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Orbit Determination Using SLR Data for STSAT-2C: Short-arc Analysis

Young-Rok Kim[1†], Eunseo Park[1], Daniel Kucharski[2], Hyung-Chul Lim[1]
[1]Korea Astronomy and Space Science Institute, Daejeon 34055, Korea
[2]Space Environment Research Centre, Mount Stromlo Observatory, ACT 2611, Australia

In this study, we present the results of orbit determination (OD) using satellite laser ranging (SLR) data for the Science and Technology Satellite (STSAT)-2C by a short-arc analysis. For SLR data processing, the NASA/GSFC GEODYN II software with one year (2013/04 – 2014/04) of normal point observations is used. As there is only an extremely small quantity of SLR observations of STSAT-2C and they are sparsely distribution, the selection of the arc length and the estimation intervals for the atmospheric drag coefficients and the empirical acceleration parameters was made on an arc-to-arc basis. For orbit quality assessment, the post-fit residuals of each short-arc and orbit overlaps of arcs are investigated. The OD results show that the weighted root mean square post-fit residuals of short-arcs are less than 1 cm, and the average 1-day orbit overlaps are superior to 50/600/900 m for the radial/cross-track/along-track components. These results demonstrate that OD for STSAT-2C was successfully achieved with cm-level range precision. However its orbit quality did not reach the same level due to the availability of few and sparse measurement conditions. From a mission analysis viewpoint, obtaining the results of OD for STSAT-2C is significant for generating enhanced orbit predictions for more frequent tracking.

Keywords: orbit determination, satellite laser ranging, STSAT-2C, GEODYN II, sparse, short-arc

1. INTRODUCTION

The Science and Technology Satellite (STSAT)-2C was developed by the Satellite Technology Research Center (SaTReC) of the Korea Advanced Institute of Science and Technology (KAIST) and launched by Korea's first launch vehicle, the Korea Space Launch Vehicle (KSLV)-1, on January 30, 2013. The purposes of the STSAT-2C mission are to test the KSLV-1 and develop a small spacecraft (Kang et al. 2014). The STSAT-2C spacecraft is equipped with a laser retro-reflector array for satellite laser ranging (SLR), and has been tracked by the global network of SLR stations (International Laser Ranging Service - ILRS) since March 29, 2013 (Pearlman et al. 2002). SLR is the most precise technique for measuring the distance between a satellite and the tracking station and the ILRS manages operation and data processing of SLR. Fig. 1 illustrates the concept of SLR and Fig. 2 shows the organization of ILRS. In Korea, mobile and stationary systems for SLR tracking have been developed since 2008 by Korea Astronomy and Space Science Institute (Lim et al. 2010; Seo et al. 2010; Jo et al. 2011; Lim et al. 2011; Nah et al. 2013). The mobile SLR system development was finished and it delivers adequate ranging observations with a few mm precision (Park et al. 2012; Choi et al. 2014). The ILRS associate analysis center is also operated by same institute (Kim et al. 2012, 2013b).

The main SLR application of STSAT-2C is precise orbit determination (OD). The OD analysis with SLR observations for STSAT-2C can contribute to research on extremely low orbital environments (~300 km) and modeling accuracy assessment by using radial orbit error analysis. Therefore, it is an important issue to secure sufficient SLR tracking data.

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[†]**Corresponding Author**
E-mail: yrockkim@kasi.re.kr, ORCID: 0000-0002-0862-0146
Tel: +82-42-865-5908, Fax: +82-42-865-3358

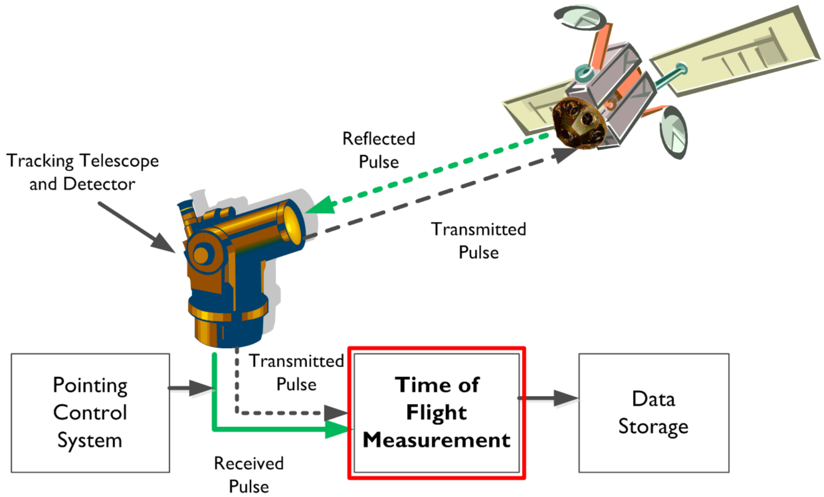

Fig. 1. The concept of satellite laser ranging.

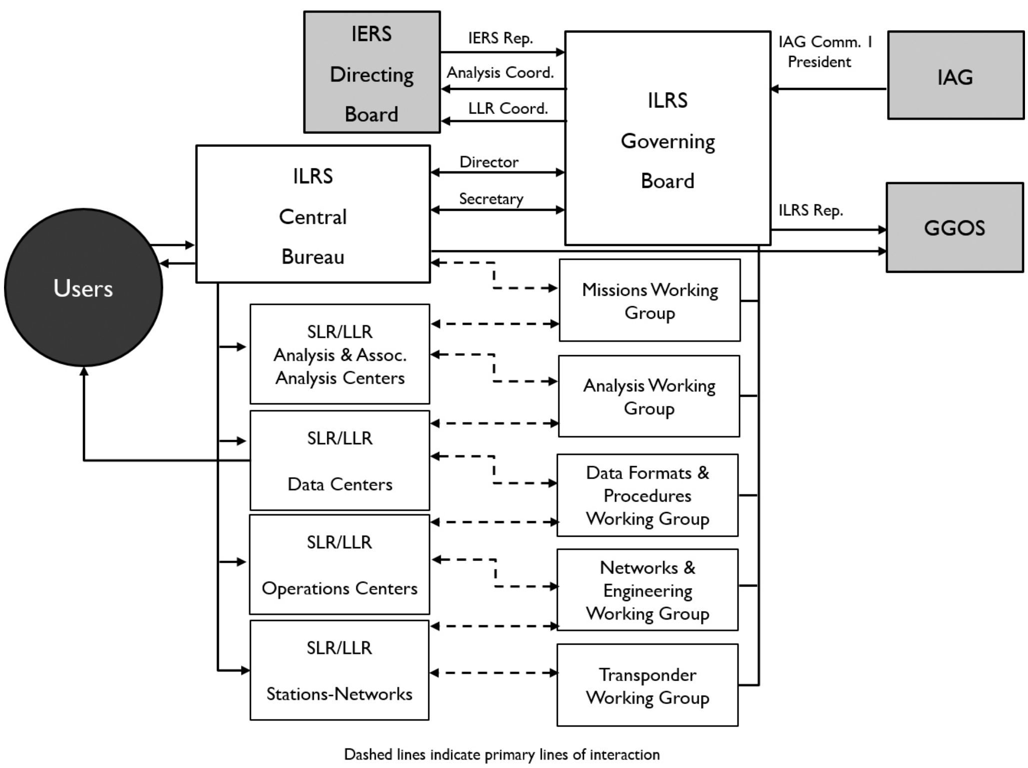

Fig. 2. The organization of International Laser Ranging Service.

The SLR tracking statistics during a 12-month follow-up period are presented in Table 1. The total passes and normal point (NP) observations during the last year are 204 and 2,215, respectively. The acquired amount of NPs is very low and sparse compared to the other laser-tracked low-earth orbiting satellites due to inexact orbit predictions for SLR tracking. For example, in the first week of April 2014 alone, the Jason-2 mission achieved 240 passes and 4,482 NPs. In this light, the SLR tracking for the STSAT-2C can be regarded as extremely sparse measurement conditions. As the STSAT-2C was utilized for successful orbit injection of KSLV-1, it was assigned a highly elliptical orbit (300 km – 1,500 km). While a GPS-based technique is generally used for positioning of non-geodetic satellites, radar-based two-line element (TLE) is utilized for orbit acquisition of STSAT-2C. Thus very poor orbit predictions have been provided for STSAT-2C for SLR tracking. As a result, it can be tracked only when the satellite is in a visible period. SLR tracking and OD using

Table 1. ILRS tracking statistics for STSAT-2C (2013/03 – 2014/04).

Station ID	Name (location)	Start time (yyyymmdd hh:mm:ss)	End time (yyyymmdd hh:mm:ss)	Number of passes	Number of NP
1824	Golosiiv	20130401 17:37:58	20140406 02:09:42	4	28
1873	Simeiz	20130508 00:57:46	20131229 16:09:58	11	148
1893	Katzively	20130419 01:01:02	20140417 01:15:51	18	149
7090	Yarragadee	20130401 12:10:50	20140411 20:57:19	80	973
7105	Greenbelt	20130410 09:33:33	20140410 09:10:09	16	275
7110	Monument Peak	20130411 02:12:54	20130411 02:16:16	1	13
7119	Haleakala	20140313 06:55:26	20140313 06:58:33	1	8
7237	Changchun	20130329 12:24:55	20140406 19:04:40	22	110
7249	Beijing	20131219 11:35:59	20131219 11:37:55	1	8
7359	Daedeok	20130412 10:52:52	20130930 10:46:46	2	6
7821	Shanghai	20140315 11:21:41	20140405 19:31:28	3	16
7825	Mt Stromlo	20130708 09:20:09	20131217 10:49:25	5	16
7839	Graz	20130425 00:52:24	20140417 01:22:40	20	279
7840	Herstmonceux	20130401 21:05:28	20140414 02:24:09	15	124
7845	Grasse	20130903 22:26:07	20130903 22:29:21	1	14
7941	Matera	20130927 17:56:31	20140116 13:33:22	4	48

NP: normal point.

SLR observations are very challenging issues in the SLR community. Although a SLR-based strategy is a baseline for STSAT-2C OD, providing steady results has proved difficult.

Lee & Alfriend (2007) pointed out that an inaccurate initial orbit and sparse measurements can result in unstable solutions of orbit estimation. To overcome this problem, various estimation algorithms such as unscented transformation and a particle filter have been suggested by Lee & Alfriend (2007), Park et al. (2010), and Kim et al. (2011, 2014b). Another way to avoid sparseness is to use a short-arc estimation strategy. Although this approach does not guarantee the best orbit accuracy, it can give the results of orbit estimation and prediction under very sparse measurement conditions. It has been demonstrated that the short-arc approach is very helpful for OD and prediction of low-Earth orbiting (LEO) objects including space debris (Sang & Bennett 2014; Bennett et al. 2015). From a practical perspective, the short-arc OD approach in a sparse measurement condition is more advantageous than a new estimation strategy.

Kim et al. (2013a, 2014a) have implemented an orbital analysis for a few arcs of STSAT-2C using a short-arc approach. It has been reported that OD using SLR observations for STSAT-2C can be successfully accomplished despite the very sparse measurement condition. In the current study, almost all passes of one year were included in a short-arc OD strategy and the results were analyzed by post-fit residuals. For some periods, orbit overlaps results are investigated for the orbit quality check. As the estimation intervals of atmospheric drag and empirical acceleration affect the convergence property of OD for STSAT-2C using short-arc, a non-regular daily-based processing strategy with variable estimation intervals is applied. The aim of the current study is to obtain successful OD results for STSAT-2C using SLR short-arcs in order to improve the orbit predictions for SLR tracking. Section 2 summarizes the OD strategy and software settings and Section 3 describes the results of the post-fit residuals and orbit overlaps of short-arc OD. Section 4 gives conclusions.

2. ORBIT DETERMINATION USING SLR DATA

In this section, the strategy for OD of STSAT-2C using SLR data is summarized. The NASA/GSFC GEODYN II software is used for SLR data processing (Pavlis et al. 1998). The arcs for OD are prepared using a few passes with a minimum number of measurements for the parameter estimation. In this study, the existence of 10 NPs in one arc was adopted as a minimum condition for arc length determination. The final selected arcs for OD are presented in Table 2. The specific modeling and the estimation parameters are presented in Table 3. The arc length chosen for the OD was changed by the observation conditions, which originated from the number of NPs and the continuity of passes. The shortest and the longest arc length are 1 and 7 days, respectively. The number of stations used for the analysis also differs for each arc. In Table 2, some arcs comprised observations from only one station, given that most of the SLR observations for the STSAT-2C were actually obtained by only one station in that period. Generally, such passes must be extended to include the data from other stations, or to be rejected from the OD process. However, to retain as many OD arcs as possible for the study, the short arcs recorded by only one station

Table 2. Summary of the STSAT-2C arcs (2013/03 – 2014/04).

Arc	Station ID	Arc length (day)	Start time (yyyymmdd hh:mm:ss)	End time (yyyymmdd hh:mm:ss)	Number of NP
13-01	7105,7110	2	20130410 09:33:33	20130411 02:16:16	28
13-02	1824,1893,7237,7840	4	20130416 00:58:41	20130419 02:47:29	39
13-03	7105	3	20130424 07:53:08	20130426 09:46:40	55
13-04	7105,7839	2	20130501 00:51:28	20130502 07:53:54	96
13-05	7105,7839	1	20130510 00:47:52	20130510 07:54:19	57
13-06	1873,1893,7105,7839,7840	5	20130514 06:01:08	20130518 23:08:03	172
13-07	1893,7839	1	20130521 21:11:04	20130521 23:08:48	37
13-08	1873,7839	1	20130528 21:02:40	20130528 22:57:20	42
13-09	7839,7840	2	20130830 21:00:56	20130831 22:48:09	27
13-10	7840, 7845	3	20130901 00:25:29	20130903 22:29:21	45
13-11	1893,7840	5	20130905 22:16:10	20130909 20:07:00	33
13-12	1873,1893,7237	2	20130912 14:39:48	20130913 19:37:35	32
13-13	7090, 7105	4	20130917 11:54:35	20130920 11:39:45	48
13-14	7090,7359,7825,7941	4	20130927 08:57:07	20130930 10:46:46	17
13-15	7090	2	20131020 20:49:49	20131021 20:45:15	29
13-16	7090	1	20131125 15:03:43	20131125 16:49:23	34
13-17	7090	2	20131203 15:15:16	20131204 15:05:01	27
13-18	7090	3	20131207 14:29:36	20131209 14:00:14	42
13-19	7090,7825	5	20131208 12:28:23	20131212 13:26:07	42
13-20	1893,7090,7237	2	20131213 13:08:42	20131214 17:42:57	61
13-21	1873,7090,7825,7839,7941	3	20131216 12:35:12	20131218 16:56:58	78
13-22	7090	3	20131219 11:54:31	20131221 13:14:21	59
13-23	7090,7237,7839	3	20131223 10:44:52	20131225 12:23:48	59
13-24	1824,1873,1893,7237	4	20131226 09:57:46	20131229 16:09:58	47
14-01	7090	2	20140221 14:50:00	20140222 14:38:18	78
14-02	7090	7	20140224 03:11:47	20140302 13:49:50	50
14-03	7090	2	20140305 12:39:00	20140306 14:09:27	28
14-04	7090	3	20140309 13:02:39	20140311 12:29:21	84
14-05	7090,7119,7821	5	20140312 12:06:56	20140316 12:26:58	36
14-06	1824,7090,7821	3	20140404 19:52:40	20140406 21:10:36	68
14-07	1893,7090,7105,7840	2	20140410 02:16:48	20140411 20:57:19	54
14-08	1893,7839	1	20140417 01:07:04	20140417 01:15:51	19

NP: normal point.

were included. Short arcs obtained by only one station are commonly accepted for OD of STSAT-2C, and therefore it is reasonable to include these arcs in the analysis.

The estimation frequency of the parameters such as the drag coefficients and the empirical acceleration coefficients can affect the precision of the OD for LEO satellites. For Starlette, 24 hour and 12 hour intervals are used for drag coefficient estimation (Lejba et al. 2007; Lejba & Schillak 2011). Jeon et al. (2011) and Jagoda & Rutkowska (2013) use 8 hours and 7 days for the OD of Starlette. Lejba & Schilliak (2011) demonstrated that more frequent estimation of the empirical acceleration parameters can improve the precision of the post-fit residuals of Starlette and Stella. However, in very sparse measurement conditions, convergence of estimation by the least-squares batch cannot be guaranteed if the number of estimation parameters increases. For the sparse data distribution of STSAT-2C some arcs necessitate the use of only specific intervals for convergence. Improvement of the tracking geometry by expanding the arc length is an alternative except for the cases where the observed arcs of orbit are separated by large time-gaps. In this study, a suitable selection strategy of the estimation intervals is therefore accomplished for every arc including a tuning process. Five different intervals are used for the drag coefficient estimation: 6, 8, 12, 24, and 48 hours. For the empirical acceleration coefficients 5 estimation intervals are applied: 8, 12, 24, 48, and 72 hours. In order to achieve stable convergence, the empirical acceleration coefficient are not estimated for several arcs. Generally, empirical acceleration parameters are estimated to compensate incomplete modeling errors of LEO satellites. However, in the present study, they are used as tuning parameters due to very sparse measurements. As a consequence, different OD strategies were utilized for each arc in order to overcome the inconsistent conditions created by the sparse measurements of STSAT-2C.

To eliminate outlying range residuals, a 7.0 sigma editing strategy is applied; in contrast the common sigma criterion in the analysis of LAGEOS and ETALON observations is 3.0 or 3.5 (Kim et al. 2013b). The relatively large sigma

Table 3. Details of models and estimation parameters for STSAT-2C orbit determination.

Model/Parameter	Description	References
Reference frame		
Reference system	Inertial reference system	
Polar motion	C04 IERS	
Station coordinates	SLRF2008	Altamimi et al. (2007, 2011)
Precession/nutation	IAU2000	Mathews et al. (2002)
Numerical integration	Cowell's method	
Step size	30 s	
Arc length	Variable (1 – 7 day)	
Dynamic models		
Earth gravity	GGM02C (200x200)	Tapley et al. (2005)
Planetary ephemeris	JPL DE-403	Standish et al. (1995)
Atmospheric density	MSIS-86	Hedin (1991)
Earth tide	IERS convention 2003	McCarthy & Petit (2004)
Ocean tide	GOT00.2	Ray (1999)
Earth albedo	Applied	Pavlis et al. (1998)
Relativistic correction	Applied	Pavlis et al. (1998)
Dynamic polar motion	Applied	Pavlis et al. (1998)
Empirical accelerations	Radial, along, and cross-track	
Measurement models		
Observations	15 s NPs (EDC)	ftp://edc.dgfi.badw.de/pub/slr
Data editing	7.0 sigma editing	
Tropospheric refraction	Mendes & Pavlis	Mendes et al. (2002), Mendes & Pavlis (2004)
Center of offset of the LRA (X,Y,Z)	(-203.54, -167.67, 928.05) mm	ILRS webpage
Estimation parameters		
Position and velocity of satellite		
Atmospheric drag coefficients	Variable (6 – 48 hour)	
Empirical acceleration coefficients	No or variable (8 – 72 hour)	

LRA: laser retro-reflector array, NP: normal point.

editing value is used to prevent failure of least-squares estimation due to a lack of observations. The center of the offset correction of the laser retro-reflector array for STSAT-2C applied in the OD analysis is given at the ILRS web page and is presented in Table 3. As the OD characteristics and results for STSAT-2C are very sensitive to the initial conditions and to the estimation configuration, an extensive iterative process including manual tuning was required to find the prior initial values and for proper selection of the estimation parameters. The prior value of the initial orbit was first obtained from the predicted orbits by the KAIST prediction center (KAI), the main provider of STSAT-2C orbit predictions. Due to the low accuracy of the TLE-based KAI's prediction, manual tuning was performed to reduce errors at the first iteration of the OD analysis. The successfully determined orbital parameters of the first arc are used as the initial conditions for the consecutive arc.

3. RESULTS

In this section, the OD results and the orbit quality assessments are investigated. The post-fit residuals, which show how well the estimated orbit fits the SLR measurements, and orbit overlaps, which demonstrate the quality and the consistency of the determined orbits, are presented.

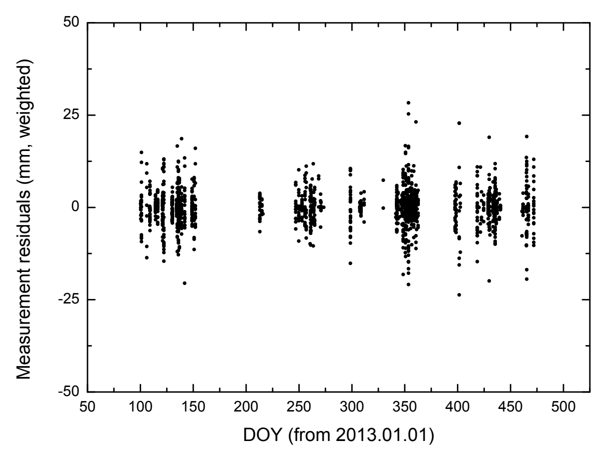

Fig. 3. Measurement residuals of STSAT-2C orbit determination (2013-2014).

3.1 Post-fit Rsiduals

For STSAT-2C, the determined weighted root mean square (RMS) values of the post-fit residuals for 2013 and 2014 are 0.60 and 0.70 cm, respectively. The results are presented in Table 4 and Fig. 3. Table 4 shows the post-fit residuals and the coefficient estimation intervals for STSAT-2C OD.

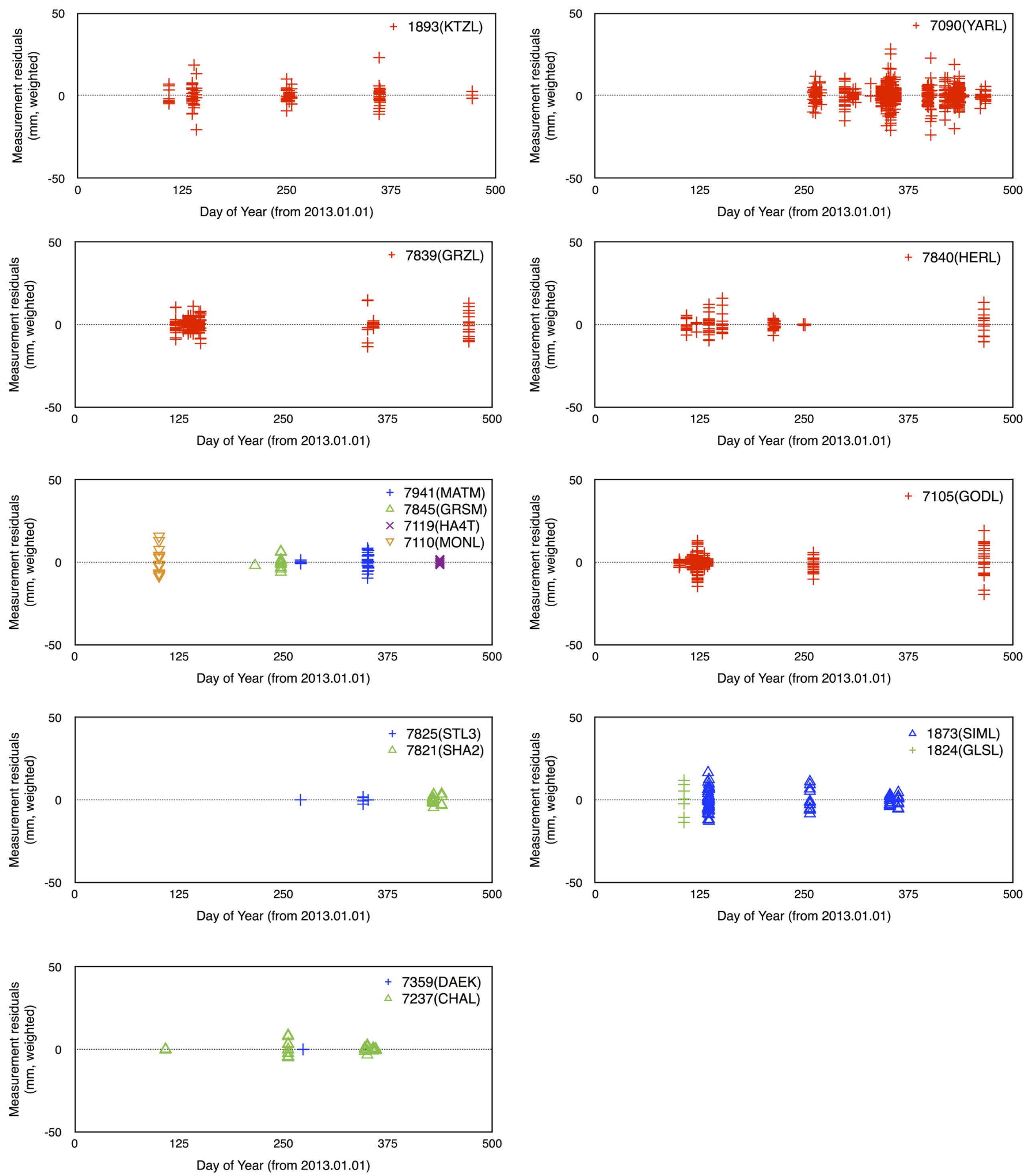

Fig. 4. Measurement residuals of each station (2013-2014).

The weighted RMS of the post-fit residuals for most arcs is less than 1 cm. Fig. 3 shows the residuals of the weighted measurement residuals according to the day of the year from January 1, 2013. Fig. 4 and Table 5 show the residuals of each station for the total period. Fig. 4 displays the station residual precision of STSAT-2C OD. In Table 5, the mean measurement residual (weighted RMS) for each station and its observation-weighting are summarized. These residuals do not indicate the absolute precision of stations because each station has a different weight value by observation-

Table 4. The post-fit residuals and coefficient estimation intervals for STSAT-2C orbit determination.

Arc	Week	Drag	Accel.	WRMS (cm)	Arc	Week	Drag	Accel.	WRMS (cm)
13-01	0410 – 0411	24H	12H	0.74	13-17	1203 – 1204	8H	48H	0.24
13-02	0416 – 0419	8H	No	0.67	13-18	1207 – 1209	8H	No	0.39
13-03	0424 – 0426	24H	12H	0.34	13-19	1208 – 1212	24H	48H	0.44
13-04	0501 – 0502	8H	24H	0.72	13-20	1213 – 1214	24H	48H	0.76
13-05	0510 – 0510	8H	24H	0.26	13-21	1216 – 1218	8H	24H	0.75
13-06	0514 – 0518	8H	8H	0.74	13-22	1219 – 1221	12H	No	1.09
13-07	0521 – 0521	24H	No	0.82	13-23	1223 – 1225	8H	No	0.36
13-08	0528 – 0528	24H	No	0.31	13-24	1226 – 1229	8H	48H	0.95
13-09	0830 – 0831	8H	No	0.89	14-01	0221 – 0222	48H	48H	0.54
13-10	0901 – 0903	8H	72H	0.43	14-02	0224 – 0302	8H	72H	0.73
13-11	0905 – 0909	24H	48H	0.60	14-03	0305 – 0306	48H	No	1.19
13-12	0912 – 0913	6H	No	0.73	14-04	0309 – 0311	48H	72H	0.47
13-13	0917 – 0920	24H	72H	0.61	14-05	0312 – 0316	24H	72H	0.35
13-14	0927 – 0930	24H	No	0.36	14-06	0404 – 0406	24H	24H	0.60
13-15	1020 – 1021	48H	No	0.31	14-07	0410 – 0411	24H	24H	0.86
13-16	1125 – 1125	6H	No	0.80	14-08	0417 – 0417	24H	No	0.86

WRMS: weighted root mean square.

Table 5. Measurement residuals of each station.

Station	σ	WRMS (cm, mean)	Station	σ	WRMS (cm, mean)
1824(Golosiiv)	4	0.96	7358(Daedeok)	1	0.00
1873(Simeiz)	10	0.49	7821(Shanghai)	4	0.29
1893(Katzively)	4	0.56	7825(Mt Stromlo)	1	0.11
7090(Yarragadee)	1	0.48	7845(Grasse)	1	0.39
7105(Greenbelt)	1	0.40	7839(Graz)	1	0.49
7110(Monument Peak)	1	0.79	7840(Herstmonceux)	1	0.43
7119(Haleakala)	10	0.13	7941(Matera)	1	0.30
7237(Changchun)	4	0.16			

σ: observation-weighting sigma, WRMS: weighted root mean square.

weighting sigma (σ) and the number of observations is quite unbalanced. The value of σ is determined by the tracking performance of each station. First, ILRS core stations, which have a stable NP quality and a long-term tracking history, have σ=1. Next, the weighting σ of other stations is assigned as 1, 4, or 10 according to the ILRS station quality report. If the observation-weighting value is above 1 for a station, SLR data of that station are underweighted in OD as much as the amount of the σ-value. Fig. 5 shows the effects of drag estimation frequency through the results of the post-fit residuals. Except some arcs that have no converged results, 8 hour-based results generally show better precision than 24 hour-based results. However, this also shows that the 8 hour-based strategy for drag coefficient estimation sometimes fails to obtain converged results. This is attributed to the sparse measurement condition of STSAT-2C giving an unstable estimation solution due to the increased number of estimation parameters.

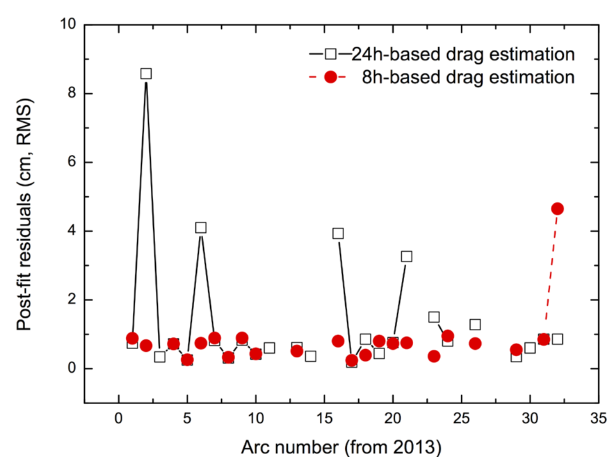

Fig. 5. Effects of drag estimation frequency.

3.2 Orbit Overlaps

Although the overlapped periods are generally arranged consecutively, we could not find continuous overlapping periods among the sparse arcs for STSAT-2C. Therefore, we extracted a few discrete overlapped periods using several arcs as shown in Tables 6 and 7. For the orbit overlaps, one arc is selected among the previously determined arcs presented in Table 4. The other arc is newly determined

Table 6. Arcs for orbit overlaps of STSAT-2C orbit determination (2013-2014).

Overlapped arc number	Arc	Overlapped period	Differences		
			Radial (m, RMS)	Along-track (m, RMS)	Cross-track (m, RMS)
1	13-02	0418 12H – 0419 12H	0.82	6.26	0.41
2	13-06	0516 12H – 0518 12H	16.95	231.89	26.84
3	13-10	0902 12H – 0903 12H	13.15	42.40	118.64
4	13-11	0905 12H – 0907 12H	8.43	123.27	72.07
5	13-13	0918 12H – 0920 12H	10.05	54.03	225.30
6	13-18	1208 12H – 1209 12H	17.30	66.07	24.49
7	13-21	1216 12H – 1217 12H	17.47	129.52	86.60
8	13-21	1217 12H – 1218 12H	33.83	722.00	141.79
9	13-23	1223 12H – 1224 12H	4.47	32.46	0.71
10	13-24	1226 12H – 1227 12H	3.96	21.14	1.26
11	14-02	0224 12H – 0226 12H	24.84	490.63	7.84
12	14-04	0310 12H – 0311 12H	53.92	288.65	961.82
13	14-05	0312 12H – 0315 12H	25.12	278.74	15.58
14	14-06	0405 12H – 0406 12H	10.91	86.77	20.52

RMS: root mean square.

Table 7. Orbit overlaps results of STSAT-2C orbit determination (2013-2014).

Arc	Arcs for overlaps	WRMS (cm)	Number of NP	Arc	Arcs for overlaps	WRMS (cm)	Number of NP
13-02	0416 – 0419	0.67	39	13-21	1216 – 1218	0.75	78
	0418 – 0419	0.41	32		1217 – 1219	0.80	92
13-06	0514 – 0518	0.74	172	13-23	1223 – 1225	0.36	59
	0516 – 0521	0.76	126		1221 – 1224	0.42	36
13-10	0901 – 0903	0.43	45	13-24	1226 – 1229	0.95	47
	0902 – 0905	0.65	28		1224 – 1227	0.51	71
13-11	0905 – 0909	0.60	33	14-02	0224 – 0302	0.73	50
	0903 – 0907	0.65	33		0222 – 0226	0.57	76
13-13	0917 – 0920	0.61	48	14-04	0309 – 0311	0.47	84
	0918 – 0920	0.36	42		0310 – 0312	0.77	79
13-18	1207 – 1209	0.39	42	14-05	0312 – 0316	0.35	36
	1208 – 1212	0.50	42		0311 – 0315	0.69	58
13-21	1216 – 1218	0.75	78	14-06	0404 – 0406	0.60	68
	1214 – 1217	0.97	106		0405 - 0406	0.59	39

WRMS: weighted root mean square, NP: normal point.

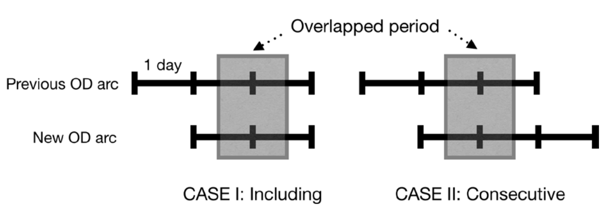

Fig. 6. Concept of orbit overlaps.

using a day close to the first arc. To include more periods, the two orbit overlap concept displayed in Fig. 6 is utilized in the section. In the first case, the new arc is included in the previous arc, and in the second case, the two arcs have a common period in the middle of the arcs. The details of the arcs' orbit overlaps and their post-fit residuals are presented in Table 6. The post-fit residuals (RMS) for all arcs' overlaps are maintained at less than 1 cm.

Table 7 shows the overlapped periods and their overlap results for STSAT-2C OD. The first and the last 12 hours of the overlapped periods are eliminated and each period is selected to have a minimum of one day's overlap. The differences in the overlapped orbits are displayed with the radial, along-track, and cross-track directions. The orbit overlaps results show values varying from 1 m to 1 km. While the post-fit residuals show small differences between two overlapped arcs, the orbit overlaps yield larger variations. This inconsistency is one of the drawbacks of SLR-based OD using sparse range observations. This is a result of orbit-fits in the OD process being performed by using only few short arcs. To avoid this situation, continuous and frequent SLR tracking is essential for STSAT-2C. The differences for the radial direction have relatively small values, less than 50 m. The differences for the along-track and cross-track directions are under 600 m and 900 m, respectively. Figs. 7 and 8 show the differences in the overlapped orbits according to the day of the year in the radial direction. Each overlapped period has its own characteristics in each

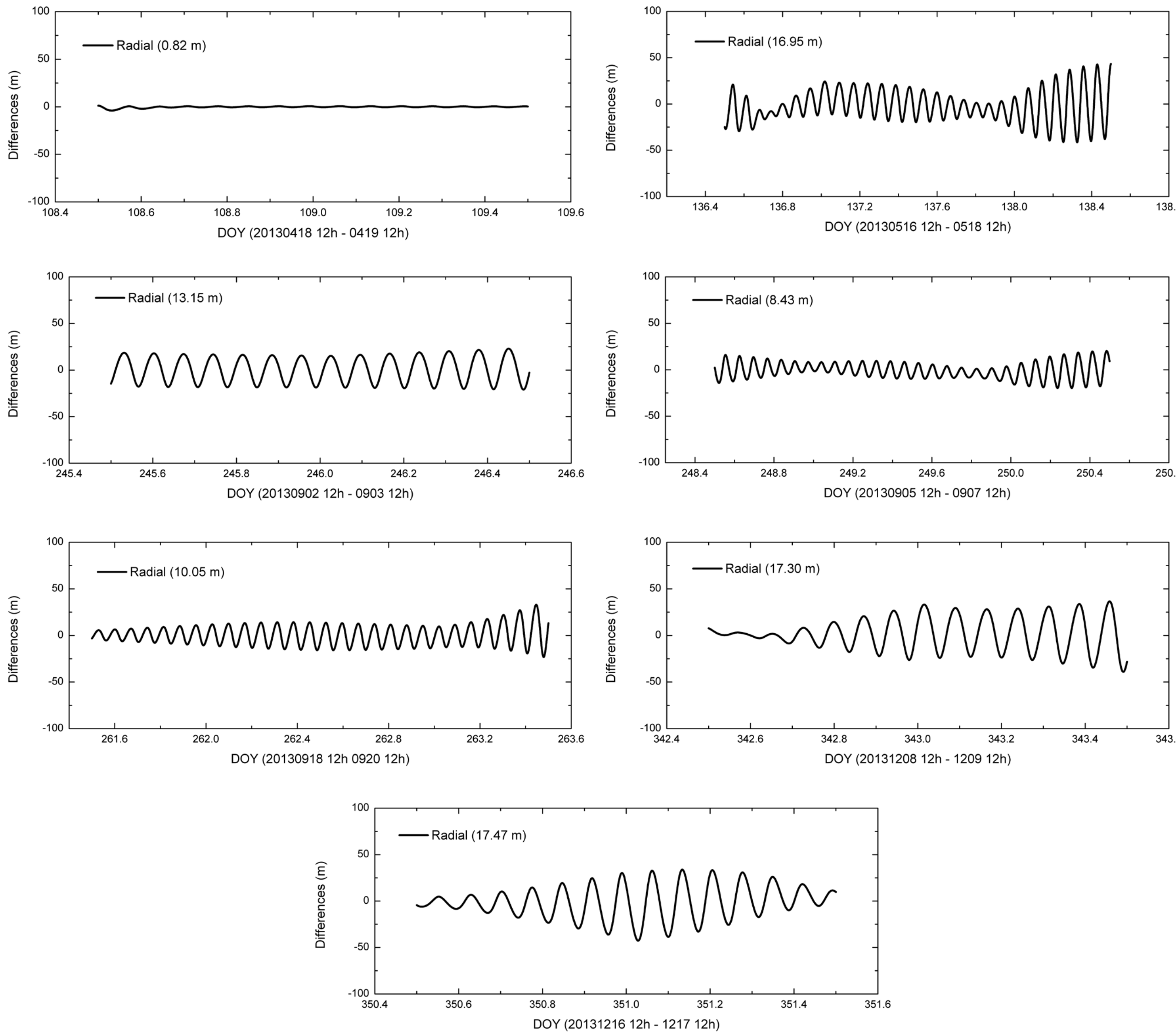

Fig. 7. Orbit overlap results (overlapped arcs 1 – 7).

direction without consistent trends. The along-track and cross-track produce widely different values according to the time. Therefore, we can infer that OD for STSAT-2C using SLR data has shortcomings in the robustness of the along-track and cross-track directions. As the unstable conditions for OD of the STSAT-2C lead to inconsistent accuracy of the orbit overlaps, improvement of the sparse measurements is needed to improve the reliability of the orbit analysis.

4. CONCLUSIONS

In this study, orbit determination (OD) for the STSAT-2C satellite using SLR observations was successfully accomplished by a short-arc approach. OD using SLR normal point (NP) observations over one year was performed by the NASA/GSFC GEODYN II software. Variable estimation intervals for the atmospheric drag coefficients and the empirical acceleration parameters and a non-regular daily-based strategy are applied because the inaccuracy of TLE-based predictions for the STSAT-2C leads to very sparse measurement conditions. The prior value of the initial orbit was obtained from the previous TLE-based predictions through an iterative manual tuning. For the orbit quality assessment, the post-fit residuals and orbit overlaps are analyzed. The weighted root mean square values of the post-fit residuals are at a precision level of under 1 cm. The radial precision of the overlaps shows 50 m accuracy. The precision

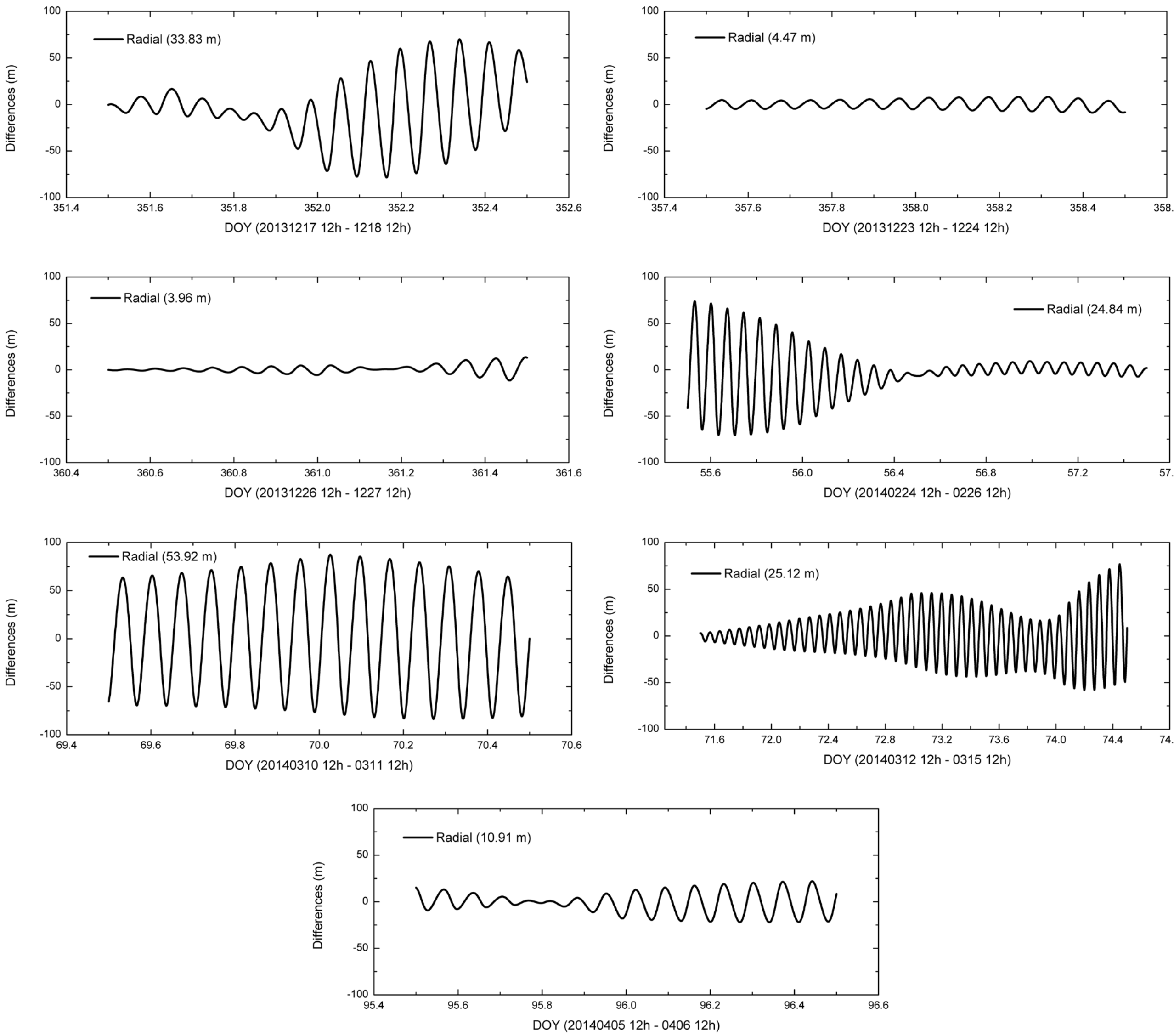

Fig. 8. Orbit overlap results (overlapped arcs 8 – 14).

of the along-track and cross-track directions is less than 600 m and 900 m, respectively. Although the post-fit residuals of STSAT-2C OD have a cm-level precision, the orbit overlap results imply that the 3D orbit accuracy is at the m-level or km-level. This indicates that the lack of SLR observations in STSAT-2C leads to the large difference between OD precision and accuracy. To overcome this inconsistency due to sparse measurement conditions, more SLR measurements through improved orbit predictions are urgently needed. In this sense, the OD for STSAT-2C based on the SLR data is a significant step towards better precision of the orbit prediction. The study of STSAT-2C orbits under sufficient SLR observations would validate the dynamic and measurement modeling accuracy in 300-1,500 km environments.

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