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Time bias analysis of STSAT-2C orbit predictions

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Abstract. *The Science and Technology Satellite (STSAT)-2C is the first Korean satellite laser ranging (SLR) satellite and its orbit predictions in the form of the Consolidated Prediction Format (CPF) are delivered by KAI and KAS prediction providers. Currently, the KAI CPFs based on two-line element are mainly provided by Korea Advanced Institute of Science and Technology. The supplementary KAS CPFs based on SLR orbit determination are distributed by Korea Astronomy and Space Science Institute. Because STSAT-2C has no GPS receiver and highly elliptical orbit (300 km-1500 km), the accuracy of orbit predictions is a critical factor for successful SLR tracking. The quality check of orbit predictions can be achieved by several indicators such as range/time biases, range residuals, and actual tracking results. From stations' point of view, time bias is the most useful information for evaluation of prediction accuracy. In this study, time biases obtained from two orbit predictions (KAI and KAS CPFs) with SLR normal points that exist in CPFs period of 2015. Because SLR normal points of STSAT-2C have very sparse distribution, different two calculations of time bias are used for convincing analysis. For independent validation, time bias values offered by Katzively station with full-rate observations processing and Yarragadee station with tracking information are utilized. This study provides a practical performance review of current CPFs for STSAT-2C and discusses a strategy for reducing time biases of STSAT-2C orbit predictions.*

Introduction

The Science and Technology Satellite (STSAT)-2C is the first Korean satellite laser ranging (SLR) satellite developed by Satellite Technology Research Center (SaTReC) of Korea Advanced Institute of Science and Technology (KAIST). It was launched by KSLV-1 which is the first launch vehicle of Korea and had highly elliptical orbit (300 km-1500 km) with no GPS receiver. STSAT-2C delivered 298 laser passes and 3114 normal points (NPs) during two years (2013/03-2015/05). KOMPSAT-5 (550 km) obtained 105 passes and 3028 NPs during one month (2015/05). Therefore, STSAT-2C has very sparse SLR tracking condition. Currently, two orbit predictions are available for STSAT-2C laser tracking, which are KAI and KAS predictions. One is orbit predictions based on two-line element, the other is based on orbit determination (OD) using SLR observations.

KAS Orbit Predictions

The Korea Astronomy and Space Science Institute (KASI) has been delivering orbit predictions based on OD using SLR as an ILRS prediction provider (KAS) since 2014/04/07. For orbit prediction generation, KAS prediction center uses workstation with Intel Xeon E5645@2.40GHz (64bit Linux OS) and NASA/GSFC GEODYN II software. The detail setting of GEODYN II is described in Table 1.

Table 1. The detail operation setting for GEODYN II software

Model/parameter	Description
Reference Frame	
Precession/nutation	IAU2000
Polar motion/Station coordinates	C04 IERS/SLRF2008
Numerical Integration	Cowell's method
Step size	30 s
Arc length	Variable (depend on NP acquisition condition)
Dynamic model	
Earth geo-potential	GGM-2C (200 by 200)
Planetary ephemeris	JPL DE-403
Earth tide/Ocean tide	IERS convention 2003/GOT00.2
Dynamic polar motion	Applied
Relativistic effect	Applied
Atmospheric density	MSIS-86
Solar radiation	Box-wing macro
Earth Albedo pressure	Applied
Measurement Model	
Observations	15s SLR NPs (EDC data center)
Tropospheric delay	Mendes and Pavlis
Center of offset of the LRA	-203.54, -167.67, 928.05 (mm, X, Y, Z)
Estimation Parameters	Position and velocity of satellite

The OD and predictions strategy consists of initial orbit acquisition, iterative initial orbit adjustment, and iterative OD adjustment. The statistics of KAS orbit predictions for STSAT-2C tracking on 2015/09 are shown in Table 2 and Figure 1.

Table 2. Total number of KAS orbit predictions

Month	SLR NPs Upload (#day)	CPF Upload (#day)
2015/01	4	2
2015/02	8	5
2015/03	5	4
2015/04	3	1
2015/05	17	16
2015/06	13	9
2015/07	20	18
2015/08	16	13
2015/09	16	14

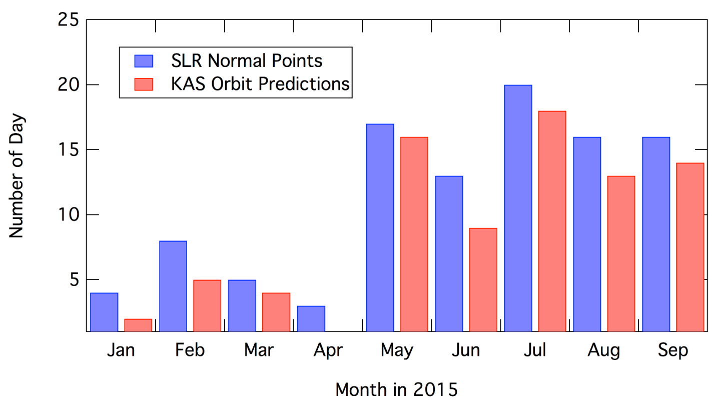

Figure 1. The number of days of KAS CPF generation.

Time Bias Calculation

The time bias information of orbit predictions is useful indicator for tracking quality verification. In this study, different two methods for time bias estimation which are real-time and post-processing. The real-time time bias estimation is determined by SLR system and software during laser tracking.

The time-bias can be also estimated using post-processing method by separated software after tracking with full-rate or NPs observations. Targets of time bias calculation in this study are STSAT-2C passes with both KAI and KAS CPFs and minimum five NPs in 2015. The method is to calculate time bias value minimizing differences between range from SLR NPs (O) and range from CPFs (C). The results include time bias value (ms) and its final range residuals root mean square (RMS) value (m) from two independent software. For validation, system-based time bias from Yarragadee station and full-rate analysis-based time bias from Katzively station are utilized.

Time Bias Results

The detail results of time bias and obtained range residuals using SLR NPs are summarized in Table 3. Figure 2 describes the time bias of STSAT-2C passes and Figure 3 shows RMS of range residuals of STSAT-2C passes.

Table 3. Time bias values and range residuals of STSAT-2C CPFs

Pass	CPFs	Periods (MMDD/hhmmss)	Station	KAI TB (ms)	KAI RMS (m)	KAS TB (ms)	KAS RMS (m)	#NP
1	#5301	0130/224105-224450	7840	580	66.1	-11780	1324.9	15
2	#5871	0328/182203-182405	7090	164	25.6	-560	41.6	11
3	#5881	0329/173551-173703	7090	196	3.9	-164	2.7	6
4		0329/191342-191545	7090	138	31.7	-142	7.9	10
5	#6341	0514/122506-123109	7090	634	597.8	-174	36980.0	25
6	#6351	0515/112753-113225	7090	-62	37.1	-746	19.9	10
7	#6381	0518/100857-101223	7090	102	245.4	-392	66.0	14
8		0518/114943-115228	7090	-108	111.7	-398	54.1	12
9		0518/221122-221252	7090	-268	21.4	-872	21.7	7
10	#6411	0521/102818-103315	7090	-124	73.9	-502	36.9	20
11		0521/223000-223158	7090	-600	218.8	-888	286.5	8
12	#6421	0522/213053-213402	7090	40	80.8	-346	29.8	14
13	#6461	0526/102539-103009	7090	210	329.1	-598	137.3	18
14	#6471	0527/092623-092832	7090	144	96.0	1426	95.0	10
15	#6661	0615/185735-190408	7090	144	65.9	-310	99.5	27
16	#6731	0622/004409-004613	1873	54	31.6	-1468	76.8	6
17	#6811	0630/005006-005409	7840	160	32.7	-126	41.5	16
18		0630/234723-235017	1873	-20	70.5	-1946	585.5	12
19	#6821	0701/012623-013101	7840	1256	148.7	-398	107.8	18
20		0701/210509-210810	1893	1774	352.4	-1528	378.7	10
21		0701/223437-224911	1893	1898	257.3	-1700	331.7	17
22	#6831	0702/232339-232521	1873	-46	3.7	-992	90.6	7
23	#6871	0706/011200-011445	7840	106	21.2	62	13.6	11
24		0706/222844-223233	1873	-4	105.6	782	149.4	17
25	#6891	0708/234059-234620	7840	-324	97.4	904	5.6	18
26	#6901	0709/142830-142937	7237	-466	24.7	2906	76.3	5
27		0709/160527-160706	7237	-530	52.5	2752	821.4	7
28		0709/210015-210330	1893	-754	85.6	3246	153.7	11
29		0709/210130-210356	1873	-1954	38.6	2050	71.5	9
30	#6911	0710/001952-002154	7840	74	27.4	-28	3.9	9
31		0710/213638-213820	1873	12	23.7	-178	9.1	8
32		0710/213700-213917	1893	216	15.4	24	5.7	10
33	#6971	0716/201328-201446	1873	446	25.0	2	3.2	5
34	#6981	0717/204811-204934	1873	-12	25.2	-646	62.8	5
35		0717/222733-222900	7840	-98	48.5	-852	4.3	6
36	#7331	0821/212817-213101	7090	450	20.2	-410	25.1	14

37	#7341	0822/015856-020108	1893	-170	9.3	-4	7.3	9
38		0822/181635-181914	7237	-124	52.1	-676	44.9	10
39	#7361	0824/174223-174318	7237	-52	51.0	-1088	97.7	5
40	#7371	0825/001253-001802	1893	-124	370.5	-2	16.6	13
41		0825/001300-001915	1873	-174	374.8	0	16.0	24
42	#7401	0828/001538-001709	1893	1464	13.5	-4	2.3	5
43	#7441	0901/233003-233416	1873	34	50.6	-2026	51.5	11
44	#7541	0911/173110-173647	7090	632	120.1	174	68.8	24
45		0911/220142-220409	1893	376	38.6	206	4.8	10
46	#7571	0914/045412-045549	7090	188	13.6	288	8.7	8
47	#7581	0915/175757-180027	7090	960	65.9	374	16.9	10
48	#7601	0917/044518-044642	7090	222	19.0	-32	4.3	6
49		0917/151503-151612	7237	490	1.9	-302	3.3	5
50		0917/171447-171822	7090	624	48.5	-370	5.5	14
51	#7611	0918/174338-174930	7090	246	163.1	-344	82.2	23
52	#7641	0921/173636-174028	7090	396	338.3	378	151.7	16

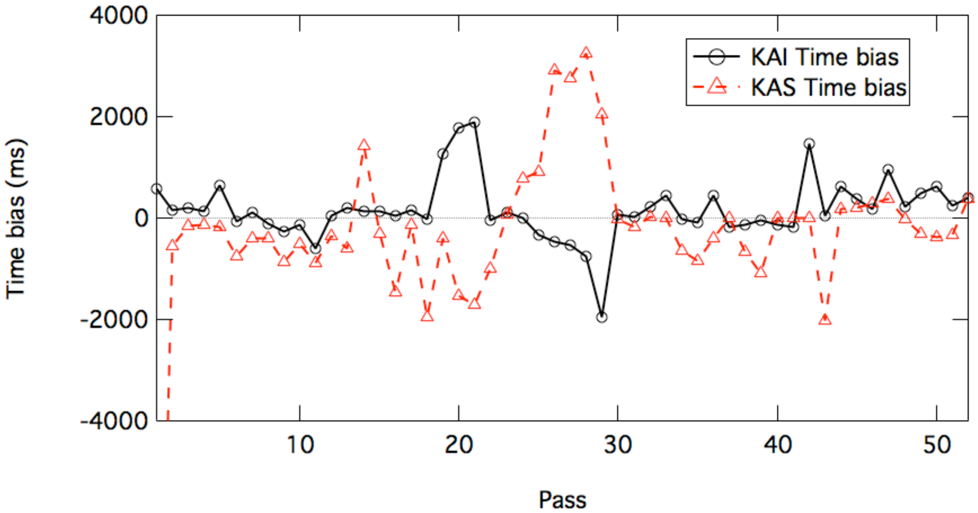

Figure 2. The time bias values of STSAT-2C passes.

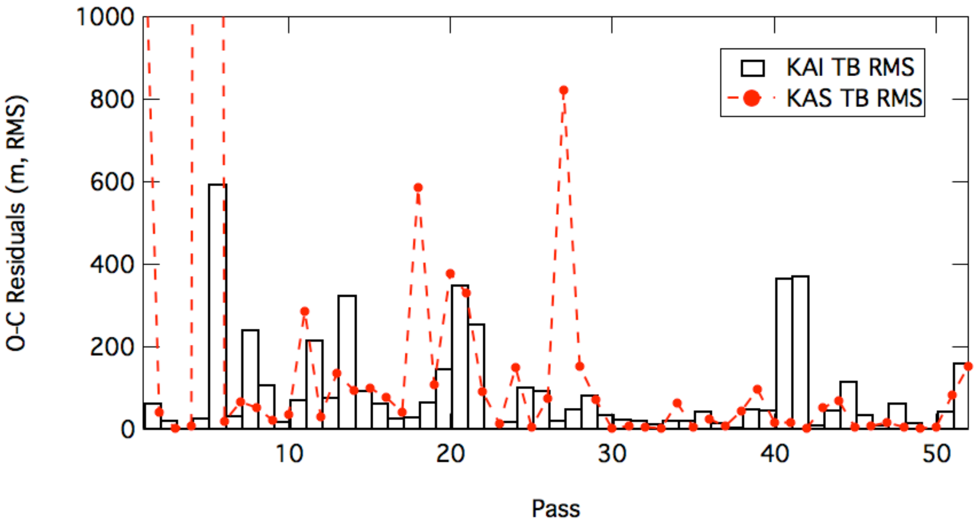

Figure 3. The RMS of range residuals of STSAT-2C passes.

Time Bias Comparisons

For comparison, total four different results of time-bias estimation are used. KAS TB and KAS TB (D) are two independent post-processed solutions using NPs. KAS TB (Katzively) is post-processed solution using full-rate data. KAS TB (Yarragadee) is a result from real-time calculation during laser tracking. Table 4 summarizes the comparison results for time bias (ms) of KAS orbit predictions. Pass in Table 4 means pass number of Table 3. Figure 4 shows time bias comparison of selected passes.

Table 4. The comparison results of estimated time-bias (ms)

Pass	CPF	Station	#NP	KAS TB	KAS TB (D)	KAS TB (YARL)	KAS TB (KTZL)
3	#5881_1	7090	6	-164	-90	-150	
5	#6351	7090	10	-746	-739	-730	
9	#6411_1	7090	20	-502	-486	-480	
10	#6411_2	7090	8	-888		-970	
14	#6471	7090	10	1426	1535	1450	
20	#6821_2	1893	10	-1528			-1571
21	#6821_3	1893	17	-1700			-1707
28	#6901_3	1893	11	3246			3197
32	#6911_3	1893	10	24			35
40	#7371_1	1893	13	-2	11		-4
45	#7541_2	1893	10	206			193

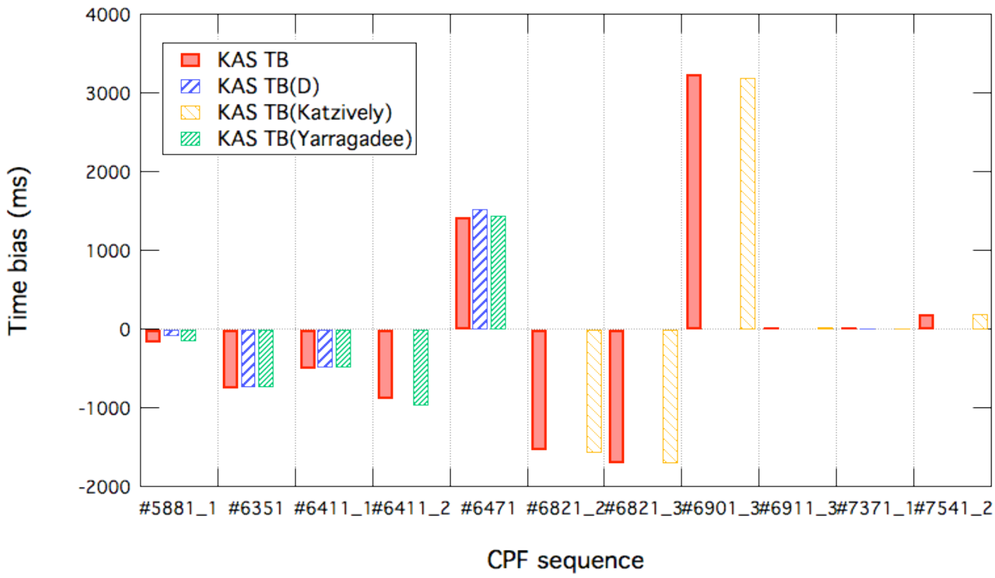

Figure 4. Time bias comparison of selected passes.

Conclusions and Future Works

In this study, the results of post-processed time bias calculation of KAI and KAS orbit predictions in 2015 are presented. Entirely, different trend of time bias between KAI and KAS orbit predictions are observed. Consistent results of four independent time bias calculation of KAS orbit predictions were obtained, which are two independent estimated time bias values from SLR NPs, full-rate by Katzively station, and real-time processing by Yarragadee station. The effects by pass characteristics (station, velocity of satellite, number of data, etc.) are bigger than the effects by orbit predictions (two-line element-based, SLR OD-based). It means that more frequent generation is needed. In future, continuous operation of KAS CPFs generation and KAS CPFs quality check by ILRS tracking supports will be lasted. Alternative strategy to deducing time-bias of STSAT-2C can be applied, for example, more frequent generation of CPFs or longer arc based OD.

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