Background Noise Suppression for Increased Data Acceptance

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Abstract. *During the collocation of the Next Generation Satellite Laser Ranging (NGSLR) System with the current NASA Standard System, MOBLAS-7, it was found that a centroid estimation of the return distribution using a 3 sigma RMS filter provided for a more accurate estimate of the target range than using peak estimates of the return distribution (~1.8 sigma RMS filter). One observed consequence of utilizing the 3 sigma RMS filter was the loss of valid passes with weaker signal due to the inclusion of background noise within and outside the signal distribution. A background noise suppression technique was developed and used prior to the centroid estimation such that these weaker signal passes were again viable and produced valid normal points. This paper will discuss the algorithm that was developed and present the effect of the algorithm on the quantity of valid normal points and the range determination of the normal points.*

Introduction

During the collocation of NASA's Next Generation Satellite Laser Ranging (NGSLR) system with the current NASA standard, MOBLAS-7, it was found that centroid estimation of the return distribution provides a more accurate estimate of the target range than a peak estimate *[Clarke et al., 2013]*. The peak estimate was determined by using an iterative 1.8 sigma multiplier filter while the centroid estimate was determined using an iterative 3.0 sigma multiplier filter. Figure 1 displays a histogram of the range residuals with the accepted observations used for range determination delineated in blue.

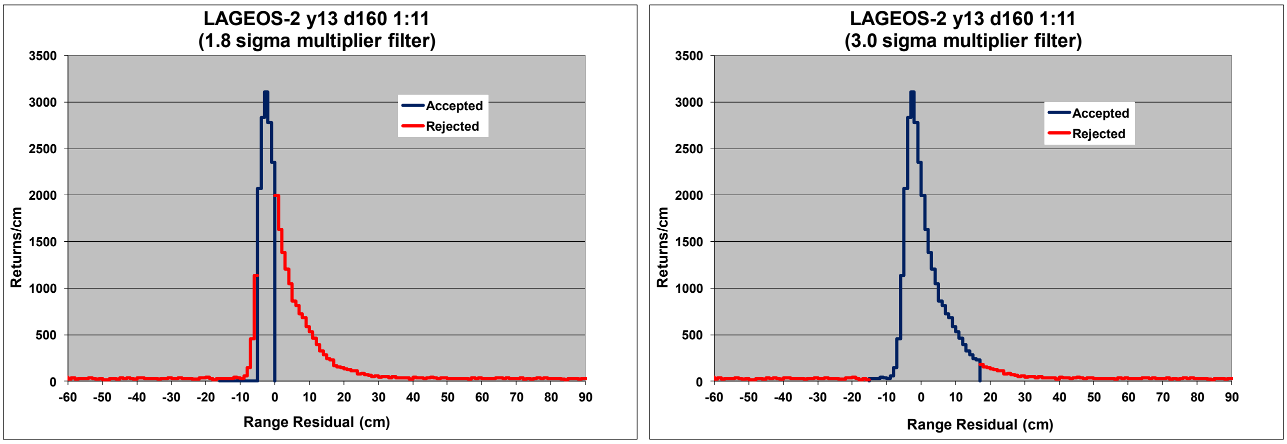

Figure 1. LAGEOS-2 Range Residual Histogram using 1.8 and 3.0 Sigma Multiplier Filters

This technique worked well when the signal was strong relative to the background noise. However, when the signal was weaker, the 3.0 sigma filter did not differentiate the signal from background noise. Figure 2 displays an example of this problem. In figure 2, the 1.8 sigma filter selects the peak of the distribution, but the 3.0 sigma filter includes all the noise displayed on the plot.

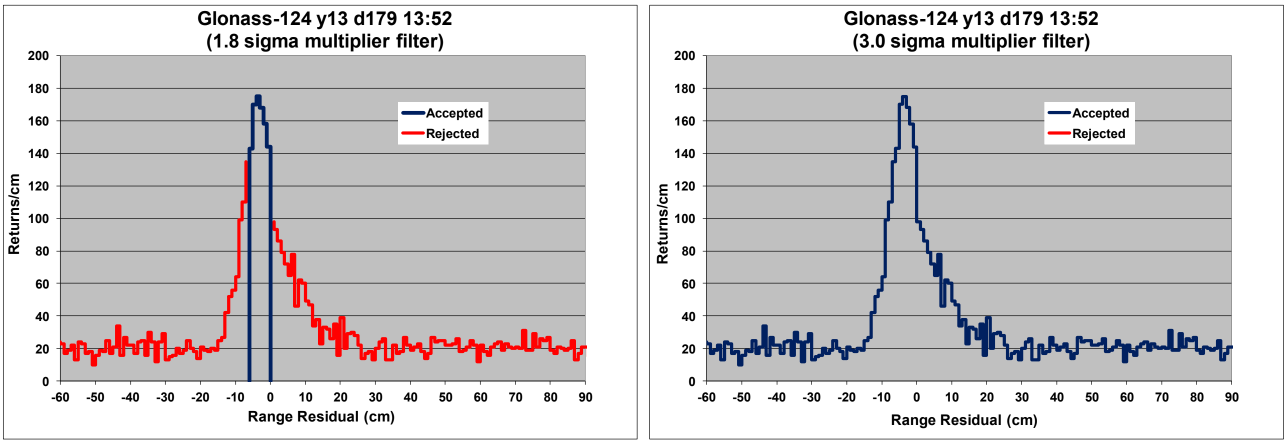

Figure 2. Glonass-124 Range Residual Histogram using 1.8 and 3.0 Sigma Multiplier Filters

In addition, the centroid estimate of the skewed return from the target is biased because the uniform distribution of the background noise is included in the centroid. Figure 3 displays this effect; the green box includes background noise. The noise is both before the signal distribution and within the signal distribution. Because of the inclusion of large amounts of noise in some centroid calculations, some passes from the collocation data set were eliminated when they had a larger than expected RMS. Figure 4 displays the number of accepted passes and normal points for LAGEOS and GNSS satellites using a 1.8 and 3.0 sigma multiplier filter. The change from the 1.8 to the 3.0 sigma filter reduced the number of accepted LAGEOS passes by 31 percent and reduced the accepted LAGEOS normal points by 18 percent. Similarly, the change reduced the accepted GNSS passes by 47 percent and reduced accepted GNSS normal points by 24 percent.

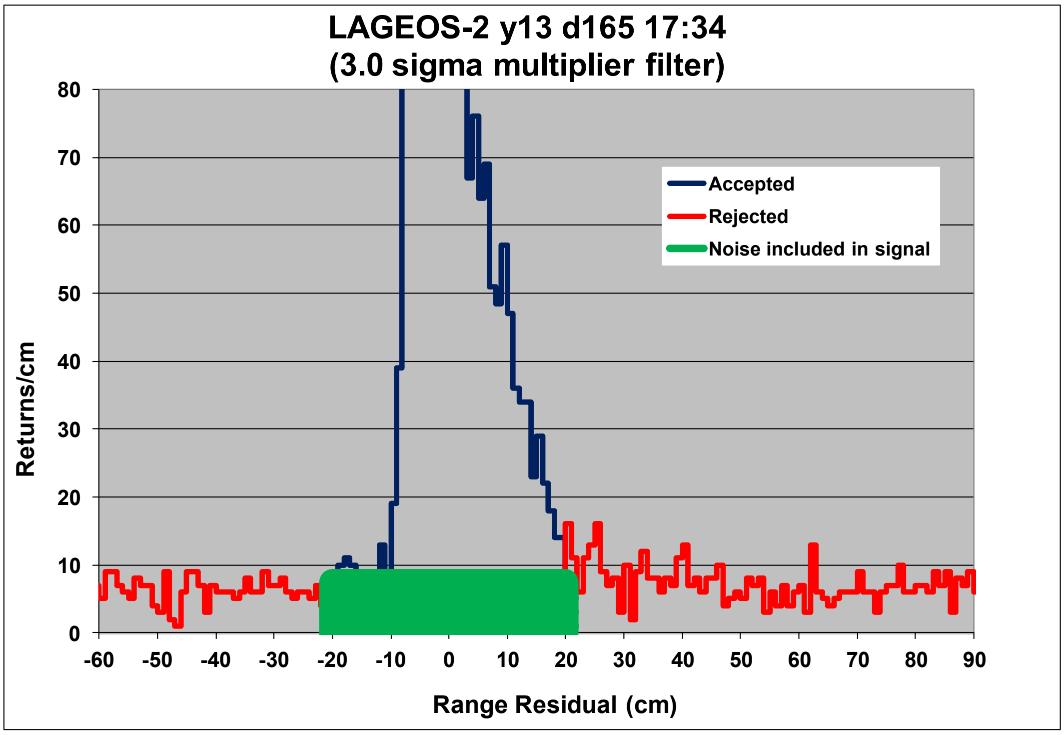

Figure 3. LAGEOS-2 Range Residual Histogram

	1.8 Sigma Filter	3.0 Sigma Filter	% Decrease
LAGEOS Passes	**51**	**35**	**31.4**
LAGEOS Normal Points	**554**	**455**	**17.9**
GNSS Passes	**30**	**16**	**46.7**
GNSS Normal Points	**94**	**62**	**34.0**

Figure 4. Effects of Applying a 3.0 versus a 1.8 Sigma Filter to the Collocation Data Set

Noise Suppression Technique

A noise suppression technique was developed to recover weaker passes that had been eliminated from the data set. In general terms, the technique consisted of determining the mean background noise rate by sampling the noise outside the signal window, then randomly editing the observations at that rate plus one sigma. The noise rate plus one sigma was chosen because it appeared to do the best job of eliminating noise, while not significantly reducing signal. The description of the algorithm is listed below. Figure 5 describes the noise suppression parameters and Figure 6 displays the parameters on a range residual plot.

Δt	Length to time bin step
Δs	Size of range residual bin step
Δr	Range window used to sample background noise
Rw_{min}	Minimum of range residual window *(range residual less than value are rejected)*
Rw_{max}	Maximum of range residual *(range residuals greater than value are rejected)*
E_{bn}	Expected number of background noise returns *(given noise rate + 1σ)*

Figure 5. Noise Suppression Parameters

The algorithm processes data in time bins of Δt size, starting at the beginning of the pass. For each time bin the following steps are performed:

1) Reject all data outside of a range residual window from Rw_{min} to Rw_{max} (The residual window is centered on the signal and is small subset of the entire range gate. The size is set so that it is large enough is to give a good estimate of background noise near the signal, but does not include any anomalies that may exist elsewhere in the range gate)

2) Estimate background noise rate using counts in a smaller range window outside the signal (counts in the Δr by Δt box)

3) Perform noise suppression in residual steps of Δs, starting at Rw_{min} and ending at Rw_{max}. For each step, the noise suppression is performed using the following algorithm:

    a. If the number returns in the step (counts in the Δs by Δt box) is less than the expected noise returns, E_{bn}, then all the returns are rejected.

    b. If the number returns are greater than E_{bn}, then E_{bn} of the total returns in the step are rejected. The reject returns are chosen using a random number generator.

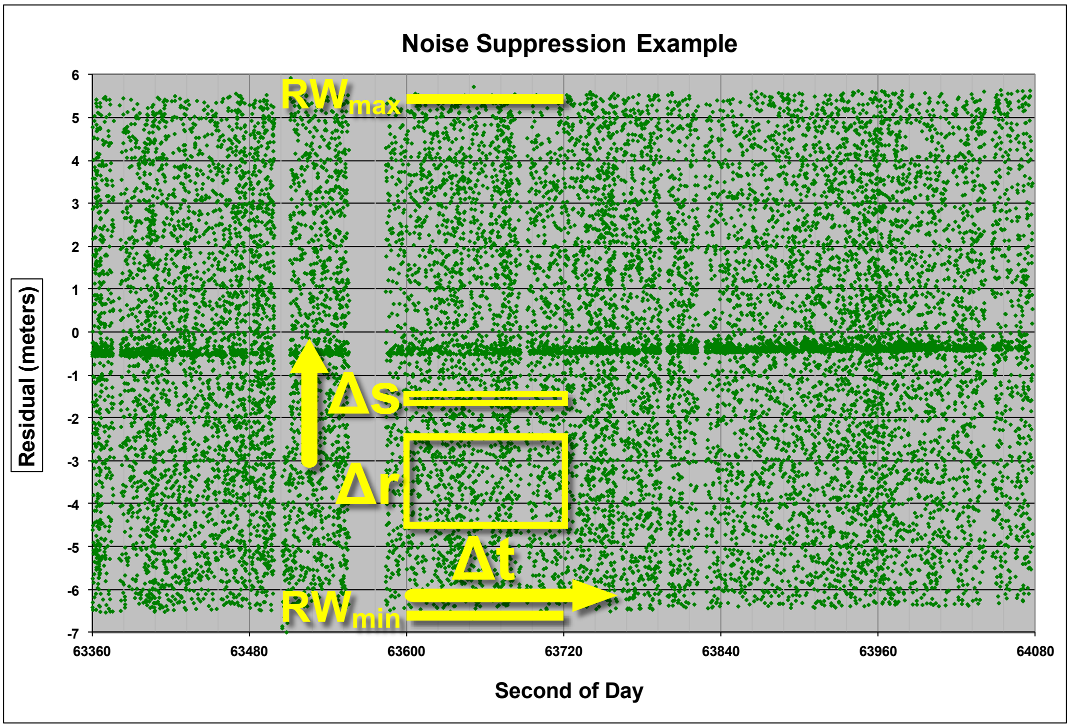

Figure 6. Noise Suppression Parameters and Examples on a Range Residual Plot

Results of Noise Suppression

Figure 7 display the results of noise suppression on two weaker signal passes. The top three plots [1-3] in each set display the raw residuals. This data displays the residual from the predicted orbit after being corrected for refraction. No additional smoothing or sigma multiplier filtering has been applied to the residuals. Plot 1 displays the residuals before noise suppression has been applied. Plot 2 displays the residuals after noise suppression has been applied. In plot 2, it can be observed that the noise suppression eliminates virtually all of the background and very little of the signal. Plot 3 displays the residuals edited during noise suppression. In plot 3 there is little or no sign of a signal signature in the edited residuals. The bottom two plots [4-5] display data after further processing. This data has been smoothed and an iterative three sigma filter has been applied. The observations rejected by the three sigma filter are indicated in red. The accepted observations, which are colored green, are used to form the normal points. In plot 4, the accepted data without noise suppression includes large amounts of noise outside the signal counts. In plot 5, almost entirely signal counts are accepted when processed following noise suppression.

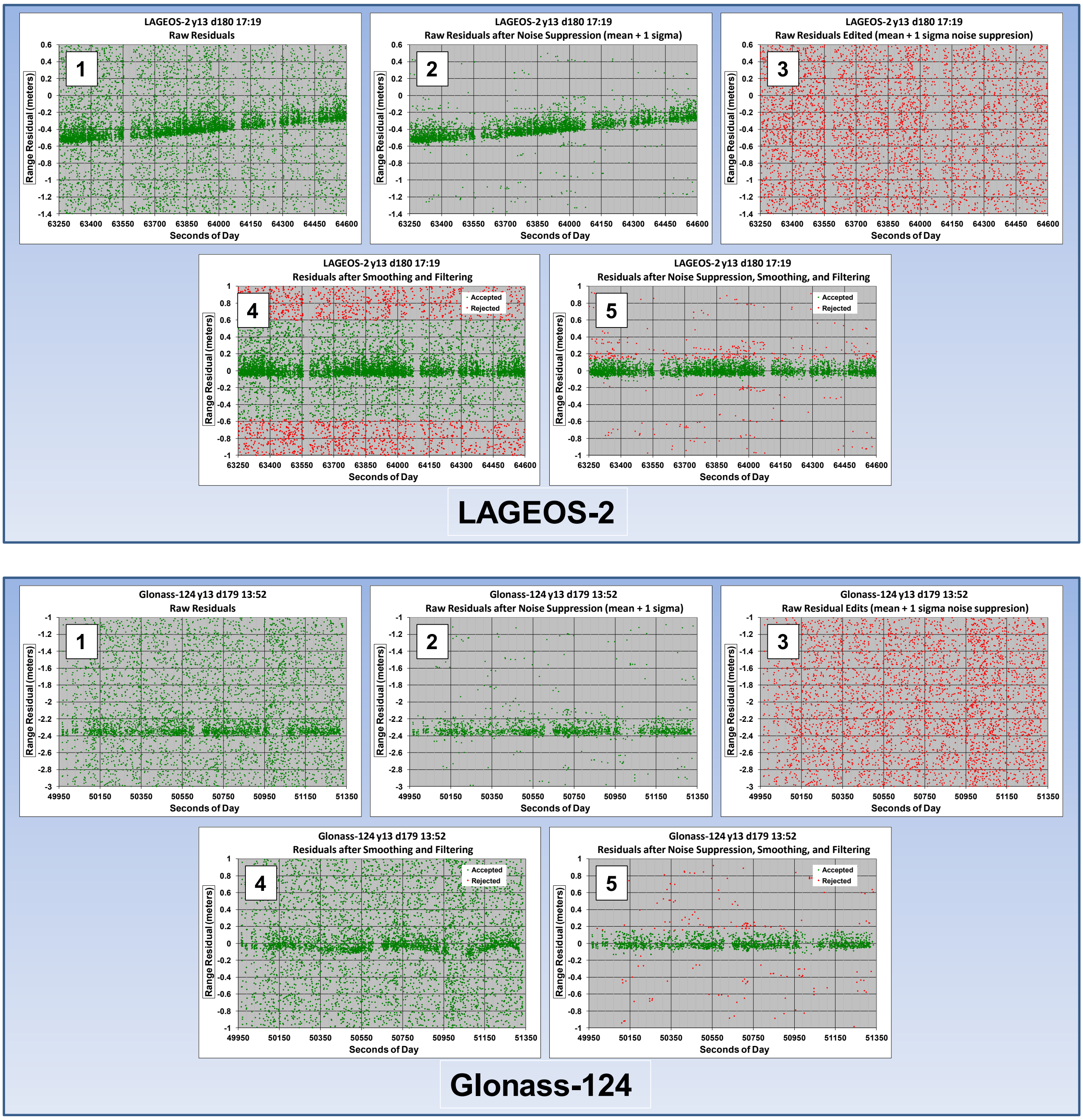

Figure 7. Effects of Noise Suppression on a LAGEOS-2 and Glonass-124 pass

(1) Range residuals **without** noise suppression
(2) Range residuals **with** noise suppression
(3) Range residuals edited during noise suppression
(4) Processed range residuals using data **without** noise suppression
(5) Processed range residual using data **with** noise suppression

Processing the collocation data set while applying noise suppression increased the number of LAGEOS and GNSS normal points significantly as demonstrated in Figure 8. There was a 30 percent increase in accepted LAGEOS normal points and about a 50 percent increase in accepted LAGEOS passes. There was a larger increase for the GNSS satellites where both accepted normal points and passes increased about 200 percent. Figure 9 displays the collocation summary with and without noise suppression. The mean range difference between NGSLR and MOBLAS-7 decreased by about two and half millimeters when noise suppression was applied to the data set. The mean range difference is in good agreement with theoretical predictions based on the single photon and multiphoton receiver systems of NGSLR and MOBLAS and pulse spreading caused by the LAGEOS retroreflector array. *[Degnan, 1994; Fan et al., 2001]*. Although there were 139 additional normal points in the data set, only 6 were qualified for collocation because most of these normal points were observed in daytime or poor seeing conditions when MOBLAS-7 data volume was inadequate to meet the collocation requirement.

	No Noise Suppression	With Noise Suppression	% Increase
LAGEOS Passes	**35**	**52**	**48.6**
LAGEOS Normal Points	**455**	**594**	**30.5**
GNSS Passes	**16**	**50**	**212.5**
GNSS Normal Points	**62**	**184**	**196.8**

Figure 8. Effects of Applying Noise Suppression to the Collocation Data Set on Data Volume

Lageos	Mean Range Difference [NGSLR - Moblas-7] (mm)	Number of Normal Points	Standard Deviation (mm)	Standard Deviation of Mean (mm)
Without noise suppression	**12.81**	**270**	**4.98**	**0.30**
With noise suppression	**10.26**	**276**	**4.86**	**0.29**
Theoretical Prediction *[Degnan, 1994; Fan et al., 2001]*	**10 to 13**	**n/a**	**n/a**	**n/a**

Figure 9. Effects of Applying Noise Suppression to the Collocation Data Set on LAGEOS Range Difference

References

Degnan, J. 1994. "Effects of detection threshold and signal strength on LAGEOS range bias" 9th International Workshop on Laser Ranging, Canberra, Australia, November 7-11.

Fan J., et al. 2001. "Theoretical analysis and numerical solution of laser pulse transformation for satellite laser ranging" Science in China (A), Vol. 44, No.7, July.

Clarke, et al. 2013. "Effects of detection threshold and signal strength on LAGEOS range bias" 18th International Workshop on Laser Ranging, Fujiyoshida, Japan, November 11-15.