Analysis of 2022 ILRS Calibration and LAGEOS Moments

Van Husson

ILRS QCB

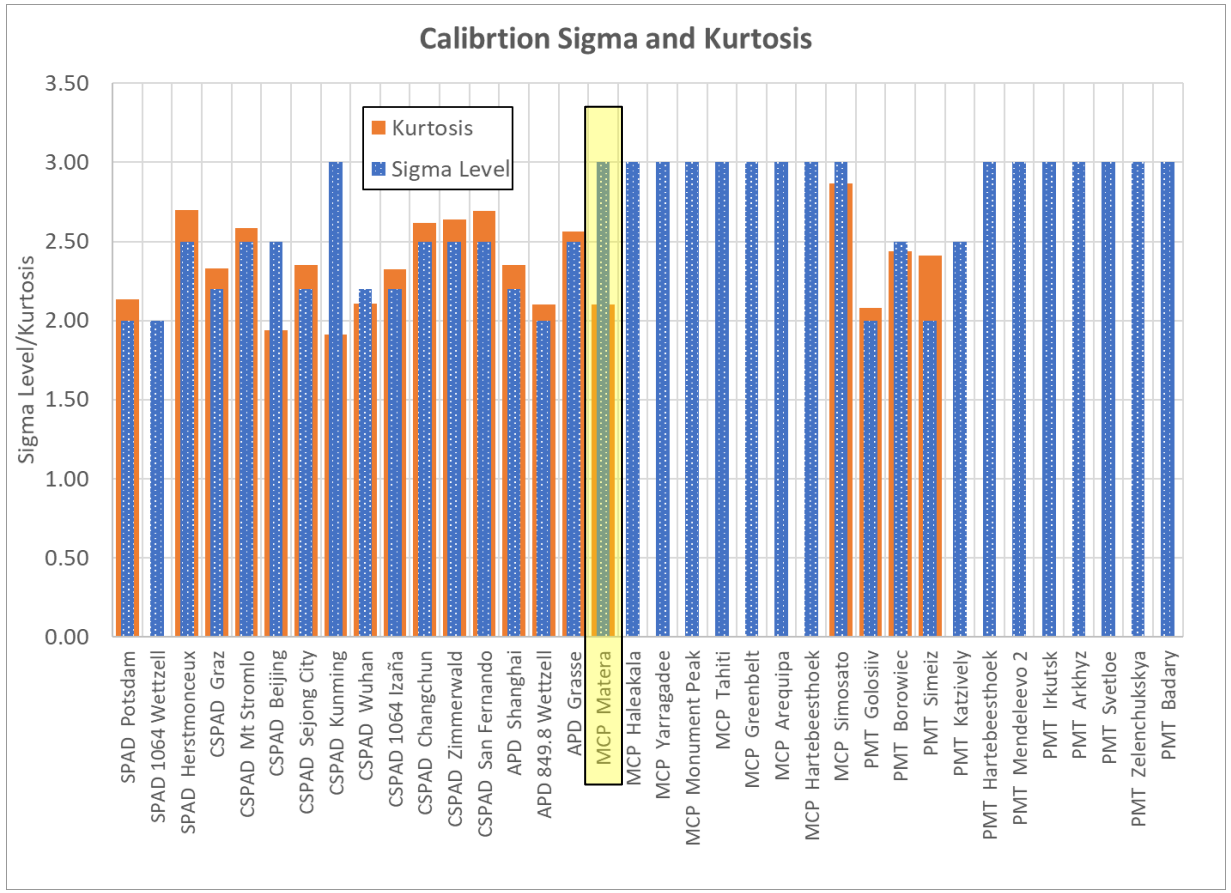
May 2023

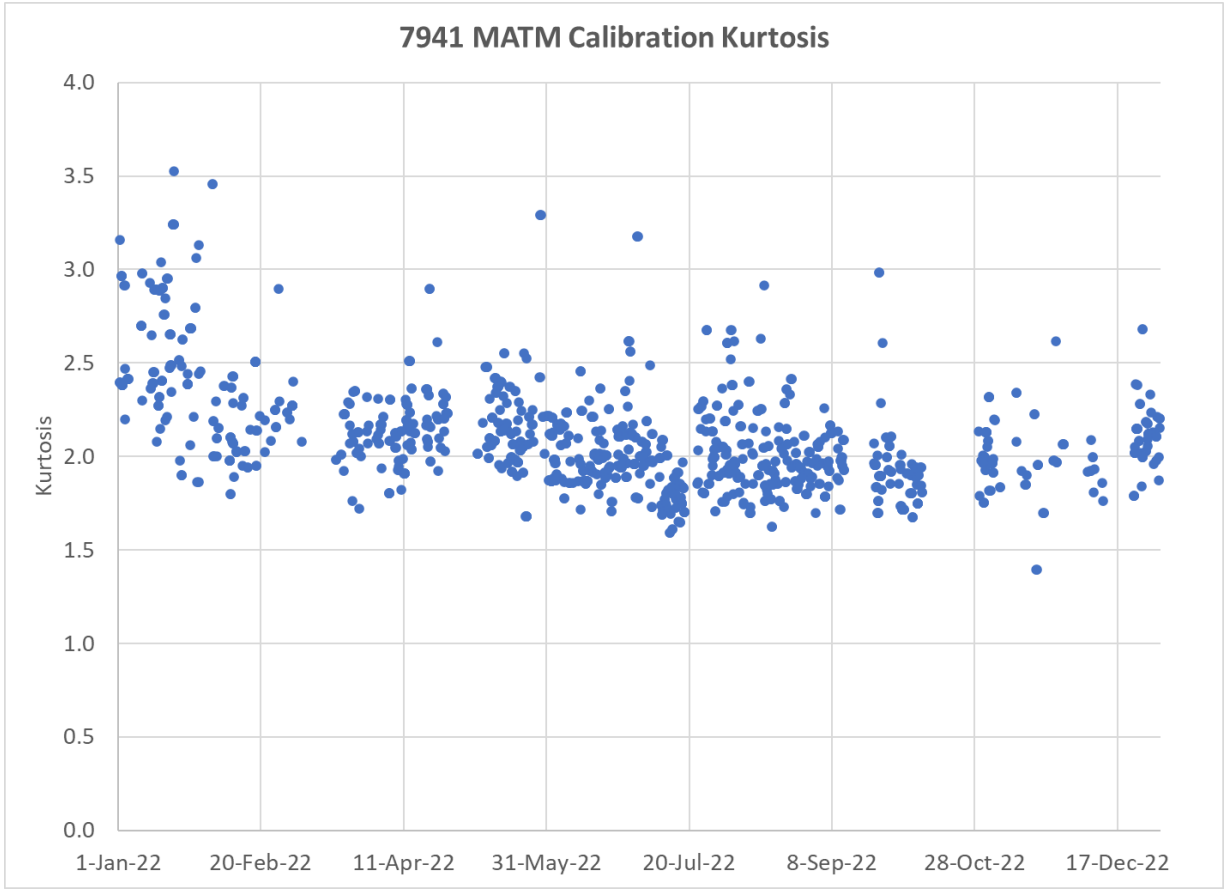
Peraton

Recap of Last QCB

- **Using Matt's OrbitNP, investigating a negative LAGEOS skew in Izana (7701) uncovered an undocumented LE edit criterion. The new station in Tsukuba (7306) was always using the same LE edit criteria. Both stations have since updated their site logs to indicate the LE edit criteria**
  - Matt noticed that the Izana and Tsukuba fullrate data filter flag was not properly set for excluded returns
  - Jose recommends that stations add excluded returns (e.g. within 5 sigma) to their CRD fullrate data, which will assist in computing satellite center of mass corrections
- **Action: Van was to investigate other apparent discrepancies between kurtosis and the calibration and satellite editing criteria in the site logs**

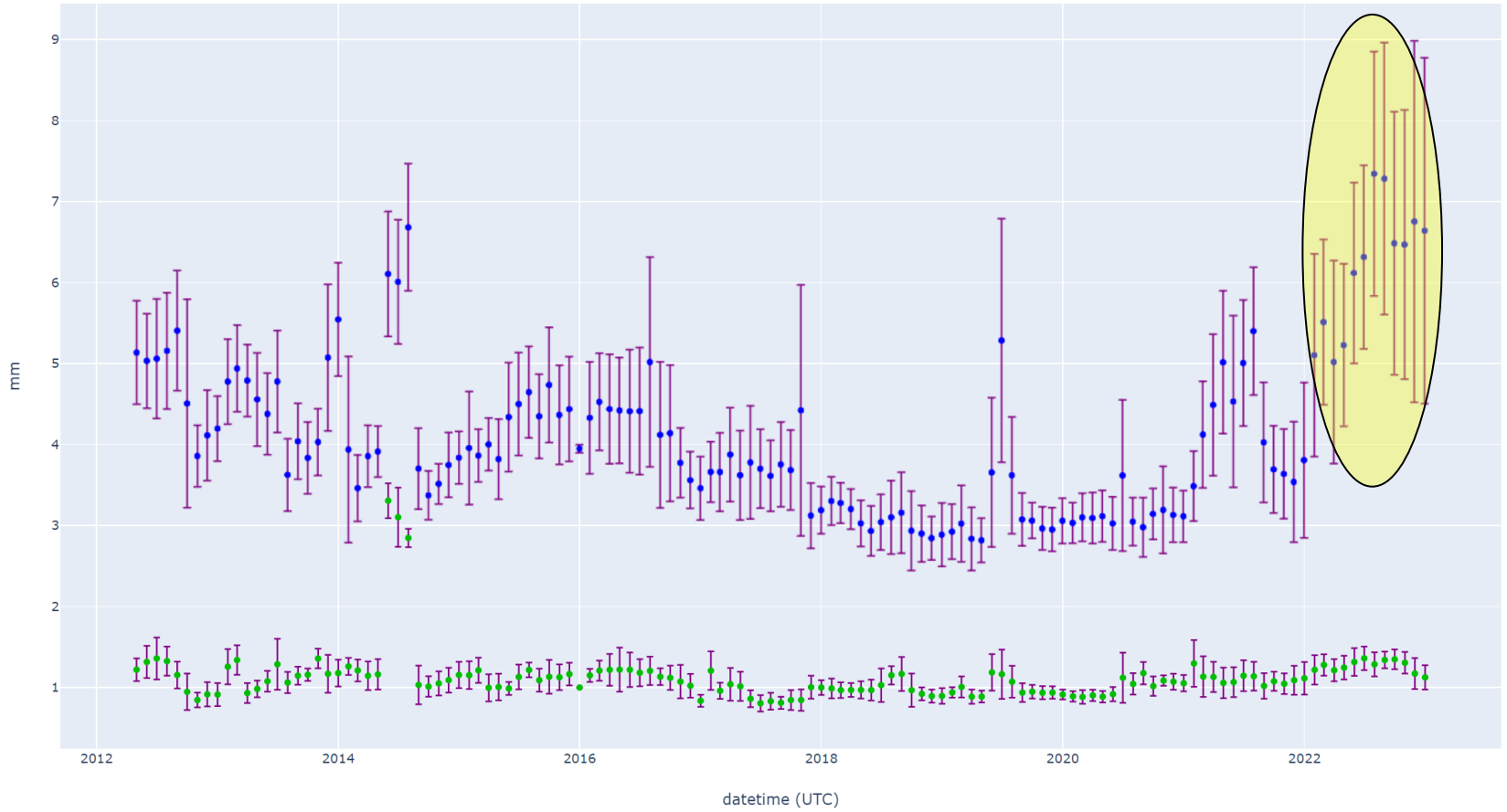
Sigma Level vs Kurtosis





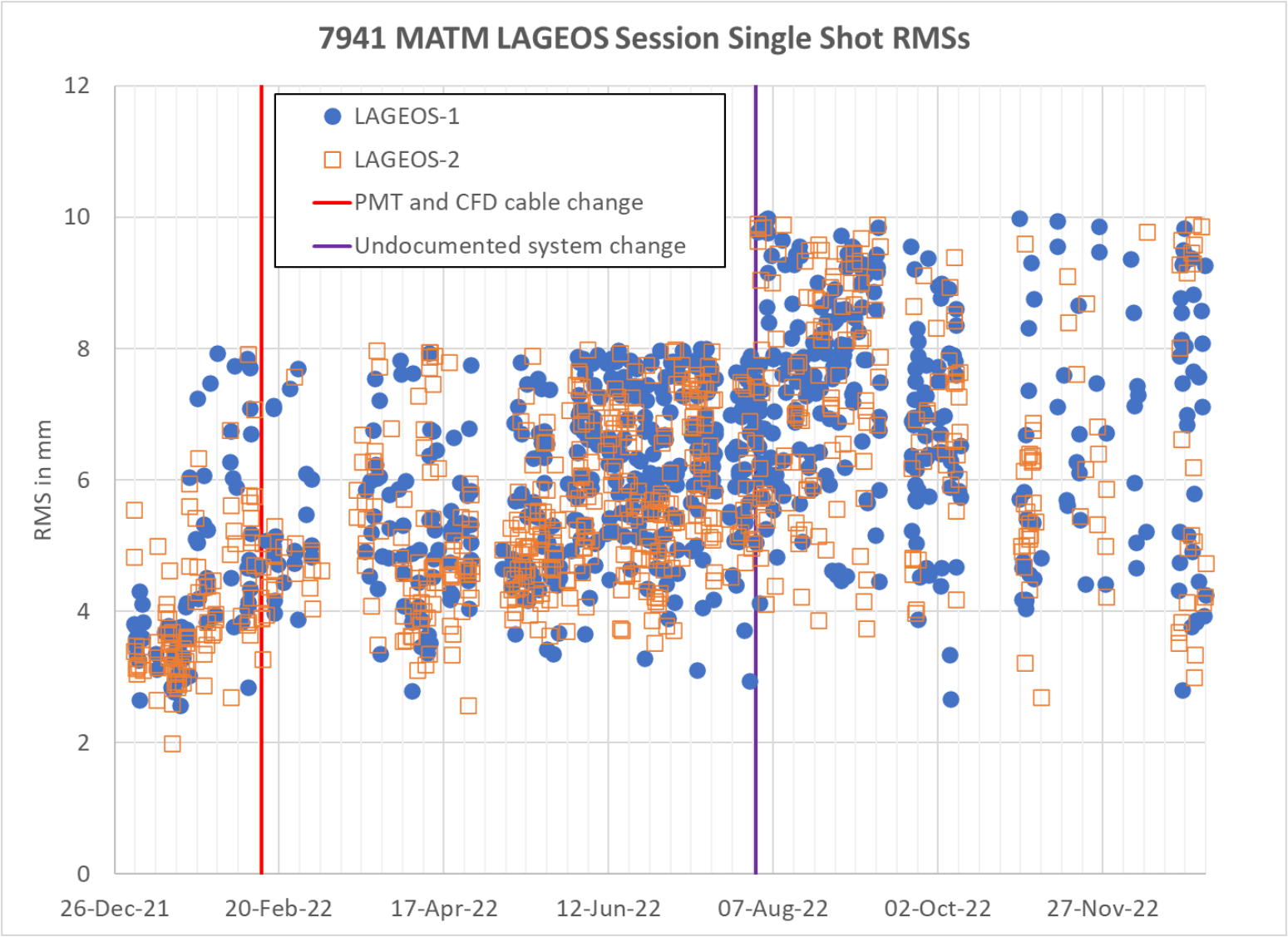
- Calibration sigma levels and kurtosis on the left chart. MLRO (7941 MATM) in Matera had a noticeable difference between the 3 sigma edit listed in their site log and the mean kurtosis value in their CRDs
- Right chart is a time series of 2022 Matera LAGEOS calibration kurtosis values
- MLRO is the only MCP station that automatically corrects for receive amplitude variations

7941 MATM Monthly LAGEOS and Calibration RMSs (Single Shot)



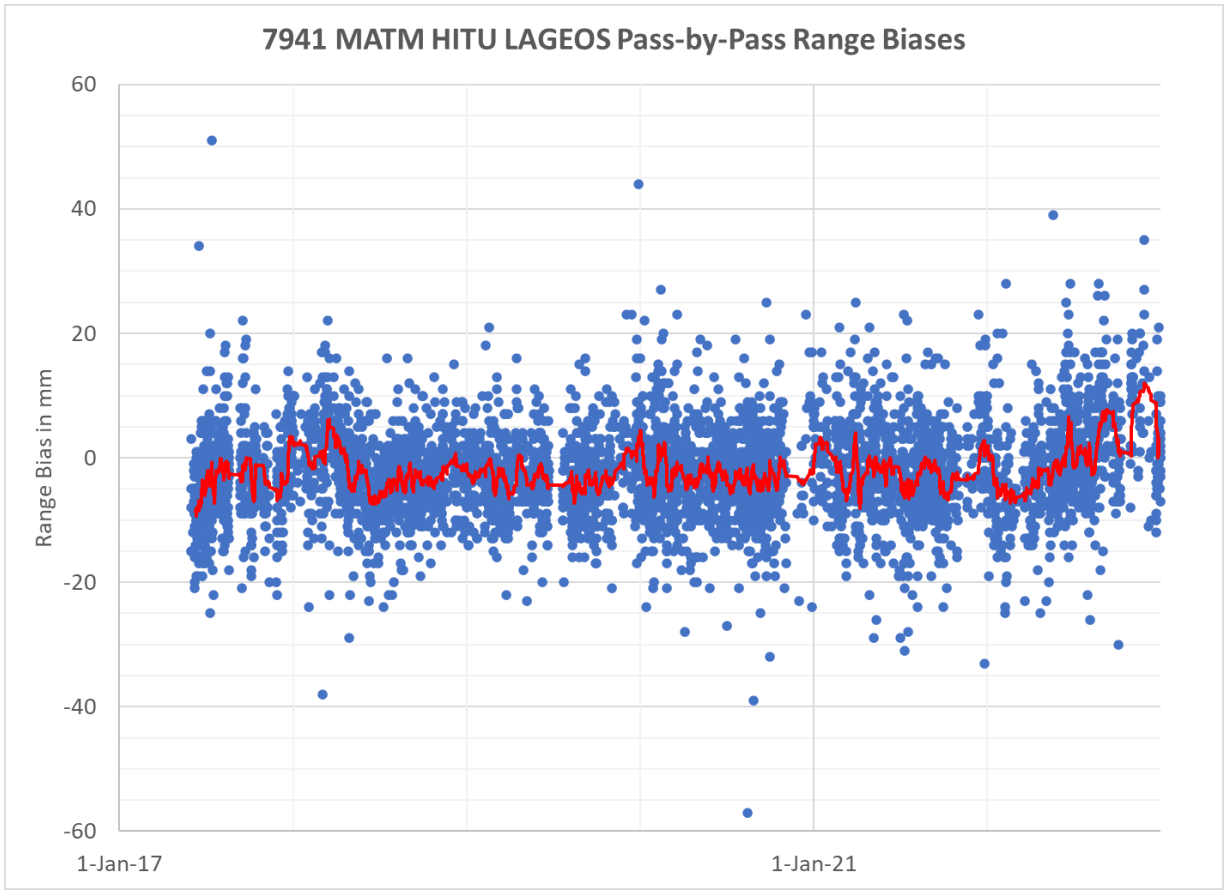
- 7941 MATM monthly LAGEOS and calibration RMSs from CRDs available on the ILRS website at: https://ilrs.gsfc.nasa.gov/network/stations/active/MATM_station_info.html?LAG
- Blue and green circles are LAGEOS and calibration RMSs; respectively
- The last increase in LAGEOS RMS (the yellow highlighted area) followed a system changes on 14-Feb-2022 (PMT replacement and CFD cable change)
- Cinzia said "the system was experiencing instability with the laser since last year and a new laser will be soon installed"

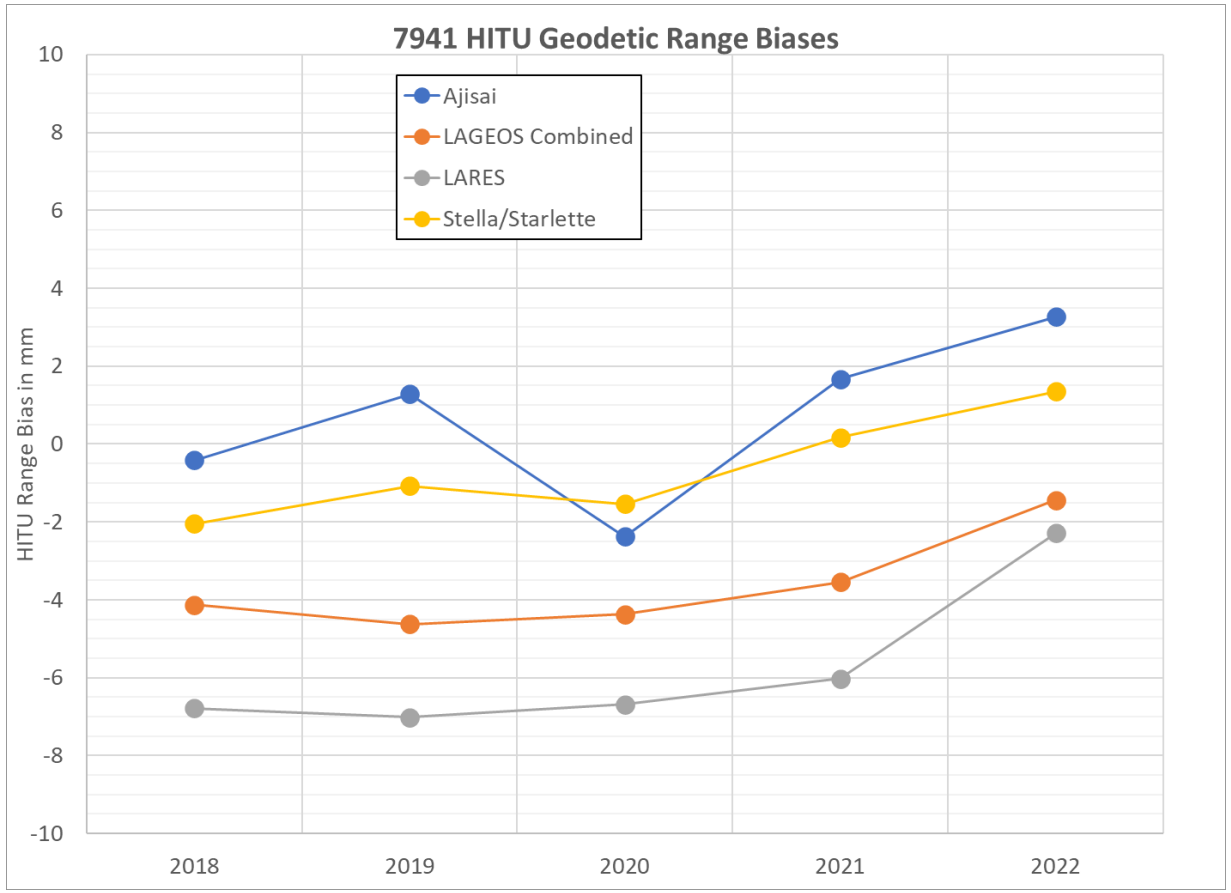
7941 MATM 2022 LAGEOS Session RMSs (Single Shot)



- Between July 31 and Aug 1, 2022, there was a noticeable increase in the LAGEOS RMS, but the only entry in the station history log https://edc.dgfi.tum.de/en/stations/7941/station_history_log/ around that time was on day 199 (July 18, 2022) when there was a cesium oscillator replacement
- Cinzia said "nothing was changed at the system level, but we stopped to make a manual and too strong cleaning of data trying to reduce the effect of the laser instability"

7941 MATM HITU Geodetic Range Biases





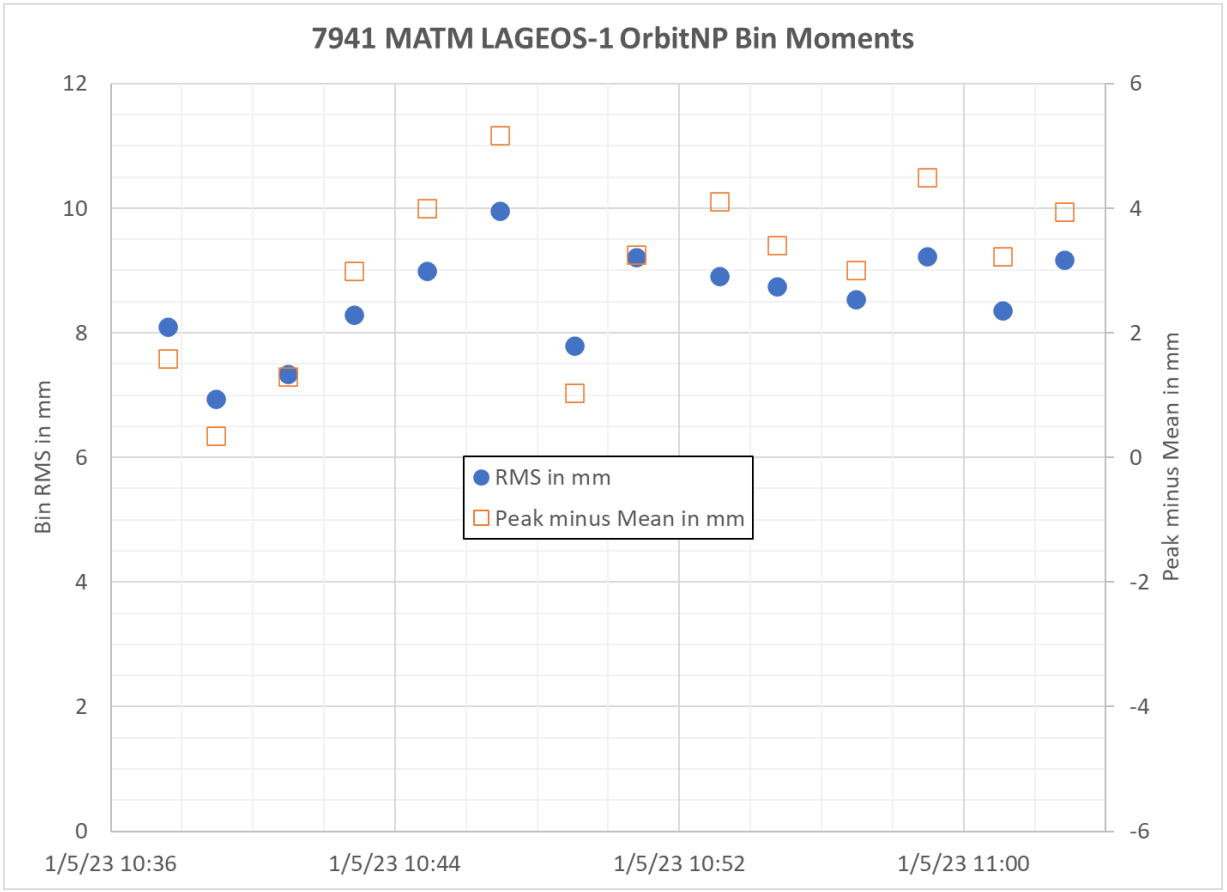
- Left chart: HITU LAGEOS pass-by-pass range bias estimates (ITRF 2014 coordinates)
- Right chart: HITU yearly geodetic ranges biases
- For 2018-2020 the yearly geodetic range bias were stable, but started to drift positive as the single shot RMSs increased after PMT and CFD changes

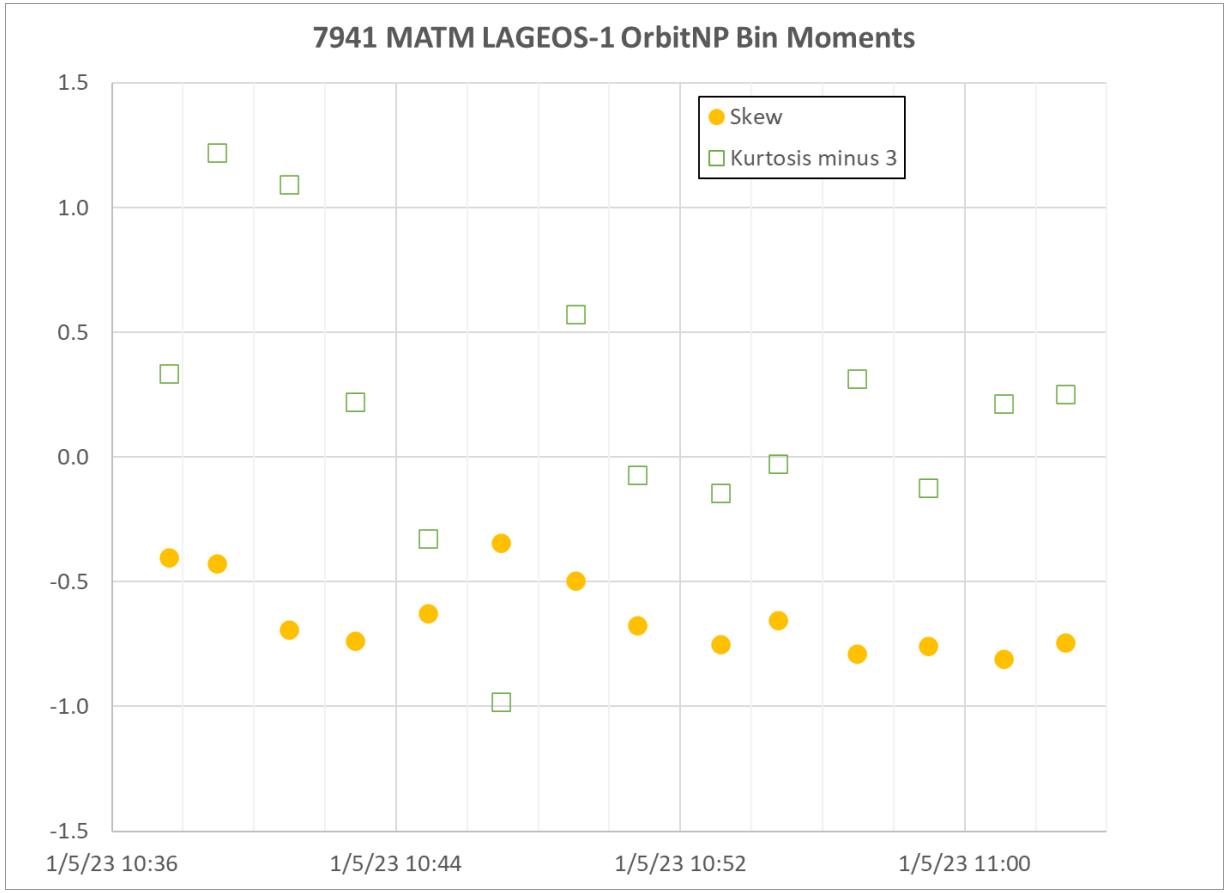
7941 MATM LAGEOS-1 Pass on 05-Jan-2023 at 10:36
Station Generated NPs vs OrbitNP NPs

Source	Seconds	Time of Flgiht	Obs	RMS in ps	skew	Kurtosis	Peak-Min in ps	Return Rate in %	Range Difference (mm)	RMS Difference in mm	Skew Difference	Kurtosis Difference	Retun Rate Difference
Onsite	38255.604000017100	0.054336473744	314	52.9	-0.405	0.175	na	26.2					
OrbitNP	38255.604000017100	0.054336473734	314	54	-0.404	0.336	10.6	47	1.44	-0.16	0.00	-0.16	-20.80
Onsite	38337.504000017000	0.052989262922	815	46.3	-0.414	1.128	na	67.9					
OrbitNP	38337.504000017000	0.052989262927	815	46.3	-0.425	1.22	2.3	68.1	-0.70	0.00	0.01	-0.09	-0.20
Onsite	38458.904000017100	0.051077876088	820	48.6	-0.695	1.09	na	68.3					
OrbitNP	38458.904000017100	0.051077876089	820	49	-0.692	1.093	8.7	68.4	-0.13	-0.06	0.00	0.00	-0.10
Onsite	38570.304000017000	0.049429096468	553	54.9	-0.753	0.257	na	46.1					
OrbitNP	38570.304000017000	0.049429096467	553	55.3	-0.736	0.22	20	46.7	0.10	-0.06	-0.02	0.04	-0.60
Onsite	38693.404000017100	0.047744698438	227	59.7	-0.62	-0.371	na	18.9					
OrbitNP	38693.404000017100	0.047744698438	227	60	-0.625	-0.328	26.7	20.1	-0.01	-0.04	0.01	-0.04	-1.20
Onsite	38817.204000017100	0.046219409246	130	66.3	-0.339	-0.97	na	10.8					
OrbitNP	38817.204000017100	0.046219409247	130	66.4	-0.344	-0.981	34.5	11.6	-0.16	-0.01	0.00	0.01	-0.80
Onsite	38942.704000017000	0.044871007764	715	51.7	-0.511	0.579	na	59.6					
OrbitNP	38942.704000017000	0.044871007767	715	52	-0.496	0.574	6.9	60.9	-0.51	-0.04	-0.02	0.01	-1.30
Onsite	39047.304000017000	0.043917573218	417	61.4	-0.679	-0.073	na	34.8					
OrbitNP	39047.304000017000	0.043917573217	417	61.5	-0.676	-0.073	21.7	34.8	0.15	-0.01	0.00	0.00	0.00
Onsite	39187.504000017000	0.042908194284	378	59.2	-0.749	-0.137	na	31.5					
OrbitNP	39187.504000017000	0.042908194285	378	59.4	-0.75	-0.143	27.4	31.7	-0.12	-0.03	0.00	0.01	-0.20
Onsite	39284.604000017100	0.042403375266	367	57.7	-0.649	-0.047	na	30.6					
OrbitNP	39284.604000017100	0.042403375267	367	58.3	-0.653	-0.027	22.7	34.3	-0.09	-0.09	0.00	-0.02	-3.70
Onsite	39418.104000017000	0.041984900877	507	57.2	-0.798	0.333	na	42.3					
OrbitNP	39418.104000017000	0.041984900878	507	57	-0.788	0.314	20.1	43.9	-0.12	0.03	-0.01	0.02	-1.60
Onsite	39538.604000017100	0.041890972946	213	61.3	-0.736	-0.157	na	17.8					
OrbitNP	39538.604000017100	0.041890972945	213	61.6	-0.757	-0.124	30	17.8	0.13	-0.04	0.02	-0.03	0.00
Onsite	39666.204000017100	0.042089279476	418	55.9	-0.786	0.22	na	34.8					
OrbitNP	39666.204000017100	0.042089279472	418	55.8	-0.808	0.213	21.5	35.7	0.60	0.01	0.02	0.01	-0.90
Onsite	39770.504000017000	0.042476753734	418	60.3	-0.664	0.105	na	34.8					
OrbitNP	39770.504000017000	0.042476753742	418	61.2	-0.744	0.252	26.3	36.9	-1.18	-0.13	0.08	-0.15	-2.10
								Ave	**-0.04**	**-0.05**	**0.01**	**-0.03**	**-2.39**

- ❑ **Bin epochs and observations agree exactly ☺**
- ❑ **Small differences in the Time of Flights (ToFs) due to bin RMS differences. Average difference is essentially zero ☺**
- ❑ **Small differences in the bin moments ☺**
- ❑ **Small differences in return rate except the first bin ☺**
- ❑ **The onsite program does not compute bin peak minus mean**

7941 MATM LAGEOS-1 Pass on 05-Jan-2023 at 10:36 (OrbitNP Bin Moments)

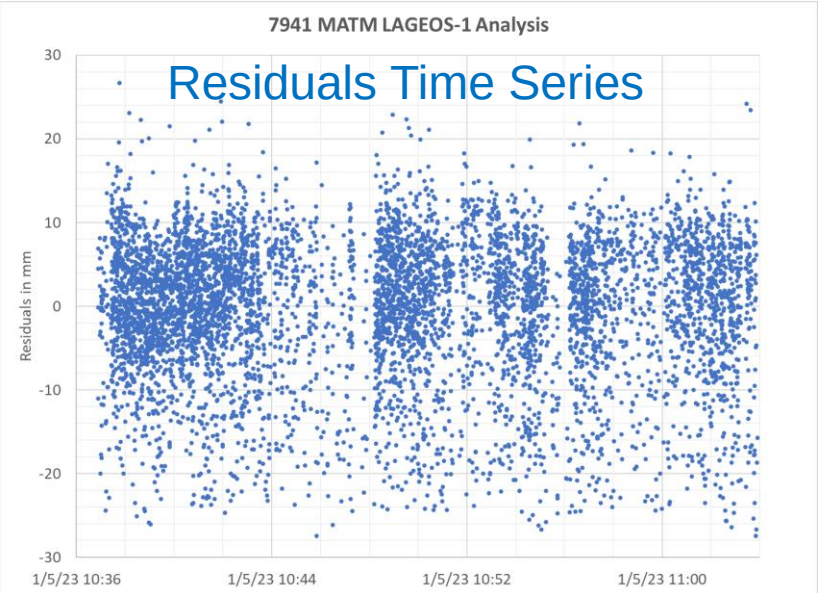


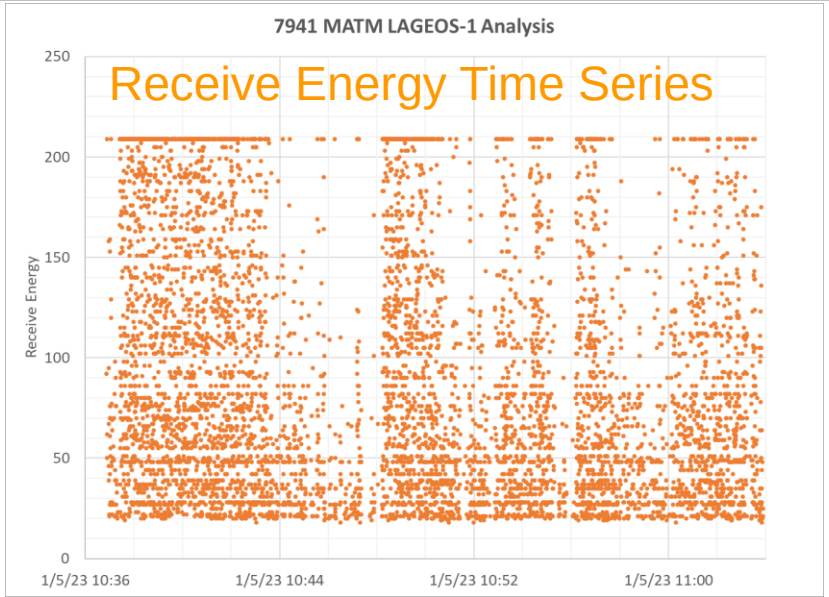


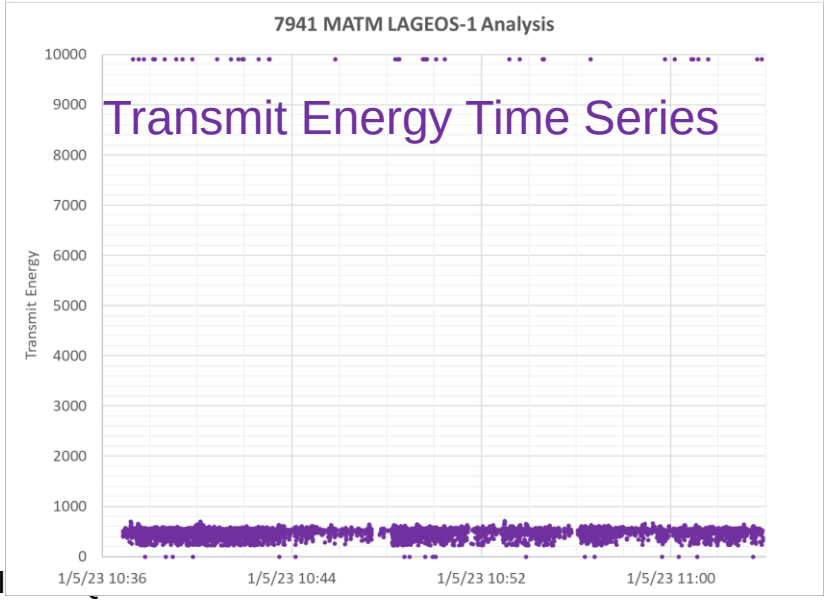
	Skew	Kurtosis	Peak-Mean
RMS Correlation with	-0.141	-0.937	0.946

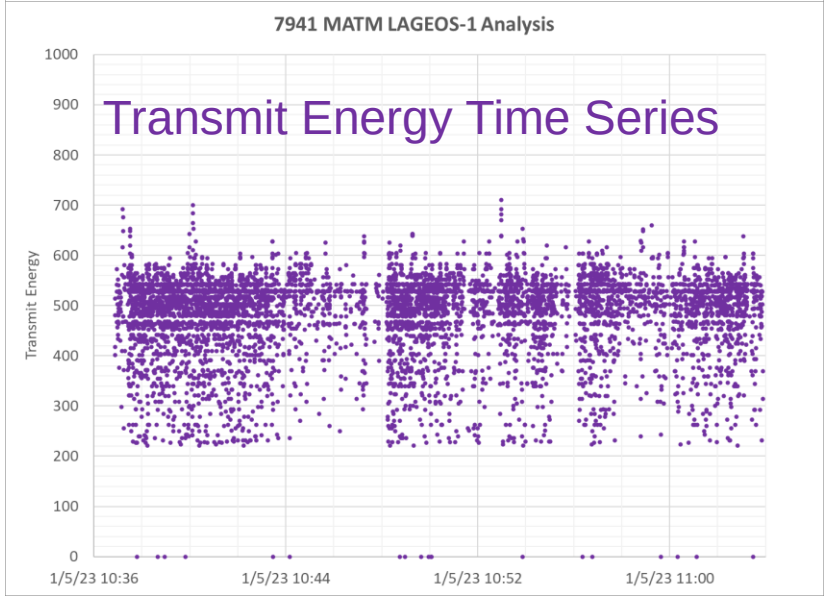
- Left chart: Bin RMS and peak minus mean
- Right chart: Bin skew and kurtosis
- Positive correlation between bin RMS and peak-mean
- Negative correlation between bin RMS and kurtosis

7941 MATM LAGEOS-1 Pass on 05-Jan-2023 at 10:36



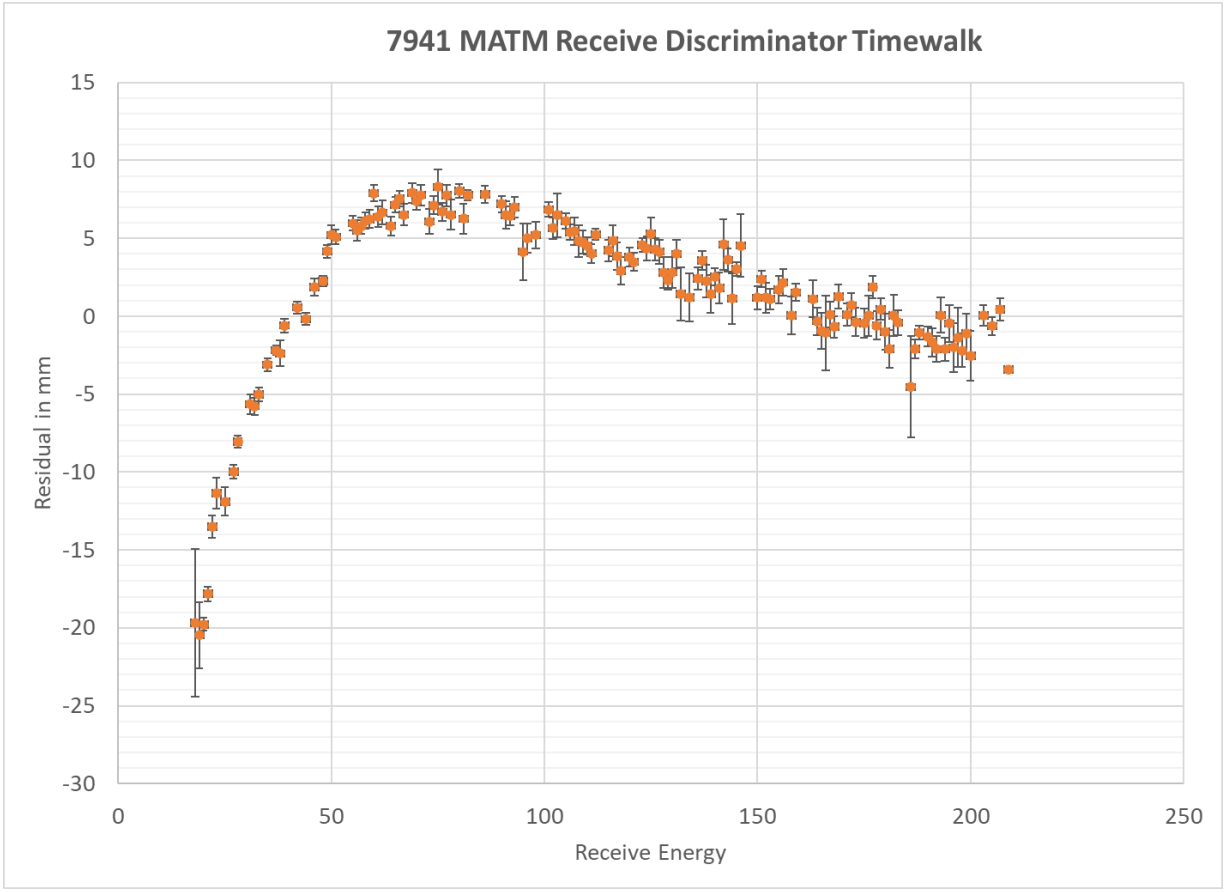


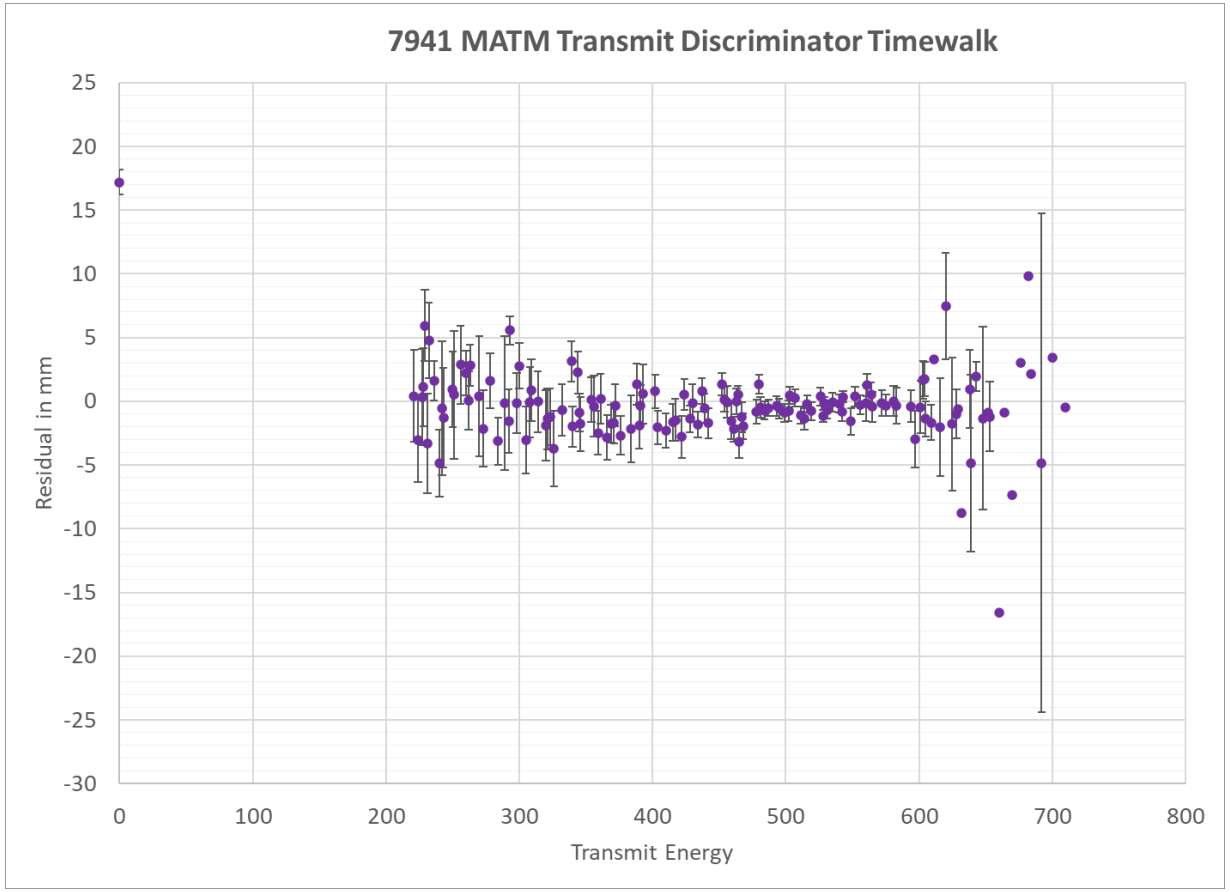




- Top left chart: LAGEOS-1 residuals are skewed negative
- Top right chart: No receive energies below 18 and some receive energies stuck at 209
- Bottom Left Chert: Some Transmit Energies stuck at zero at 9900
- Bottom Right Chart is a zoom-in of the Bottom Left Chart
- Is there a correlation between the residuals and receive or transmit energy?

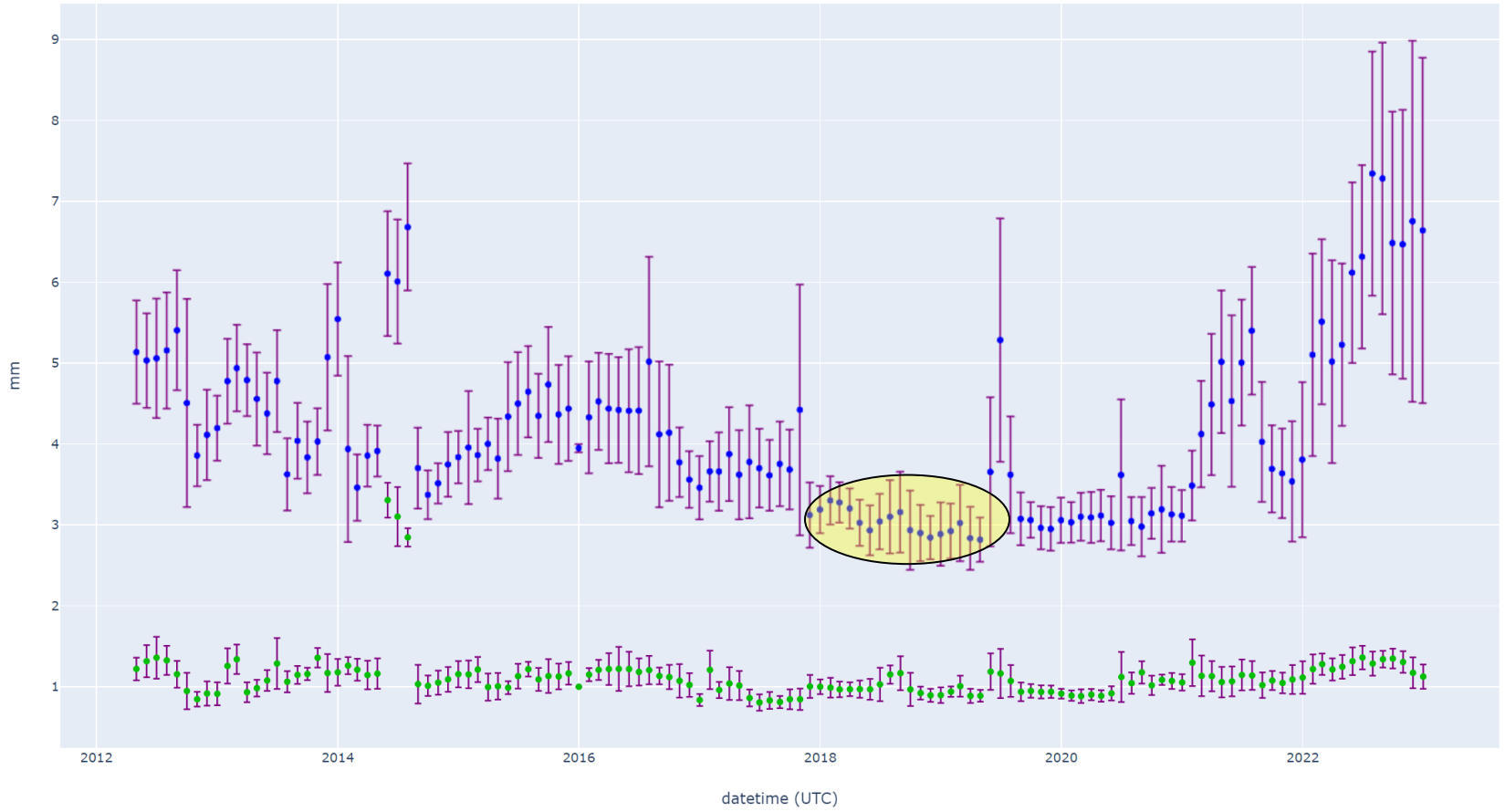
7941 MATM LAGEOS-1 Pass on 05-Jan-2023 at 10:36





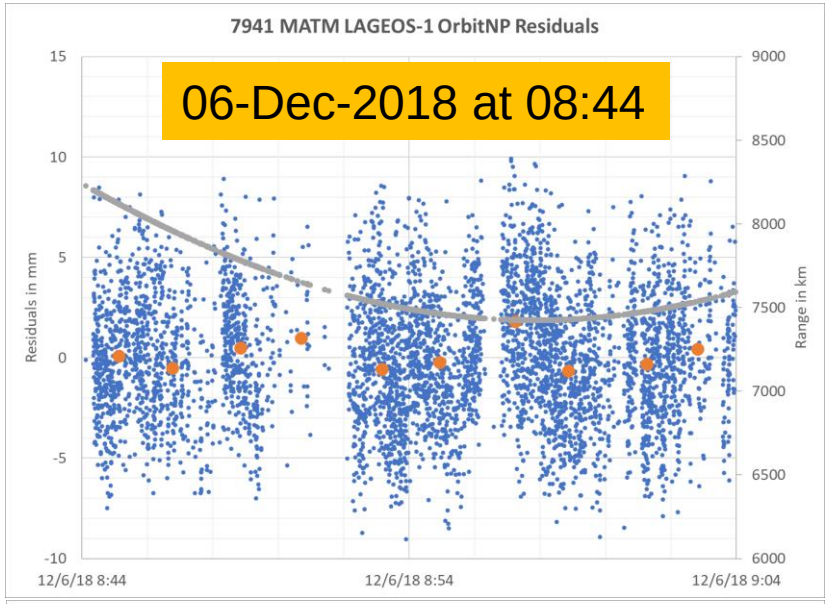
- Left Chart: Excessive Receive Discriminator Timewalk (>20 mm)
- Right Chart: Transmit Discriminator Timewalk. Ignoring the zero transmit energy value, the timewalk curve is relatively flat

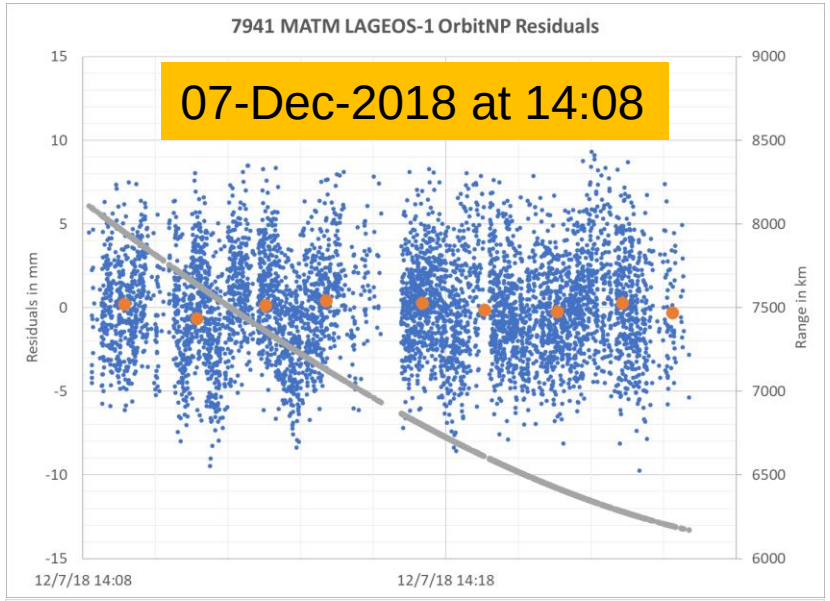
7941 MATM Monthly LAGEOS and Calibration RMSs (Single Shot)

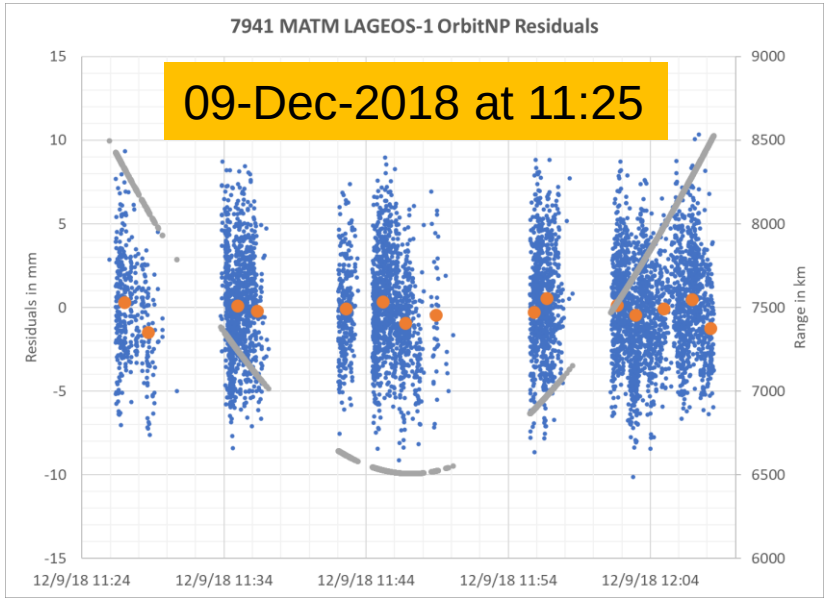


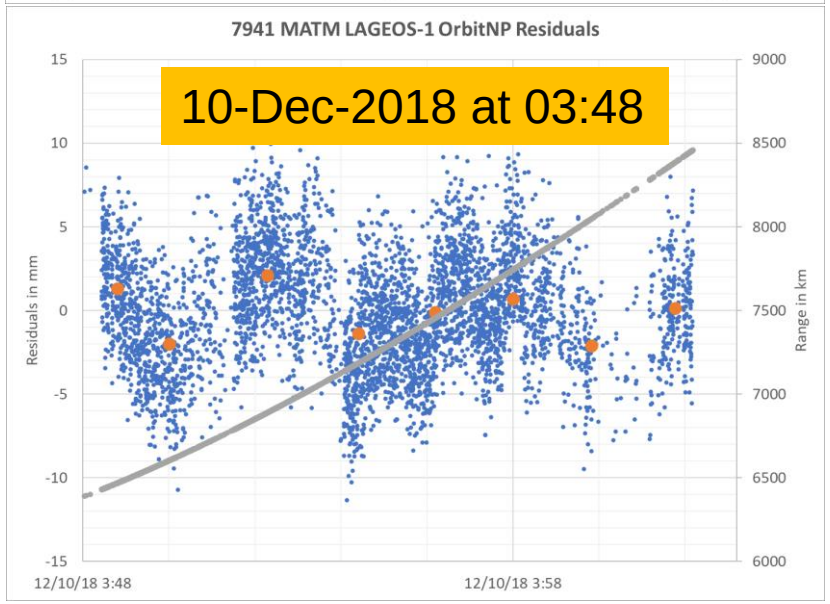
- In 2018 and 2019, MLRO LAGEOS single shot RMSs were sometimes below 3 mm
- The lowest single shot RMS from SPAD systems using a 2 cm LE filter is 5 mm

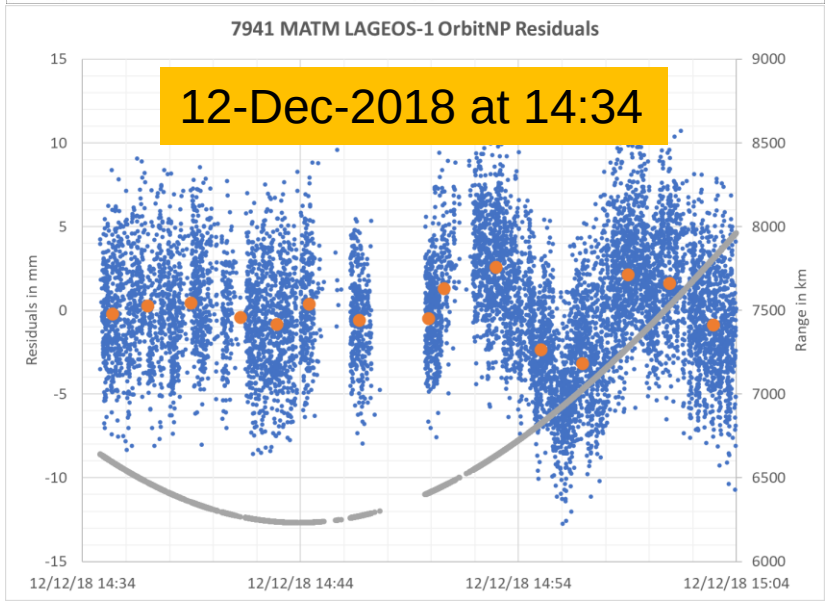
7941 MATM LAGEOS-1 OrbitNP Analysis





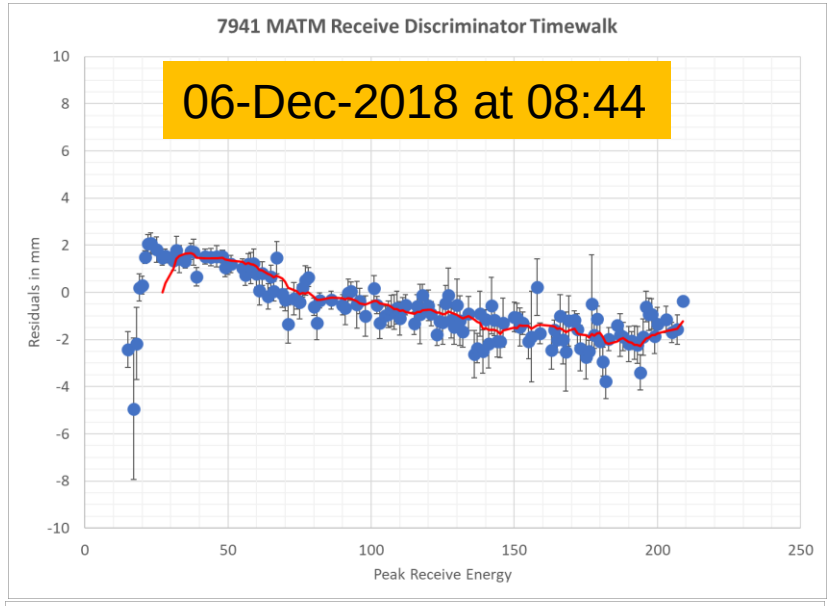


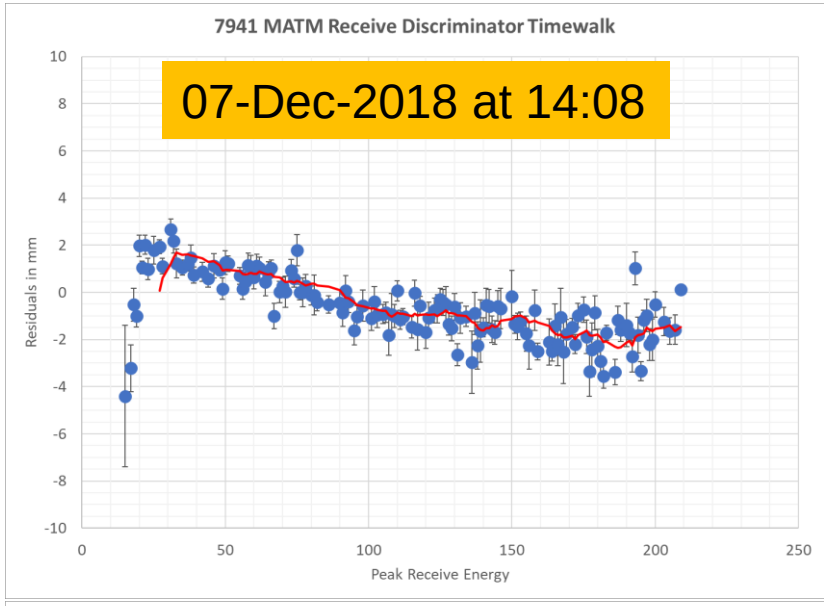


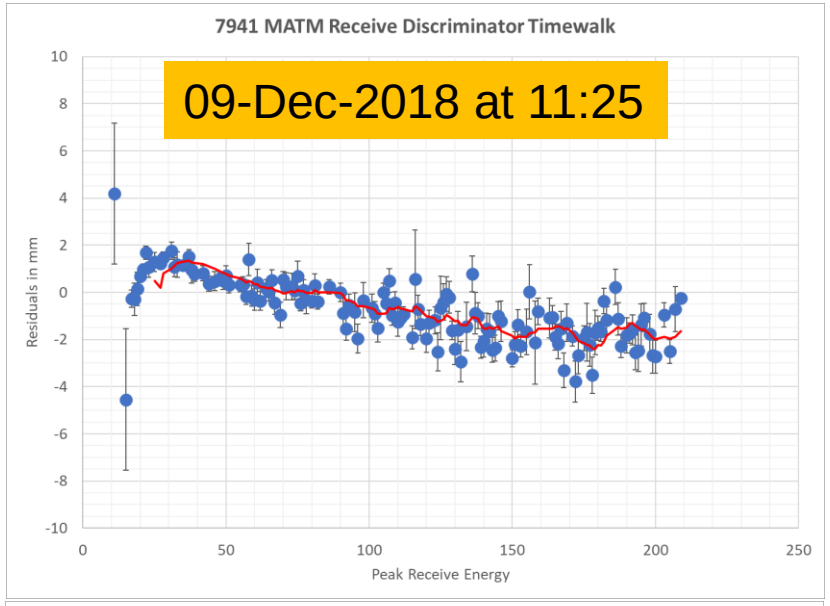


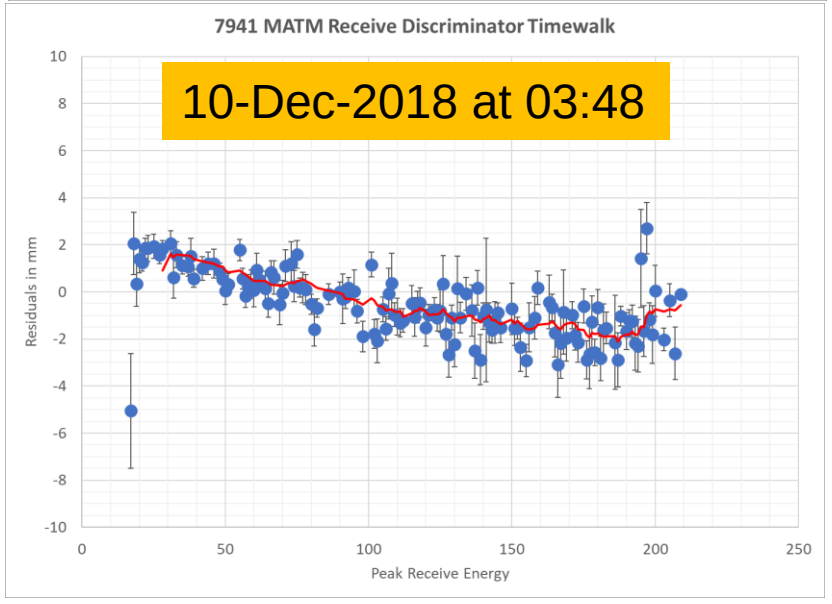
- **There are some interesting trends in the residuals (e.g. 10-Dec-2018 and 12-Dec-2018).**
- **Could these trends be caused by LAGEOS-1 velocity aberration and/or changes in the far field diffraction pattern?**
- **The next slide shows the residuals as a function of receive energy on these same passes.**

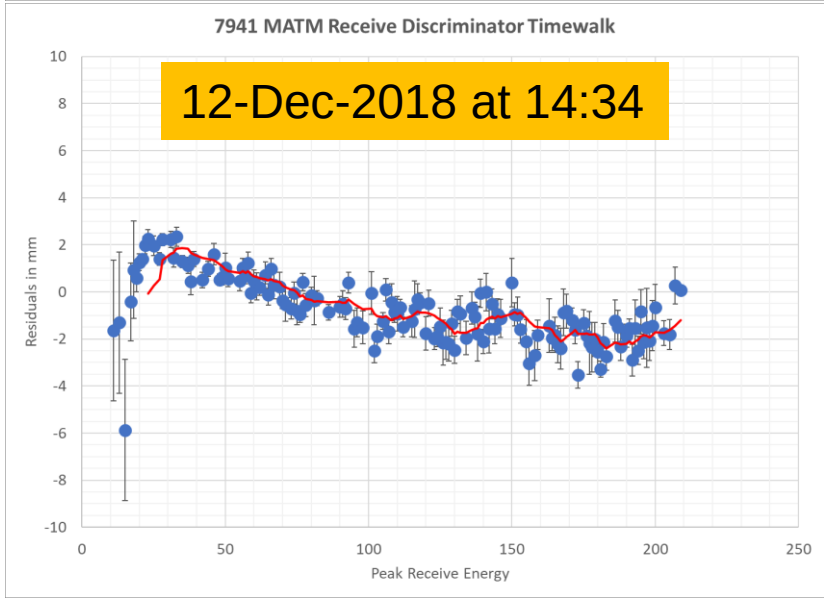
7941 MATM LAGEOS-1 Receive Energies Analysis

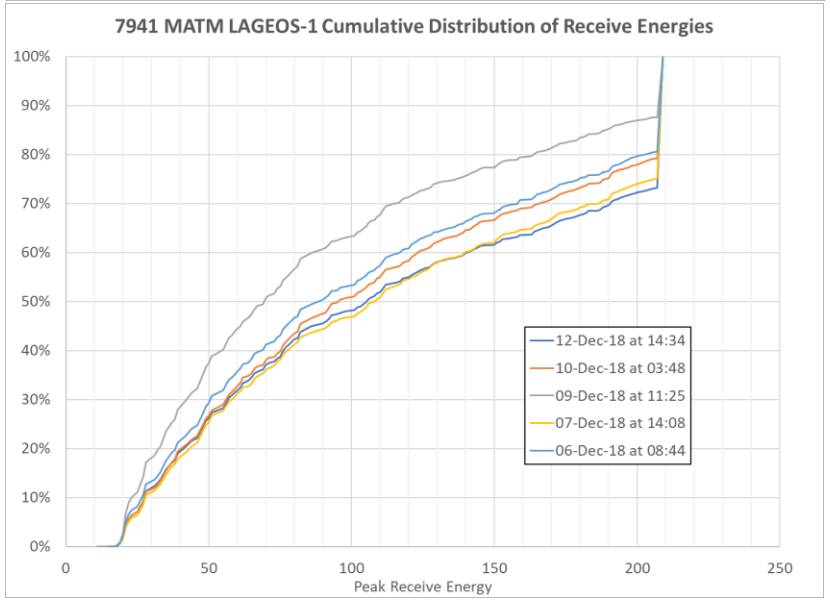




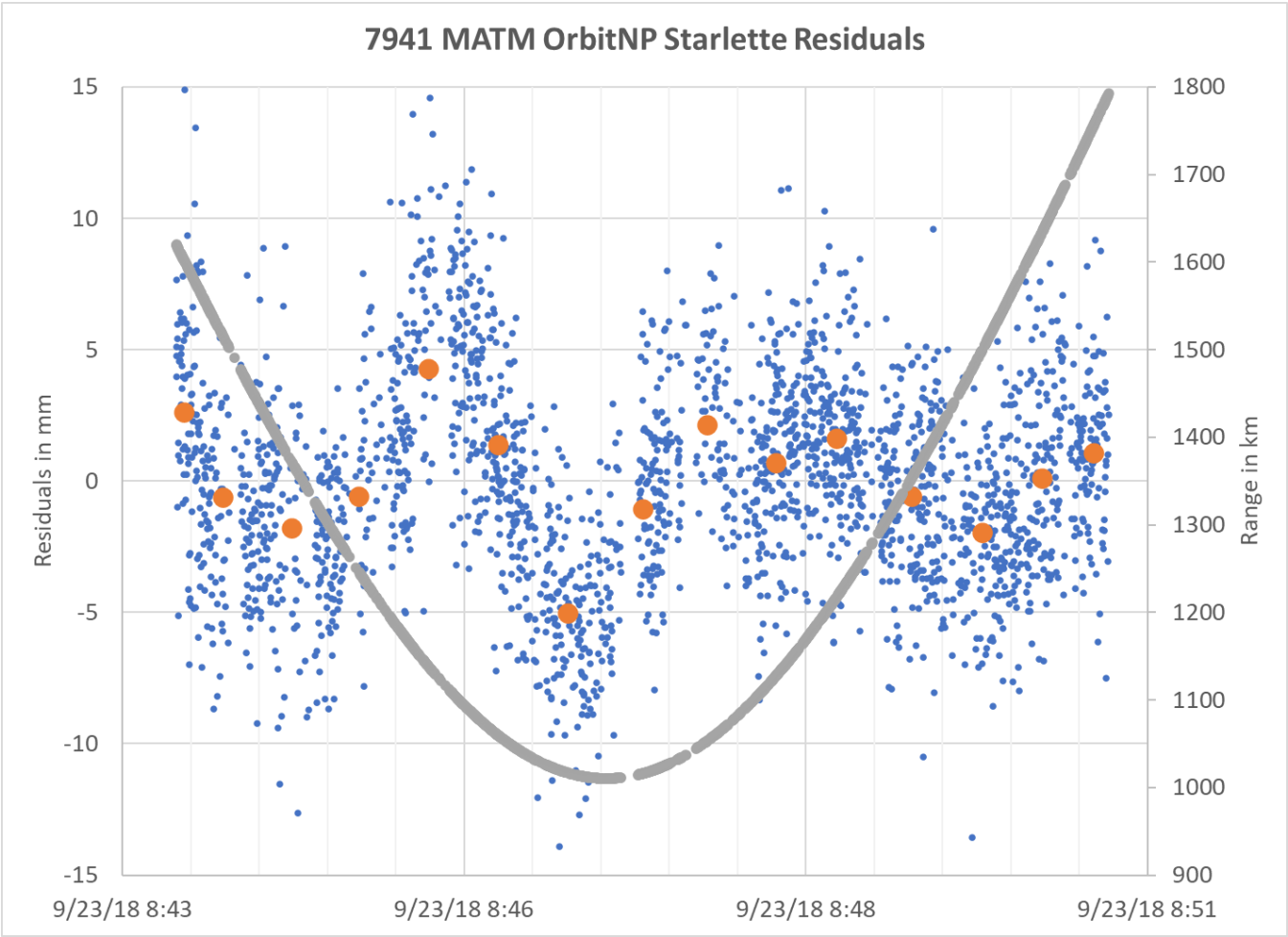








A MLRO Starlette pass in September 2018



- In Toshi's pass-by-pass analysis, the NP precision on this pass was 2 mm and the single shot RMS was 3 mm.
- Could these trends be caused by Starlette velocity aberration and/or changes in the far field diffraction pattern?

Summary/Questions/Conclusions

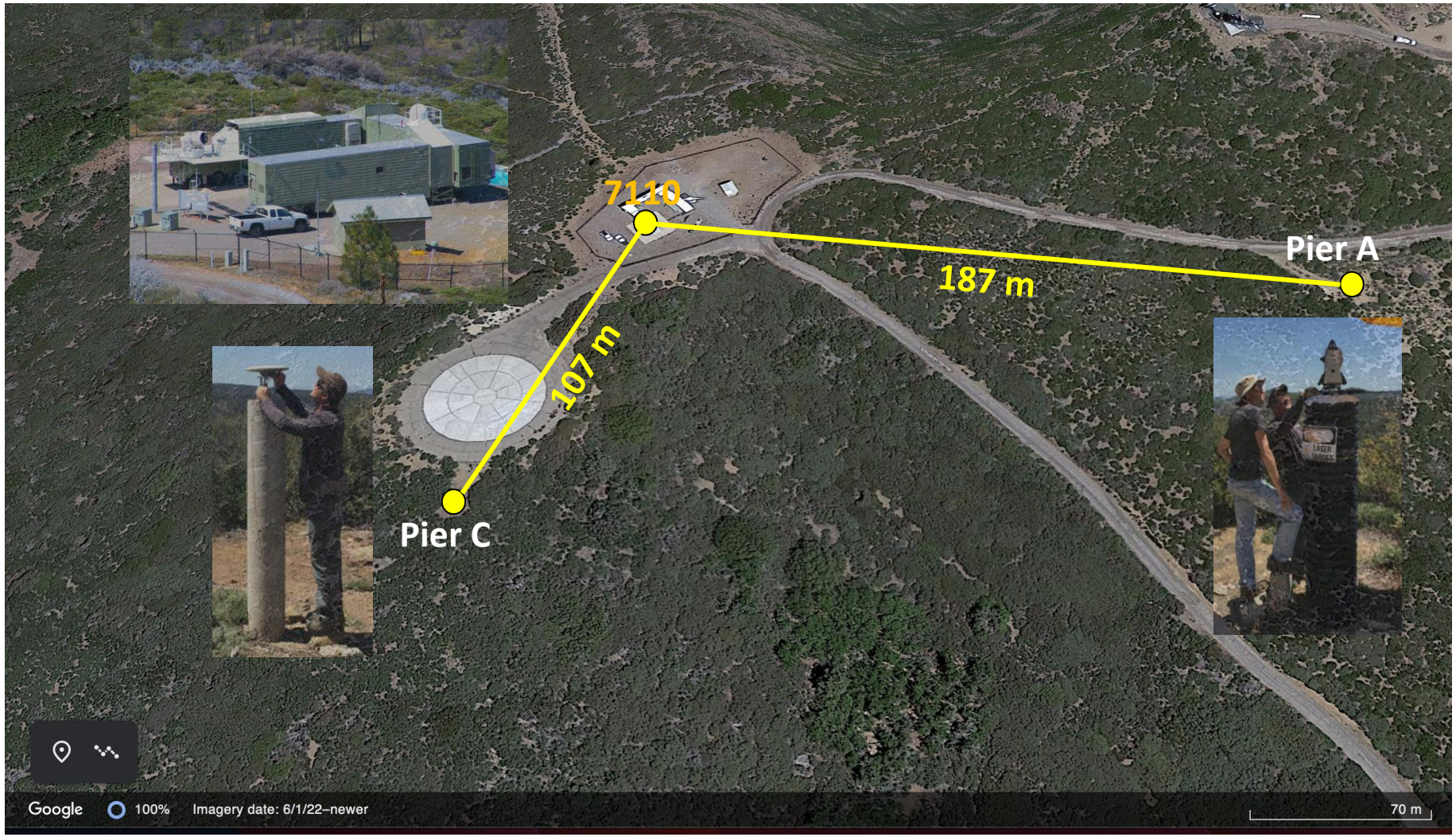
- MLRO data quality was degraded in 2022 due to laser instability and a few mm level bias change was detected on all geodetic satellites
- Has there been a problem with the receive energy measurement since the values seemed stuck at higher energies and does that impact the automatic correction for receive energy timewalk?
- What is the root cause of some of the interesting mm level residuals trends from OrbitNP on the geodetic satellites? Could these patterns be caused by the velocity aberration and/or changes in the far field diffraction pattern?
- Based on the LAGEOS receive energy analysis from data in December 2018, the higher receive energies are biased toward the leading edge. Based on a previous meeting, MOBLAS 4 (7110 MONL) exhibited a similar trend but with more peak-to-peak variation when the receive discriminator timewalk was modelled.

MOBLAS-4 (7110 MONL) MINICO Results

Van Husson

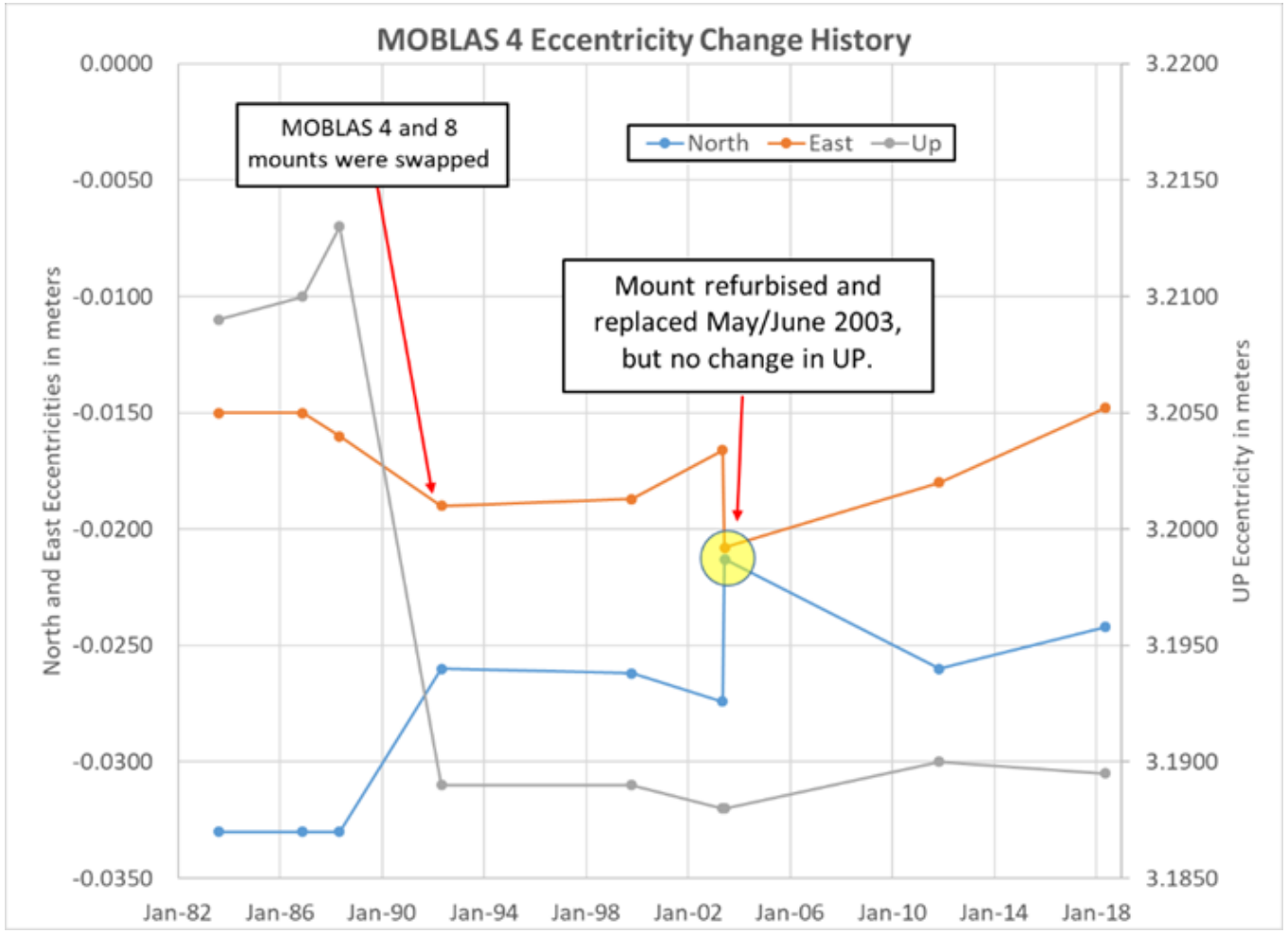
May 2023

MOBLAS-4 at 7110 MONL (Monument Peak)



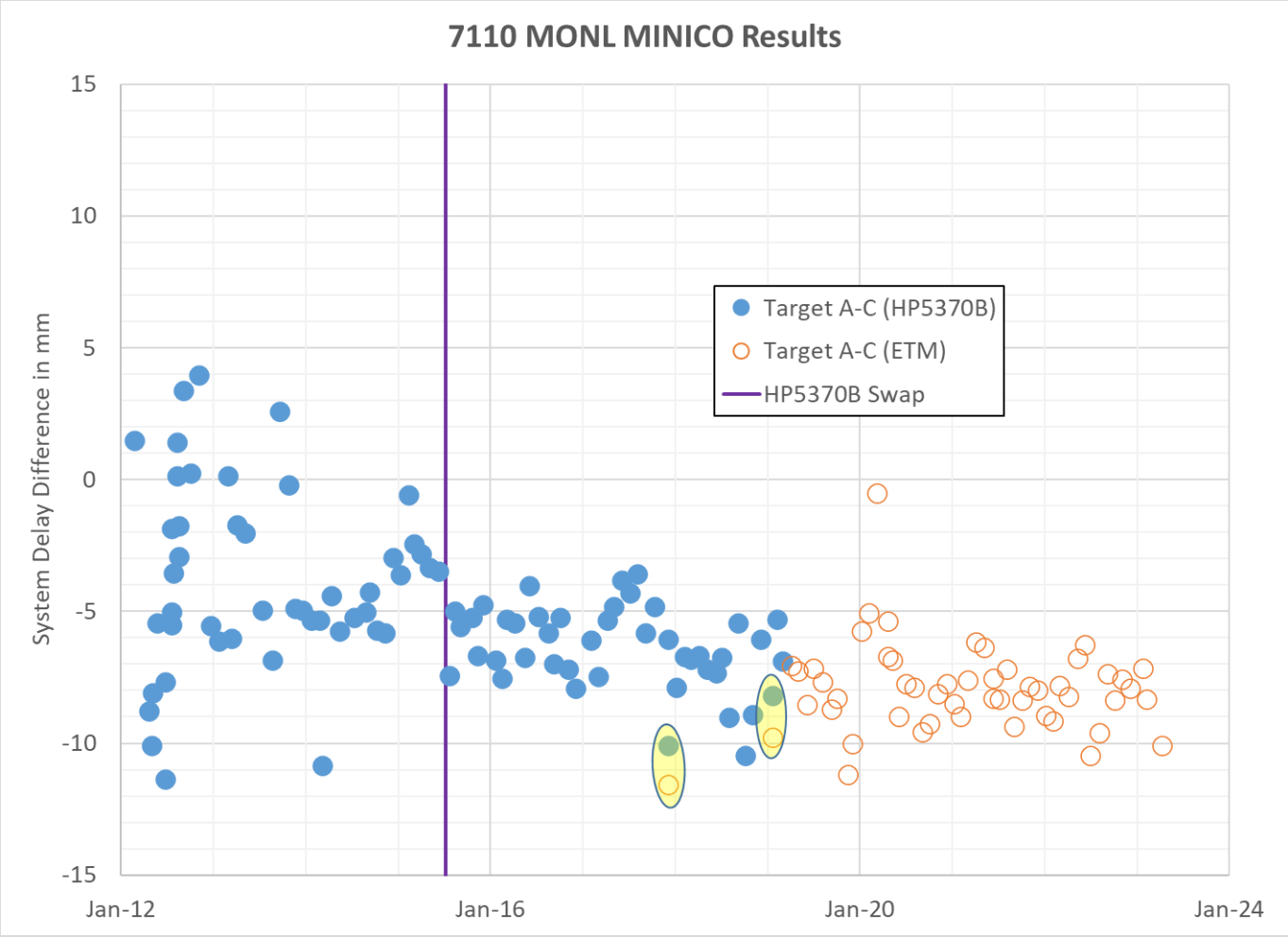
- MOBLAS-4 has two calibration targets A and C separated by more than 90 degrees. Target A is prime
- If the system reference point moved horizontally, the distance to both targets could change by different amounts

MOBLAS-4 Local Survey Results
System Eccentricities



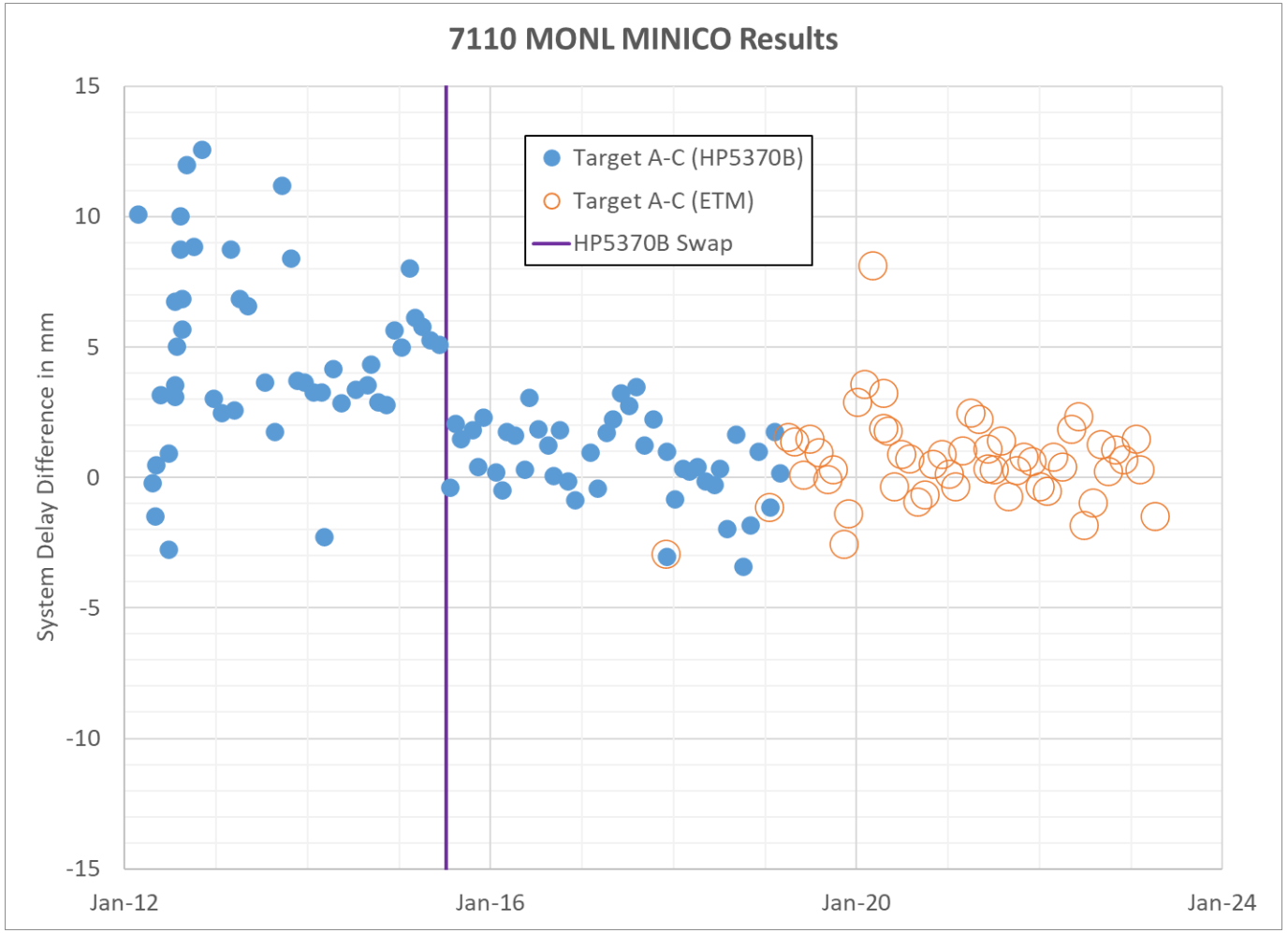
- Time series of MOBLAS-4 system eccentricities at 7110 MONL
- The last two surveys were in November 2011 and May 2018
- If the calibration targets remained stable, any horizontal changes in the System Reference Point (SRP) could alter the distance to the calibration targets

7110 MONL MINICO Results (based on November 2011 Survey)



- These are the HP5370B and ETM MINICO results based on the November 2011 survey
- The ETM became the operational time of flight measurement device in March 2019
- Notice that there were two MINICOs, highlighted in yellow, taken with both the HP5370B and the ETM with a consistent 1.5 mm offset. This offset is due to non-linearities in the HP5370B time interval unit
- This results indicate the Target distances have changed since November 2011
- A new survey was conducted in May 2018, 6.5 years after the previous survey (see next slide)

7110 MONL MINICO Results (based on May 2018 Survey)



- These are the HP5370B and ETM MINICO results retroactively applying the May 2018 survey results and removing the 1.5 mm HP5370B non-linearity bias
- The impact on HP5370B non-linearities prior to the last HP5370B swap on July 8, 2015, are unknown.
- Based on analysis by Troy Carpenter of the November 2011 and May 2018 surveys, there was few mm movement in both calibration piers and the invariant point with a net result of a relative 9 mm change in the two calibration target distances. The prime target distance changed more than 5 mm.
- Below are the MINICO summary statistics since July 2015 (eliminating one ETM outlier). The mean values are well within the uncertainty in the survey measurements

Statistic	ETM	HP5370B
Average Offset in mm	0.58	0.69
Standard Deviation in mm	1.27	1.55

Summary/Conclusions

- A 7110 +5.7 range bias since day 137, 2018 was documented in the Data Handling file pre ITRF2020 to account for the change in the prime target's distance. There could be other mm level range biases in the 7110 data, but this is a known error
- Below are the 7110 range bias estimates, in mm, from four altimeter satellites. In 2019, there was a 3 mm error in the Sentinel GNSS zenith delay increasing the range bias estimates for every SLR station by 3 mm

Satellite	2019	2020	2021	2022
Sentinel 3A	9.6	5.6	2.1	4.0
Sentinel 3B	10.2	5.4	2.0	4.2
Sentinel 6			2.4	5.3
Icesat		5.7		
Average	9.9	5.6	2.2	4.5

- Can we now update the onsite target distances to remove these known systematic errors in the MINICO results?
- The May 2018 local survey results (system eccentricities and target distances) can be back dated until least until July 8, 2015
- Based on the MINICO results, there is a good chance the 7110 range bias changed when the HP5370B counter was swapped with another HP5370B on July 8, 2015

Subject: [ilrs-cb] FW: Mt Stromlo 7825 CRD Data Integrity Issue
Date: Wednesday, May 17, 2023 at 9:04:17 AM Eastern Daylight Time
From: Husson, Van (PERATON) via ilrs-cb
To: ILRS Central Bureau, SLR Data Operations Center

FYI… I sent Mt Stromlo another email yesterday about their 20 and 21 records. Here is their quick response.
Regards, Van

From: Abdu Abohalima <aabohalima@eosspacesystems.com>
Sent: Tuesday, May 16, 2023 11:46 PM
To: Husson, Van (PERATON) <vhusson@peraton.com>
Cc: Chun Morton <cmorton@eosspacesystems.com>; Randall L <ricklefs@csr.utexas.edu>; Michael Lachut <mlachut@eosspacesystems.com>
Subject: [EXTERNAL] RE: Mt Stromlo 7825 CRD Data Integrity Issue

Hi Van,

Thanks for raising those points! Our report generating code is separate to our processing tool, we have recently updated the reporting code to fix some bugs. Those changes are consistent with the dates you mentioned. I'm not sure why the version of the code that includes the 21 records only includes 3 of the 20 records. I'll investigate this further and in the meantime will revert to the previous version of the code that covered the period March 30th to April 29th (without the 21 records).

Regarding the second issue related to the 20 records being too far from the H4 end time. In certain weather conditions, we recently had issues with our mets sensor that introduces gaps in the data collection. Our processing code takes the next available Mets record after the sensor resumes data collection. I was not aware of this as an issue, there has been no change regarding that part of the data processing. However, I'll flag this with our software team and work on a fix asap.

Cheers,
abdu

Abdu Abohalima
Technical Officer
Mob +61 431 156 168 | Main 02 6222 7981

From: Husson, Van (PERATON) <vhusson@peraton.com>
Sent: Wednesday, 17 May 2023 06:10
To: Abdu Abohalima <aabohalima@eosspacesystems.com>
Cc: Chun Morton <cmorton@eosspacesystems.com>; Randall L <ricklefs@csr.utexas.edu>
Subject: RE: Mt Stromlo 7825 CRD Data Integrity Issue

Dear Abdu,

I did a little more research into your CRD Normal Point data since 2022. It appears there are two different versions of your software that are being used when generating your CRD 20 and 21 meteorological records.

Below are the timespans were different meteorological processing algorithms appeared to be used:
Prior to September 16, 2022: no 21 Meteorological Supplement records and numerous 20 Meteorological records per CRD
September 16 – 27, 2022: three 21 and three 20 records per CRD
September 28-March 28, 2023: no 21 records and many 20 records per CRD
March 29, 2023: three 21 and three 20 records per CRD
March 30 to April 29, 2023: no 21 records and many 20 records per CRD
April 30 to the present: three 21 and three 20 records per CRD

When there are three 21 and three 20 records per CRD, the seconds of day in the very last 21 and 20 records are sometimes more than 1 hour after the end time listed in the H4 header record. According to our ILRS AutoQC algorithm (reference: https://ilrs.gsfc.nasa.gov/docs/2019/ILRS_OperationCenter_QCspecifications_v1.3.pdf), when this occurs, the data is to be flagged an ERROR. If CRD is flagged as an ERROR, the CRD is not supposed to forwarded to end users.

Since SLR data accuracy is very dependent upon accurate barometric pressure measurements, it is best to have 20 meteorological records that are in close proximity to the epochs (seconds of day) of the 11 range records. Some stations provide a 20 record whose epochs correspond to the epochs of each 11 record. The 21 meteorological records are optional and you are the only ILRS station that provides a 21 record.

Best regards and clear skies, Van
Van S Husson
NASA SLR Data Operations Center
ILRS Central Bureau

From: Abdu Abohalima <aabohalima@eosspacesystems.com>
Sent: Thursday, May 11, 2023 6:52 PM
To: Husson, Van (PERATON) <vhusson@peraton.com>
Cc: Randall L <ricklefs@csr.utexas.edu>; Chun Morton <cmorton@eosspacesystems.com>
Subject: [EXTERNAL] RE: Mt Stromlo 7825 CRD Data Integrity Issue

Hi Van,

Thanks for raising this with us, it appears to be a bug in the software in some rare cases. We will look into it and update the logs once corrected. We have not made any changes to the data processing software recently.

Cheers,
abdu

Abdu Abohalima
Technical Officer
Mob +61 431 156 168 | Main 02 6222 7981

From: Husson, Van (PERATON) <vhusson@peraton.com>

Sent: Friday, 12 May 2023 07:00
To: Abdu Abohalima <aabohalima@eosspacesystems.com>; Chun Morton <cmorton@eosspacesystems.com>
Cc: Randall L <ricklefs@csr.utexas.edu>
Subject: Mt Stromlo 7825 CRD Data Integrity Issue

Dear Mt Stromlo,

Recently, the following CRD pass segment failed our Automatic Quality Control (AutoQC). There are some erroneous 11 data records causing the 11 records to be out of time sequence. See the 11 records highlighted in yellow. Notice the seconds of day are all the same and the time-of-flights are very small and all the same.

This appears to be a software bug. If you have made any onsite data processing changes please update your station change history at https://edc.dgfi.tum.de/en/stations/7825/station_history_log/

Thanks for your attention,
Van
Van S Husson
ILRS Central Bureau
NASA SLR Data Operations Center (DOC)

```
H1 CRD  2 2023 05 05 03
H2      STL3 7825 90 01  4 ILRS
H3 lageos2 9207002 5986    22195 0 1 1
H4  1 2023 05 02 11 39 33 2023 05 02 11 49 47  0 0 0 0 1 0 2 0
C0 0 532.10 IDAA IDAB IDAJ IDAV IDAS IDAM IDAC
C1 0 IDAB Nd-YAG 1064.00 60.00 10.00 12.0 10.00 1
C2 0 IDAJ CSPAD 532.00 20.00 11.0 100.0 ECL 12.0 2.00 90.0 0.1 na na na 0
C3 0 IDAV TrueTime_XLi TrueTime_OCXO MRCS na 0.2322
C5 0 IDAS eosTrackingServer.exe 1-0-5 Profits 7.0
C6 0 IDAM Vaisala PTB330 M4620100 Vaisala HMP155 P4711022 Vaisala HMP155 P4711022
C7 0 IDAC STN 69.5920 1.22 0.0090 0.020 Profits 7.0
H5  1 23 050100 HTS 12100
40 38370.000000000000 0 IDAA 8831 2617 69.592 158313.5 -2.7 19.0 0.100 -0.400 -6.7 2 2 0 3 0.0
41 32280.000000000000 0 IDAA 4661 1387 69.592 158314.9 96.7 19.3 0.200 -0.400 -6.7 2 3 0 1 0.0
41 44460.000000000000 0 IDAA 4170 1230 69.592 158312.2 92.7 18.7 0.100 -0.400 10.7 2 3 0 2 0.0
11 41978.211648423778 0.049428551091 IDAA 2  120.0     6    42.00    0.06   -1.62      0.00    6.19  0     0.1
11 42026.349566728888 0.048910577539 IDAA 2  120.0    33    67.90    0.47   -0.67     22.30    9.79  0     0.1
11 41973.001515630429 0.000000025059 IDAA 2  120.0     0     0.00    0.00    0.00      0.00    0.00  0     0.0
11 42305.366233222579 0.046264265569 IDAA 2  120.0   142    62.90    0.66   -0.45      7.00   24.36  0     0.3
11 42365.182900026826 0.045784589990 IDAA 2  120.0    32    65.90    0.63   -0.73    -18.80   28.07  0     0.4
11 42551.316233225174 0.044515535039 IDAA 2  120.0   198    55.20    0.59   -0.59     -0.70   52.11  0     1.1
11 41973.001515630429 0.000000025059 IDAA 2  120.0     0     0.00    0.00    0.00      0.00    0.00  0     0.0
11 41973.001515630429 0.000000025059 IDAA 2  120.0     0     0.00    0.00    0.00      0.00    0.00  0     0.0
30 41972.881567999997 230.962569 36.592372 0  2 0 na na
30 41974.172960000011 230.921532 36.627617 0  2 0 na na
30 42588.198559999997 203.028409 51.930645 0  2 0 na na
```

20 41955.080474000002 926.53 282.14 92.0 0
21 41955.080474000002 2.70 354.09 clear na 0.00 na 0 259.45
20 41975.082474000003 926.52 282.15 91.9 0
21 41975.082474000003 2.50 347.79 clear na 0.00 na 0 260.55
20 43034.905356000003 926.60 281.95 94.3 0
21 43034.905356000003 1.90 330.02 clear na 0.00 na 11 252.85
50 IDAA 60.0 0.600 -0.500 -6.8 4
H8
H9

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