Assessment of SLR observation performance using LAGEOS data

Gang Zhao, You Zhao, Mingguo Sun, Huanhuan Yu
Changchun Observatory, NAOC, CAS, China
zhaog@cho.ac.cn; youzhao@cho.ac.cn; sunmg@cho.ac.cn; yuhh@cho.ac.cn

Abstract

From the beginning of 2008, Changchun Observatory has carried out routine short-arc (3-day) orbit determination and station residual analysis on LAGEOS SLR data. Meanwhile, we commence analysis in some aspects of related issues. In this report, the satellite precise orbit determination results and its preliminary applications are presented. Influences of gravity models - JGM-3, EGM96, GGM02C – have been checked and compared. We find these models are nearly equivalent for mm-level orbit determination with maximum difference less than 3%. Results of short-arc orbit determination which show our orbit determination accuracy around 1.2cm with moderate difference are presented. After comparison of SLR stations' observation precision, the TB and RB analysis on some high performance stations and some stations we concerned are presented in detail. The value and variation of terrestrial coordinates of some stations are also computed and discussed. We expect such analysis will build a bridge between our theoretical research and observational work.

1. Introduction

Satellite Laser Ranging (SLR) has experienced continuous and highly development. The application of SLR observation data on space geodesy, geodynamics, and geophysics has obtained fruitful production. LAGEOS-1/2 are two important targets of SLR observation. Precise orbit determination and subsequent residual analysis of orbit RMS on LAGEOS-1/2 are very useful for study on related issues. The accuracy of LAGEOS short-arc orbit determination today is on cm level.

As a productive station, Changchun Observatory (7237) has provided large numbers of SLR observation data with moderate precision for more than 20 years. It has made great and continuously efforts in SLR equipment and technology.[1] How to make use of SLR data and resource of experiential staffs sufficiently is an important issue for our future development. In these two years, Changchun Observatory has begun precise orbit determination making use of SLR data, especially on LAGEOS data. From the beginning of 2008 on, we have realized routine short-arc POD (precision orbit determination) and residual analysis on SLR data of LAGEOS-1/2, which is publicized on our website (www.cho.ac.cn) and is updated around once a week. In this report, we presented preliminary results and application of our SLR POD work.

2. Data processing methodology

Some characters make LAGEOS-1/2 especially suitable targets for satellite POD. Fairly simple and accurate modeling can be easily got from their spherically symmetric figuration. Altitude around 6000 km make the effect of atmospheric drag and high order/degree geopotential coefficients, which are hard to assign exactly, can be safely ignored. Long observation duration over 30 years for LAGEOS-1 and 16 years for LAGEOS-2 – triggered

plenty of detailed investigation on both short-term and long-term POD, so many perturbation factors and parameters had been well defined.
Table 1 demonstrated the properties of LAGEOS-1/2 which were used in POD processing.

Table 1. Satellite characters

	LAGEOS-1	LAGEOS-2
Satellite ID	7603901	9207002
Mass	411 kg	405 kg
CM (center of mass) offset	0.251 m	0.251 m
Cross section	0.283 m^2	0.283 m^2

Table 2. Strategy of POD solution

Numerical Integration	
integrator	Krogh-Shampine-Gordon
step length	fixed-step, 150s
Reference Coordinate System	
inertial	J2000.0
terrestrial	ITRF2000
precession	IAU1976
nutation	IAU1980
Measurement Model	
plate tectonic motion	NNR-NUVEL1
earth solid tides	
rotational deformation	
ocean tide loading	CSR4.0
tropospheric refraction	Marini/Murry model
Dynamical Model	
earth gravity field	JGM-3 30*30
n-body perturbation	JPL ephemerides DE403 (sun/moon)
ocean tide model	CSR4.0+TEG4
relativistic correction	1-body
solar radiation pressure	conical
earth radiation and albedo	
thermal radiator (y-bias)	
empirical drag	
empirical RTN acceleration	
Estimated Parameters	
satellite state vector	3-position, 3-velocity
empirical drag coefficients	
solar radiation pressure coefficients	
earth radiation parameters	
empirical acceleration	R, T, N
earth rotation parameters	xp, yp, dut1/dt

Table 3. Orbit determination precision of three geopotential models

	JGM-3	EGM96	GGM02C
LAGEOS-1	0.012416 m	0.012764 m	0.012607 m
LAGEOS-2	0.012371 m	0.012571 m	0.012258 m
Mean	0.012393 m	0.012667 m	0.012432 m

Dynamical orbit determination is popularly used methodology in satellite POD.[2] Not only orbital elements are solved, but also combined dynamical parameters are estimated during the processing of dynamical orbit determination. For insuring cm-level orbit determination precision, in POD processing on LAGEOS-1/2, models and parameters should be carefully selected. The adopted reference system, perturbing forces and parameters in our POD procedure are listed in Table 2.

The observation data analyzed in this study covered 1200 days from March 1, 2005 to June 12, 2008. Such long duration can level down the effect of some random factors such as short-term bad station performance, and can also check up the stability and reliability of our work. During such a long period, almost every SLR station has observed LAGEOS-1/2. In our study, observation data are included as much as possible with different calculation weights based on historical experience.

3. Gravity field test

Three gravity models are taken into account here for testing availability of our POD method. For the improvement of modern geopotential determination and relatively low degree/order (30*30) necessarily used in LAGEOS-1/2 POD processing, it should be no obvious difference among POD results of different gravity fields.

The test models include JGM-3, which is recommended in IERS conventions 1996[3], EGM96, which is recommended in IERS conventions 2003[4], and GGM02C, which is got from the combination of satellite GRACE and *terrestrial* gravity measurement[5]. We set the resolved arc length 15 days (i.e. 80 arcs in 1200-day duration). The mean values of orbital precision were presented in Table 3.

We can see the difference among these models is on mm level. The maximum difference is 2.21%. In other words, gravity field models have no influence on present cm-level POD. And also, high correlation among RMS of these models was also found. That is to say the selection of any gravity models is equivalent in our investigation.

We also compiled preliminary statistics on quantity and quality of station observation used 15-day-arc data. We find acknowledged high-performance stations, such as Yarragadee, Graz really held good achievements on both quantity and quality. The weighted RMS, i.e. mean orbital residual of data from high-performance stations is around or a bit more than 1.0 cm. For Changchun, the RMS sometimes exceeds 3 cm.

4. Short-arc POD

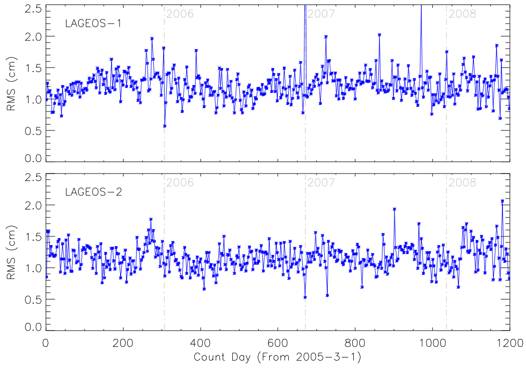

Figure 1. Short-arc orbit determination precision

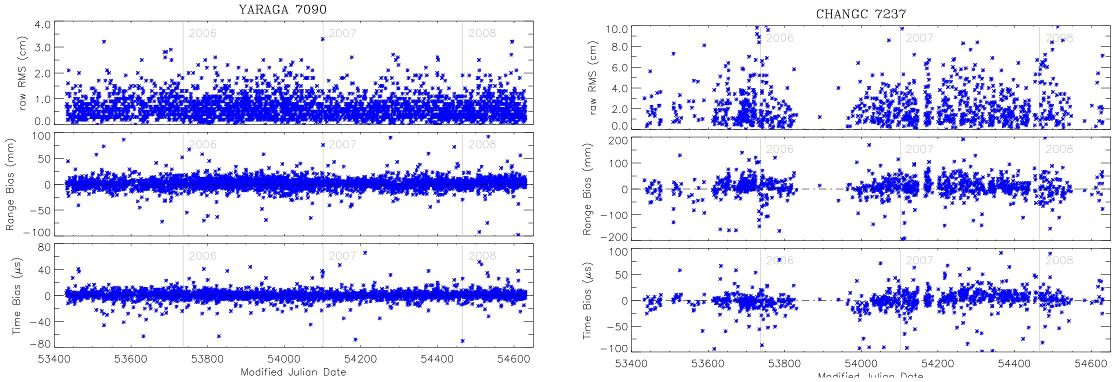

Figure 2. POD RMS, RB, TB of Yarragadee (7090) and Changchun (7237) determined using LAGEOS-1 data

Short-arc (often 3-day) approach is frequently used for the solution of LAGEOS POD, and the cm-level accuracy should be reached, otherwise the POD will lose much of its meaning. We implemented 3-day arc POD on LAGOES-1/2 throughout the whole 1200-day duration with the POD methodology detailedly described above. Figure 1 shows the RMS of each arc. Mean RMS for LAGEOS-1 and LAGEOS-2 is 1.22 cm and 1.17 cm, respectively. But we should also notice large RMS come forth in very few arcs. The reason need to be further investigated.

Based on the results of short-arc POD, we calculated RMS, range bias (RB) and time bias (TB) per arc per station which we concerned. These three indices reflect the difference between observational value and theoretical value of POD from various aspects, and are the most important indices for evaluation of station observation. High performance station held rather low value and Changchun held moderate value on these indices, just like Figure 2 showed.

5. Station coordinates estimation

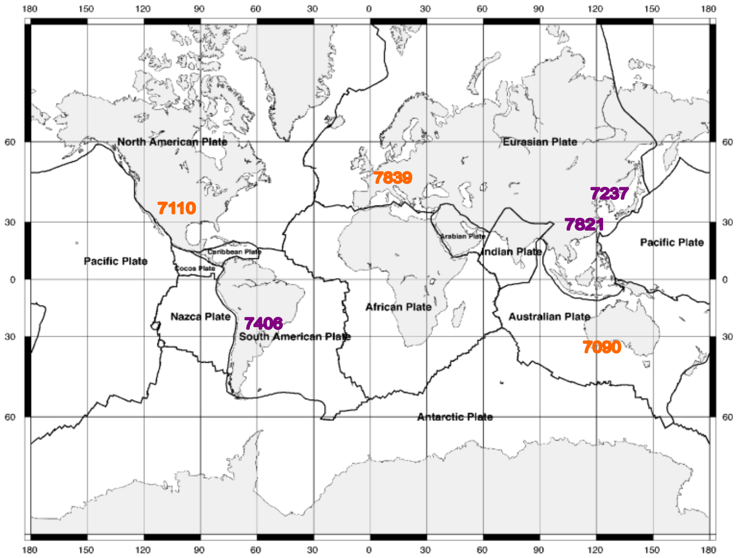

Figure 3. Sketch of location of six station in tectonic plates

A set of terrestrial coordinates of SLR stations was adopted in ITRF 2000 frame and was maintained as input constants during routine POD procedure above. Yet station coordinates vary along with time in some degree.[6] Two reasons required us considered this factor more carefully. First, no well-recommended coordinates provided in ITRF 2000 frame for the SLR stations put into operation in recent years. Second, for all stations, the coordinates are not fixed actually. Even after the influences of geometrical tides, ocean loading and some other factors are eliminated reasonably by modeling, the variations which are difficult to explain at present will also appear in station coordinates. Some suppose the variations are correlated with meteorologic parameters but without confirmation. In POD processing, we found inaccurate value of single station coordinates could put no notable impact on whole orbit determination precision, but could reduce the RMS of the station itself remarkable.

In this step, we set the coordinates of six SLR stations – Yarragadee (7090), Monument Peak (7110), Graz (7839), Changchun (7237), Shanghai (7821) and San Juan (7406) - as estimated parameters. The location of six stations is illustrated in Figure 3. The first four located in quite far away from the boundary of earth tectonic plates. The last two began observing no more than three years, so their coordinates have not been well defined.

The displacement of coordinates along three directions - height, longitude and latitude – was determined. Examples are showed in Figure 4. For all station coordinates, variations are clearly although with different amplitudes. There seems to be periodicities, or quasi-periodicities in variations of coordinates. How to explain them is another complex problem.

6. Summary

Changchun Observatory has the foundation in SLR POD work now. Routine POD and residual analysis on LAGEOS-1/2 has begun from the beginning of 2008. Our present-day orbit determination precision is about 1 to 2 cm.

In the case of our study, the choice of gravity model has slight effect on precision of LAGEOS orbit determination. The influencing magnitude is on sub-mm level.

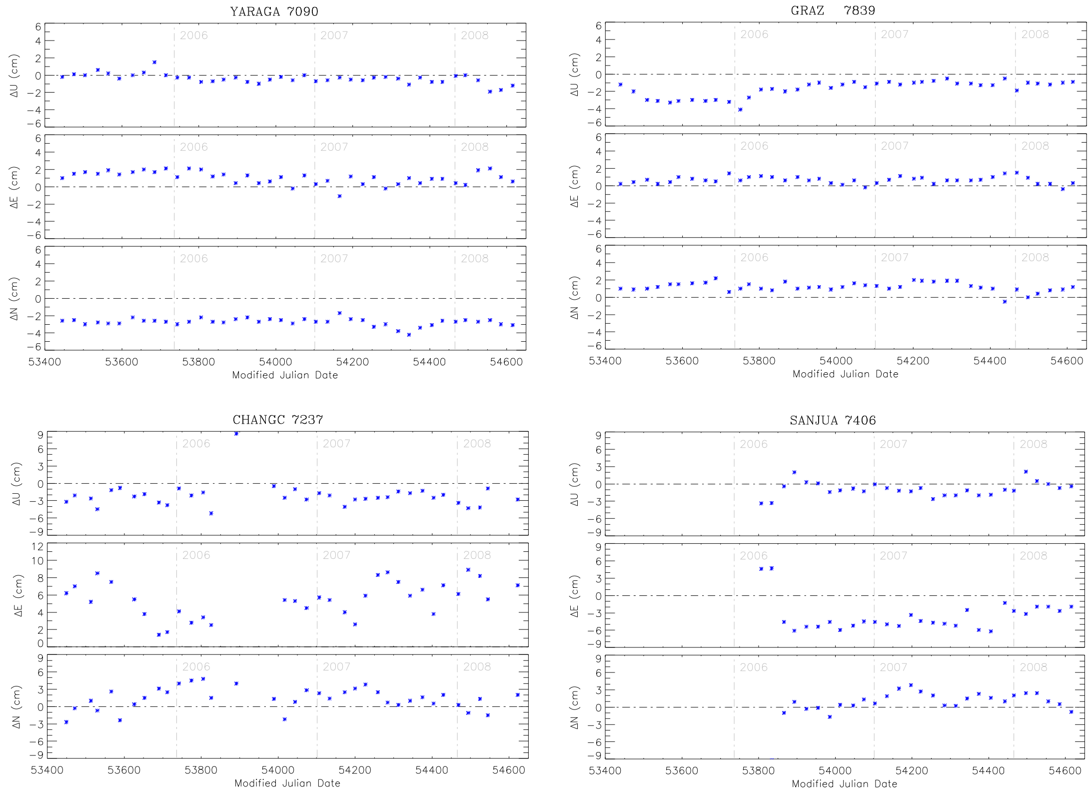

Figure 4. Coordinates of Yarragadee, Graz, Changchun and San Juan determined using LAGEOS-1 data

The station coordinates can also be determined in POD process, and the proper value can do help to improve orbit determination precision. The cause of variability of station coordinates need to be further investigated. What we can do using POD results, how to apply them in relevant geodynamic and geophysical problems, how to combine them with our observational duty, need seriously consideration. We wish the POD work in Changchun will build a bridge to connect theoretical research and observational work.

References

1 Zhao Y., Fan C.B., HAN X.W., et al., *Progress of Changchun SLR*, Proc. of 16th International Workshop on Laser Ranging, Poznan, Poland, 2008

2 Vetter J.R., *Fifty years of orbit determination: development of modern astrodynamics methods*, Johns Hopkins ApL Technical Digest, Vol. 27, No. 3, 2007

3 McCarthy D. D. (ed.), *IERS Conventions (1996)*, IERS Technical Note 21, Observatoire de Paris, 1996

4 McCarthy D.D. and Petit G., *IERS Conventions (2003)*, IERS Technical Note 32, Frankfurt am Main: Verlag des Bundesamts fur Kartographie und Geodasie, p.127, 2004

5 Tapley B., Ries J., Bettadpur S. et al., *GGM02 - An improved Earth gravity field model from GRACE*, Journal of Geodesy, Vol. 79, p.467–478, 2005

6 Angermann D., GerstlM., Kelm R. et al., *Time evolution of an SLR reference frame*, Advances in Space Research. Vol. 30, No. 2, p.201–206, 2002