NGSLR's measurement of the retro-reflector array response of various LEO to GNSS satellites

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NASA's Next Generation Satellite Laser Ranging System (NGSLR) has successfully demonstrated daylight and night-time tracking this year to satellites from LEO to GNSS orbits, using a 7-8 arcsecond beam divergence, a 43% QE Hamamatsu MCP-PMT with single photon detection, a narrow field of view (11 arcseconds), and a 1 mJ per pulse 2kHz repetition rate laser. We have compared the actual return rates we are getting against the theoretical link calculations, using the known system configuration parameters, an educated guess at the sky clarity, and signal processing to extract the measured signal from the background noise.

From Degnan [1] the link calculation representing the expected signal return per fire from the satellite is:

$$n_{pe} = \eta_q \left(E_T \frac{\lambda}{hc}\right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2}\right)^2 A \eta_r T_a^2 \quad \text{where:}$$

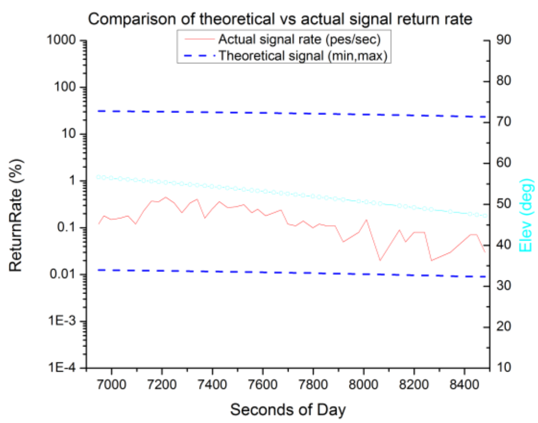
n_{pe} = expected photoelectrons received per fire
η_q = detector quantum efficiency (QE=0.43, but used counting efficiency instead = 0.28)
E_T = per pulse transmit energy (800 microJoules)
λ = wavelength (532nm)
η_t = transmit path transmission (0.514)
σ = array cross section [2]
R = range to satellite
A = area of telescope (40 cm diameter telescope with no obscuration)
η_r = receive path transmission (0.572 night; 0.388 day using 0.2 A daylight filter)
T_a = atmospheric transmission (1-way), with $T_a^2 = T_z^{2\sec(Z)}$ and where T_Z is the zenith transmission and Z is the zenith angle. The sky transmission at zenith was assumed to be 0.5 which corresponds to "clear".
G_t = transmitter gain is a function of the beam divergence half angle (θ_t = 3.5 arcsec) and the mount pointing error (θ):

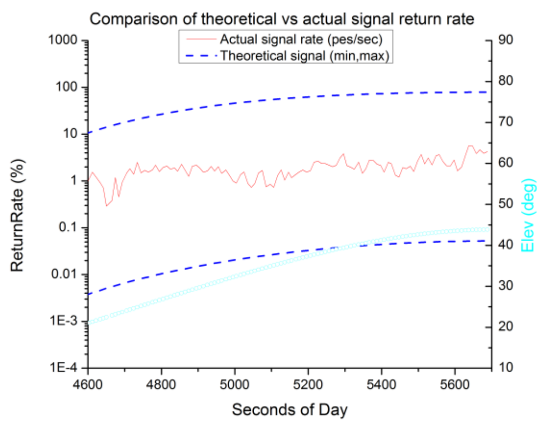
$$G_t = \frac{8}{\theta_t^2} exp\left[-2\left(\frac{\theta}{\theta_t}\right)^2\right]$$

The laser energy was measured with a Scientech Power Energy Meter model 364. The laser divergence was measured with Photon Inc Beam Profiler, placing the imaging head in the image plane of a 750 mm FL lens and recording the far field spot size. The system transmissions were calculated from the known reflective characteristics of the optics and the number of optics in the path. The detector counting efficiency was calculated from the manufacturer measured quantum efficiency times the active area of the detector. The retro-reflector array values were taken from the ILRS website [2].

The measured data was the NGSLR full rate data. A polynomial was fit to the difference between the measured minus the predicted ranges (after the predicted ranges had been corrected for refraction and system delay). A 3.5 to 4.0 sigma filter was used to reject the noise. The return rate per fire was calculated as an average from data that was binned in 2.5 second intervals for low Earth orbiting satellites (AJISAI, BEC, STARLETTE), 10 seconds for LAGEOS, and 30 seconds for GNSS (Galileo and GLONASS). The theoretical value corresponding to the measured return rate was calculated for comparison: Probability of detection = 1 – exp(-n_{pe}).

The results from this comparison show a fairly good agreement between the theory and the measured values assuming pointing errors from zero to 7 arcseconds. The LAGEOS actual return rates at NGSLR are typically 1%, while the theory predicts between 0.01% to 100% depending upon elevation angle and pointing error. The GNSS actual return rates are typically around 0.1% with the theory predicting anywhere from below 0.01% to about 20-30% depending upon elevation angle and pointing error. Two example plots are shown below. The navy blue dashed line represents the theoretical calculations with the higher value corresponding to zero pointing error and the lower corresponding to 7 arcsecond pointing error. The red line is the measured return rate. The light blue line corresponds to the right vertical axis and is the satellite elevation in degrees. The left plot is GLONASS-123 (152/01:55Z), and the right plot is LAGEOS-1 (102/01:16Z).





The full suite of plots, along with the table of satellite lidar cross sections used, can be found in the presentation on the Workshop website and at [3]. For more details on NGSLR tracking of GNSS satellites, see reference [4].

References:

[1] J.J. Degnan, "Millimeter Accuracy Satellite Laser Ranging: A Review", in Contributions of Space Geodesy to Geodynamics: Technology, D. E. Smith and D. L. Turcotte (Eds.), AGU Geodynamics Series, Volume 25, pp. 133-162, 1993.

[2] D. Arnold, http://ilrs.gsfc.nasa.gov/docs/2003/CrossSectionReport.pdf

[3] http://space-geodesy.nasa.gov/docs/2012/NGSLR_array_response_v4.pdf

[4] J. McGarry, et al, "NASA's Next Generation Satellite Laser Ranging (NGSLR) System Experience Ranging to GNSS Satellites", in this Proceedsings.