Results and Analyses of Debris Tracking from Mt Stromlo

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Abstract

In the last 2 years, EOS Space Systems has conducted three debris tracking campaigns using its Space Debris Tracking System at Mt Stromlo. The first one was an optical (passive) tracking campaign undertaken between 8 May and 23 May 2012. The second one was a laser tracking mission in July/August 2012, and the third was also a laser tracking campaign in April/May 2013. One of the main objectives of these campaigns was to assess the performance of the short-term (1-2 days) debris orbit prediction (OP), from tracking data at a sole station. This paper presents the results and analyses of the short-term OP performance assessments. It shows that the 1-day OP accuracy better than 20 arc seconds is achievable using only 2 passes of tracking data over 24 hours.

1. Introduction

Currently many of the SSA applications use the openly accessible catalogue of two line elements (TLE), which is maintained from using the radar and optical tracking data. However, it is often found that this open-access catalogue does not provide the required orbit accuracy, for example, for debris collision warnings. A miss of such a warning would result in catastrophic space environment disasters like the collision between operational Iridium 33 and defunct Kosmos 2251 on February 10, 2009, which generated more than 1600 catalogued and hundreds more uncatalogued objects in the LEO (Low Earth Orbit) region [1].

Providing accurate orbital predictions (OP) of debris objects is a fundamental part of space surveillance and space situational awareness (SSA). Multiple research efforts have been undertaken at EOS Space Systems (EOSSS) to provide better space surveillance services. One effort has been the development of laser tracking of space debris started early in the first decade of this century. At present, laser ranging to debris objects during a terminator period is a routine practice at the EOS Space Debris Tracking System (SDTS) at Mt Stromlo, Canberra, Australia. To obtain a successful laser track however, the target needs to be aligned with the laser boresight. This is achieved using a visible-light wide-field acquisition camera. The use of visible light acquisition limits the laser tracking operation to 2 terminator sessions each day, even though the laser tracker itself is not so restricted. To improve efficiency and capacity it is desirable to extend the operation to non-terminator periods. In order to enable non-terminator tracking, one of the conditions is that the OP are sufficiently accurate that the laser beam can be blind pointed to the target based on orbit predictions and the signals are returned (blind acquisition).

In previous studies [2, 3], short-term (1~3 days) OP performance from using the tracking data at Mt Stromlo was addressed, and promising results were obtained. It was shown that, when two or more laser passes were available over a time period of less than or equal to 48 hours, the 1-3 day angular prediction errors were usually less than 50 arc seconds. In another study [4], it showed that the 20-arc second OP accuracy for the next 24 hours from using 2-3 passes of laser/optical tracking data span over about 24 hours was achievable.

These results were obtained from OP experiments for objects that were tracked during two tracking campaigns operated in 2012 at the EOS SDTS. The first one was an optical (passive) tracking campaign undertaken between 8 May and 23 May 2012 during which about 75 objects were tracked, and many of them were tracked on many days. The second trial was a laser tracking effort in July/August 2012 and about 80 objects were tracked.

From April 23 to May 10, 2013, another laser tracking campaign was carried out to collect data for a more comprehensive study of the short-term (1~2 days) OP performance using limited tracking data from Mt Stromlo. 15 objects, 8 of them having perigee altitude below 650km, were deliberately and consistently tracked allowing the OP performance assessment, although poor weather interrupted the data collection. The low perigee objects were chosen for studying the atmospheric drag effect on OP performance.

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This paper presents the results of the short-term (1~2 days) debris OP performance using the tracking data from the three campaigns, and is the latest one in the series of EOSSS debris OP performance enhancement research.

In the following, the EOS SDTS is introduced briefly in Section 2. Section 3 discusses the problems related to the debris orbit determination (OD) and OP using tracking data from the sole station. The 1~2 day OP results using the tracking data on two consecutive nights are presented and analysed in Section 4, followed by some conclusions in Section 5.

2. EOS Space Debris Tracking System

The core of the EOS SDTS is a laser tracking sub-system which fires laser signals to a targeted space object and receives the signals reflected (returned) from the object. The time difference between the firing and receiving epochs is a measure of the two way distance between the tracking station and the object. The principle and system operations are exactly the same as those of a traditional satellite laser ranging system (SLR).

The difficulties with the debris laser tracking lie mainly in two aspects. The first one is that, because debris objects have no laser retro-reflectors on board, the laser power needs to be significantly increased to make sure sufficient signals are returned from distant space objects to be detected by the system receiver. Producing a high quality laser beam with high repetition rate is a difficult task. The second problem is due to the poor accuracy of orbit predictions. A real-time orbit update system is needed to provide sufficiently accurate orbit predictions for the laser tracking system. The real-time orbit update is made possible by high-quality optical tracking, and consequently, a drawback of the system is that the objects have to be sun-lit visible to the optical tracking cameras.

Fig. 1. EOS Space Research Centre at Mt Stromlo

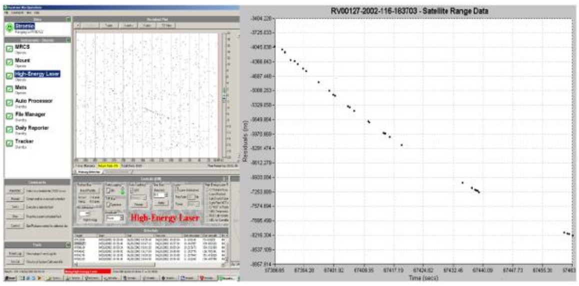

Fig. 2. Example of Laser Ranging to Debris Object

Fig. 1 shows the EOS Space Research Centre at Mt Stromlo, where the EOS SDTS is located. A capability demonstration campaign, the RazorView project, was conducted between 20 July and 8 August, 2004. Nearly 100 objects were tracked by the system during the RazorView campaign [5]. Fig. 2 shows an example of returned (left) and processed (right) debris tracking laser signals.

It was shown in [6, 7] that space debris objects could be tracked by the system with an RMS accuracy better than 1.5m for the ranges and about 1.5 arc seconds for the angular data. The 3-dimensional measurements of positions of debris objects provide a better basis than other ground-based debris tracking methods for debris orbit determination and prediction. When the laser ranging data is used for the orbit determination of LEO debris objects, the orbit determination accuracy can be as good as a few metres [6].

3. Debris Orbit Determination and Prediction Using Single Station Tracking Data

The main purpose of collecting tracking data of a debris object is to determine and predict the orbit of the object with better accuracy. Accurate satellite OD is possible, if dense and high quality tracking data is available, and the satellite-specific information (the attitude, area-to-mass ratio, etc.) is known. In fact, orbits of a number of LEO satellites with SLR or GPS tracking data are determined with cm accuracy. Even so, the accurate OP for these satellites is still a challenge, largely due to the uncertainties in the atmospheric mass density modelling.

For debris objects, two distinct problems exist:

(i) tracking data is either sparse or ill-distributed, and

(ii) the critical ballistic coefficients are mostly unknown.

Under these conditions, the OD itself becomes a difficult task because the solution system is geometrically weakly constrained or even singular. Such an OD solution, if produced, will almost certainly cause substantial errors in the predicted orbit. The authors experienced many frustrations in the early stages of this study, when tracking data of a debris object was processed in the OD program, which was designed and tested with global SLR data. For a debris object, little was known except the TLE which was provided for the tracking operation. Following the standard OD procedure where the ballistic coefficient (as well as the solar radiation pressure coefficient) is treated as a fitting parameter along with the state vector at the initial epoch, it was often that the OD computation failed to converge, or unusable OP results were produced, due to the two problems mentioned above.

There are ways to ease or solve the problem of geometrical weakness in the debris OD solution system. One straightforward way is to introduce more constraining information into the solution system. For debris objects, the publicly accessible TLE data appears a usable information source for achieving OD computation convergence. EOS has been using the TLE-generated positions as weakly weighted observations in the debris OD computations [8], which has been developed based on the ideas of [9]. In this way, the OD process will certainly converge even when only one pass of optical tracking data is available. However, the accuracy of the subsequent OP is usually too low to have any practical usefulness for high accuracy applications, such as the non-terminator laser ranging.

The second problem, the lack of *a priori* knowledge about the ballistic coefficient of debris object of interest, appears more serious. Without the knowledge of the ballistic coefficient, the drag effect for objects below 800km in altitude cannot be properly accounted for. When sufficient data is available, the alternative approach, treating the ballistic coefficient as a fitting parameter, is usually applied in OD processes. In cases where only sparse or ill-distributed data is available, even with the utilisation of weakly-weighted TLE-generated positions as supplementary observations, the OD process will usually fail to converge, or a converged solution will be of poor quality.

Realising the importance of having known the ballistic coefficients in OD processes, EOS has developed a method of estimating the ballistic coefficients of LEO objects (<800km in altitude) from their historical TLE data [10]. The method has been tested with objects of known external ballistic coefficients, and agreement within about 10% is achieved between the external values and the estimated values [10, 11]. For many of the LEO debris objects, TLEs over more than 10 years are available, and so their ballistic coefficients can be estimated with reasonable accuracy. It will be shown in the following that for quality OP results, it is critical to fix such estimated coefficients in OD processes when only sparse tracking data is available.

These developments have been integrated into EOS' orbit analysis software system, which processes satellite and debris ranging and optical tracking data using the full set of forces (the Earth gravity, third-body gravities, tides, drag, radiation, etc). The results presented below are produced by this system.

4. 1-2 Day Debris Orbit Prediction Accuracy Using Tracking Data on Two Consecutive Nights

4.1 Angles-Only Orbit Determination and Prediction

It would usually need 2-3 passes of tracking data over 48 hours on three consecutive nights to be able to produce quality OP from the OD where the ballistic coefficient is treated as a fitting parameter. If only two passes over 24 hours on two consecutive nights are available, it is mostly difficult to estimate the ballistic coefficient in the OD, and the consequent OP is of little use. Figure 3 shows some examples of the 1 and 2 day OP errors from using angular tracking data (azimuth and elevation) spanning 24 hours. The perigee altitudes of Object 6909 and Object 27133 are about 884km and 656km, respectively. It is seen that the errors (biases) are in the order of one thousand arc seconds.

Figure 4 shows the significantly reduced OP errors when 3 passes of angular tracking data over 48 hours are used in the OD process in which the ballistic coefficient is treated as a fitting parameter. It is seen that the OP errors can be less than 10 arc seconds for 1-day prediction. EOS experiences indicate that, if 3 or more days of tracking data are available, the orbital determination with the ballistic coefficient as a fitting parameter would generally produce good OP results.

However, it would be a hard task to track an object on three consecutive nights because of visibility, scheduling conflicts and weather conditions. Therefore, one would ask whether angular tracking data of two passes on two consecutive nights could be sufficient for reasonably accurate OP, and the authors found that this could be achieved if the accurate ballistic coefficient was known and **fixed** in the OD process. This requirement has driven the research on the accurate determination of ballistic coefficient of debris objects from their archived long-term TLE datasets.

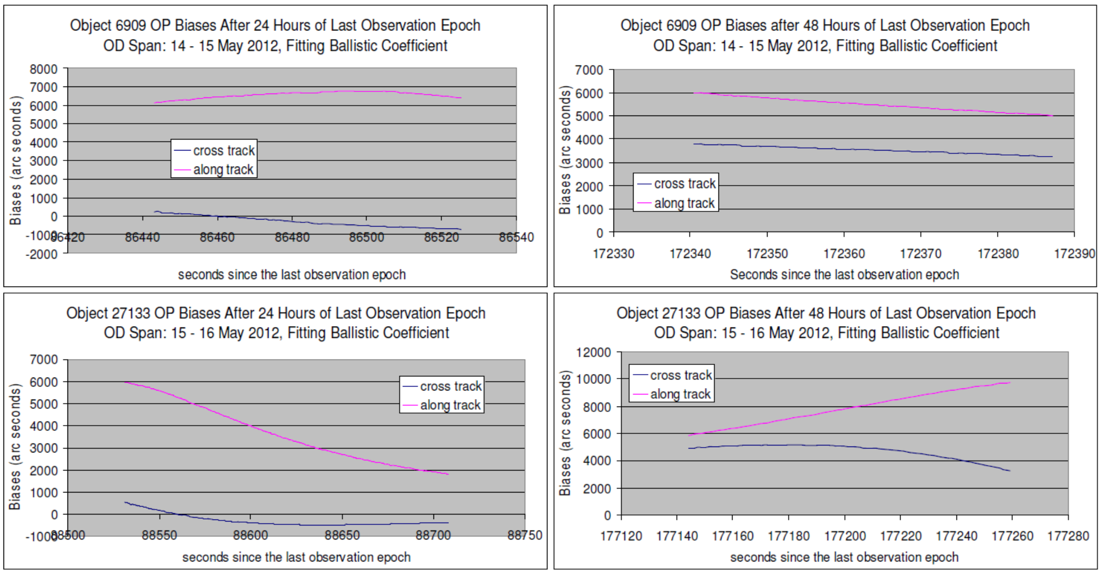

Fig. 3. Examples of OP Errors when the Ballistic Coefficient is Fit in the OD using 2 Passes Over 24 Hours

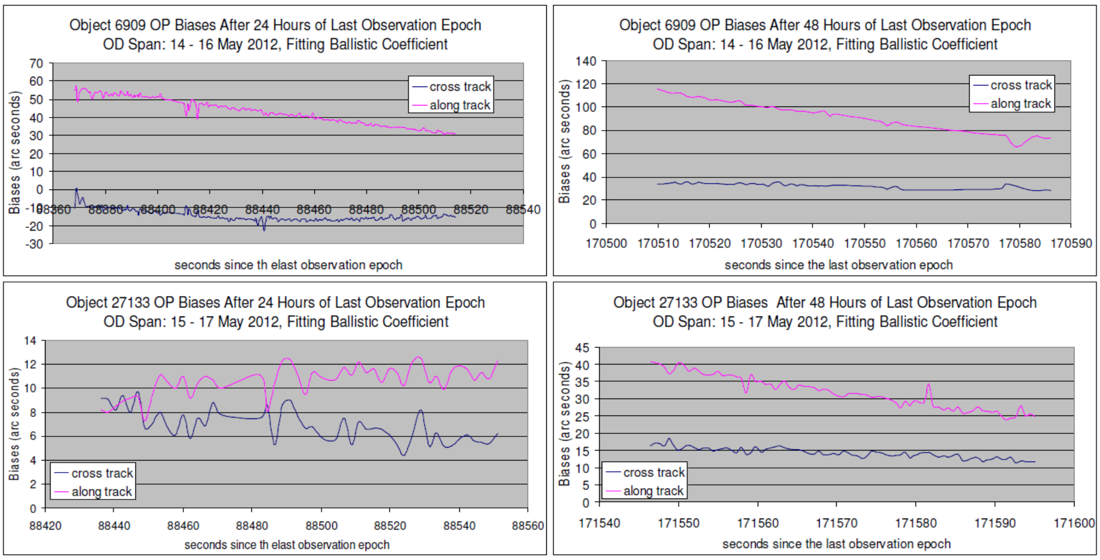

Fig. 4. Examples of OP Errors when the Ballistic Coefficient is Fit in the OD using 3 Passes Over 48 Hours

Using the method in [10], the ballistic coefficients are estimated of those objects tracked during the May 2012 optical tracking campaign, which have perigee altitudes less than 1000km and were launched before 2004, and they are listed as **EOS BC** in Table 1. Also listed are the ballistic coefficients estimated using the **B*** parameters of the TLE datasets (also see method details in [10]), as well as the ballistic coefficients estimated from the **OD computations** using all the available optical tracking data. It is seen that the B*-based ballistic coefficients are consistently smaller than the EOS BC values by a factor of 3~5. The OD estimated ballistic coefficients are relatively close to the EOS BC, an indication that the method of estimating EOS BC is reliable and accurate to better than 10% [10, 11]. It is acknowledged that Object 19359 has failed in the EOS BC estimation, while a few objects have failed in the estimation of ballistic coefficients during the OD computations. In Table 1 and the following tables, the pink-colour is used to indicate the objects having perigee altitudes below 650km.

With the ballistic coefficients known to a reasonable accuracy level, there is no need to estimate it in the OD computations. In such case, even only tracking data of two passes over two consecutive nights is available, accurate short-term OP is possible, and this was demonstrated below using the tracking data from the optical campaign. Table 2 shows the distribution of the tracking data of those objects which have tracking data available for the OP validation using tracking data, where the number on the first row is the day number in the month of May 2012, a single star indicates only one pass was tracked on the night, and double star indicates two passes were tracked on the night. For example, Object 6909 has tracking data between 14 May and 23 May. Therefore, the OP using tracking data on 14-15 May can be compared with the tracking data on 16-23 May.

Table 1: Ballistic Coefficients of Some Objects Tracking During May 2012 Campaign

NORAD ID	EOS BC	B*-Based BC	OD Estimated BC	Perigee Alt (km)
155	0.158352	0.060026	0.15070	737
3522	0.027117	0.005269	0.02794	775
4135	0.056228	0.015068	0.03278	789
4716	0.544590	0.094265	0.52668	914
4751	0.491232	0.085124	0.58366	966
5847	0.024315	0.005305	failed	944
6160	1.676340	0.331448	1.42274	814
6276	0.023719	0.004391	0.02354	796
6909	0.077056	0.012056	0.08096	884
7575	0.013877	0.005972	0.02200	819
7839	0.072793	0.020847	0.07194	607
10954	0.021067	0.012371	failed	549
11573	0.017314	0.003595	0.01034	760
12283	0.031705	0.006836	0.03102	741
12791	0.017791	0.003487	failed	766
13472	0.519519	0.110051	0.39270	855
13573	0.041283	0.008192	0.04180	885
13804	0.602841	0.113419	0.64262	845
15483	0.021998	0.005310	0.01298	759
16204	0.017348	0.003419	0.03168	948
16209	0.088060	0.015170	0.03630	982
17271	0.148196	0.026338	0.19668	881
18290	0.034370	0.007935	0.02662	681
18697	0.083418	0.021820	0.06820	725
19359	failed	Failed	0.17600	760
19573	0.015059	0.007980	0.01892	563
19769	0.016547	0.003763	0.01496	761
21153	0.025995	0.005473	0.05126	958
21439	3.281428	0.841839	0.41382	937
21475	0.055892	0.011909	1.54836	957
22208	0.028231	0.005721	0.03234	957
22379	0.214140	0.035843	0.17336	818
23007	0.085511	0.014838	0.07744	754
24903	0.002882	0.001285	0.07106	775
24949	0.000918	0.001285	0.01936	776
25104	0.000918	0.001285	failed	775
25108	0.000918	0.001285	failed	776
25187	0.660647	0.117652	0.62964	847
25227	0.680969	0.124862	0.55836	858
25276	0.000918	0.001285	0.0407	776
25319	0.036442	0.001285	failed	765
25736	0.078781	0.017829	0.06534	735
26151	0.169647	0.003365	0.22132	728
26321	0.217765	0.041445	0.17952	651
26416	0.224896	0.040470	0.21362	658
27133	0.033028	0.004807	0.02838	656
27598	0.019297	0.002738	0.01848	791
27640	0.026016	0.004414	0.02552	820
27847	0.042888	0.005191	0.04246	814

Table 2: May 2012 Tracking Data Distribution

	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Perigee	Apogee
155					*		*	*	*								737	821
3522						*			*	*	*	*	*		*	**	775	816
4716				*						*		*	*	*		*	914	930
6160	*	*	*		*	*			*								814	935
6276							*			*		*	*	*	*	*	796	848
6909					*		*	*	*	*	*	*	**	*	*	*	884	1115
7575													*	*	*		819	893
7839				*			*	*	*	*	*	*	*		*	*	607	893
12283							*		*	*	*	*	*		**	*	741	876
13573													*	*	*	*	885	988
15483				*			**	*	*	*	*	*	*			*	759	787
16209	*	*	*	*	*	*	*	*	*	*							982	1008
18290	*	*	*	*	*	*	*		*	*		*			*		681	819
19769	**	*	*	*	*	*	*	*		*				*			761	793
21153		*	*		*	**		*	*								958	1000
22208						*	*	*	*	*	*	*		*			957	1006
24903		*	*		*	*											775	778
26151									**		*	*	*		**	*	728	1688
27133	*			*	*	**		*	*	*	*	*	*		*	*	656	725
27598		*	*	*	**	*	*	*	*	*	*	**	*		*	*	791	804
27640								*		*	*		*	*	*	*	820	840
27847			*	*	**	*				*	*	*	*				814	827

Table 3: May 2012 Tracking Data: 2-Day OD Cases

	8	9	10	11	12	13	14	15	16	17	18	19	20	21
155							#							
3522									#	#	#	#		
4716												#	#	
6160	#	#			#									
6276												#	#	#
6909							#	#	#	#	#	#	#	#
7575													#	
7839							#	#	#	#	#	#		
12283									#	#	#	#		
13573													#	#
15483							#	#	#	#	#	#		
16209	#	#	#	#	#	#	#	#						
18290	#	#	#	#	#	#			#					
19769	#	#	#	#	#	#	#							
21153		#			#									
22208						#	#	#	#	#	#			
24903		#												
26151											#	#		
27133				#	#			#	#	#	#	#		
27598		#	#	#	#	#	#	#	#	#	#	#		
27640										#			#	#
27847			#	#	#					#	#			

Table 3 lists the OD cases whose OP results can be validated using the tracking data after the OD span. For example, the "#" on May 14 for Object 155 means the OD case exists using the tracking data on 14 and 15 May.

For this study, the focus is on the short-term (1-2 days) OP. Table 4 presents the possible 1-day OP assessment cases. The number in Table 4 is the OP Case Number. For example, the "1" on May 16 for Object 155 means an assessment of 1-day OP using OD of previous 2-days can be made. There are in total 79 1-day OP assessments.

Similarly, the possible 2-day OP assessment cases are given in Table 5. For example, the "1" (2-day OP Assessment Case 1) on May 19 for Object 3522 means that a 2-day OP assessment exists, using the OD of tracking on May 16-17. There are 74 2-day OP assessment cases.

Table 4: May 2012 Tracking Data: One-Day OP Assessments

	10	11	12	13	14	15	16	17	18	19	20	21	22	23
155							1							
3522									2	3	4			
4716												5		
6160	6													
6276												7	8	9
6909							10	11	12	13	14	15	16	17
7575													18	
7839							19	20	21	22	23			
12283									24	25	26			
13573													27	28
15483							29	30	31	32	33			
16209	34	35	36	37	38	39	40	41						
18290	42	43	44	45	46									
19769	47	48	49	50	51	52								
22208						53	54	55	56	57				
26151											58			
27133				59				60	61	62	63			
27598		64	65	66	67	68	69	70	71	72	73			
27640													74	75
27847			76	77						78	79			

Table 5: May 2012 Tracking Data: Two-Day OP Assessments

	11	12	13	14	15	16	17	18	19	20	21	22	23
3522									1	2		3	
4716													4
6160		5											
6276												6	7
6909							8	9	10	11	12	13	14
7839							15	16	17	18		19	
12283									20	21		22	
13573													23
15483							24	25	26	27			
16209	28	29	30	31	32	33	34						
18290	35	36	37	38		39			40				
19769	41	42	43	44	45		46						
21153		47			48								
22208						49	50	51	52		53		
24903		54											
26151												55	
27133					56			57	58	59		60	
27598		61	62	63	64	65	66	67	68	69		70	
27640										71			72
27847			73							74			

The OP performance can be measured by the difference between angular track data and their corresponding values computed from the predicted orbit. Table 6 presents the maximum 1~2 day angular OP errors. These OP errors are also shown in Figure 5. It can be seen from Table 6, that

- There are a few failed OD cases. These OD cases are related to large errors in observations or short tracking passes.
- The maximum 1-day OP error is 119 arc seconds, and the maximum 2-day OP error is 1430 arc seconds.
- The median 1-day OP error is 17 arc seconds, and the median 2-day OP error is 30 arc seconds.

Table 6: Maximum 1~2 Day OP Errors – May 2012 Optical Tracking

1-Day OP Case	Max OP Errors (arc sec)	2-Day Op Case	Max OP Errors (arc sec)
1	5	1	7
2	11	2	66
3	12	3	15
4	35	4	83
5	32	5	950
6	**119**	6	9
7	5	7	27
8	13	8	63
9	17	9	45
10	75	10	14
11	23	11	12
12	10	12	16
13	12	13	15
14	19	14	12
15	9	15	56
16	13	16	56
17	5	17	40
18	15	18	118
19	18	19	8
20	45	20	11
21	9	21	12
22	31	22	8
23	25	23	9
24	5	24	40
25	14	25	22
26	7	26	20
27	8	27	31
28	failed	28	48
29	20	29	65
30	23	30	129
31	12	31	78
32	10	32	29
33	20	33	60
34	25	34	27
35	27	35	25
36	33	36	88
37	60	37	155
38	20	38	36
39	15	39	49
40	27	40	36
41	6	41	26
42	25	42	58
43	8	43	39
44	77	44	20
45	21	45	43
46	13	46	32
47	29	47	98
48	13	48	12
49	44	49	20
50	21	50	8
51	19	51	45
52	16	52	33
53	26	53	16
54	14	54	17
55	13	55	19
56	34	56	86
57	6	57	20
58	failed	58	24
59	39	59	22
60	32	60	failed
61	17	61	56
62	13	62	96
63	10	63	38
64	11	64	9
65	52	65	23
66	9	66	30
67	23	67	**1340**
68	21	68	163
69	14	69	15
70	failed	70	27
71	108	71	26
72	7	72	8
73	11	73	failed
74	13	74	132
75	16		
76	failed		
77	27		
78	103		
79	108		

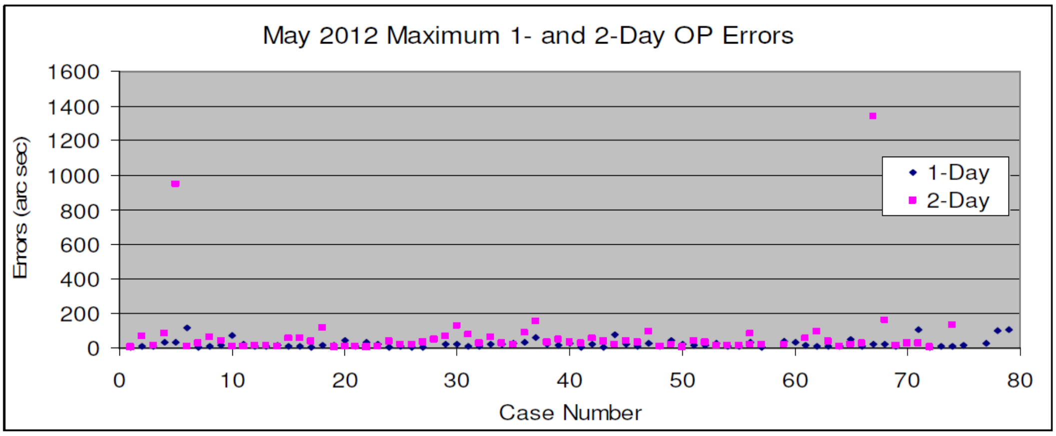

Fig. 5: May 2012 Tracking Data 1-2 Day OP Performance

4.2 Laser Ranging Orbit Determination and Prediction

In July/August 2012 and April/May 2013, two debris laser ranging campaigns were performed. Among others, the assessment of the short-term OP performance was a main objective. Table 7 lists the July/August 2012 laser tracking data distribution of the objects which were tracked at least on two consecutive nights, so that an OD computation can be performed, where the first row is day number in either the month of July or August. And similarly, Table 8 presents the April/May 2013 laser tracking data distribution of the objects which were tracked at least on two consecutive nights. Table 9 listed the ballistic coefficients estimated from TLE datasets.

Note that 8 of 15 objects in Table 8 have perigee altitude less than 650km. They are deliberately chosen to allow the OP assessments for low perigee objects which are subject to more significant atmospheric drag effect. In particular this year is the year of maximum solar activity.

Table 7: July/August 2012 Laser Tracking Data Distribution of Some Objects

	26	27	28	30	31	1	2	3	6	7	8	9	10	Perigee	Apogee
3522			*	*			*		*	*		*	*	775	817
4716	*	*									*			914	929
6276		*	*		*						*			796	849
7575					*	*			*	*	*	*	*	822	892
7839		*	*							*	*			608	891
23088										*	*			840	848
24869				*	*									776	779
25736		*								*	*			736	745
27598				*				*	*	*				791	805
27640				*	*		*		*				*	820	841

Table 8: April/May 2013 Laser Tracking Data Distribution of Some Objects

	23	24	25	26	27	28	1	2	4	5	6	7	8	9	10	Perigee	Apogee
1430		*	*	*	*		*	*		*	*		*		*	720	799
2125			*		*		*	*		*		**	*	*	*	596	821
2621	*	*	*			*		*		*	*				*	587	677
2980			*		*			*		*	*	*		*		628	772
5557		*		*	**			*	*	*			*		*	767	840
6275		*	*	*	*		*	*	*		*		*	*	*	775	828
8956		*	*		*	*	*	*	*	*	*			*		639	683
11060				*	*			*					*			824	841
13923		*				*	*	*	*	*	**	*			**	786	810
17122					*	*	*	*	*				*	*	*	663	676
23606			*	*	*	*	*		*	*			*		*	599	607
25475		*	**	*		*	**		*		*		*	*	*	787	791
26121	*	*	*				*		*	*	*		*	*		561	657
26702		*			*			*	*	*	*	*		*	*	565	571
26703				*	*				*	*			*	*	*	587	590

Table 9: Estimated Ballistic Coefficients of Some Laser-Tracked Objects

NORAD ID	EOS BC
3522	0.027117
4716	0.544590
6276	0.023719
7575	0.013877
7839	0.072793
23088	0.078508
24869	0.000918
25736	0.078781
27598	0.019297
27640	0.026016
1430	0.017550
2125	0.020737
2621	0.013191
2980	0.021273
5557	0.032421
6275	0.044721
8956	0.039856
11060	0.029133
13923	0.027703
17122	0.048679
23606	0.035404
25475	0.107778
26121	0.038335
26702	0.025546
26703	0.015177

Considering the availability of angular tracking data, the available 1-day and 2-day OP assessment cases are listed in Tables 10 and 11, respectively.

Table 10: Laser Data 1-day OP Assessment Cases

July/August 2012

NORAD ID	6	7	8
7575	1	2	3
27598	4		

April/May 2013

	25	26	27	28	6	7	9	10
1430		5	6					
2125							7	8
2621	9*							
2980						10		
6275		11	12	13				14
8956					15			
13923					16	17		
17122								18
23606			19*	20*				
25475		21						22
26121	23*				24			
26702					25	26		
26703								27

Table 11: Laser Data 2-day OP Assessment Cases

July/August 2012

NORAD ID	2	9	10
3522		1	
7575		2	3
27640	4		

April/May 2013

NORAD ID	27	28	30	4	7	8	9	10
1430	5					6		
2125								7
2980							8	
5557					9			
6275	10	11		12				
8956	13*		14*	15				
13923				16	17			
17122				18				
23606		19*						
25475		20						
26121						21		
26702					22		23	
26703					24			

It was found that, for April/May 2013-tracked objects of perigee altitude below 650km, the OP errors before May 1 could be minimised by reducing the ballistic coefficients given in Table 9 by 20%. It is understandable that the 20% factor is effectively a method of the atmospheric mass density model calibrations.

Figure 6 shows the effect of using different fixed ballistic coefficient on the OP errors for Object 2621, which has the perigee altitude 587km. The four figures are respectively for the OP errors 1, 4, 8 and 10 days after the last observation pass. The benefit from reducing the ballistic coefficient by 20% is quite significant. This shows the importance of calibrating atmospheric mass density models.

In Tables 10 to 12, a "*" is attached to a case number which indicates the use of the ballistic coefficient reduced by 20%.

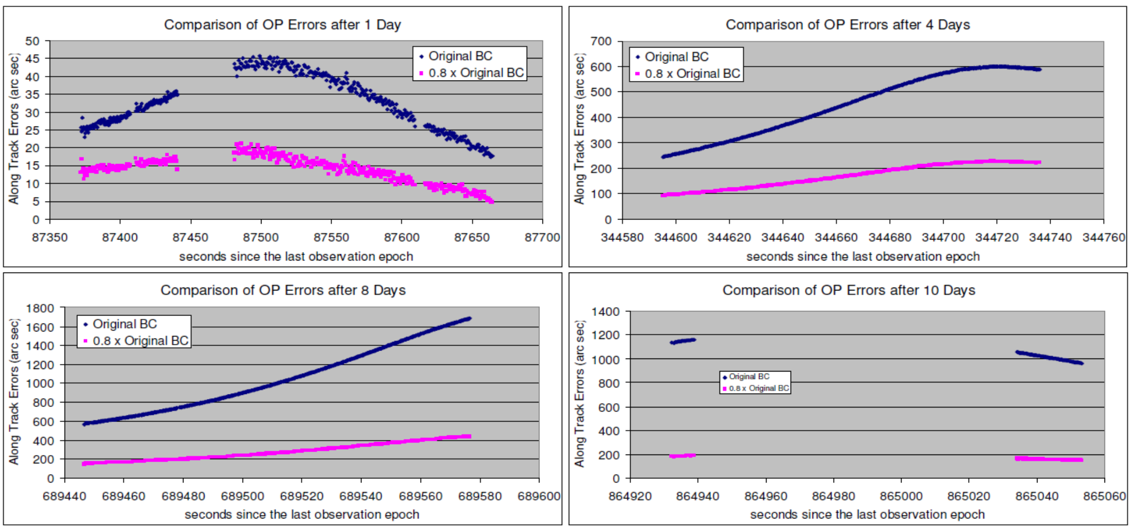

Fig. 6: Effects of Varying Ballistic Coefficient on OP Errors
Object 2621, OD Span 23 – 24 April, 2013

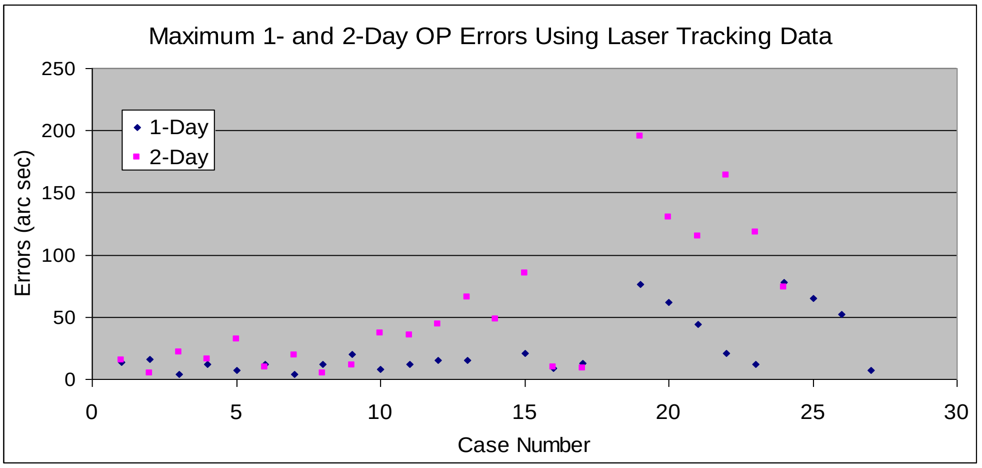

Fig. 7: 1-2 Day OP Performance Using Laser Tracking Data

Table 12 gives the maximum 1- and 2-day OP errors. From Table 12 and Figure 7, it is seen that

- There are a few failed OD cases. Again, these OD cases are related to large errors in observations or short tracking passes.
- The maximum 1-day OP error is 78 arc seconds, and the maximum 2-day OP error is 195 arc seconds. They are significantly less than the corresponding values with respect to optical tracking data.
- The median 1-day OP error is 14 arc seconds, and the median 2-day OP error is 35 arc seconds. The median 2-day OP error using the laser tracking data is larger than that using the optical tracking data, mostly due to the large number of objects having low altitudes.

Table 12: Maximum 1~2 Day OP Errors – Laser Tracking Data

1-Day OP Case Number	Max OP Errors (arc sec)	2-Day Op Case Number	Max OP Errors (arc sec)
1	14	1	15
2	16	2	5
3	4	3	22
4	12	4	16
5	7	5	32
6	12	6	10
7	4	7	19
8	12	8	5
9*	20	9	11
10	8	10	37
11	12	11	35
12	15	12	44
13	15	13*	66
14	failed	14*	48
15	21	15	85
16	9	16	10
17	13	17	9
18	failed	18	failed
19*	76	19*	195
20*	62	20	130
21	44	21	115
22	21	22	164
23*	12	23	118
24	78	24	74
25	65		
26	52		
27	7		

If only the objects with perigee altitudes above 650km are considered (see Figure 8), it is found that

- The maximum 1-day OP error is 76 arc seconds, and the maximum 2-day OP error is 130 arc seconds.
- The median 1-day OP error is 13 arc seconds, and the median 2-day OP error is 16 arc seconds.
- From the maximum and median values of the 1- and 2-day OP errors, it is clear that the short-term OP performance using laser tracking data is superior to that using optical tracking data.

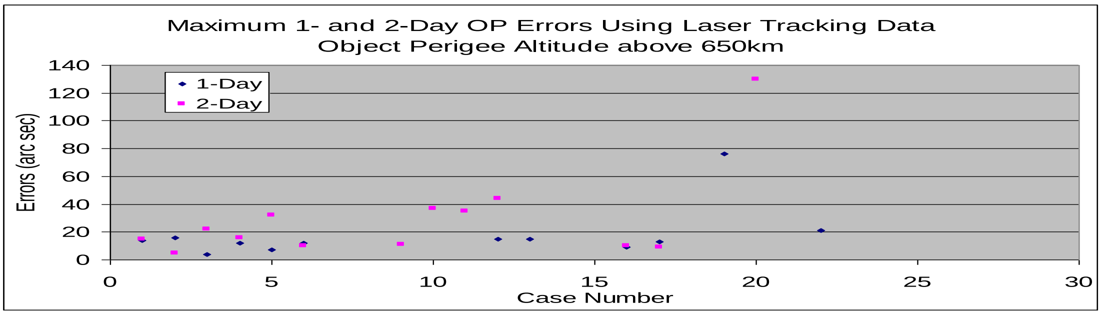

Fig. 8: 1-2 Day OP Performance Using Laser Tracking Data, Object Perigee Altitude above 650km

5. Conclusions

Previous experiments have shown that reasonable OP accuracy using single station data is possible if the tracking data spans over 3 or more days. However, it would be a hard job that an object is optically or laser tracked on 3 or more nights due to visibility, scheduling conflict and weather conditions. This paper has shown that, when the ballistic coefficient of an object is known and fixed in the OP process, the short-term (1~2 days) OP accuracy better than 20 arc seconds is achievable even if only tracking data on two consecutive nights is available. The results from using the laser tracking data are superior to those using only the optical data.

This paper has only used the tracking data from the EOS SDTS at Mt Stromlo. The OP errors in the space far away from Mt Stromlo may be significantly larger than the values presented here, and that assessment needs external tracking data and precision orbit data.

The sample sizes in the OP assessments are still relatively small, so some fluctuations in the error statistics (maximum and median values) may arise. The assessment and research efforts will be continued.

6. Acknowledgements

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