Combination of SLR and GPS ground and LEO data for the determination of the Terrestrial Reference Frame

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Abstract

We investigate the impact of adding Satellite Laser Ranging (SLR) data to Global Positioning System (GPS) ground and low-earth orbiter (LEO) observations for the determination of the geocenter coordinates and the terrestrial scale, along with their stability. To obtain an independent measure of inter-technique site ties, we impose no a priori constraint on the ties between collocated SLR and GPS ground stations. Challenges with integration of SLR data stem from the relative scarcity of SLR tracking data and presence of uncalibrated SLR biases. We present results from a simulation as well as preliminary results from the combined processing of ground GPS tracking data, Jason-2 GPS tracking data and SLR observations to Jason-2 and LAGEOS (LAG) 1 and 2 from mid-2010 to end of 2014. We discuss our methodology and the various approaches taken to quantify the effect of SLR data on the quality of our frame solution and highlight some of the challenges encountered in exploiting space-based collocations to improve the terrestrial reference frame. In particular, we show that while the formal errors retrieved from our estimation process suggest that including SLR observations should significantly improve geocenter determination and the stability of the reference frame, practical issues currently prevent us from achieving the levels of stability and accuracy expected based on a covariance analysis.

Highlights

▪Context: We investigate combining SLR and GPS data by performing precise orbit determination (POD) for the GPS constellation, Jason-2 (JA2) and the LAGEOS (LAG) 1 and 2 satellites. We show results from a simulation targeting the effects of SLR systematic and random measurement errors on the determination of the frame parameters as well as from real data inversion.

▪Objective: to quantify the impact of SLR data when combined with GPS observations on the determination of the reference frame; to gain insight into the need for ground, space or combined ground/space ties when determining the geocenter position and TRF scale parameter.

▪Approach: weekly arcs corresponding to SLR weeks from May 2010 through Dec. 2014 are processed. GPS and LEO satellites states and clocks are estimated simultaneously with station positions, tropospheric delays and other parameters. 5 cases are considered: GPS ground data only, GPS ground+LEO data, GPS ground/JA2 data+JA2 SLR data, GPS ground data+LAG SLR data, GPS ground data+JA2 GPS/SLR +LAG SLR . No ground ties are used.

▪Conclusion: ties are needed to connect GPS and SLR datasets; JA2 serves as a space tie but challenges associated with SLR data editing and station-dependent biases estimation lead to degraded performances when combining GPS and SLR observations to JA2 only. Including SLR observations to the LAG satellites significantly improves the multi-technique solution but further investigation is required to assess which of the GPS-only or multi-technique solution is preferred. Simulation results suggest relative data weights are critical for mitigating frame errors.

▪Future prospects:
-comparing using ground ties only, JA2 as a space tie only, a combination of ground and space ties
-implementation of site-dependent bias estimation in filtering process
- investigation of SLR data weight impact on frame determination

Methodology

▪Weekly Lageos orbits obtained from ILRS BKG (Bundesamt fur Kartographie und Geodasie) analysis center.
▪Weekly Jason-2 orbits generated from week-long-arc Jason-2 reduced-dynamics precision orbit determination using GIPSY-OASIS software.

▪Inability to estimate station-dependent biases in the core network solution process ➔ a priori coarse estimation of station-dependent biases based on time series of prefit residuals.

▪Data pre-processing: exclusion of some SLR stations from processing based on prefit residuals scatter; correction of estimated site-dependent at the observation level prior to core estimation process.

▪Network selection: 40 globally distributed GPS sites, number of SLR stations ranging from 1 to 16 depending on arcs for both GPS+JA2 and GPS+Lageos cases depending on arc,

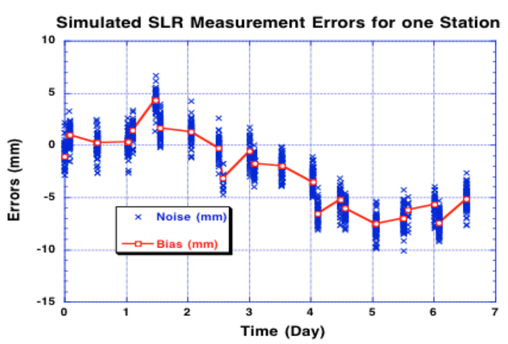
▪SLR data weight: 5 mm; GPS data weight: 2 mm (LC), 20 cm (PC)
▪A priori station position deviation: 1km for GPS sites, 10 m for SLR sites
▪IGS antenna calibrations are used for this investigation.

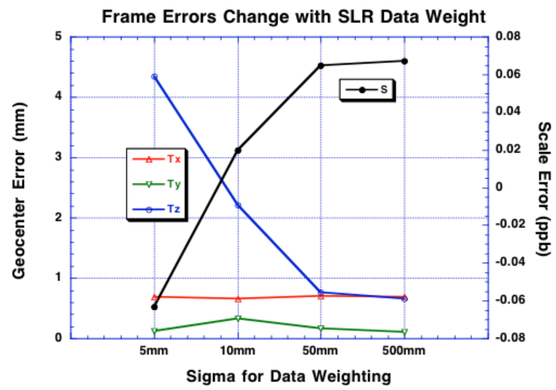
Simulation setup and results

▪**Strategy:**
- 40 GPS stations and 16 SLR stations
- 7-day orbit arc for GPS and LEO satellites
- Error sources added to simulated truth: pass-dependent bias modeled as random walk and white measurement noise added to SLR observations
- Perform fiducial-free network and reduced-dynamic orbit solution
- Reference frame determination error measured as Helmert transformation between the estimated network position and the truth network position
- Final error assessment drawn from average of 4 7-day realizations over a year, separated by 3 months.

▪**Results:** down-weighting the SLR data relative to the GPS observations helps reduce errors in the determination of the geocenter Z-coordinate.

LEO GPS: PC – 20 cm, LC – 3mm
Ground GPS: PC – 50cm, LC – 6.5mm
--o-- SLR pass-dependent bias (2mm/pass random walk);
x SLR white noise for measurement point (1mm).





Performance analysis

▪Impact of adding SLR dataset to GPS dataset measured by:
-impact on frame parameters determined by GPS sites only (fig. 1, table 2): only the GPS sites are used to build a frame and compare with JPL's realization of ITRF08 (JPL08P).
-formal errors analysis (table 1): additional satellites and/or measurements should theoretically improve the frame solution.

- Scatter is greatly increased when SLR observations to JA2 only are added to GPS data, esp. in TX and TZ; suggesting that JA2 is not enough of a tie on its own to properly constrain the solution. Adding SLR observations to JA2 and the 2 LAG satellites strengthen the space tie, reduces the scatter and visibly impacts the frame solution; suggesting the deficiencies observed in the GPS ground+JA2 SLR/ GPS case arise from the relative scarcity of SLR data to JA2.

- Adding JA2 helps all geocenter components, esp. TZ. Adding SLR measurements for JA2 degrades the overall solution, esp. TZ. Adding SLR observations to JA2 and the LAG satellites resolves the issues noted with SLR observations to JA2 only. Adding SLR measurements for Lageos does not affect the GPS sites significantly due to the lack of space and ground tie.

	GPS ground only				GPS ground + JA2			
	TX	TY	TZ	S	TX	TY	TZ	S
mean	-5.82	0.63	-14.07	-1.25	-4.80	1.44	-6.98	-1.45
std	3.73	4.20	6.63	1.84	3.36	4.22	9.43	1.90
rms	6.91	4.24	15.55	2.22	5.85	4.46	11.72	2.39
	GPS ground + JA2 GPS/SLR				GPS ground + LAG SLR			
	TX	TY	TZ	S	TX	TY	TZ	S
mean	-13.68	8.37	-20.55	-0.65	-5.55	3.77	-16.39	-1.98
std	56.34	54.0	72.32	5.65	4.15	4.08	6.65	1.53
rms	57.86	54.53	75.03	5.68	6.93	5.55	17.68	2.49
	GPS ground + JA2 GPS/SLR + LAG SLR							
	TX	TY	TZ	S				
mean	-4.31	3.40	-7.04	-2.30				
std	3.67	4.31	10.74	1.62				
rms	5.66	5.49	12.83	2.81				

Table 2: Statistics on estimated frame parameters resulting from fit of solution to JPL08P frame. Units are mm. Colors added for readability.

	GPS ground only				GPS ground + JA2			
	TX	TY	TZ	S	TX	TY	TZ	S
offset	-5.945	0.562	-13.47	-0.830	-4.982	1.227	-6.303	-1.025
offset sigma	0.081	0.082	0.108	0.138	0.073	0.074	0.080	0.143
rate	-0.992	0.029	-0.358	-0.269	-0.639	0.036	-0.186	-0.163
rate sigma	0.053	0.054	0.072	0.035	0.046	0.047	0.049	0.036
	GPS ground + JA2 GPS/SLR				GPS ground + LAG SLR			
	TX	TY	TZ	S	TX	TY	TZ	S
offset	-11.49	3.668	-25.43	-1.349	-5.859	3.813	-16.43	-1.578
offset sigma	0.077	0.077	0.078	0.138	0.092	0.095	0.122	0.133
rate	-0.826	0.635	0.584	-0.109	-0.341	0.134	-0.080	-0.142
rate sigma	0.050	0.051	0.050	0.036	0.062	0.064	0.082	0.034
	GPS ground + JA2 GPS/SLR + LAG SLR							
	TX	TY	TZ	S				
offset	-4.484	3.493	-6.732	-1.788				
offset sigma	0.077	0.078	0.080	0.137				
rate	-0.332	0.010	-0.316	-0.170				
rate sigma	0.051	0.052	0.051	0.035				

Table 1: Results of fit to JPL08P frame from frame built using GPS sites only. Units are mm and mm/yr for rates.

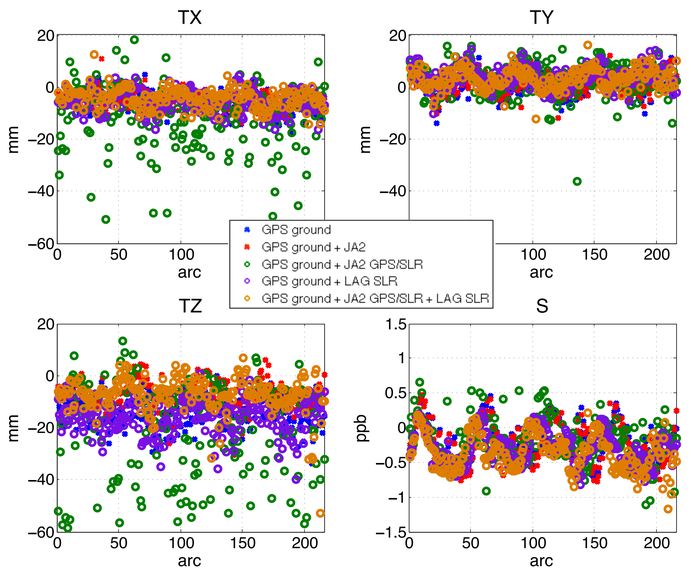


Figure 1: Times series of geocenter coordinates and terrestrial scale relative to JPL08P using GPS network only. Gross outliers manifesting in GPS+SLR combined solutions are not shown.