51:28	05/02 07:53:54	96	2 days	7105,7839
2	05/10 00:47:52	05/10 07:54:19	57	1 day	7105,7839
3	05/14 06:01:08	05/18 23:08:03	172	5 days	1873,1893,7105,7839,7840

The condition for OD of STSAT-2C is poor, and therefore it requires exhausting iterative process including manual tuning to find a prior initial values for OD. A priori values of initial orbit are obtained from CPFs at first. Because of the accuracy of CPFs is low, manual tunings to reduce errors at first iteration are performed. If we performed OD successfully, prediction values from determined arc are used for next OD. Finally, estimation frequencies including drag and empirical acceleration coefficients, and arc length are changed for better OD precision.

Results

Post-fit residuals

First orbit quality assessment is performed by the post-fit residuals check. The post-fit residual value as weighted root mean square (RMS) of each arc is displayed at Table 5. The RMS value of Arc 1 is 0.71 cm. The RMS values of Arc 2 and 3 are 0.30 and 0.60 cm, respectively. Convergence characteristics of each arc is displayed at Figure 3. In this figure, we can see that RMS values of O-C residuals start at a few meters level and end to post-fit values. Figure 4 shows the measurement residuals at total period. We can see that large residuals at some period because they are no weighted residuals. Table 6 shows the RMS value of measurement residuals of each station. The RMS values of three stations (7105, 7839, and 7840) are small, while those of other two stations (1873 and 1893) are relatively large. They are weighted in OD process.

Table 5. The post-fit residuals of STSAT-2C orbit determination

Arc	Day	Weighted RMS (cm)	No. NP
1	0501 – 0502	0.71	96
2	0510	0.30	57
3	0514 - 0518	0.60	172

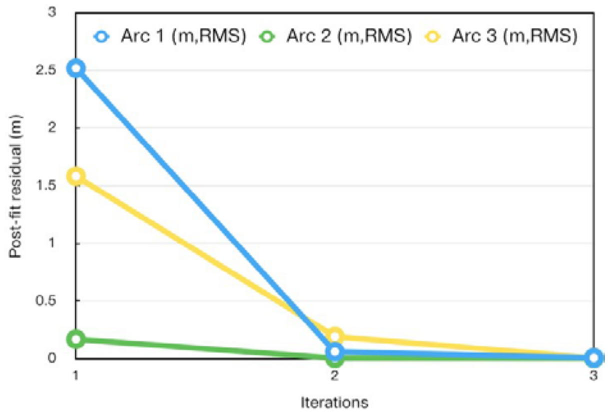

Figure 3. Convergence characteristics.

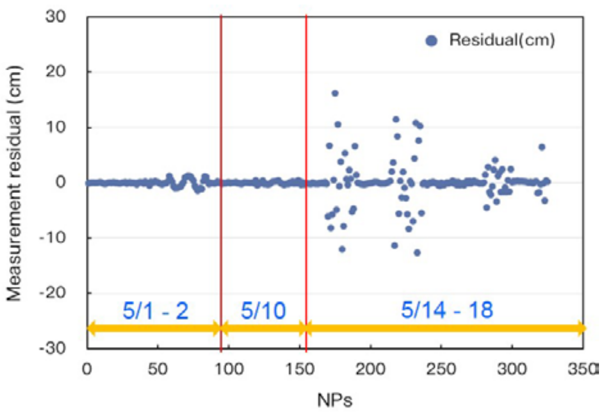

Figure 4. Measurement residuals.

Table 6. Measurements residuals of each station

Station	RMS (cm)	Station	RMS (cm)
7105	0.47	1873	6.93
7839	0.16	1893	2.48
7840	0.27		

Orbit overlaps

Next orbit quality assessment results are orbit overlaps. In general, overlapped periods are generated consecutively. Unfortunately, we cannot find good overlap periods among arcs. Therefore, we only make overlapped period using Arc 3. One day (12h 15 – 12h 16) are used for orbit overlaps. For orbit overlaps, two arcs are prepared, which are already determined arc (Arc 3) and newly determined arc (day 15-16). The concept of orbit overlaps in this study is displayed at Figure 5. As shown in Table 5, post-fit residual of overlapped arc 1 (Arc 3) has 0.60 cm as RMS value. The RMS value of newly determined overlapped arc 2 is 0.59 cm. There are slightly small differences between two overlapped arcs. However, differences between two determined orbits are a few meters level. Figure 6 show the differences of determined orbits in radial, along-track, and cross-track directions. The differences between two overlapped arcs are under about 10 m. It is because OD is performed by short and sparse arcs. We can check the orbit accuracy by orbit overlaps are best at the mid-point of arcs.

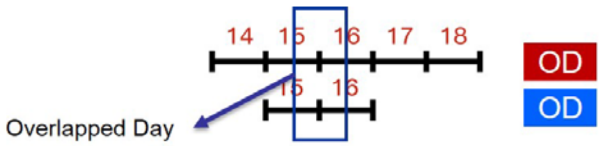

Figure 5. Concept of orbit overlaps (12h 15 – 12h 16).

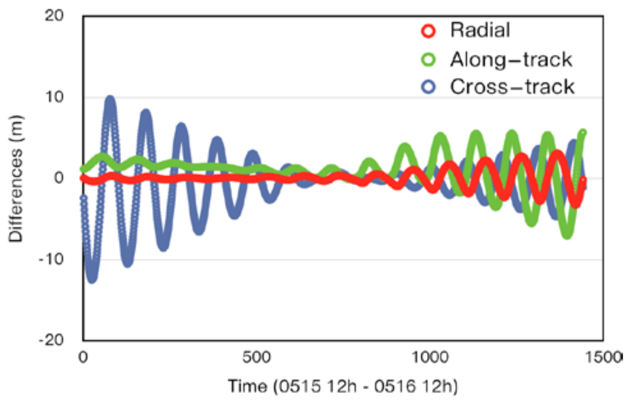

Figure 6. Orbit overlaps.

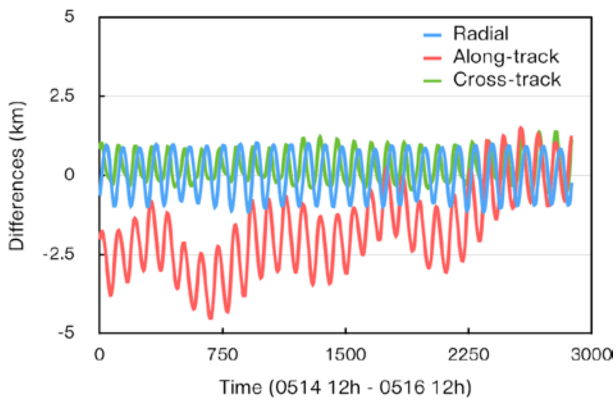

Figure 7. CPF analysis.

CPF analysis

Additionally, we performed the analysis using CPF and OD results. We calculated the differences between CPF by KAI and estimated orbit in this study. At the period from 12h 14 to 12h 16 in May, the differences between our orbit results and CPF are at the level of a few kilometers. The differences of each direction are presented at Figure 7. The RMS value of differences in radial direction is 1.675 km. The RMS values of differences in along-track and cross-track are 5.290 km and 1.329 km, respectively. This analysis is important because differences between CPFs and OD results can show the reliability of OD results to be used as enhanced CPFs.

Conclusions

In this study, we performed the orbit determination (OD) using SLR measurements for STSAT-2C. The NASA/GSFC GEODYN II software is used for OD, 3 arcs in May, 2013 are selected for orbit analysis. A priori value of initial orbit was obtained by CPFs with iterative manual tuning. For orbit quality assessment, post-fit residuals and orbit overlaps are investigated. The results of post-fit residual have at the level under 1 cm precision and the results of overlaps shows the 10 m accuracy. Additionally, differences between OD results and CPF are presented for reliability confirmation. The OD for STSAT-2C shows the typical results in case of sparse and insufficient measurements condition. It can make the problems related to convergence and the accuracy of determined orbit. Therefore, it requires more observations and better strategy for OD using SLR only. It can be good alternative to make more accurate CPFs using OD results. The results of this study can help to make enhanced CPFs in order to support more tracking and precise orbits for STSAT-2C.

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