13-Po10

Comparison on orbit precisions of different types of navigation satellites based on SLR tracking data

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Introduction

Multiple global and regional satellite navigation systems, including GPS of USA, GLONASS of Russia, Galileo of EU, BeiDou (BD, Compass) of China, QZSS of Japan and IRNSS of India, are in the process of enhancement or construction. SLR, as a powerful tracking tool of space targets, has been implemented on tens of navigation satellites, of which majority are running in MEO (Medium Earth Orbit), and minority are running in GEO (Geostationary Earth Orbit), IGSO (Inclined GeoSynchronous Orbit) or some other types of orbits. SLR has also been taken as a precise orbit determination (POD) method or an independent way of orbit external validation.

This poster summarizes the status and characters of SLR observation on some major navigation satellites in recent years, describes the framework of SLR-only POD processing, assesses the SLR-derived orbit accuracy by the form of internal fitting, orbit overlap and orbit comparison, and make discussion and recommendation on our results.

SLR observation

- **Data format :** Normal Point / CRD Normal Point
- **Time span :** Jan, 2005 – Jun, 2013
- **Targets :** GPS MEO (-35, -36)
  GLONASS MEO (-102, -109, -110, -118, -129, -130)
  Galileo MEO (-101, -102, -103, -104; GIOVE -A, -B)
  BD MEO (-M1, -M3) / BD GEO (-G1) / BD IGSO (-I1, -I3)

- **Statistical characters :**
  - Number of stations is around 30 for each MEO, 7 for GEO, and 14 for IGSO.
  - Temporal distribution of data points is quite uneven: sparseness or fairly large gaps present sometimes.
  - Spatial distribution of sub-satellite points is asymmetry: North > South, East > West
  - Tracking difficulty : GLONASS MEO ~ Galileo MEO ~ BD MEO > GPS MEO > BD IGSO > BD GEO

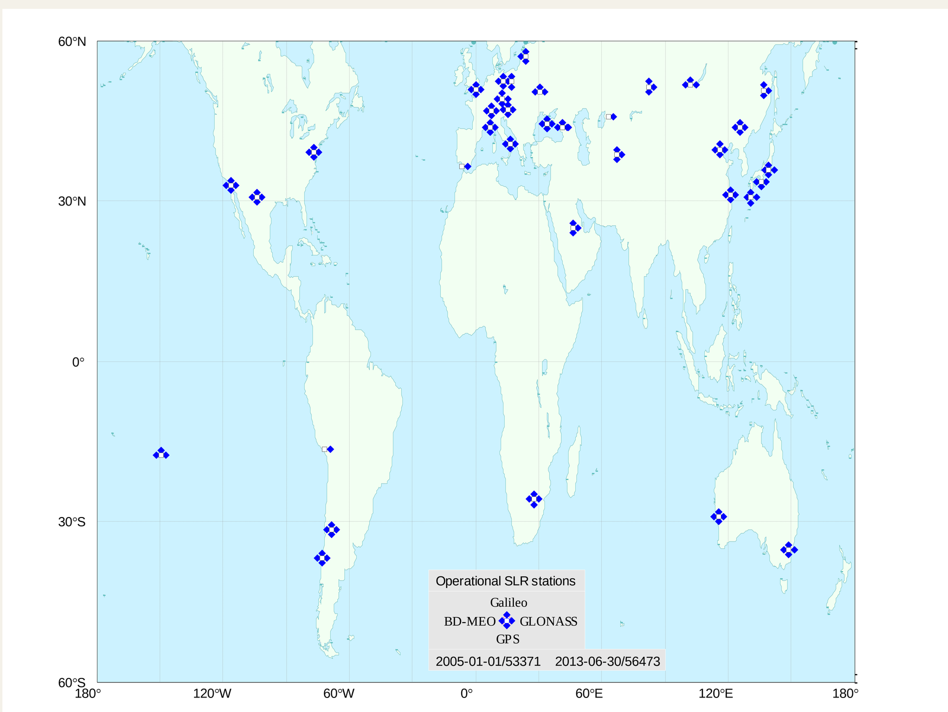

Figure 1. Geographical distribution of SLR stations (for MEO navigation satellites)

Table 1. Temporal density of SLR observation on navigation satellites

Satellite series	GPS	GLONASS	Galileo	BD-MEO	BD-GEO	BD-IGSO
Daily mean (points)	12	20	18	17	7	9

POD Strategy

- **Approach :**
  - fully dynamic, least-squares estimation, batch processor
- **Integration :**
  - 7-day arc length, 14-order fix-step integrator
- **Dynamic models :**
  GGM02C gravity model: truncated to 20 × 20 for MEO, 10 × 10 for GEO / IGSO; ◦ JPL DE405 N-body ephemerides; ◦ solar radiation pressure: simple Box-Wing; ◦ additional Y-bias; ◦ Wahr solid tide; ◦ CSR4.0 ocean tide; ◦ Schwarzschild general relativistic effect; ◦ RTN empirical acceleration.
- **Measurement models :**
  laser center-of-mass correction; ◦ tropospheric delay; ◦ relativistic delay; ◦ station eccentricity correction; ◦ solid tide correction; ◦ ocean tide loading; ◦ tectonic displacement.
- **Reference systems :**
  J2000.0 inertial system; ◦ ITRF2000 coordinate system.
- **Estimated parameters :**
  satellite initial state vector (3D position and velocity); ◦ solar radiation pressure coefficient; ◦ Y-bias coefficient; ◦ harmonic T/N empirical acceleration coefficients.
  - All parameters are estimated globally.

- **Attitude control mode :**
  - yaw-steering mode : Z axis towards nadir, Y axis perpendicular to sun-earth-satellite plane, X axis orthogonal with Y and Z axis.
  - yaw-fixing mode : Z axis towards nadir, Y axis perpendicular to instantaneous orbital plane, X axis orthogonal with Y and Z axis.
  - GPS, GLONASS, Galileo, BD MEO and BD IGSO belongs to yaw -steering mode in general (certain axis could be along negative direction).
  - BD GEO belongs to yaw-fixing mode.

Orbit accuracy

- **Internal accuracy :**
  - Expressed as RMS of residuals, internal accuracies show the fitting level of SLR tracking data to SLR-derived orbit, and are calculated to the arcs containing no real or suspicious maneuver or attitude adjustment moment.
  - Results :
  - For each MEO, internal accuracy is around 2 - 4 cm; for each GEO or IGSO, internal accuracy can be better than 1cm. The utilization ratios of SLR data are over 85% usually.

- **Orbit comparison :**
  - For current navigation satellites, multi-frequency microwave pseudo -range and carrier-phase signals are the major data sources in POD processing. Independent from microwave observation, SLR is a valuable and unique technique for orbit precision analysis.
  - For GPS and GLONASS satellites, GNSS sp3 final precise orbits are taken as reference orbits in comparison; for BD satellites, microwave-derived orbits are taken as reference orbits. The differences in 3D position and in direction R, T and N are important reflection of SLR-derived orbit precisions.
  - Results :
  - Temporal and spatial distribution of SLR data throw great impact on the fitting of two types of orbits.
  - The differences in R, T and N direction are relevant to the satellites' orbital periods : amplitudes of the differences present one oscillatory cycle per day for GEO and IGSO, while present two oscillatory cycles per day for MEO, which are the consequences of errors in satellites' spatial attitude control or relative model fitting.
  - The oscillation frequencies of differences in 3D positions are twice as in R, T or N direction, which are the results of inter-modulations of periodic signals with different phases.
  - For GEO, the agreement between two types of orbits is the lowest: 3D position RMS more than 2m, R component more than 0.5m; for IGSO, the agreement is moderate: 3D position RMS around 1-2m, R component around or less than 0.5m; for MEO, the agreement is highest.
  - For MEO, GPS and BD MEO show low-degree fitting compared with GLONASS on average: for GLONASS, 3D position RMS can be on the level of 20-30cm quite frequently; for GPS or BD MEO, 0.5m 3D position RMS is fairly good. This situation can be attributed to two possible reasons: difference on SLR observation density or Box -Wing model accuracy. The difference in R direction is on the level of several cm.
  - For all of navigation satellites, radial differences are smallest in general. In some cases, the differences in N direction are greater than those in T direction, and systemic biases or drifts present, especially in T direction and at the edges of the arc, which might be caused by the rather poor geometric configuration of spatial distribution of SLR data.

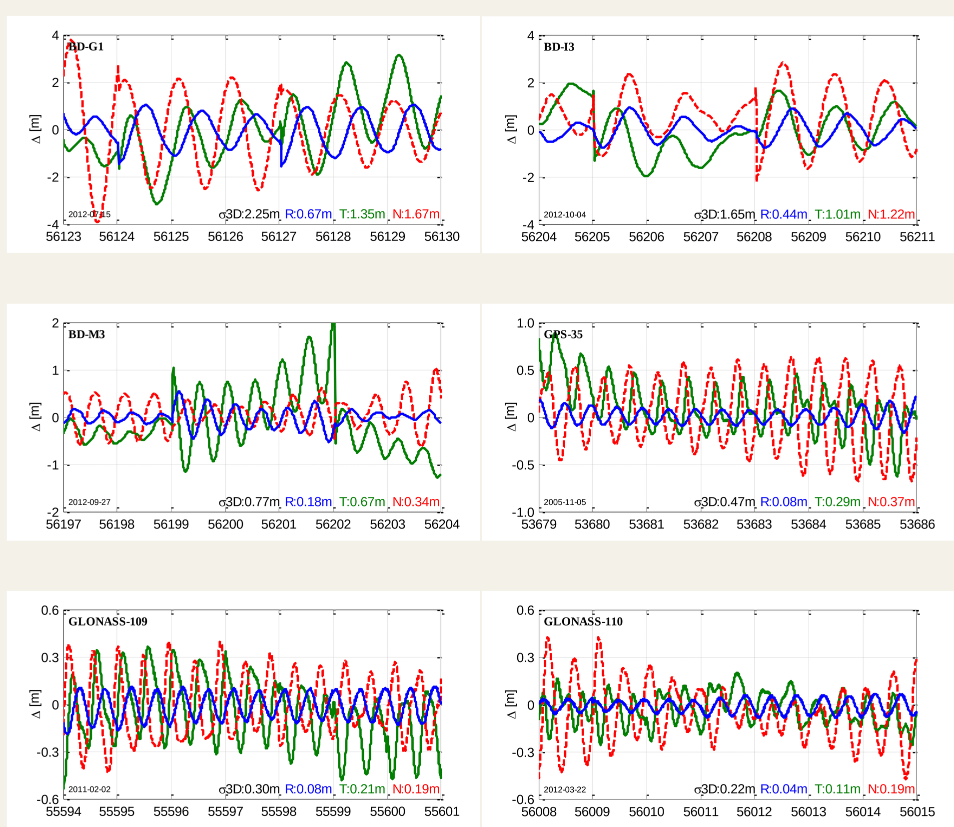

Figure 2. Comparisons between SLR-derived orbits and microwave-derived orbits

- **Orbit overlap :**
  - 2-day overlap window can be obtained from a pair of 7-day orbit arcs with 5-day difference in initial epochs. The SLR observation in such overlap window are same, but the orbits in two arcs are estimated independently and can be considered as uncorrelated. The difference in overlap window is an indication of POD quality.
  - Compared with direct orbit comparison, overlap comparison needs the support of longer stable SLR tracking.
- Results :
  - The differences in overlap window also show periodic characters relevant to the satellites' orbital periods.
  - The rank of overlaps agreement in descending order is: MEO, IGSO, MEO, similar to orbit comparison.
  - The overlaps differences in R, T and N direction also share similar characters to orbit comparison. In N direction, the difference is more significant. In R direction, the difference can be well below 10cm.

Figure 3. Overlaps between SLR-derived orbits and microwave-derived orbits

Summary & Perspectives

SLR-derived orbits of certain navigation satellites, including GPS, GLONASS, Galileo and BeiDou are evaluated and compared quantitatively. Given the amount of SLR tracking data, 7-day arcs are calculated.

The post-fit residuals are a few cm universally. For MEO, the 3-D RMS of orbit overlaps (2-day over 7-day) or comparisons with radio-derived orbits (7-day) are tens of cm, and the radial precisions are around 4-10 cm. The results of GLONASS satellites are slightly better than those of GPS or BeiDou in this analysis, which may be caused by different quantities of tracking data. The orbit precisions of MEO are better than GEO / IGSO generally.

For navigation satellites, SLR is almost the only independent POD method besides microwave solution. Global ILRS network provides the possibility of continuous tracking on multiple types of navigation satellites, but its support to POD needs to be strengthen. More stations with better geometry and intensive monitoring will be beneficial to take the potential advantage of SLR.

Further improvement in SLR POD processing would lie in accuracy of laser center-of-mass offset, refinement of POD modeling (e.g. solar radiation pressure), and proper parameter estimation configuration (piecewise methods, number of empirical parameters, etc). The verification and origin of systemic biases between SLR and microwave orbits need to be further investigated.

References

Appleby G, Otsubo T. Comparisons of SLR Observations and Orbits with GLONASS and GPS Microwave Orbits. 12th ILRS Workshops, Matera, Italy, 2000

Deleflie F, Melachroinos S, Perosanz F, Laurain O, Exertier P. GIOVE-A and GPS-35 satellite orbits: analysis of dynamical properties based on SLR-only tracking data. 15th ILRS Workshops, Canberra, Australia, 2006

Steigenberger P, Hugentobler U, Hauschild A, Montenbruck O. Orbit and clock analysis of Compass GEO and IGSO satellites. J Geod, 87:515-525, 2013

Steigenberger P, Hugentobler U, Montenbruck O, Hauschild A. Precise orbit determination of GIOVE-B based on the CONGO network. J Geod, 85:357-365, 2011

Zhao G, Zhou S S, Zhou X H, Wu B. Precise Orbit Determination of BeiDou Satellites Using Satellite Laser Ranging. 4th China Satellite Navigation Conference, Wuhan, China, 2013

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