

A First Look at Lageos 1 & 2 Observations from Stafford, Virginia



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NRL's Optical Test Facility (Stafford)

The Optical Testing Facility (OTF) at Midway Research Center (MRC) in Stafford, VA:

1. High-precision Brashear one meter telescope and gimbal system
2. Three buildings containing operations room, various 1550nm and 1064nm laser systems, high sensitivity detectors, and timing electronics
 - illuminates > 30 orbiting LEO, MEO, GEO s/c via ILRS membership
 - coordinates with Laser Clearinghouse, FAA; Safety integrated air radar



Mission Support:

- NRL has a history of tracking LEO, GPS, and other challenging targets
- ILRS and several DoD customers (NASIC, AFRL, NGA):
 - Routinely conduct SLR campaigns
 - Diagnosing timing systems, update Drag models, GPS performance evaluation
 - Participate in the engineering checkouts
 - Support other facilities upon request
- Recent and Potential Future Tasking:
 - SLR for NRL's Atmospheric Neutral Density Experiment (ANDE)
 - Special Purpose Inexpensive Satellite (SpinSat)
 - Laser tracking for Charged Aerosol Release Experiment (CARE)
 - SLR of past Global Positioning System (GPS) s/c SVN 35 & 36
 - SLR for GPS Block III s/c with laser reflector array

OTF Capability

- 7+ years of Satellite Laser Ranging (SLR) experience on DoD and other targets using this facility
- Can conduct joint operations with NRL Radio facilities at MRC and Blossom Point
- Optical trains at both 1064nm and 1550nm for transmission of both laser ranging and free space optical communication signals

Telescope Specifications:

- 1 meter primary mirror
- F/89, 12.640m focal length system
- Az/EI gimbal configuration
- Coude path allows for input from multiple optical trains
- Monostatic - shared transmit and receive aperture
- Pointing accuracy of at least 2 arcsec RMS all sky
- Maximum slew rate of 25deg/s Azimuth and 15deg/s Elevation

Laser Systems:

- Beam divergence for all systems is typically between 80 to 200 μ rad full angle ($1/e^2$), dependent on weather

1064nm Ranging:

- Max average power = 2.5 W (Max energy = 0.250J/pulse)
- Pulsewidth = 200ps FWHM
- PRF: 10 Hz

1064nm kHz Ranging:

- Max average power = 2.5 W (Max energy = 0.250J/pulse)
- Pulsewidth = 100ps FWHM
- PRF: 1000 Hz

Receiver System:

1064nm Detection

- Si Avalanche Photodiode
- Various manufacturers
- 1 μ rad field of view
- Tennelec CFD Model 454
- Stanford 620 counter
- HP 5370 used as calibration standard



Full-rate Residuals for Lageos 1 & 2

SLR observations for Lageos 1 and 2 are collected at the OTF (Stafford) during engineering evaluation and checkout campaigns for various DoD missions. These data are stored on computer systems at MRC in a raw internal form. When needed, the data are extracted from their raw form, pre-processed and written to ILRS formatted files. As a first look at the performance of the geodetic SLR observations at Stafford, these formatted full-rate data were processed using the GEODYN software provided by NASA Goddard Space Flight Center (GSFC). Range residual statistics are provided Table 1. Adjusted orbits were compared to reference ephemerides from the ASI Analysis Center (AC).

Data Analysis

- IERS 2010 Conventions generally implemented/adopted; main departure from Conventions is:
 - geopotential field (F. Lemoine): static field from GRACE+GOCE (GOCO02s), for terms up to L=4, harmonic fits to an SLR/DORIS time varying gravity (TVG) time series (1993-2012), and for L=5-20, annual harmonics from a GRACE solution
- ILRS Conventions generally adopted
 - latest SLRF2008 coordinates; fixed to a priori values
 - Stafford positions observed in 2003 w.r.t. ITRF2000; transformed to ITRF2008 for this work
 - velocities adopted from NOAA's CORS "IGS08" velocity field (geodesy.noaa.gov/CORS/)
 - IERS C04 EOPs used; fixed to a priori values
 - Weekly (7-day) arcs
 - Data Handling file implemented
 - satellite center of mass corrections used
 - Stafford station not included in these lists; a value of 0.249 m was used
 - Tropo correction model: Mendez and Pavlis (2004)
 - Elevation angle cutoff: 12 degs
 - With exception for Stafford, pass-by-pass biases estimated when needed
 - Weekly orbit states adjusted
 - Stafford data heavily down-weighted
 - Along-track & cross-track harmonic accelerations at midpoint of each weekly arc
 - MSIS static atmosphere density model

Results and Future Work

Table 1 summarizes the range residuals for the stations used in the processing runs. Note that the 3D mean differences between our weekly orbital arcs and those from the ASI AC range from ~0.13 cm to ~1.9 cm with an average 3D RMS of ~11 cm. The orbit differences for the more recent arcs are less scattered (RMS = ~2 cm). Pass-by-pass biases are generally smaller than ~2 cm. While these initial results seem to indicate an overall improvement in the quality of the Stafford observations since 2007, we have been unable to find an explanation for the improvement. In the meantime, remaining raw Lageos data at Stafford will be prepared/analyzed. This should help clarify historical performance of the OTF, find sources of any biases and guide future station improvements.

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Sta Name	Sta #	Start of Weekly Arc			Lageos 1 Full-rate Range Residuals			Lageos 2 Full-rate Range Residuals		
		yyyy	mm	dd	WMean [m]	RMS [m]	# Obs.	WMean [m]	RMS [m]	# Obs.
Stafford	7865	2007	10	28	-9.454	10.426	39	-9.112	10.262	160
		2007	11	4	-0.145	3.560	9005	0.045	1.797	1998
		2007	11	11	0.001	1.500	5251	0.152	0.353	164
		2010	3	7	--	--	--	-0.036	0.171	955
		2013	12	8	0.050	0.073	705	0.029	0.070	1704
McDonald	7080	2007	10	28	0.003	0.026	785	0.000	0.023	5470
		2013	12	8	0.000	0.015	659	0.000	0.013	4668
Yarragadee	7090	2007	10	28	0.000	0.012	36187	0.000	0.023	22581
		2007	11	4	0.000	0.022	28290	0.000	0.019	17862
		2007	11	11	0.000	0.030	12717	0.000	0.032	13659
		2010	3	7	0.005	0.015	10178	0.000	0.010	10030
		2013	12	8	0.000	0.012	12977	0.000	0.011	10178
Greenbelt	7105	2007	10	28	0.000	0.014	5791	0.000	0.014	18844
		2007	11	4	0.000	0.024	3659	0.000	0.014	10522
		2010	3	7	0.000	0.011	6095	0.000	0.010	10974
		2013	12	8	0.000	0.011	24478	0.000	0.011	20995
Monument Peak	7110	2007	11	11	0.000	0.028	7938	0.002	0.047	916
		2010	3	7	0.000	0.017	9780	0.000	0.015	1990
		2013	12	8	0.000	0.017	11781	0.000	0.017	5233
Haleakala	7119	2013	12	8	-0.001	0.017	472	-0.001	0.013	305
Tahiti	7124	2010	3	7	0.002	0.014	91	0.000	0.013	2187
		2013	12	8	--	--	--	-0.001	0.008	29
Changchun	7237	2007	10	28	0.000	0.024	18599	0.000	0.027	20762
		2007	11	4	0.000	0.026	6604	0.000	0.023	5240
		2007	11	11	0.000	0.036	11757	0.000	0.024	16520
		2010	3	7	0.000	0.014	128062	0.000	0.015	24614
Koganei	7308	2013	12	8	0.001	0.022	597	0.000	0.022	732
Arequipa	7403	2007	10	28	--	--	--	0.004	0.016	34
		2007	11	4	-0.009	0.040	210	0.000	0.022	244
		2007	11	11	0.014	0.060	259	0.006	0.033	231
		2010	3	7	0.006	0.013	119	0.001	0.009	108
		2013	12	8	--	--	--	0.000	0.007	25
Concepcion	7405	2007	10	28	0.000	0.046	10577	0.000	0.063	7210
		2007	11	4	0.000	0.033	98302	0.000	0.028	71354
		2007	11	11	0.000	0.051	100907	0.000	0.029	82683
Hartebeesthoek	7501	2007	10	28	0.002	0.017	496	--	--	--
		2007	11	4	-0.011	0.029	115	-0.002	0.022	358
		2007	11	11	-0.003	0.057	845	-0.003	0.024	865
		2013	12	8	0.000	0.013	5119	0.000	0.013	6111
Zimmerwald	7810	2007	10	28	-0.001	0.124	42891	0.000	0.116	31267
		2007	11	4	0.000	0.044	6694	0.001	0.041	3998
		2007	11	11	0.001	0.095	9407	0.003	0.048	5392
San Fernando	7824	2007	10	28	0.000	0.023	14041	-0.001	0.020	11276
		2007	11	4	0.000	0.024	13896	0.000	0.015	16476
		2007	11	11	0.000	0.022	5123	-0.001	0.033	6281
		2010	3	7	0.000	0.015	1346	0.001	0.013	234
Simosato	7838	2010	3	7	0.000	0.015	451	0.000	0.014	18
		2013	12	8	0.001	0.018	3739	0.000	0.015	5080
Potsdam	7841	2007	11	11	0.007	0.040	383	-0.010	0.049	286
Matera	7941	2010	3	7	0.000	0.006	54677	0.000	0.006	42028

Table 1 Weekly range residuals for Lageos 1 and 2 ILRS full-rate data. Residuals for Stafford larger than 20 m were considered blunders, and omitted from these statistics.