ILRS QCB Meeting
July 16, 2020
13:00 UT

Agenda

• Comparison of NP generated by field stations with those generated by an open source NP program	Randy (15 min) John R. (20 min)
• Processing data with the Wiener filter	Stefan (20 min)
• NP studies (20)	Matt (15 min)
• Further discussion on examination of data	Van (30 min)

Herstmonceux Open-source Normal Point Program Testing

R. Ricklefs
UT/CSR

Purpose

- The Herstmonceux normal point software was created as reference code for those testing or updating existing normal point software.
- By use of large data set, it is hoped to show that the Herstmonceux normal point software produces demonstrably acceptable results.
- Use the test(s) to quantify the performance of the Hx software vs stations' software
- Use the tests to highlight errors or issues with the Hx software
- Ultimately hope to use the software to critique stations' software and procedures

Software

- orbitNP.py
- available on the ILRS web site software page
- written by Matt Wilkinson in Python
- several changes were made in the course of these test due to problems found
- Running under Linux, although Python code should run anywhere

Data

- January 2020 full rate and normal point data from the ILRS website
- multiple stations
- LAGEOS I
  - about 750 passes with a total of about 3846 normal points
- LARES data
  - About 515 passes with a total of about 5279 normal points
  - Results still very preliminary

LAGEOS Results - I

- almost 2/3 of the normal points ranges agreed to 0.5 mm
- about 3/4 agreed to better than 1 mm

- Normal point range comparisons:
  - number closer than 0.5 mm: 2268
  - number closer than 1.0 mm: 565
  - number closer than 2.0 mm: 311
  - number closer than 5.0 mm: 138
  - number closer than 10.0 mm: 60
  - number closer than 15.0 mm: 15
  - number > or = 15.0 mm: 489

LAGEOS Results – II

For normal points with >= 15 mm difference:

- Difference in number of returns (std-test):
- return difference = 0: 292 => picked different points and have different epoch
- return difference = 1: 67
- return difference = 2: 36
- return difference = 3: 17
- return difference = 4: 8
- return difference = 5: 11
- return difference > 5: 31

Number of returns (std):

- returns <= 2: 23 => one or two-point normal points
- returns <= 5: 3
- returns <= 10: 1
- returns <= 25: 7
- returns <= 50: 11
- returns <= 100: 29
- returns <= 500: 104
- returns > 500: 284 => khz stations

Total “really bad” normal points: 462

LAGEOS Results - III

- averages, skew, and kurtosis are not quite the same as for the "standard" normal points
- Some ideas for large differences
  - Differences in hardware, OS, compilers can affect round off, filtering, etc.
    - Different points selected can change epoch appreciably
  - Extra normal points from Hx software
    - Differences in filtering?
    - Data fitting filter data differently at beginning and end of pass segments
    - Stations sometimes manually filter data

LARES Results - I

- About 1/2 of the normal point ranges agreed to 0.5 mm
- Almost 2/3 agreed to better than 1 mm
- Normal point comparisons:
  - number closer than 0.5 mm: 2116
  - number closer than 1.0 mm: 645
  - number closer than 2.0 mm: 653
  - number closer than 5.0 mm: 263
  - number closer than 10.0 mm: 42
  - number closer than 15.0 mm: 15
  - number > or = 15.0 mm: 566
- Total normal points: 4300 for same npt bin – and 131 unmatched (new in Hx files, only)

LARES Results – II

For normal points with >= 15 mm difference:

- Difference in number of returns (std-test):
- return difference = 0: 429 => picked different points and have different epoch
- return difference = 1: 47
- return difference = 2: 12
- return difference = 3: 5
- return difference = 4: 3
- return difference = 5: 3
- return difference > 5: 35

Number of returns (std):

- returns <= 2: 43 => one or two-point normal points
- returns <= 5: 2
- returns <= 10: 6
- returns <= 25: 17
- returns <= 50: 17
- returns <= 100: 49
- returns <= 500: 128
- returns > 500: 272=> khz stations

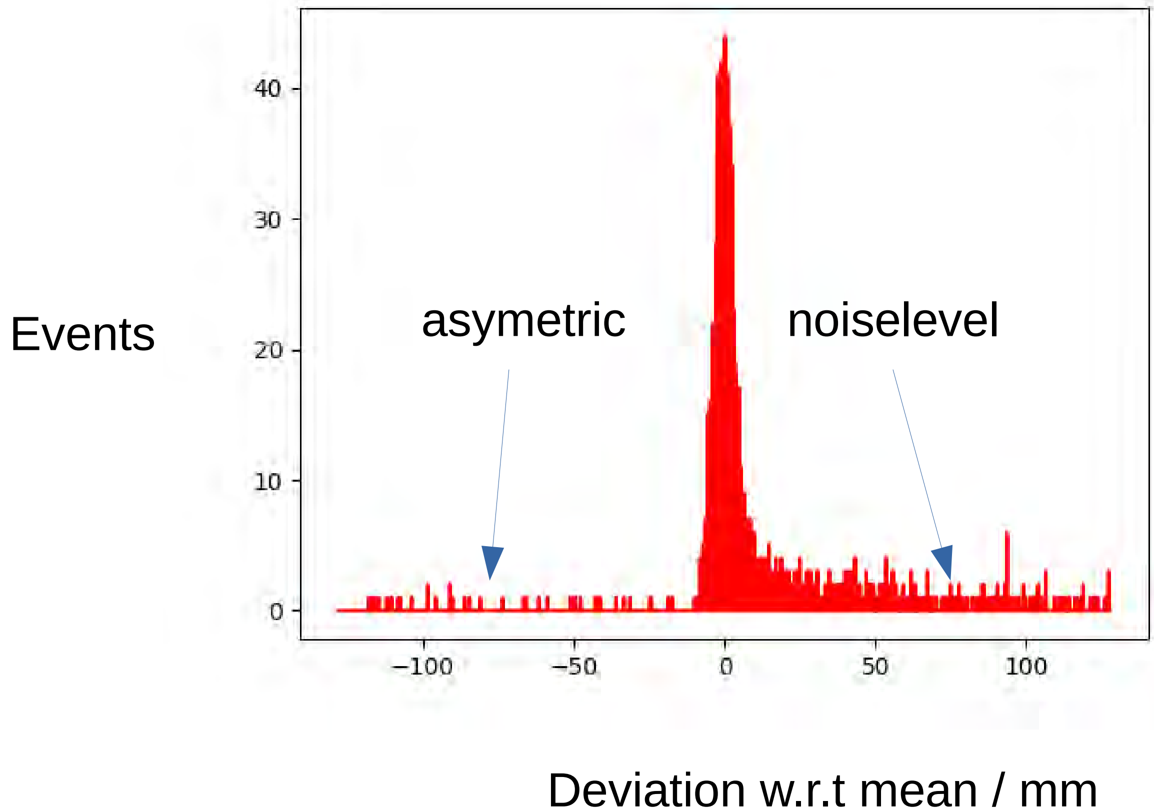
Total “really bad” normal points: 534

Where to go from here

- Orbital tests
  - Matt Wilkinson did some tests and didn't find any systematic problems.
  - John Ries has done tests on this LAGEOS data set. Results will be presented here.
- Converted DISTRIB.F into python for tests of skew, kurtosis, and peak-mean computations. Still testing the conversion.
- Look at epoch differences (will five range differences)
- Await John Ries' test of LARES data
- Suggestions?

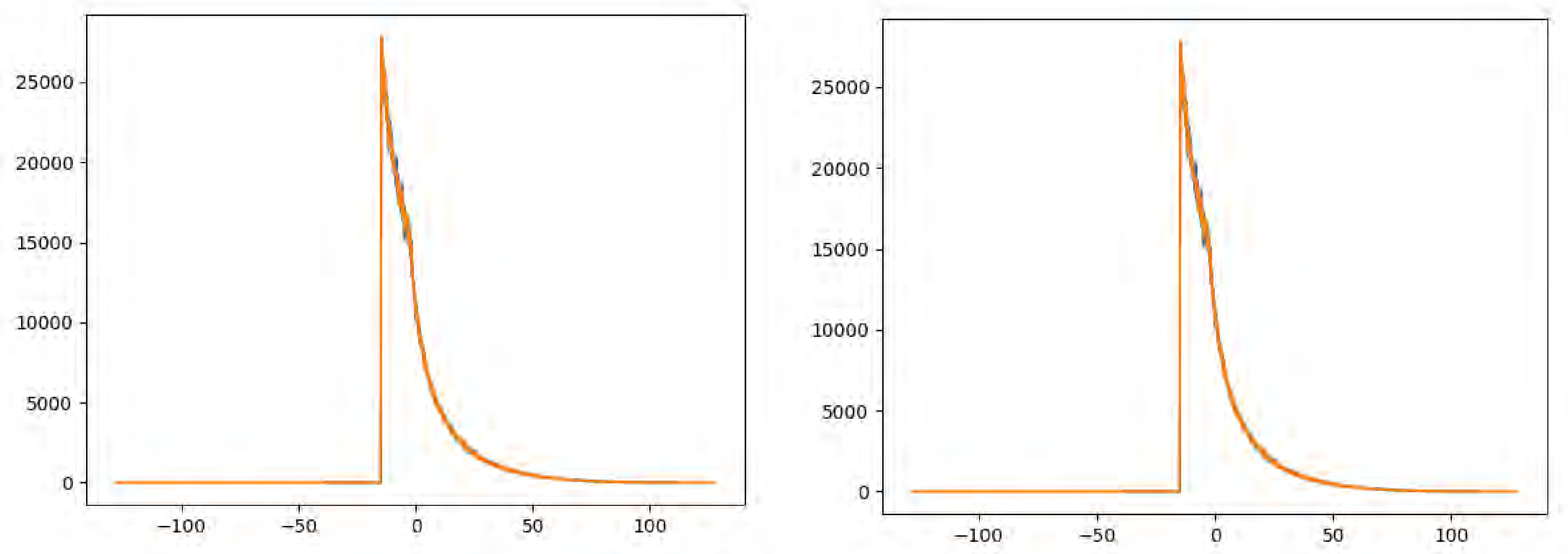
Optimal Wiener filtered Normal Points from Herstmonceux Data

Instrument Function



- effect is due to SPAD detector
- same effect visible in TIGO CONL data
- high resolution Hx data allows for 0.125mm bins
- noise is fully accounted for by Wiener Filter Algorithm

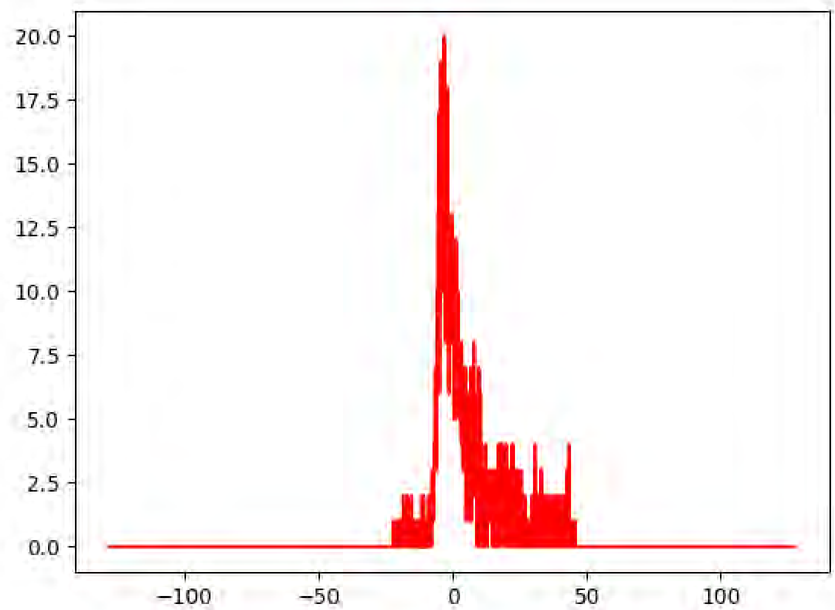
Transfer Function



- kindly provided by J. Rodriguez (exponent 1.25 L1, exponent 1.1 L2)
- high resolution Hx data allows a 0.125 mm grid (Resolution Bandwidth)
- Wiener Filter is used with various cutoff frequencies (Video Bandwidth)

Lageos1 NP-histograms

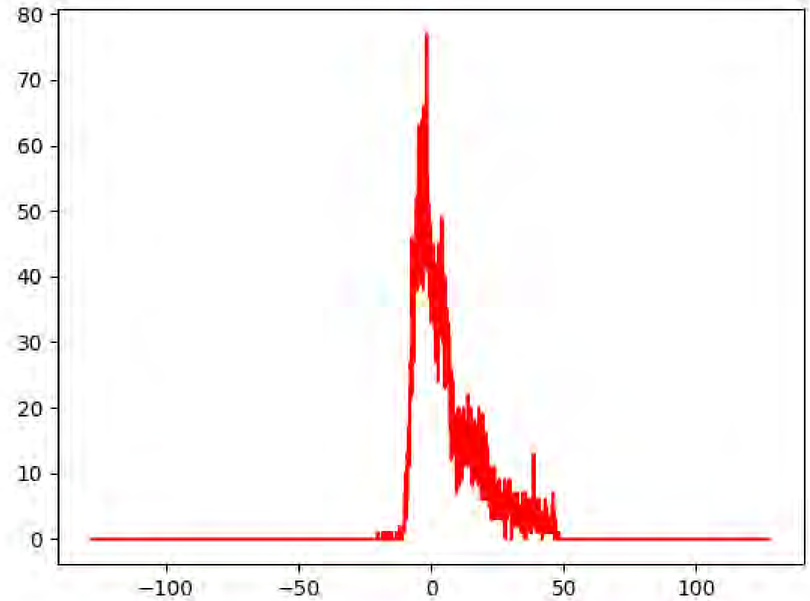
Events



Deviation w.r.t mean / mm

- leptokurtic multiple peaks, the usual case

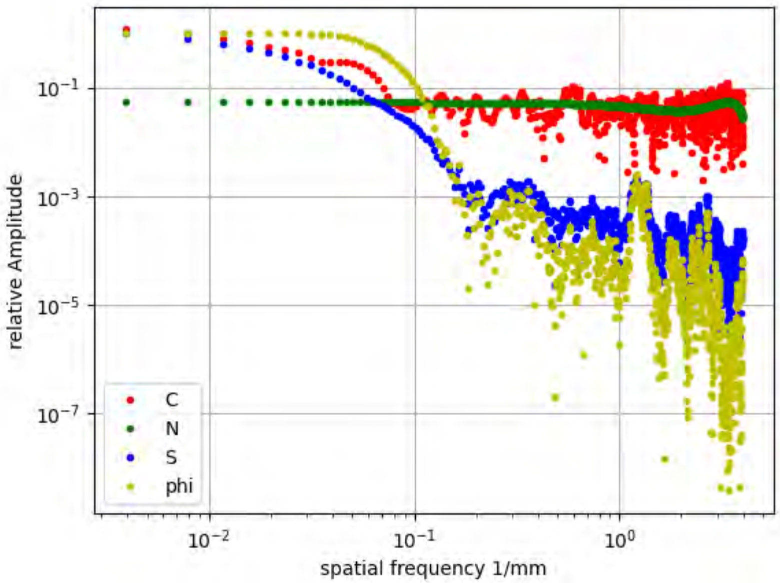
Events

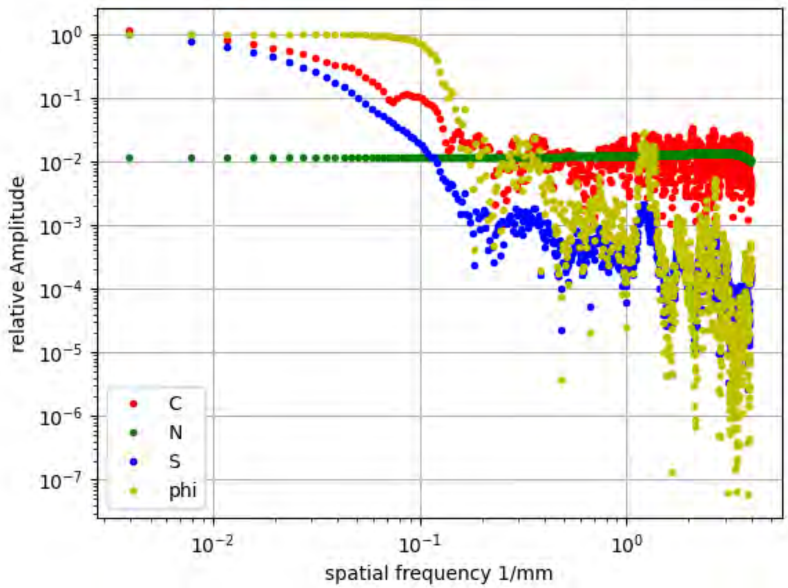


Deviation w.r.t mean / mm

-platykurtic multiple peaks cause fringes in deconvolution

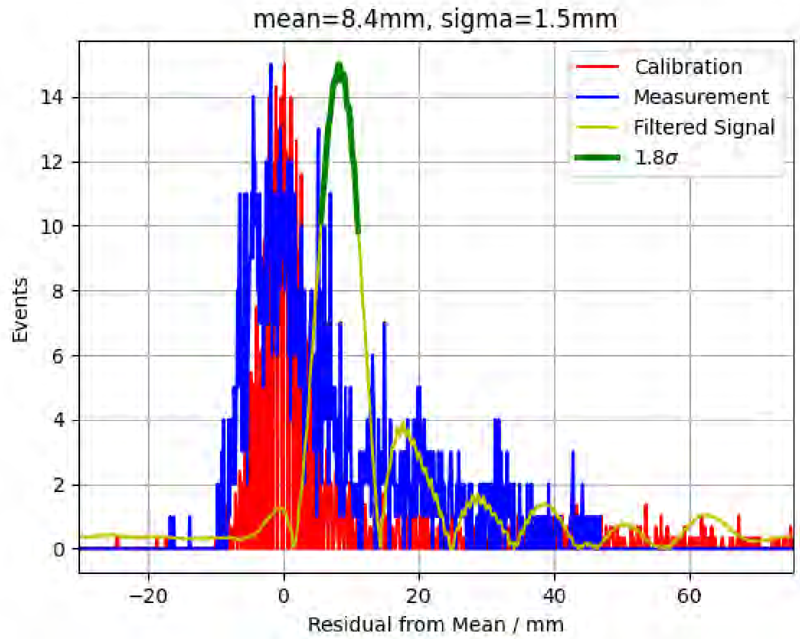
7840 Spectral Data Lageos1

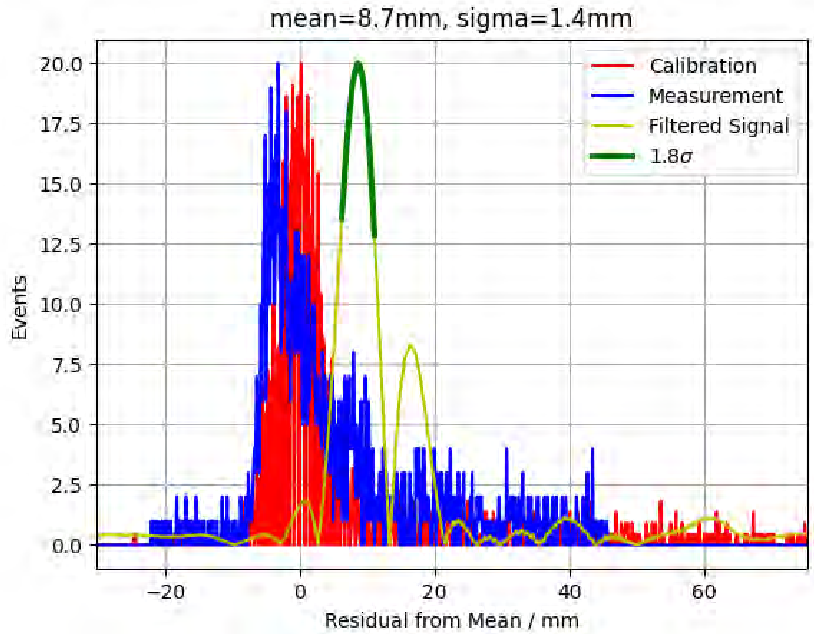




- multiple peaks cause excess in power spectrum w.r.t. incoherent model (left)
- spectral excess is more pronounced for broader leptokurtic peaks (right)
- cutoff frequency is chosen best when measurement spectrum fades into noise, 0.2 cycles/mm seems to be characteristic for Lageos.

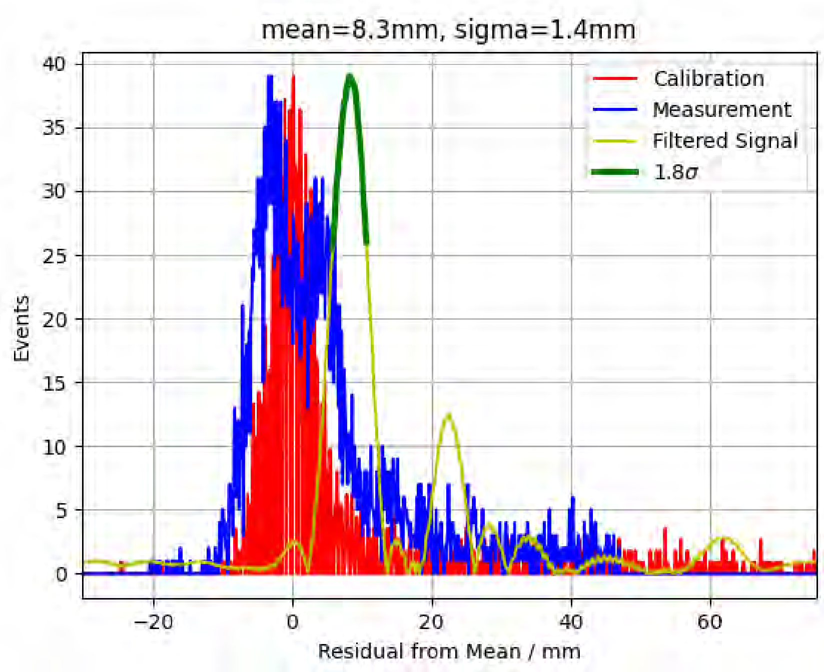
Lageos1 deconvolution

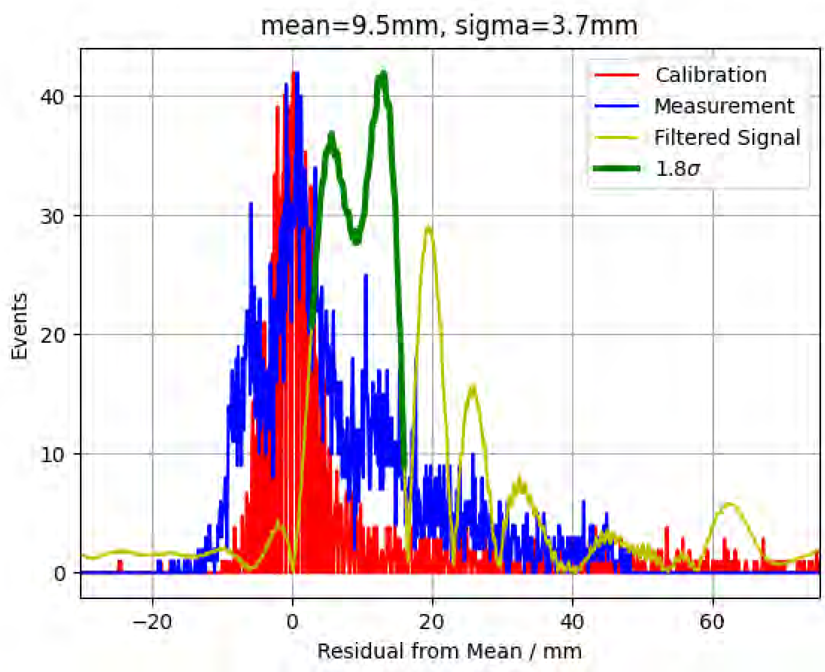




- Wiener Filter works also for sparse data
- in rare cases double peaks cause outliers when editing filtered signal with 2 sigma criterium

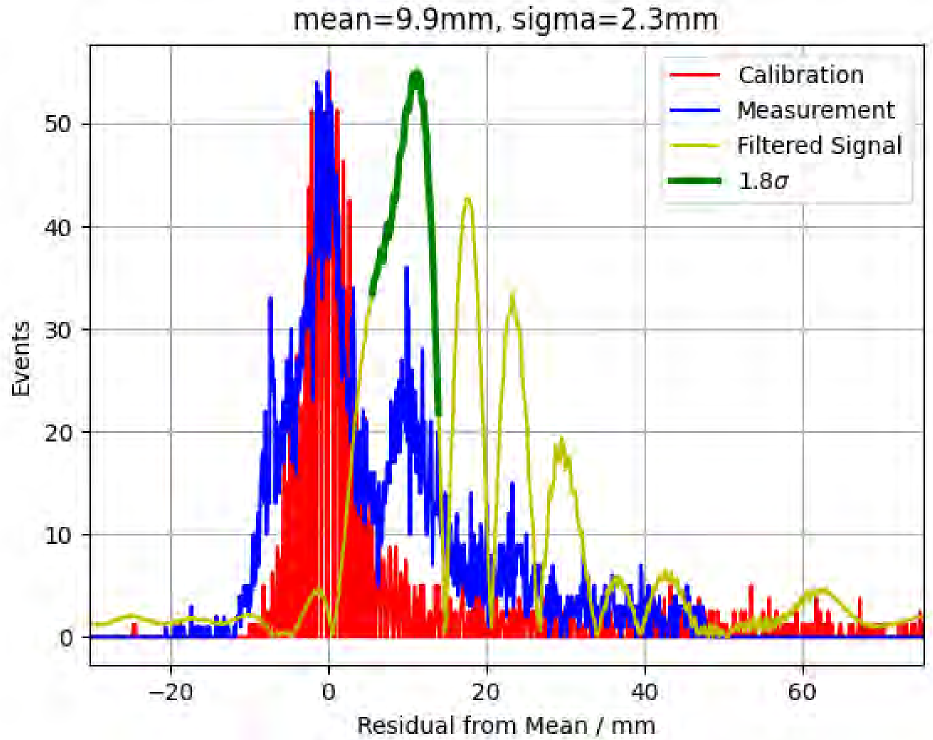
Lageos2 deconvolution





- in general Lageos2 response is more corrupted with multiple peaks than Lageos1 response
-1.8 sigma editing with high cutoff frequency (1.0/mm) of filtered signal is not a general solution

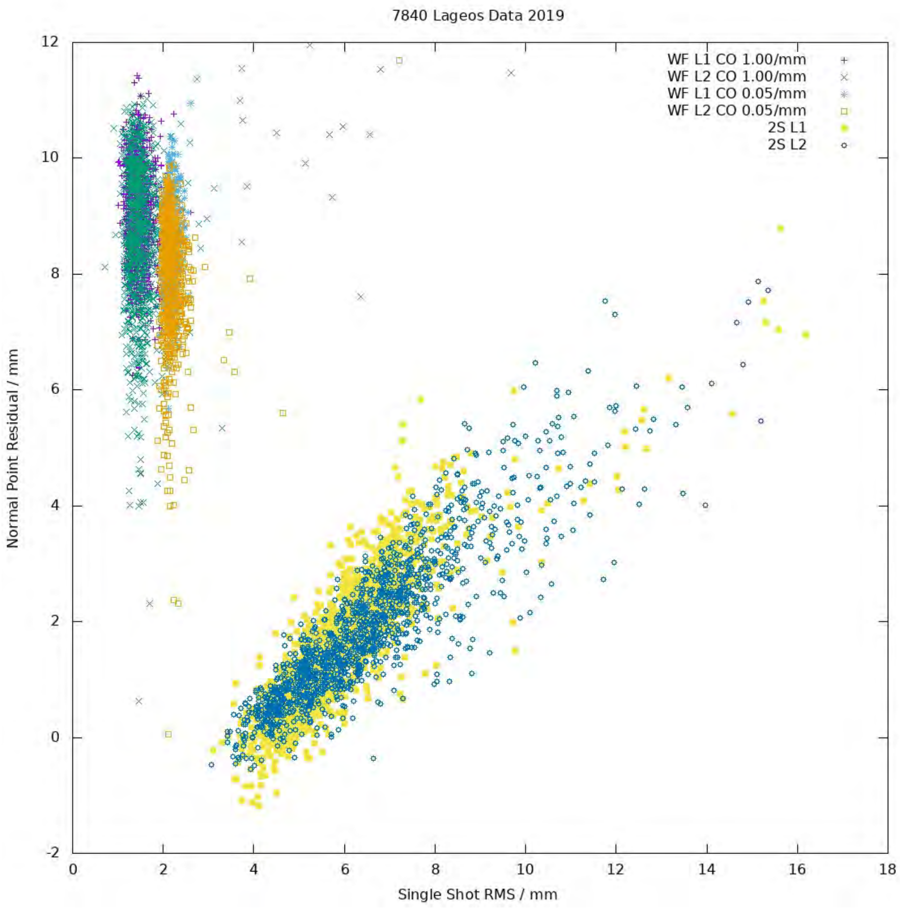
Lageos2 deconvolution co=0.05/mm



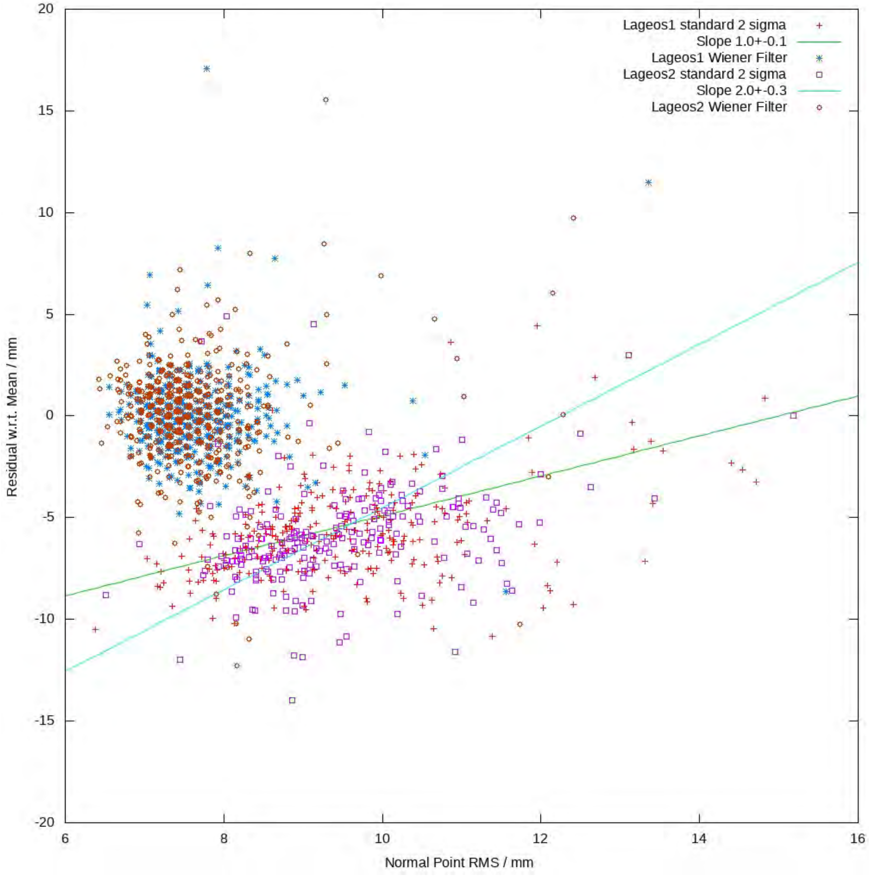
- applying a low pass filter (~ MCP bandwidth) seems to be the best option

NP Residuals vs. SS RMS

7840 Lageos 2019



7827 Lageos 2017



Conclusion

- Herstmonceux 2019 data set for Lageos1 has been processed to form Wiener filtered normal points
- algorithm has been tested on various Linux platforms including a miniconda python installation enabling for portability to other OS’s
- Lageos2 data shows in general more details in the response function
- due to the short coherence length of the Hx 10ps laser, interference effects of retro reflectors located within the coherence length show up with more contrast in comparison to systems with longer coherence length
- as long as the incoherent response function is used to define center of mass corrections, the Wiener Filter with cutoff frequency of 0.05/mm seems to be the most convenient option for editing of high resolution data
- scatter of the resulting distribution towards shorter NP residual is apparently caused by interference effects between the partial rays of the contributing retro reflectors
- further improvements rely on the knowledge of the array orientation and the ability to model the instantaneous transfer function for every normal point interval

Comparing alternative normal point formation methods

Matthew Wilkinson
NERC Space Geodesy Facility

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BGS 1835

Introduction

- The method to define normal points is **fixed** by the ILRS as the mean residual applied to a range at a central epoch within a fixed time window.

- Stations are responsible for forming their own normal points. This has resulted in different flattening methods and different levels of clipping of range residuals.

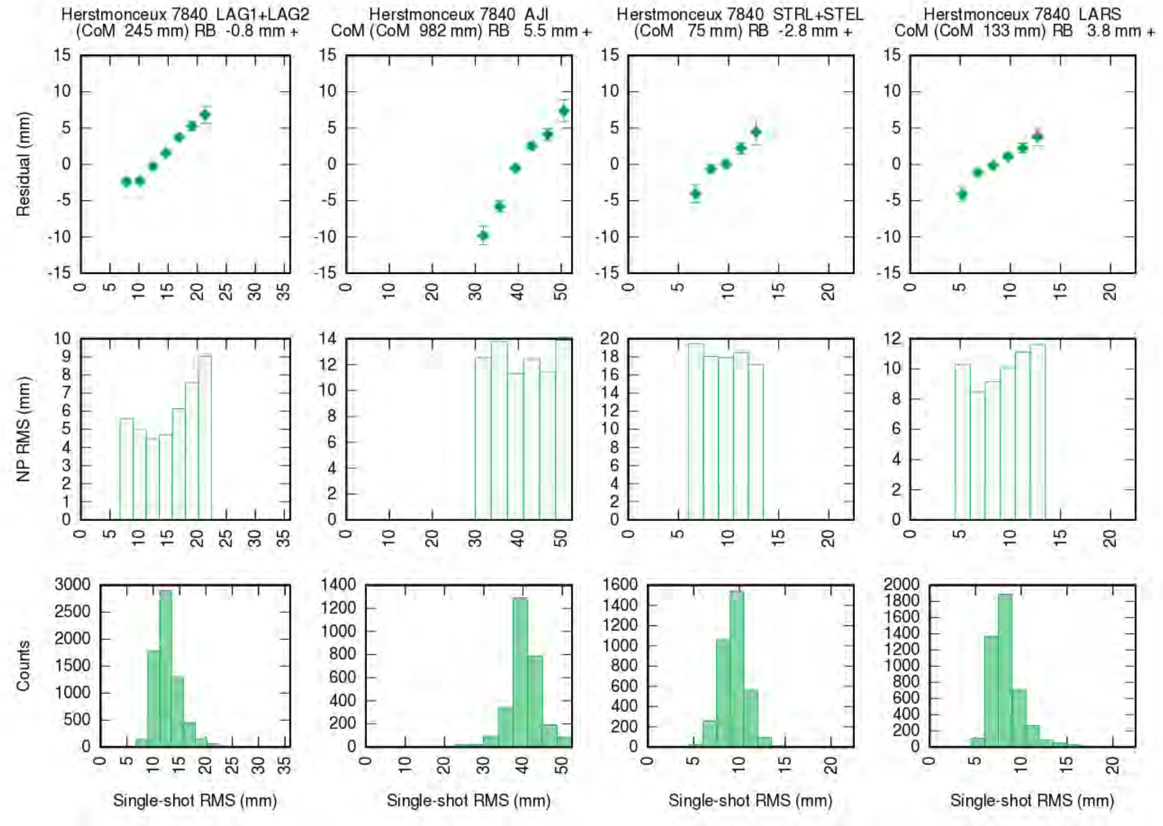
- Alternative methods to form normal points have been proposed and these will require a **centre-of-mass** correction to be calculated.

- I've produced a 2019 dataset of 'unclipped' residuals for Lageos 1 & 2 from Herstmonceux SLR data and provided these to **Stefan Riepl**. We are both producing normal points for comparison.

Range vs RMS

For a number of SLR stations, a variation was shown in the orbit fit range residuals of normal points that depends on the RMS.

This is due to the shape of the returning pulse and an inconsistency in the clipping applied on a pass by pass basis.

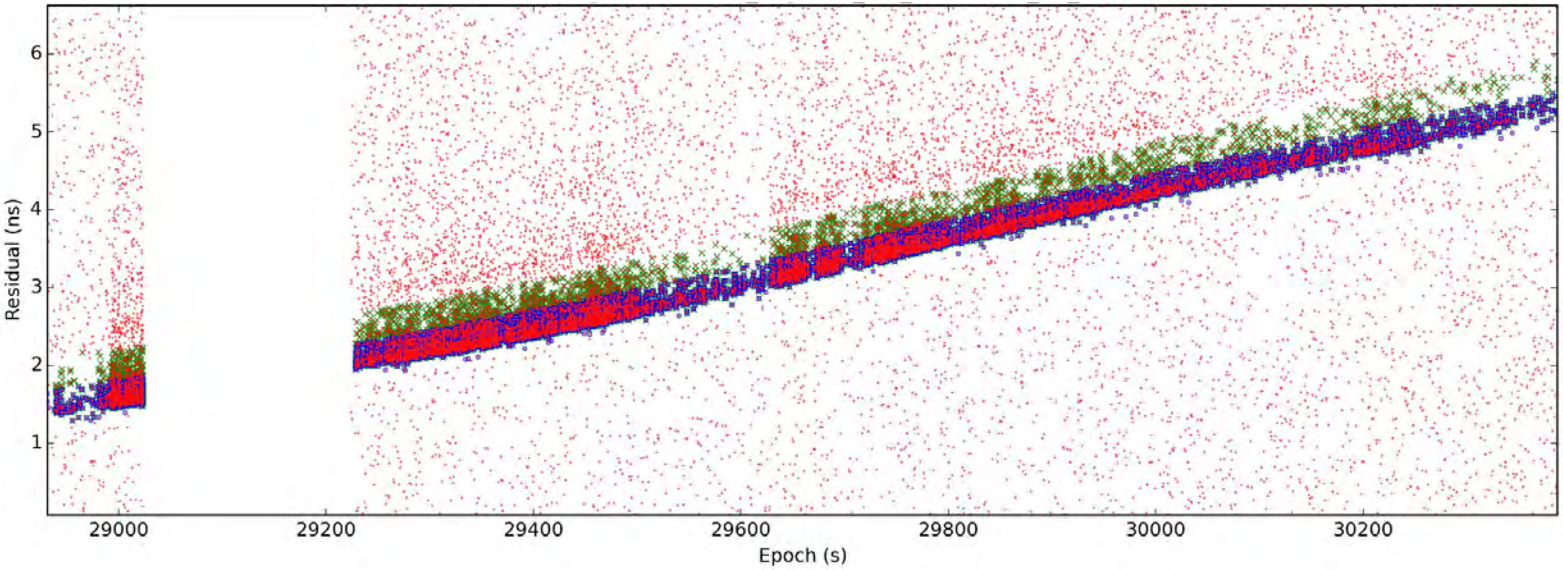


Otsubo, Systematic Range Error, IWLR, Annapolis 2014. *https://cddis.nasa.gov/lw19/Program/index.html*

Range vs RMS

To change the clipping point in a distribution it was necessary to go back to the **raw data** file.

Using the **full rate data** file it was possible to identify the track in the raw data and **reselect the track** data.

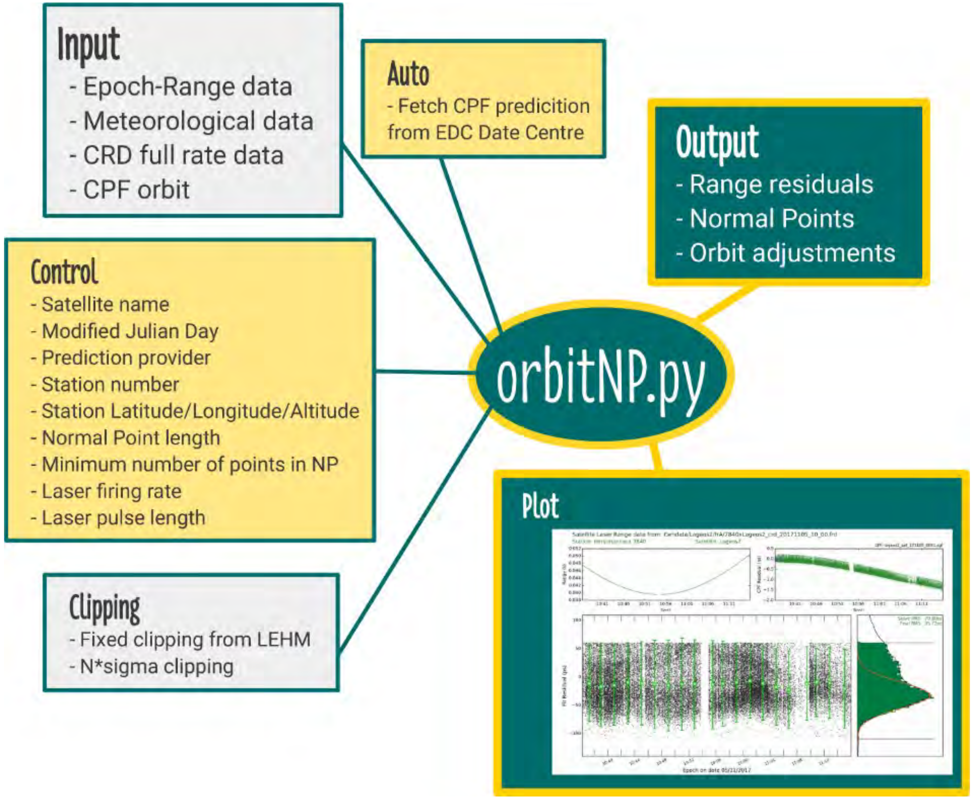


OrbitNP.py

The orbit adjustment PYTHON program from the SGF was released to the SLR community at the start of 2019.

OrbitNP.py was used to produce the flattened range residuals.

Randy Ricklefs has provided support to improve this code and develop it further.

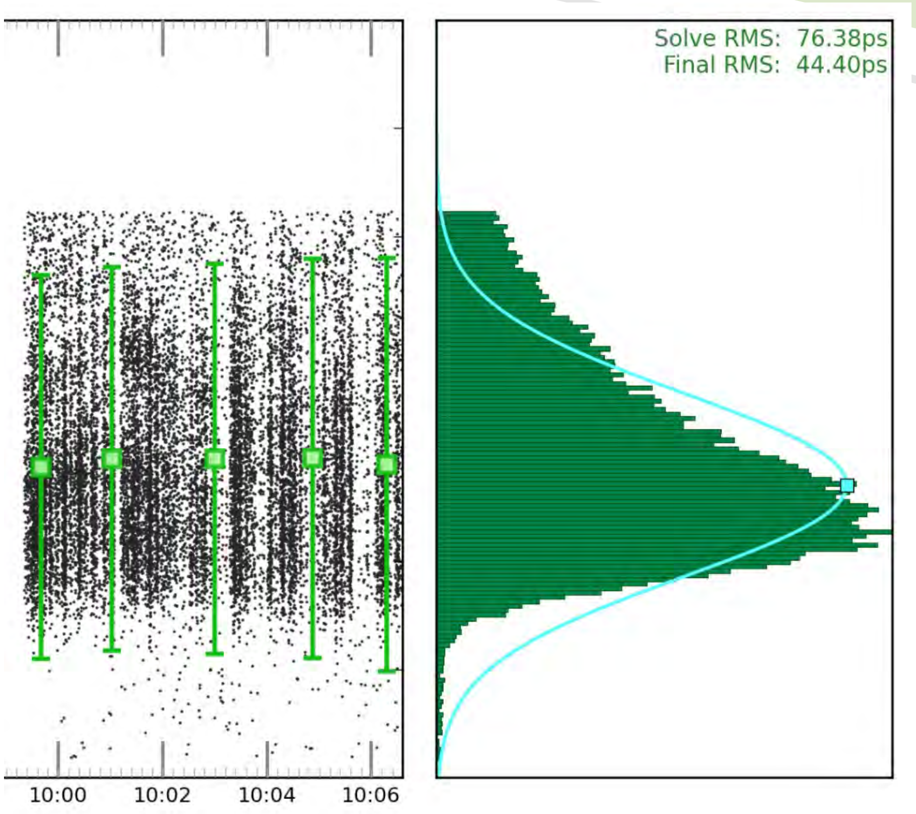


Forming Normal Points

At Herstmonceux, currently the clipping is applied at ± 3σ from the centre of a Gaussian fit.

The σ value depends on the level of signal to noise and the satellite response profile.

Because the profile is not Gaussian, if tighter clipping is applied, due to a lower σ, then the normal point range will be shorter than if looser clipping were applied.

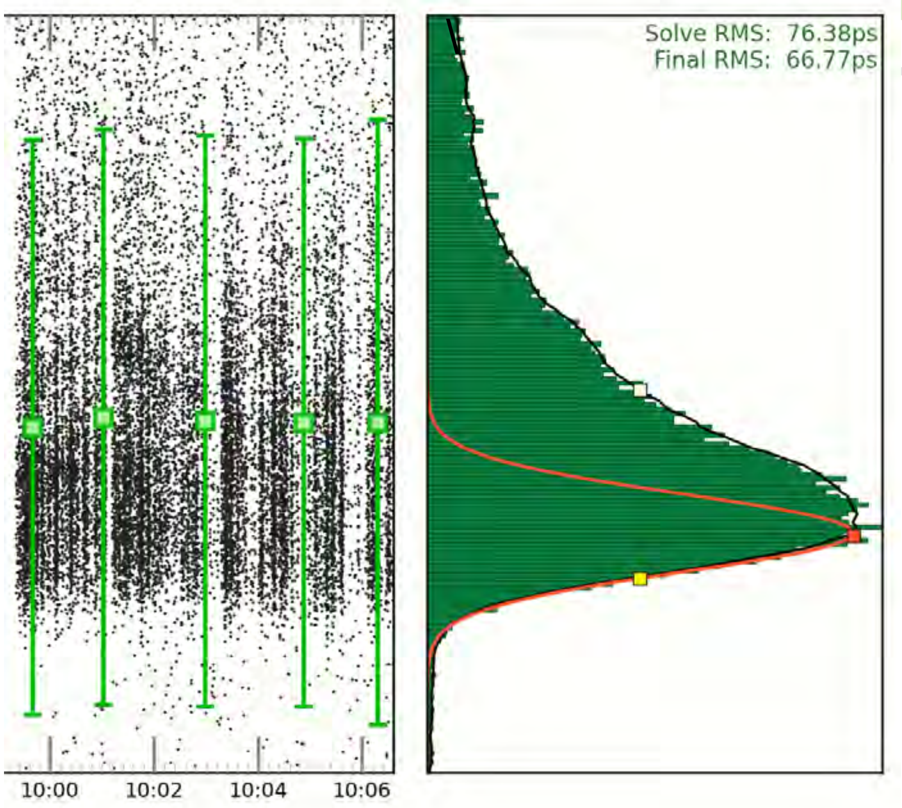


Clipping for Normal Points

To apply consistent clipping a stable point on the distribution is required, such as the leading-edge-half maximum (LEHM).

From the LEHM, fixed clipping can be applied that is set for all passes.

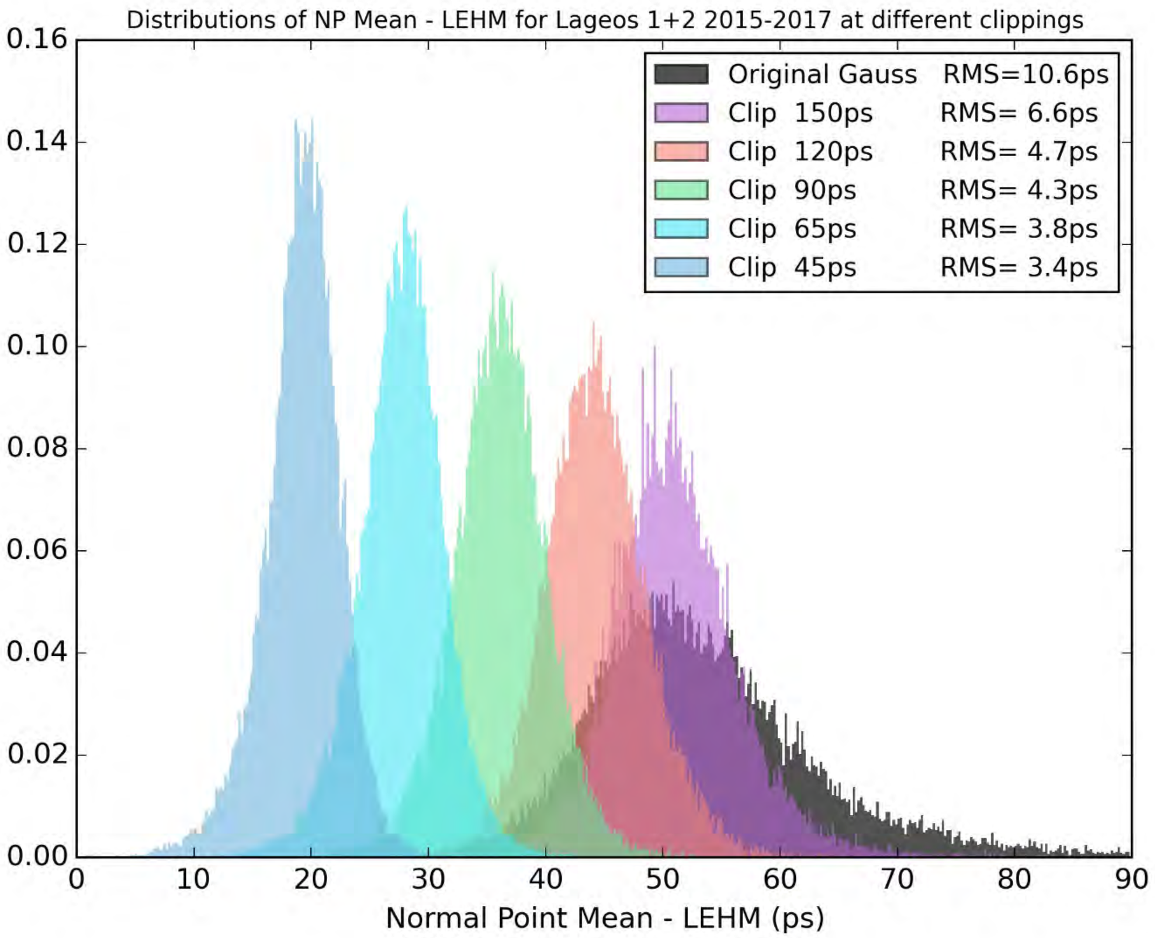
But, what level of clipping is best?



Clipping Results

NP mean – LEHM distributions from the clipped datasets are tighter.

Clearly, as the clipping applied is tighter the distance from the NP mean and the LEHM is reduced and the measurement is made closer to the front of the satellite.



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Comparing Normal Points

- It is not straight forward to compare one set of generated normal points with another.
- This is because the normal point central epoch could change, due to data filtering, and therefore the normal point range will be different.
- Any comparison must be done at the residual level.

Progress

- I provided a dataset of flattened SLR residuals to Stefan.
- I am now producing clipped normal points -30ps and +60ps from the LEHM.
- I addition I will run the SGF 'gauss' program to provide a reference residual for the current SGF method.
- The normal point residuals will then be compared for the 3 datasets.
- Any additional analysis of the Hx SLR residual dataset could be included.

Conclusions

- The normal point range residual dependency on single shot RMS can be minimised with controlled clipping about a well defined point on the satellite distribution.
- Alternatively, allowing stations to calculate normal points using other methods could avoid this bias.
- Alternative methods to calculate normal points could be compared if the corresponding centre-of-mass values were defined.

7105 Greenbelt Systematic Calibration Errors

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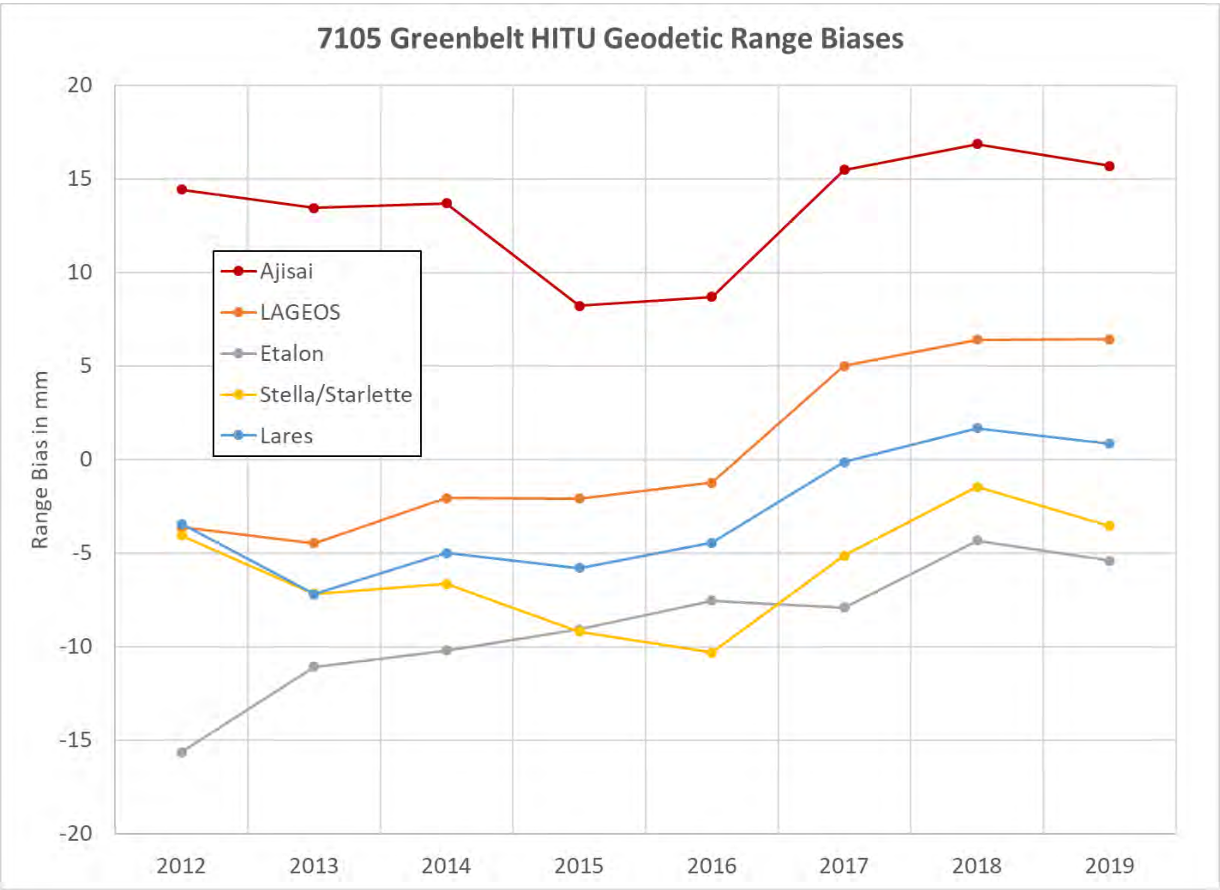
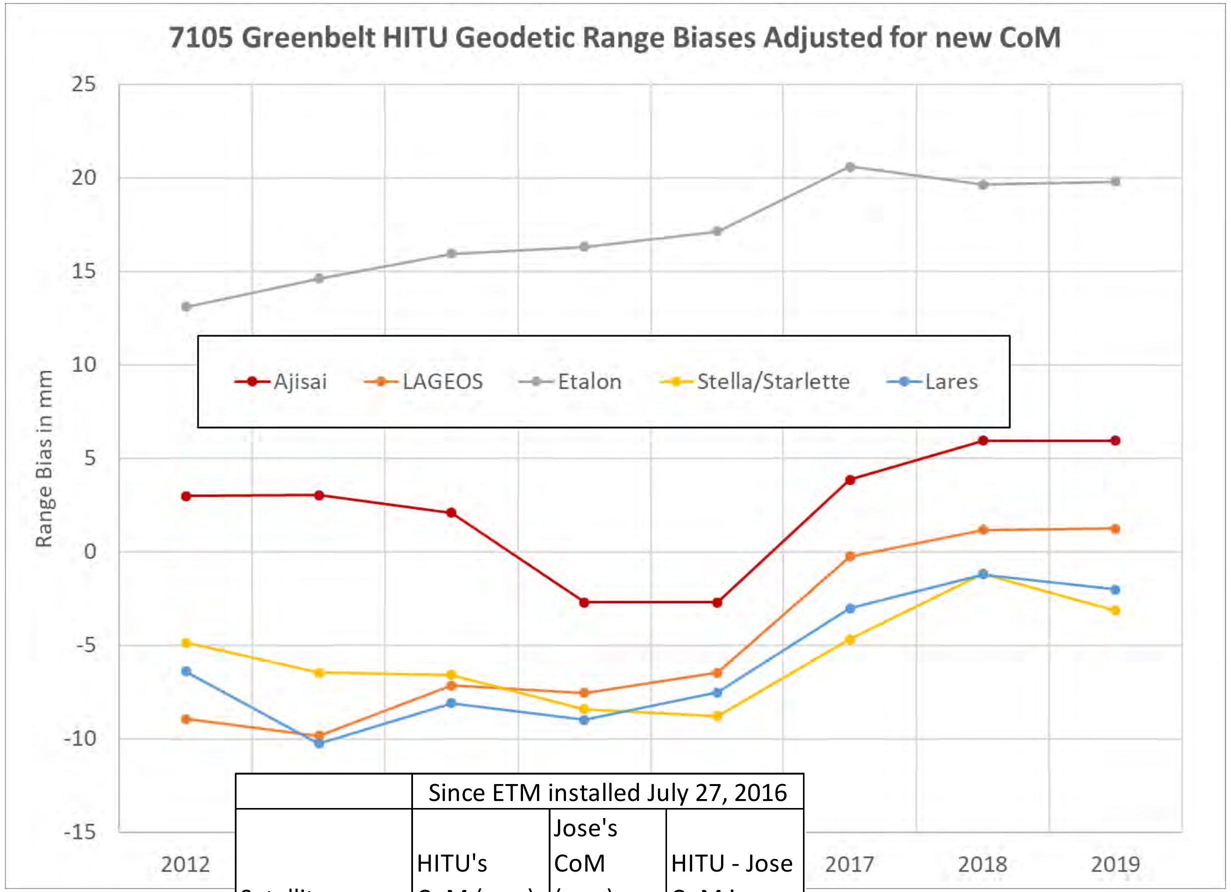
7105 Yearly Geodetic HITU Range Biases

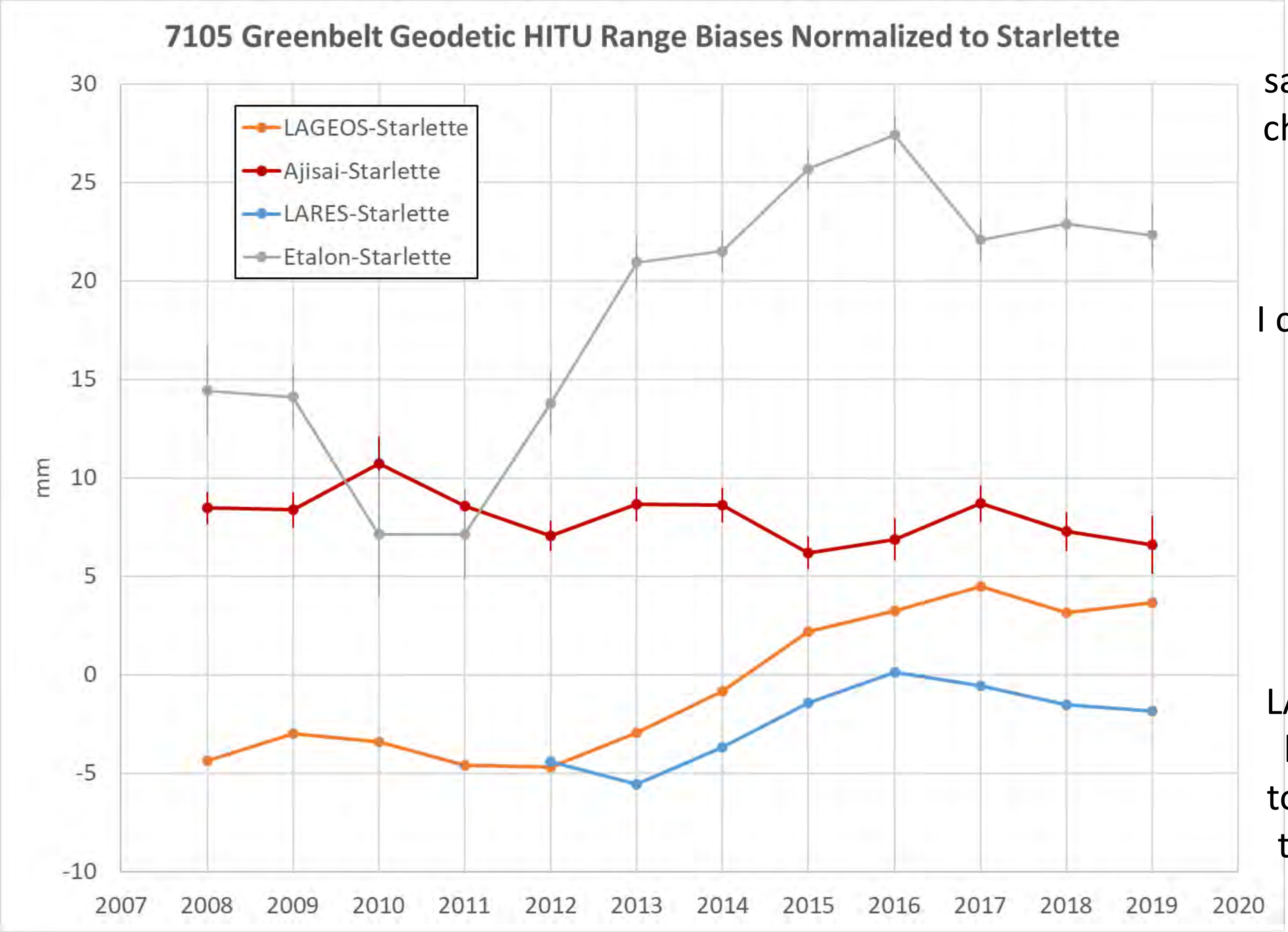




	Since ETM installed July 27, 2016		
Satellite	HITU's CoM (mm)	Jose's CoM (mm)	HITU - Jose CoM in mm
Etalon	558	583.3	-25.3
Stella/Starlette	75	76.1	-1.1
Lares	133	130.1	2.9
LAGEOS-1	251	246	5
LAGEOS-2	251	245.6	5.4
Ajisai	1010	998.5	11.5

Using Jose's new CoM correctios reduces the HITU range bias differences between satellites except for Etalon.

HITU Geodetic Range Biases Normalized



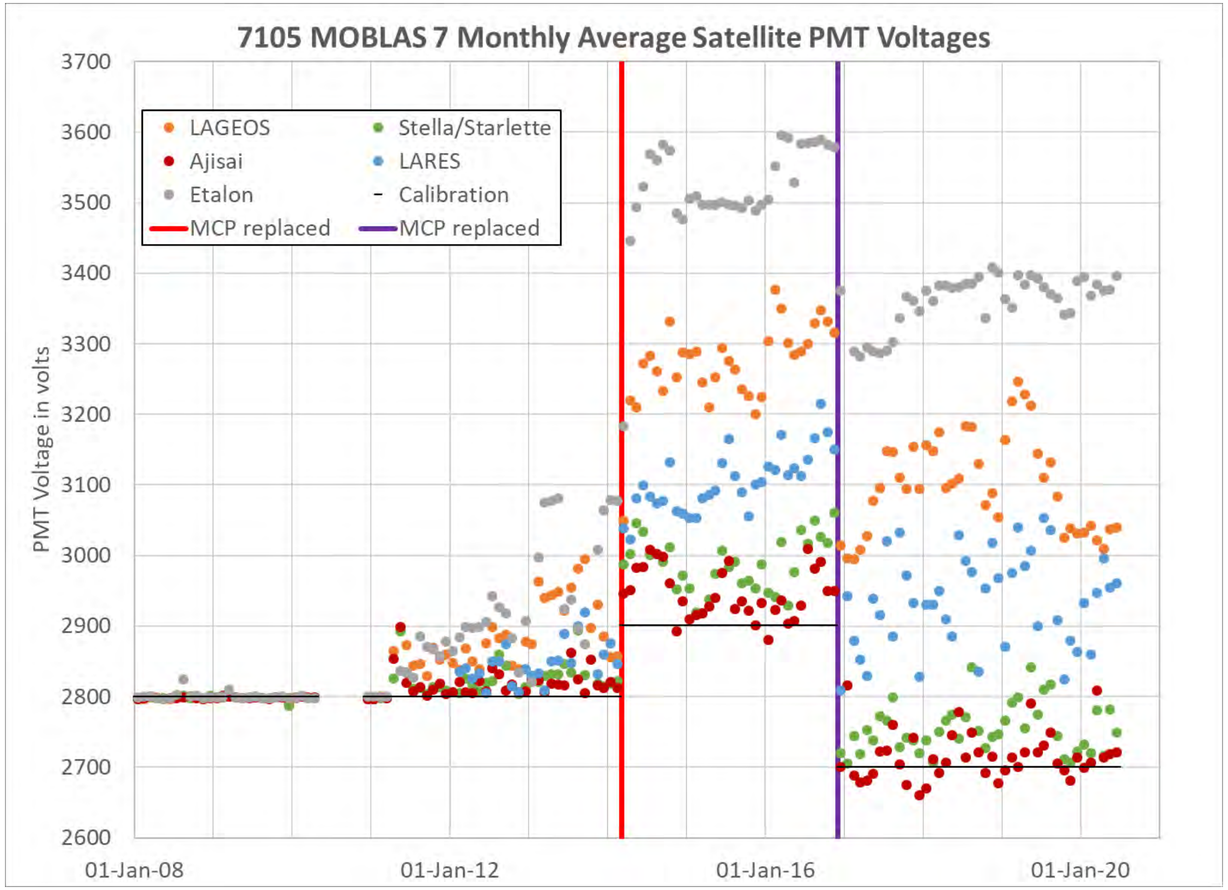
By comparing HITU range biases from one satellite to another is advantageous, because changes in HITU station position cancel along with other potential biases common to all satellites (e.g. HP5370 biases).

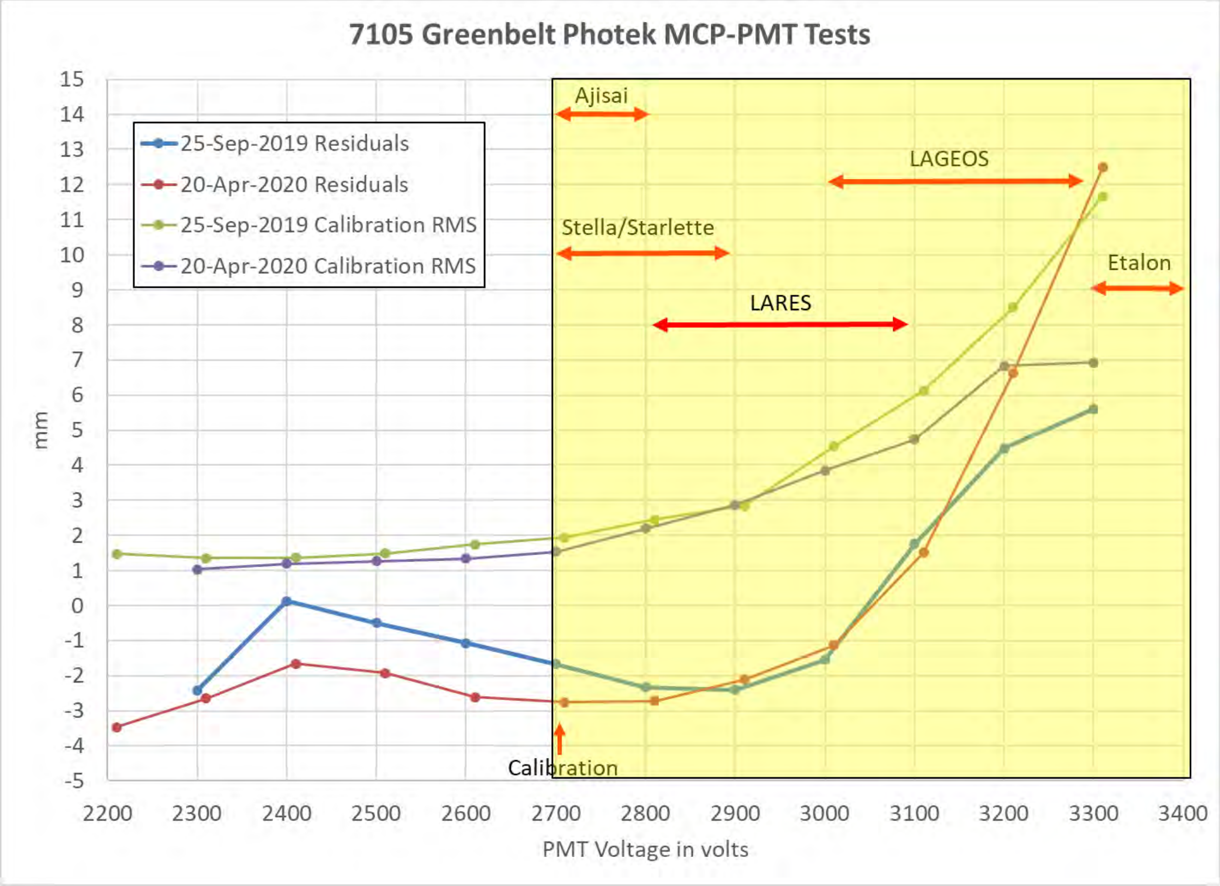
I chose to compare all 7105 HITU range biases to Starlette, because Starlette in the best calibrated in terms of the following:

1: PMT Voltage
2. Receive Signal Strength
3. Laser Fire Rate

Notice starting in year 2013, Etalon and LAGEOS range biases start to diverge and are biased in a more positive direction relative to Starlette; in 2015 LARES range biases start to diverge also in a positive direction; while Ajisai range biases relative to Starlette show little change over these 12 years.

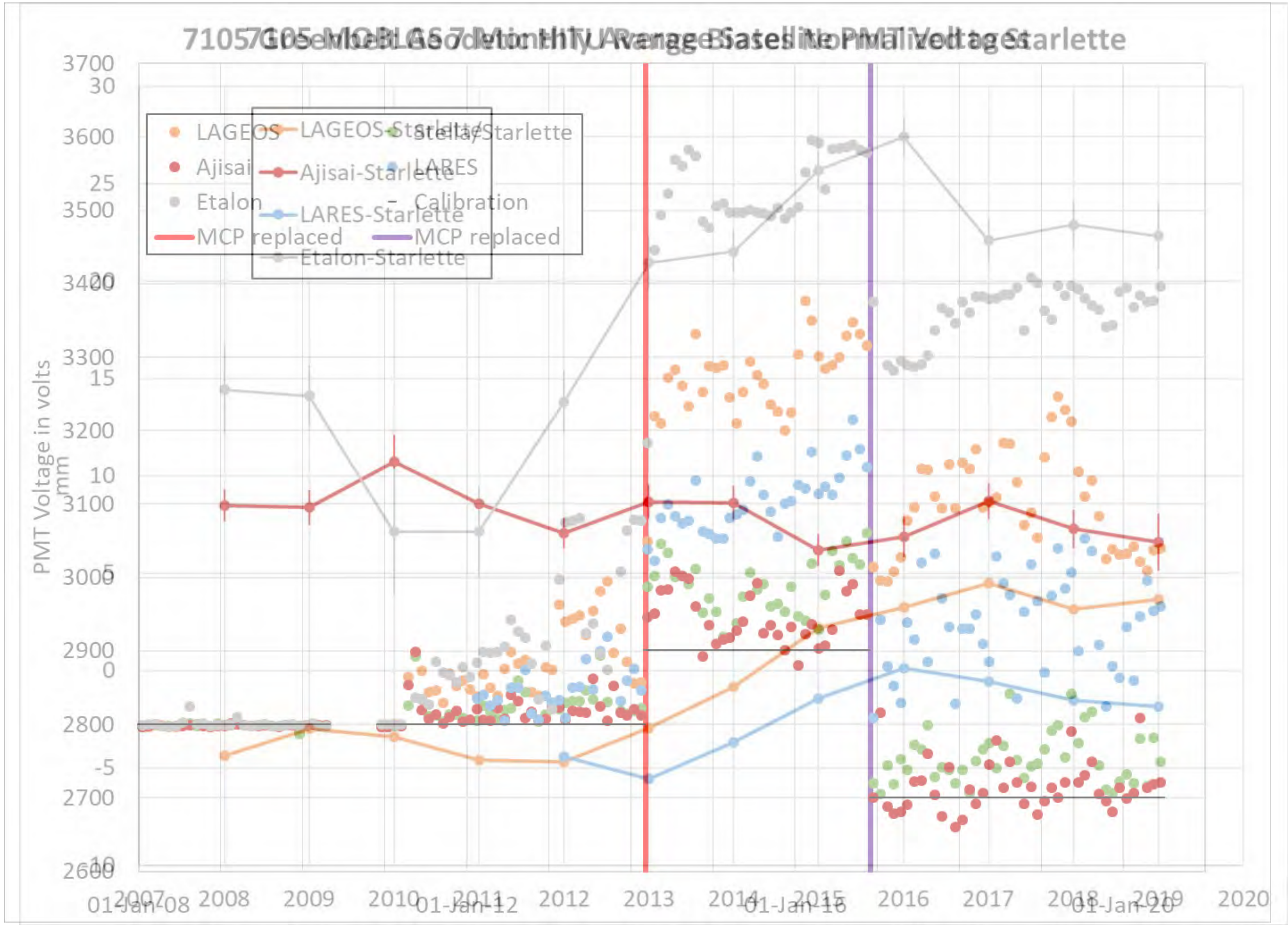
7105 Greenbelt PMT Voltage Analysis





To maximize data quantity, 7105 PMT voltages were increased starting in April 2011 (chart on the left), but calibration voltages remained constant. Based on the 7105 PMT Voltage Tests (chart on the right), the system delay and RMS can increase dramatically at the higher PMT Voltages.

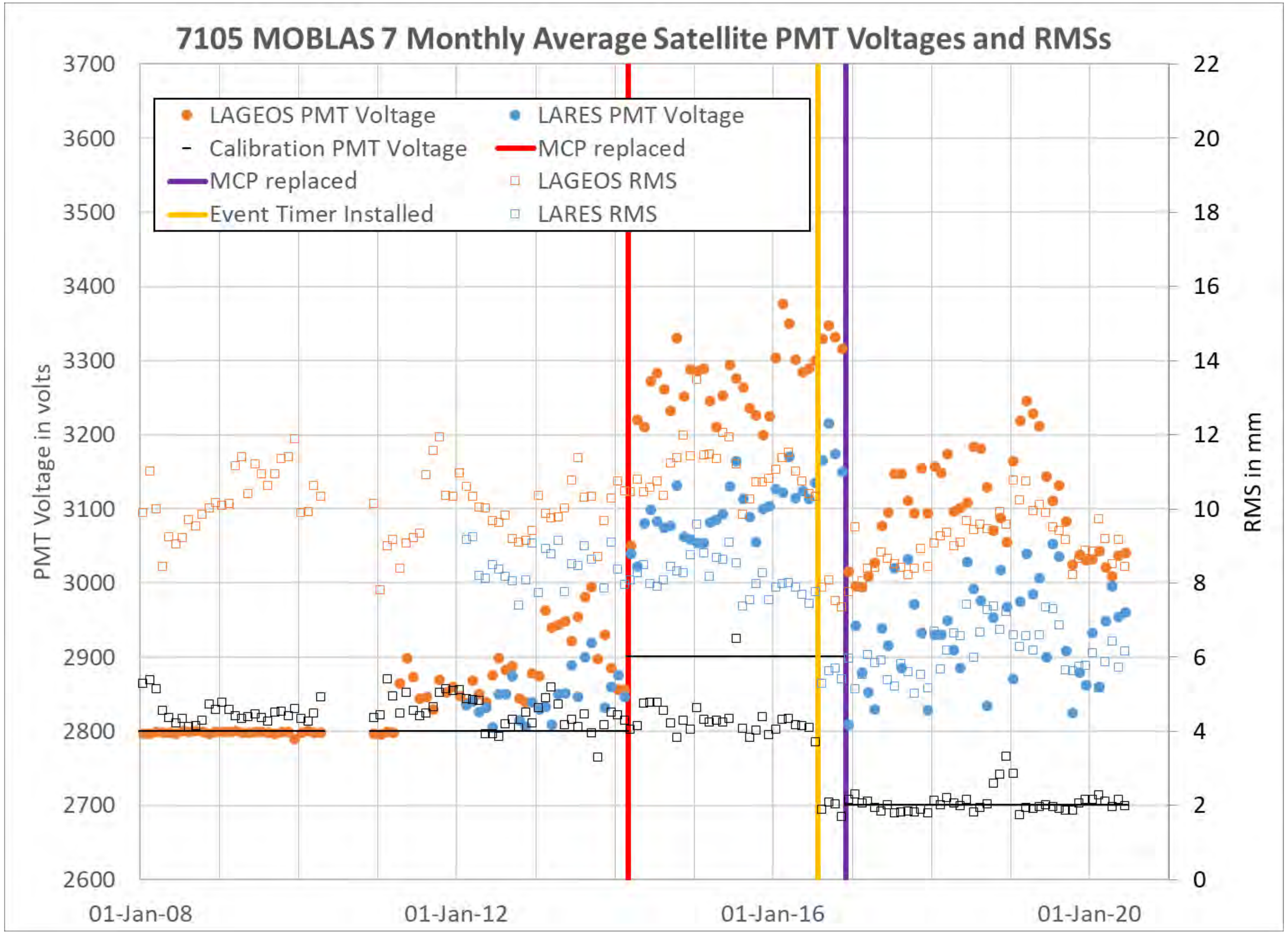
7105 Greenbelt Biases and PMT Voltages



PMT voltages are overlaid on the relative range bias changes.

As the PMT voltage differences between satellite and calibration increased, the Etalon, LAGEOS and LARES range biases moved positive as expected based on the PMT Test results.

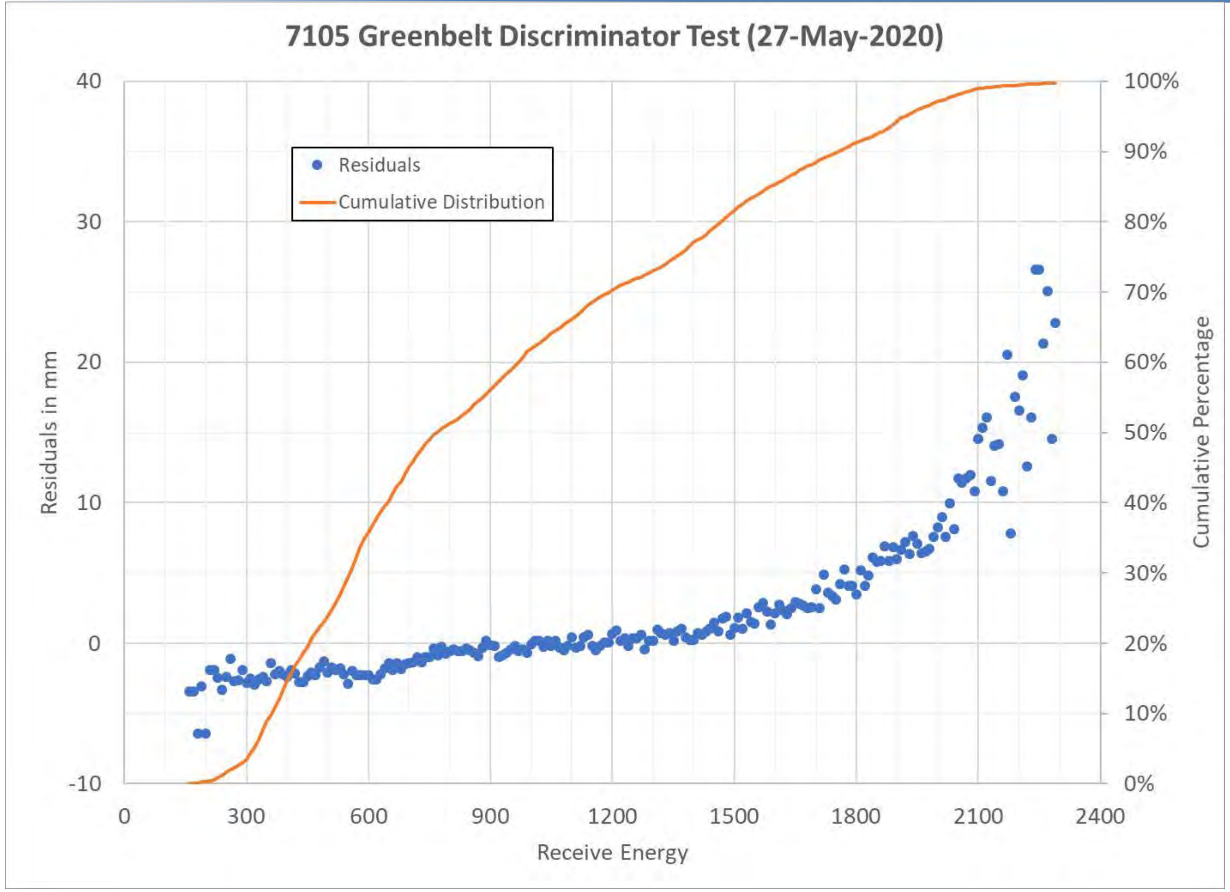
7105 Greenbelt PMT Voltages and RMSs

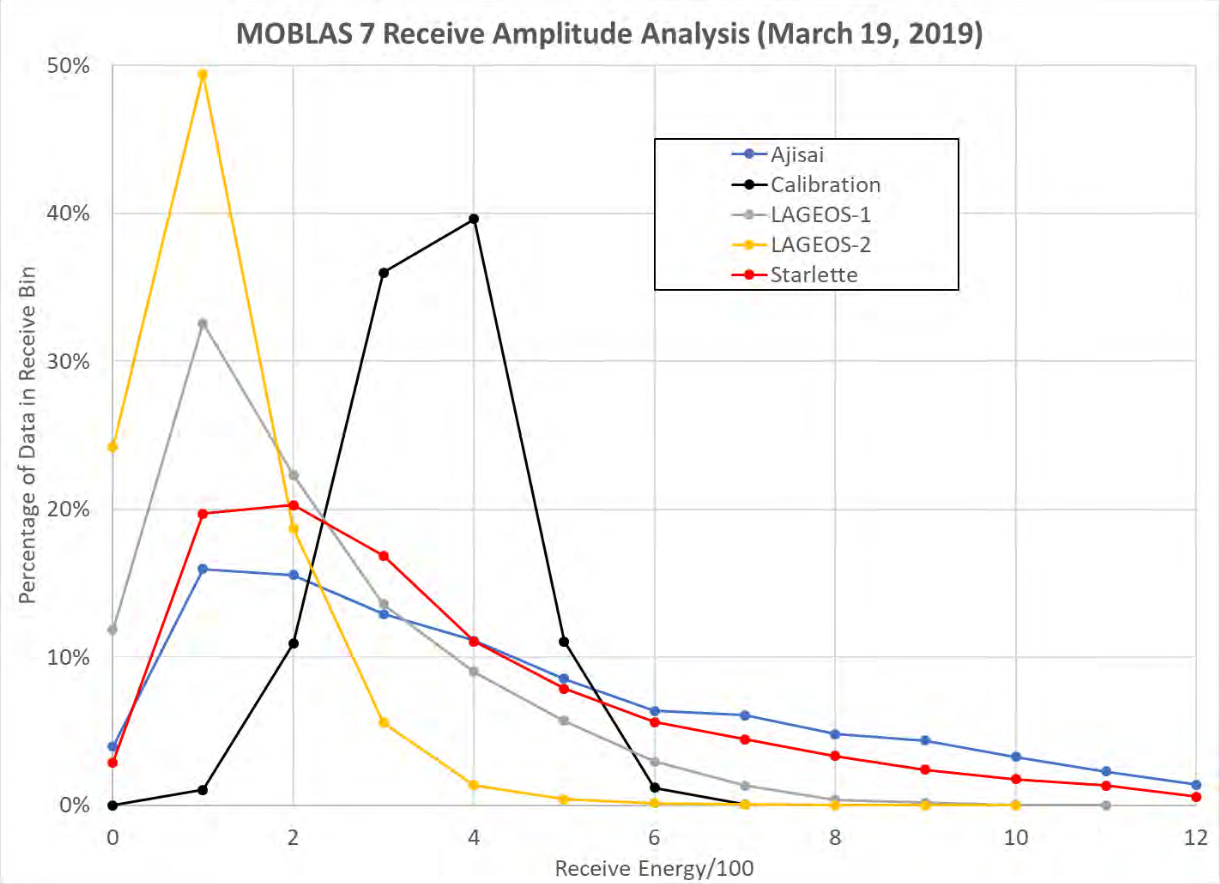


When the 7105 event timer was installed replacing the HP5370 on 26-Jul-2016, the satellite and calibration RMSs decreased. However; as the PMT voltage were increased on LAGEOS, the LAGEOS RMSs increased. But the calibration RMSs did not increase since calibration data was taken at the same lower PMT voltage.

There was a blip in the calibration RMS in late 2018 (to be discussed a little later).

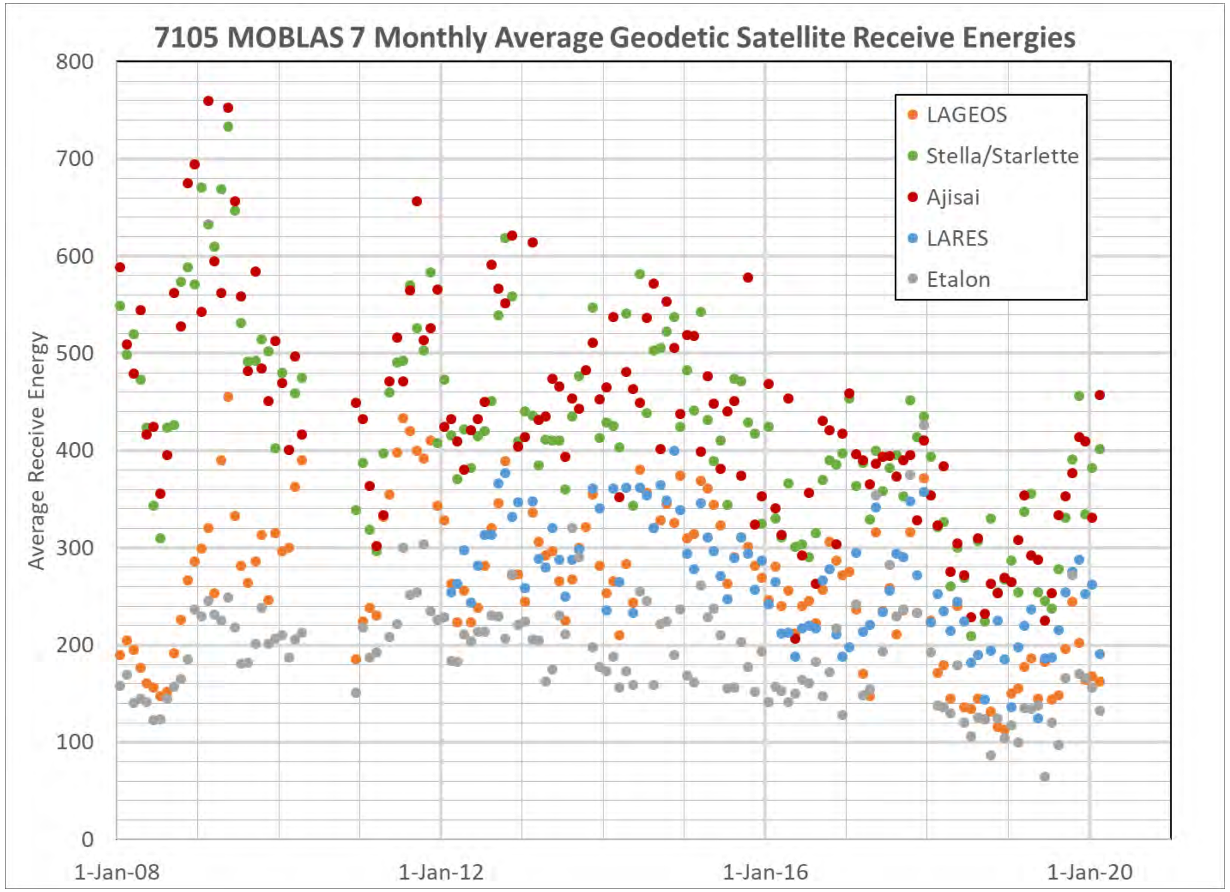
7105 Greenbelt Signal Strengths Variations

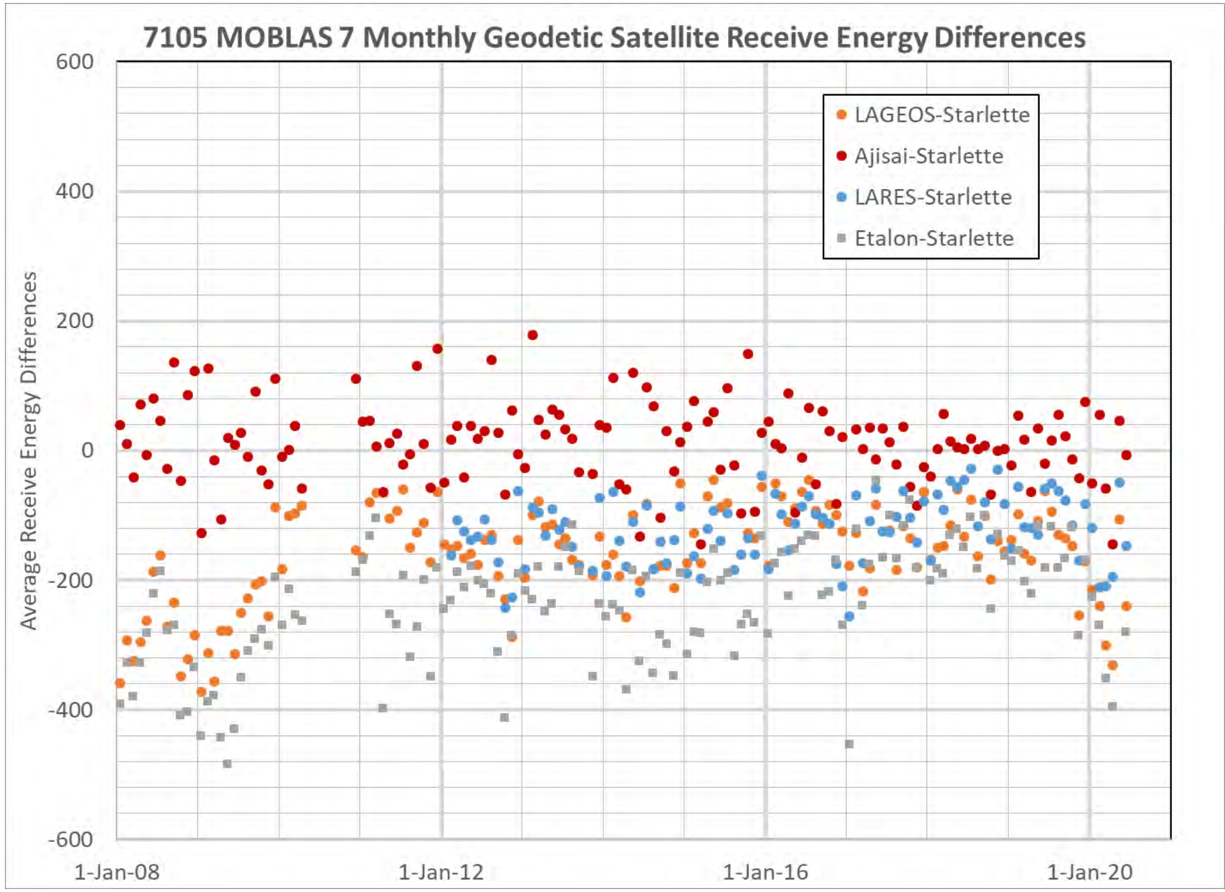




The chart of the left is from a discriminator test illustrating the timewalk in the receive discriminator. Receive timewalk characteristics can change over time. The chart on the right is the distribution of receive energies from 1 full day of tracking. CALIBRATION receive energies are distributed in the flattish portion of the receive energy curve to minimize RMS. In a typical 2 hour tracking scenario, every satellite shares the same calibration dataset, but the distribution of receive energies are satellite and pass segment dependent.

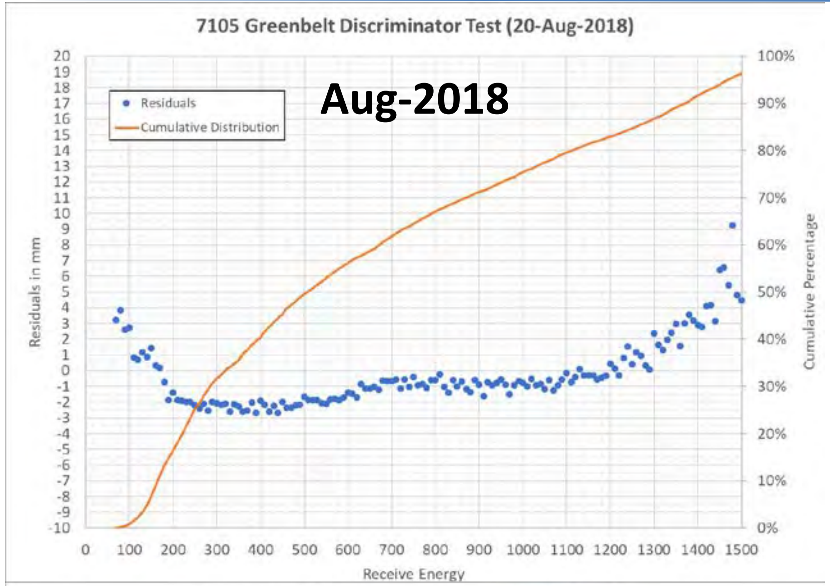
7105 Greenbelt Geodetic Receive Signal Strengths

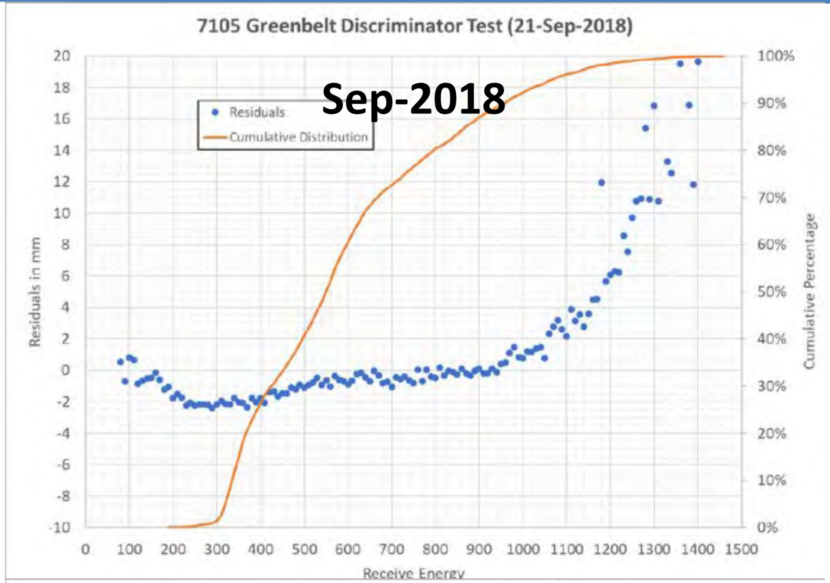


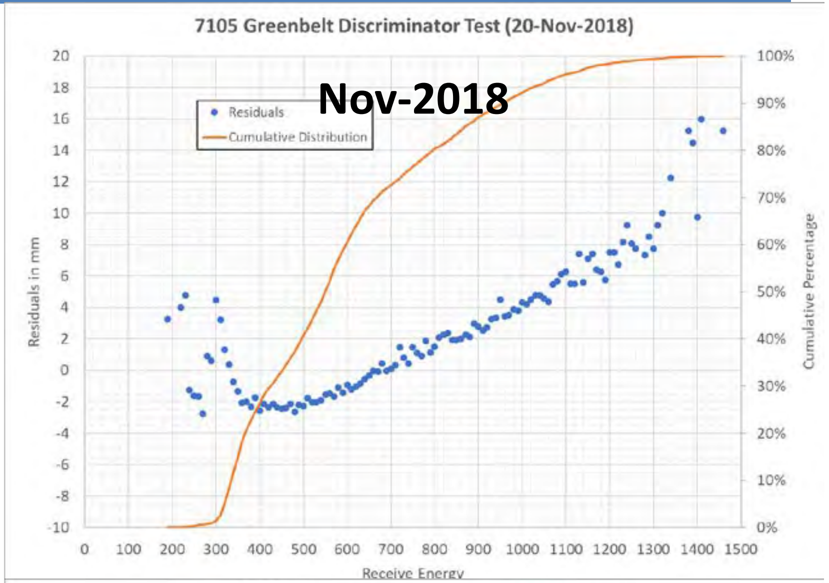


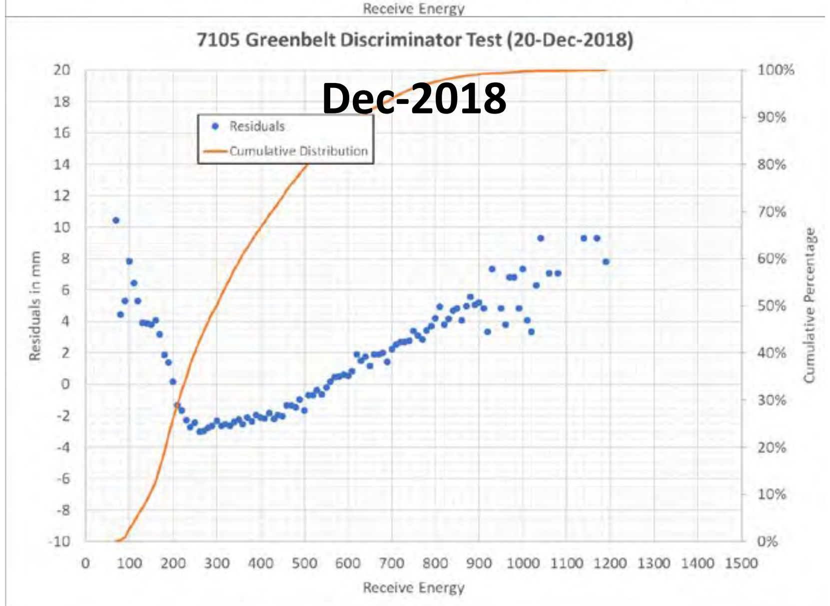
The chart on the left are the monthly average geodetic satellite receive energies and the chart on the right is the average receive energy minus the average Starlette receive energy. Based on the previous slide, Starlette and Ajisai receive energies are simulated the best during calibration. LARES, LAGEOS and Etalon relatively weak receive energies are poorly modelled during calibration and is a potential source of range bias.

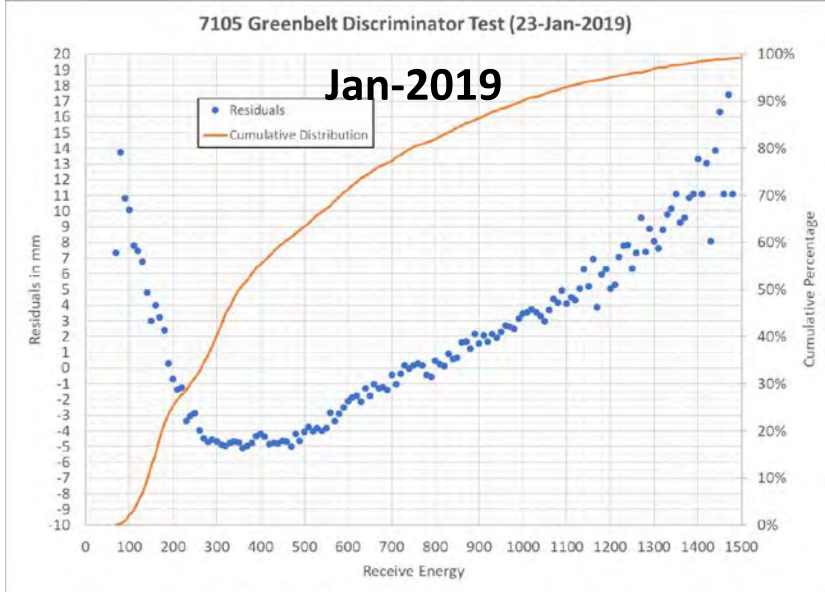
7105 Greenbelt Receive Discriminator Tests

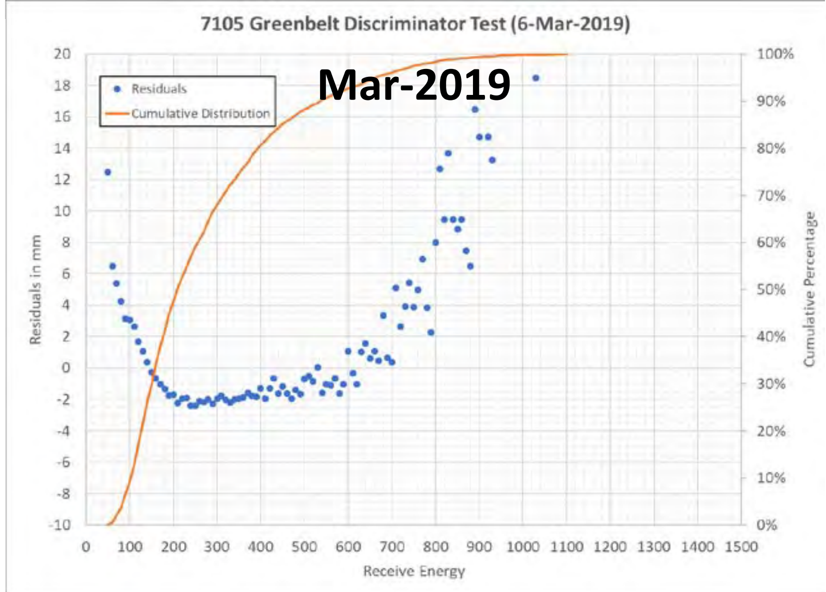




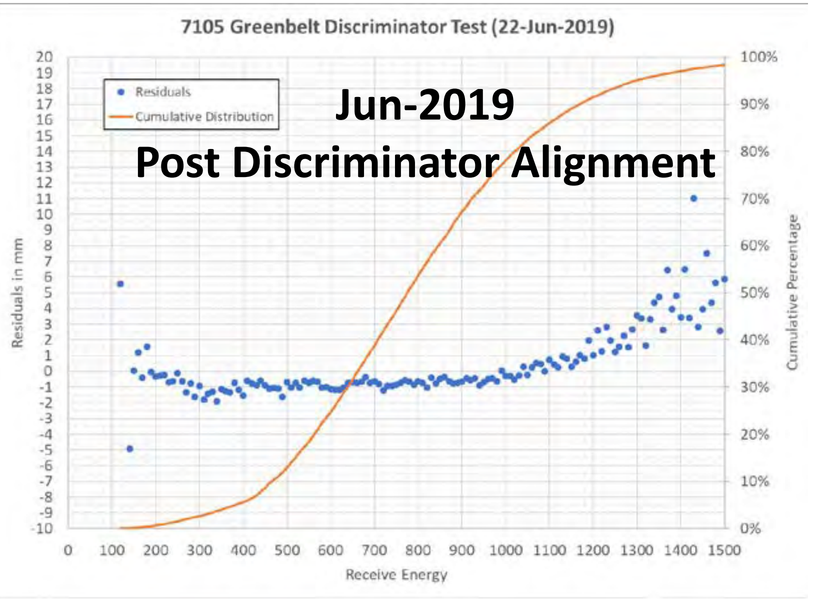


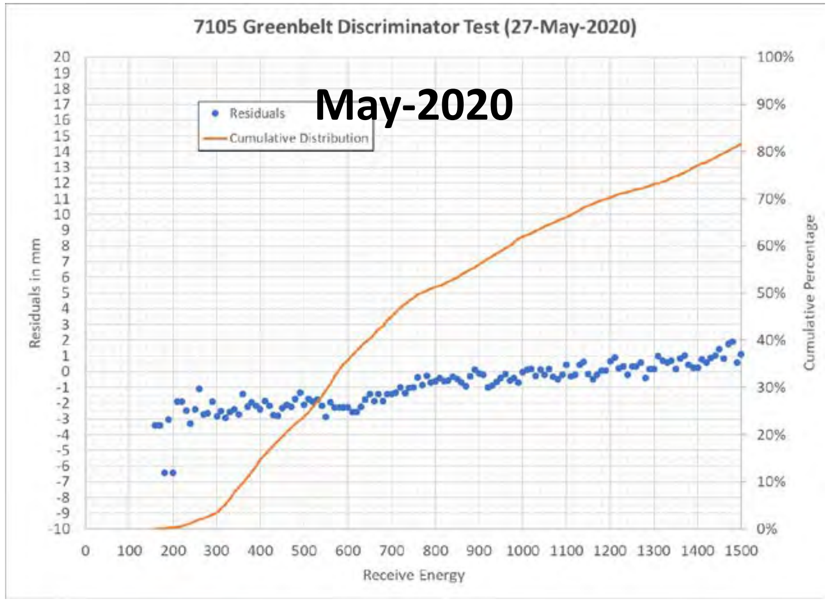


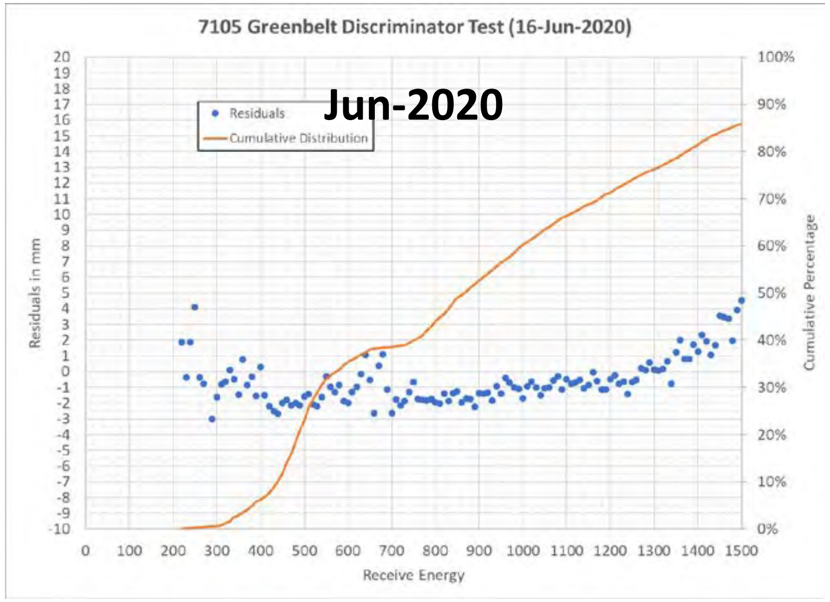




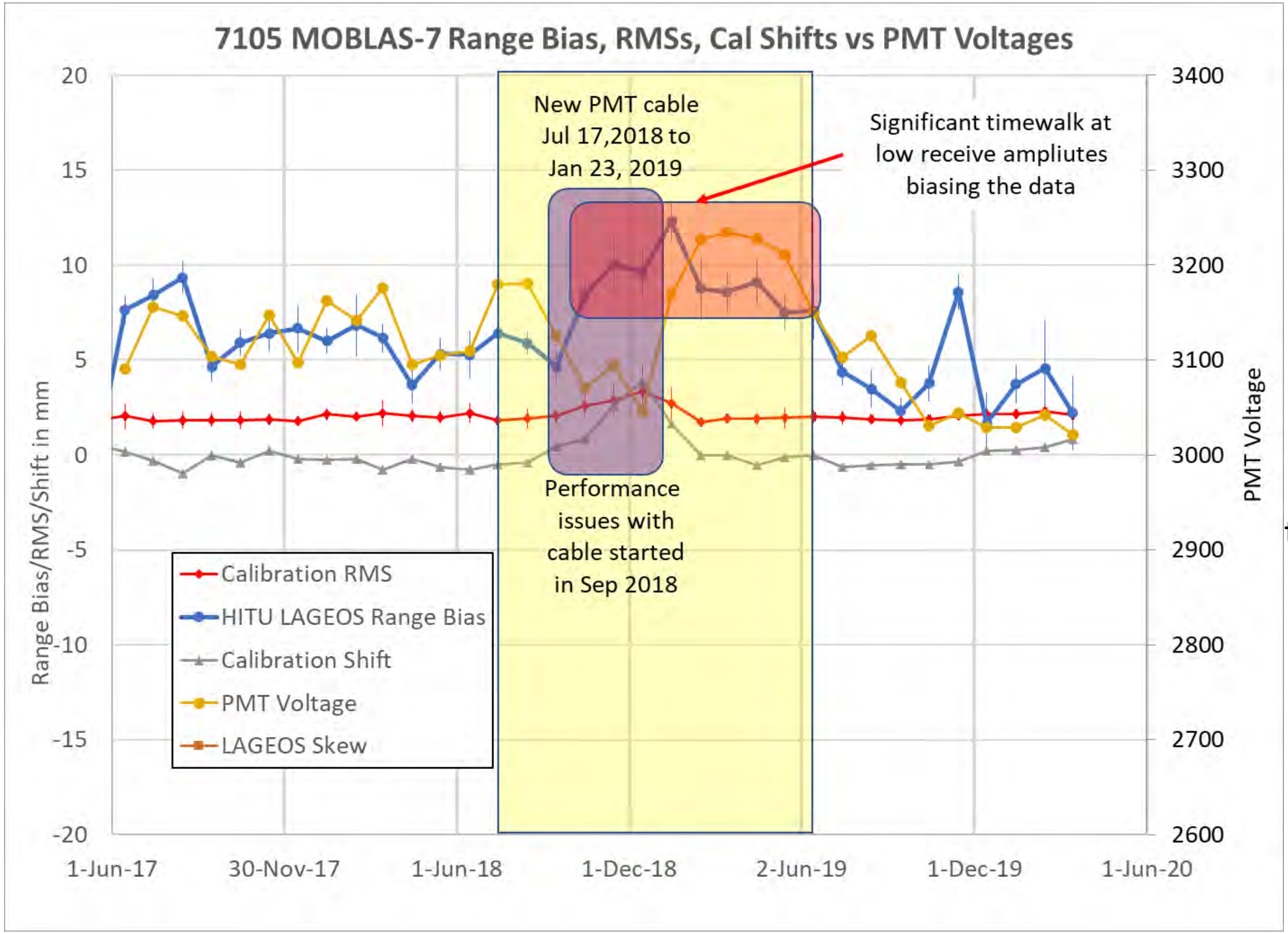
7105 Greenbelt Receive Discriminator Tests







7105 Monthly Range Biases and LAGEOS Moments

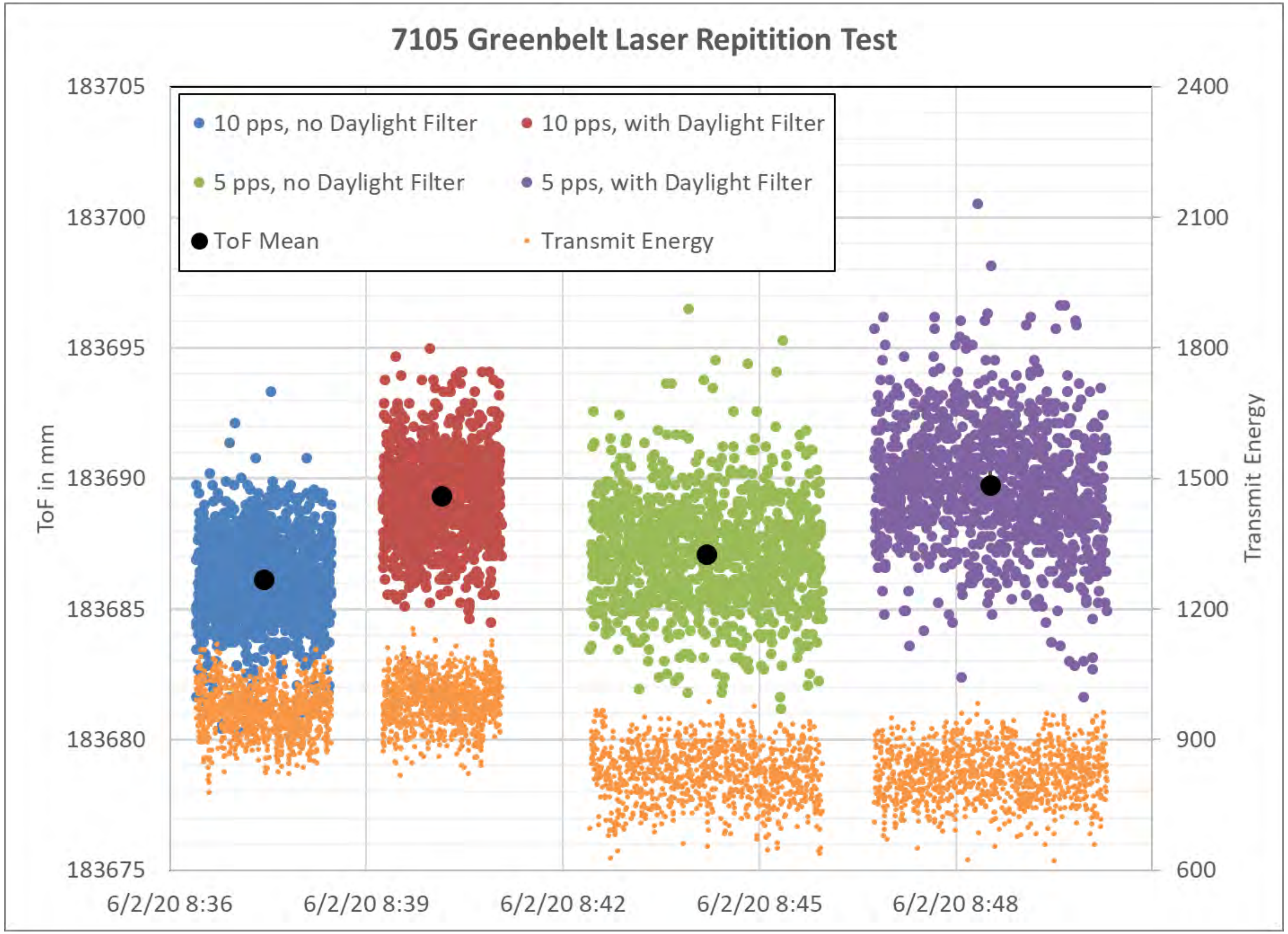


On July 17, a new PMT cable was installed. A few months later, the pre to post calibration shifts increased indicating that the performance of this cable was deteriorating. The instability in the calibration shifts (i.e. system delay) caused the increase in calibration RMS.

The LAGEOS range bias also moved more positive by more than 5 mm as the discriminator timewalk increased at the lowest receive energies.

The calibration RMSs and shift stabilized after the cable was replaced, but the biases were not reduced until the receive discriminator was realigned on 22-Jun-2019.

7105 Greenbelt Laser Fire Rates (5 vs 10 pps)



On Jul 11, 2010, a 7105 change enabled ranging at 10 pps. Sinc then calibration and LEO passes were taken at 10 pps, however, due to HP5370 and other system constraints, LAGEOS and HEOs were still taken at 5 and 4 pps; respectively.

Dependent upon the satellite range, the event timer upgrade enabled ranging to LAGEOS at either 5 or 10 pps and either 4 or 5 pps on HEOs ; respectively,.

Some characteristics (e.g. transmit energy) of the laser change between 5 and 10 pps. In this fire rate ground test presented here, there was average system delay change of 0.7 mm.

Summary and Conclusions

- The technique of comparing range bias from one satellite to another can identify mm level bias changes in a particular satellite.
- PMT voltage changes between calibration and satellite were inducing a few to several mm of range bias in station 7105 (Greenbelt).
- A combination of a bad PMT cable and excessive discriminator timewalk induced a +3 to +5 mm LAGEOS range bias in the period Sep-2018 to Jun-2019.
- When the PMT voltages weren't changing, LAGEOS and LARES range biases relative to Starlette were short by ~4 mm, while Ajisai and Etalon biases were long by several mm. Could we still have mm level errors in our geodetic CoM corrections?
- The ILRS Data Handling file needs to have another dimension, because biases can be satellite specific.