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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 (TLE) 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) in 2015 and SLR normal points which exist in CPFs period are investigated. 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.

STSAT-2C and SLR tracking

- **STSAT-2C Mission [1]**
  - **S**cience and **T**echnology **SAT**ellite-2C
  - **The first SLR satellite of Korea** developed by Satellite Technology Research Center (SaTReC) of KAIST
  - Launched by KSLV-1 (The first launch vehicle of Korea)
  - Highly elliptical orbit (300 km – 1500 km) with no GPS receiver
- **STSAT-2C SLR Tracking and Orbit Predictions**
  - **Very sparse SLR tracking condition** of STSAT-2C
    - STSAT-2C (300 km – 1500 km) : 298 passes and 3,114 normal points during two year (2013.03-2015.05)
    - KOMPSAT-5 (550 km) : 105 passes and 3,028 normal points during one month (2015.05)
  - **Current Orbit Predictions** for STSAT-2C SLR Tracking
    - KAI Predictions : Two-line element-based orbit predictions
    - KAS Predictions : SLR orbit determination (OD)-based orbit predictions

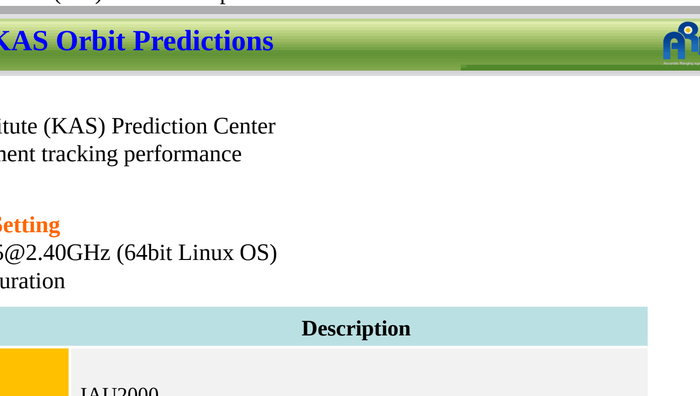
KAS Orbit Predictions

- **KAS Orbit Predictions for STSAT-2C [2]**
  - Korea Astronomy and Space Science Institute (KAS) Prediction Center
  - SLR-based orbit predictions for improvement tracking performance
  - CPF generation : 2014.04.07 - Current
- **SLR Orbit Determination and Prediction Setting**
  - H/W : Workstation with Intel Xeon E5645@2.40GHz (64bit Linux OS)
  - NASA/GSFC GEODYN II system configuration

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 normal point 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 normal points (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

- **Orbit Determination and Prediction Strategy [2, 3]**
  - Initial orbit acquisition / Iterative initial orbit adjustment / Iterative OD adjustment
- **Statistics of KAS Orbit Predictions for STSAT-2C Tracking in 2015**
  - Total number of KAS predictions : 82

Month	SLR NPs (#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



< The number of days of KAS CPF generation >

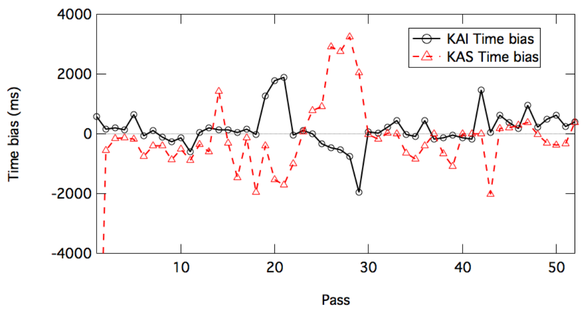
Time Bias Calculation

- **Time Bias Information of Orbit Predictions**
  - Useful indicator for tracking quality verification of orbit predictions
  - Time Bias Calculation
    - Real-time time bias estimation : determined by SLR system and software during tracking
    - **Post-processing time bias estimation** : estimated by separated software after tracking with full-rate or normal points observations
- **Time Bias Calculation of STSAT-2C Orbit Predictions**
  - Targets : STSAT-2C passes with **both KAI and KAS CPFs and minimum 5 normal points in 2015**
  - Method : Finding time bias value minimizing differences between range from normal points (O) and range from CPFs (C)
  - Results : Time bias (ms) and range residuals RMS value (m) from two independent software
  - Validations : System-based time bias from Yarragadee station and full-rate analysis-based time bias from Katzively station

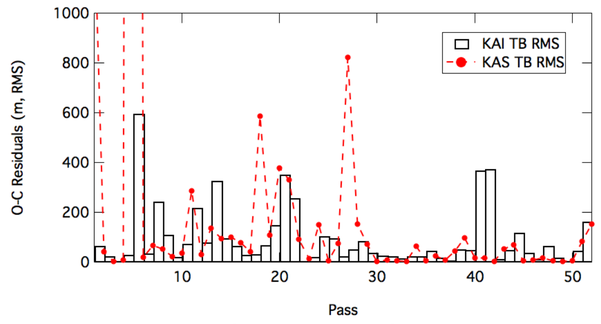
Time Bias Results

- **Time Bias Results of KAI and KAS STSAT-2C Orbit Predictions**
  - Time bias and RMS of range residuals

pass	CPFs	Periods (MMDD/hhmmss)	Station	KAI TB (ms)	RMS (m)	KAS TB (ms)	RMS (m)	#NP	pass	CPFs	Periods (MMDD/hhmmss)	Station	KAI TB (ms)	RMS (m)	KAS TB (ms)	RMS (m)	#NP
1	#5301	0130/224105-224450	7840	580	66.1	-11780	1324.9	15	26	#6901	0709/142830-142937	7237	-466	24.7	2906	76.3	5
2	#5871	0328/182203-182405	7090	164	25.6	-560	41.6	11	27		0709/160527-160706	7237	-530	52.5	2752	821.4	7
3	#5881	0329/173551-173703	7090	196	3.9	-164	2.7	6	28		0709/210015-210330	1893	-754	85.6	3246	153.7	11
4		0329/191342-191545	7090	138	31.7	-142	7.9	10	29		0709/210130-210356	1873	-1954	38.6	2050	71.5	9
5	#6341	0514/122506-123109	7090	634	597.8	-174	36980.0	25	30	#6911	0710/001952-002154	7840	74	27.4	-28	3.9	9
6	#6351	0515/112753-113225	7090	-62	37.1	-746	19.9	10	31		0710/213638-213820	1873	12	23.7	-178	9.1	8
7	#6381	0518/100857-101223	7090	102	245.4	-392	66.0	14	32		0710/213700-213917	1893	216	15.4	24	5.7	10
8		0518/114943-115228	7090	-108	111.7	-398	54.1	12	33	#6971	0716/201328-201446	1873	446	25.0	2	3.2	5
9		0518/221122-221252	7090	-268	21.4	-872	21.7	7	34	#6981	0717/204811-204934	1873	-12	25.2	-646	62.8	5
10	#6411	0521/102818-103315	7090	-124	73.9	-502	36.9	20	35		0717/222733-222900	7840	-98	48.5	-852	4.3	6
11		0521/223000-223158	7090	-600	218.8	-888	286.5	8	36	#7331	0821/212817-213101	7090	450	20.2	-410	25.1	14
12	#6421	0522/213053-213402	7090	40	80.8	-346	29.8	14	37	#7341	0822/015856-020108	1893	-170	9.3	-4	7.3	9
13	#6461	0526/102539-103009	7090	210	329.1	-598	137.3	18	38		0822/181635-181914	7237	-124	52.1	-676	44.9	10
14	#6471	0527/092623-092832	7090	144	96.0	1426	95.0	10	39	#7361	0824/174223-174318	7237	-52	51.0	-1088	97.7	5
15	#6661	0615/185735-190408	7090	144	65.9	-310	99.5	27	40	#7371	0825/001253-001802	1893	-124	370.5	-2	16.6	13
16	#6731	0622/004409-004613	1873	54	31.6	-1468	76.8	6	41		0825/001300-001915	1873	-174	374.8	0	16.0	24
17	#6811	0630/005006-005409	7840	160	32.7	-126	41.5	16	42	#7401	0828/001538-001709	1893	1464	13.5	-4	2.3	5
18		0630/234723-235017	1873	-20	70.5	-1946	585.5	12	43	#7441	0901/233003-233416	1873	34	50.6	-2026	51.5	11
19	#6821	0701/012623-013101	7840	1256	148.7	-398	107.8	18	44	#7541	0911/173110-173647	7090	632	120.1	174	68.8	24
20		0701/210509-210810	1893	1774	352.4	-1528	378.7	10	45		0911/220142-220409	1893	376	38.6	206	4.8	10
21		0701/223437-224911	1893	1898	257.3	-1700	331.7	17	46	#7571	0914/045412-045549	7090	188	13.6	288	8.7	8
22	#6831	0702/232339-232521	1873	-46	3.7	-992	90.6	7	47	#7581	0915/175757-180027	7090	960	65.9	374	16.9	10
23	#6871	0706/011200-011445	7840	106	21.2	62	13.6	11	48	#7601	0917/044518-044642	7090	222	19.0	-32	4.3	6
24		0706/222844-223233	1873	-4	105.6	782	149.4	17	49		0917/151503-151612	7237	490	1.9	-302	3.3	5
25	#6891	0708/234059-234620	7840	-324	97.4	904	5.6	18	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



< Time bias of STSAT-2C passes >

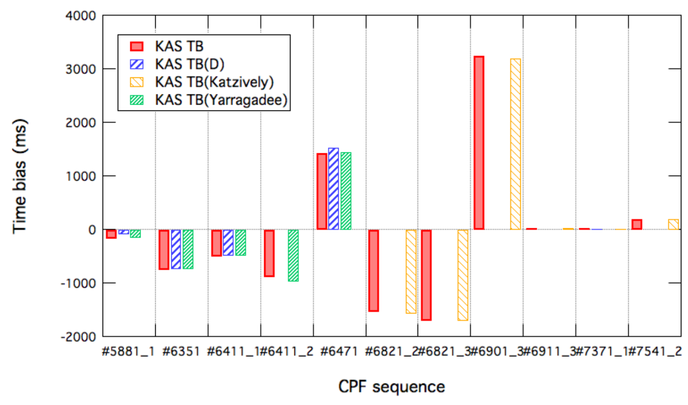


< RMS of range residuals of STSAT-2C passes >

Time Bias Comparisons

- **The Comparison Results of Time Bias for KAS Orbit Predictions**
  - KAS TB, KAS TB (D), KAS TB (Yarragadee), KAS TB (Katzively)
    - Post-processing with normal points data : KAS TB, KAS TB (D)
    - Post-processing with full-rate data : KAS TB (Katzively)
    - Real-time with tracking : KAS TB (Yarragadee)

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



< Time bias comparison of selected passes >

Conclusions and Future Works

- **Conclusions**
  - Post-processed time bias calculations of KAI and KAS orbit predictions in 2015
  - Entirely different trend of time bias between KAI and KAS orbit predictions
  - Consistent results of 4 independent time bias calculation of KAS orbit predictions
    - Two independent TB from normal points, TB from full-rate by Katzively station, TB from real-time processing by Yarragadee)
  - The effects by pass characteristics (station, velocity of satellite, number of data, etc.) > the effects by orbit predictions (TLE-based, SLR-based) → Need more frequent generation?
- **Future Works**
  - Continuous operation of KAS CPFs generation
  - KAS CPFs quality check by ILRS tracking supports
  - Alternative strategy to deducing time-bias of STSAT-2C (More frequent generation of CPFs or longer arc OD)

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