Preprocessing raw measurements to calculate NPT

E. Burmistrov, S. Kononayeva, P. Kupriyanov

(presented by Erricos C. Pavlis)

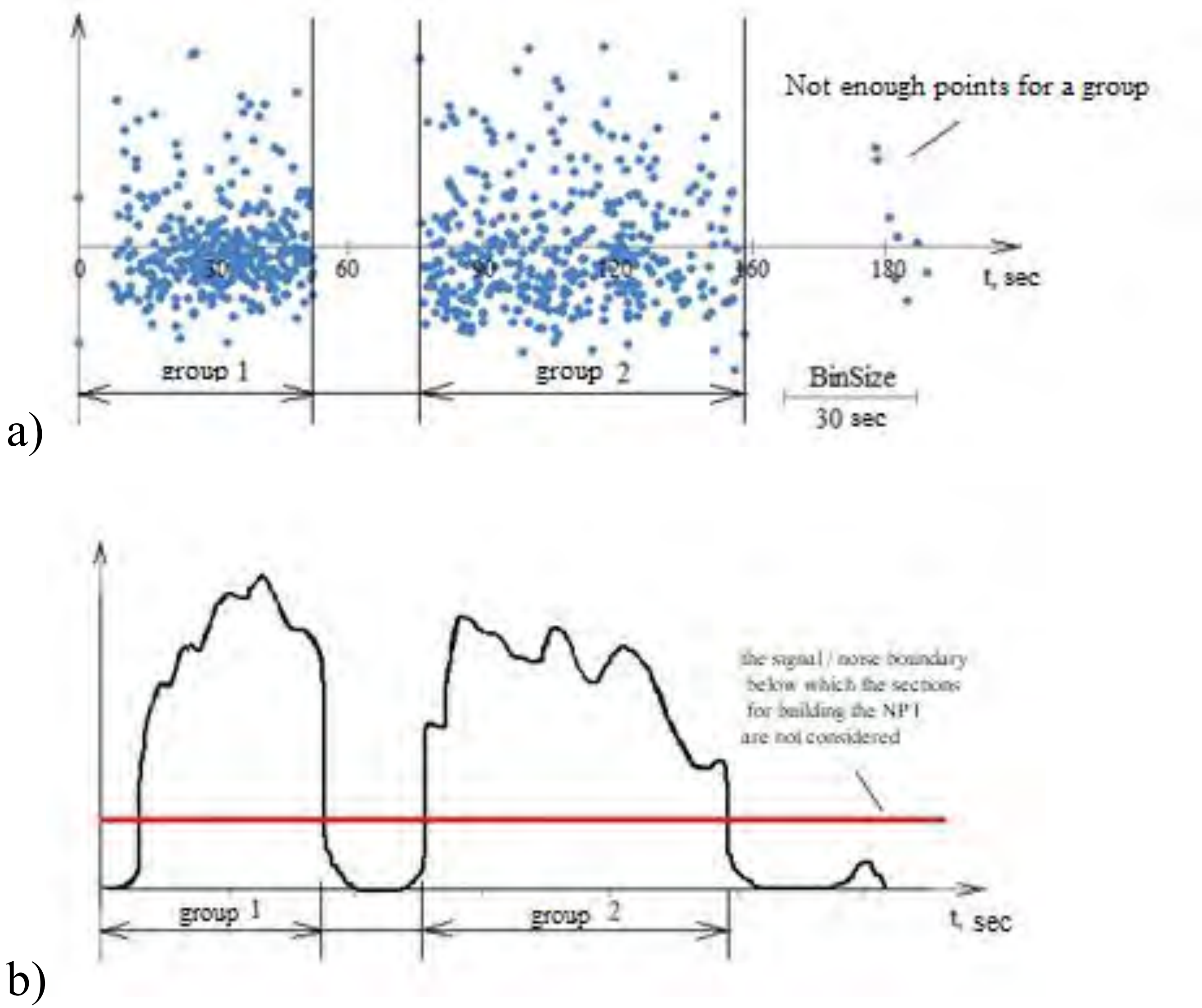


Figure 1. Dividing the session into groups based on the density of measurements along the session.

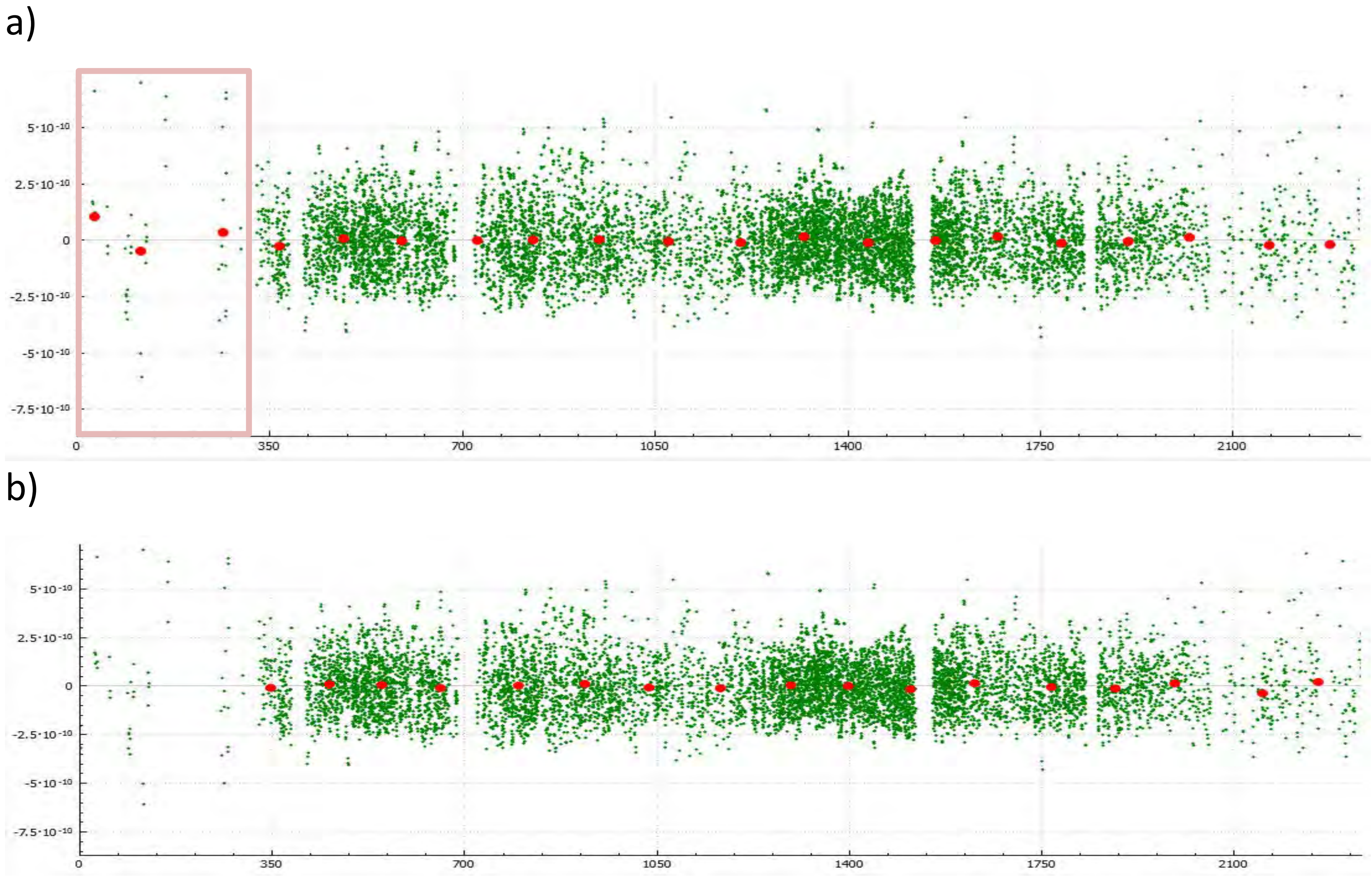


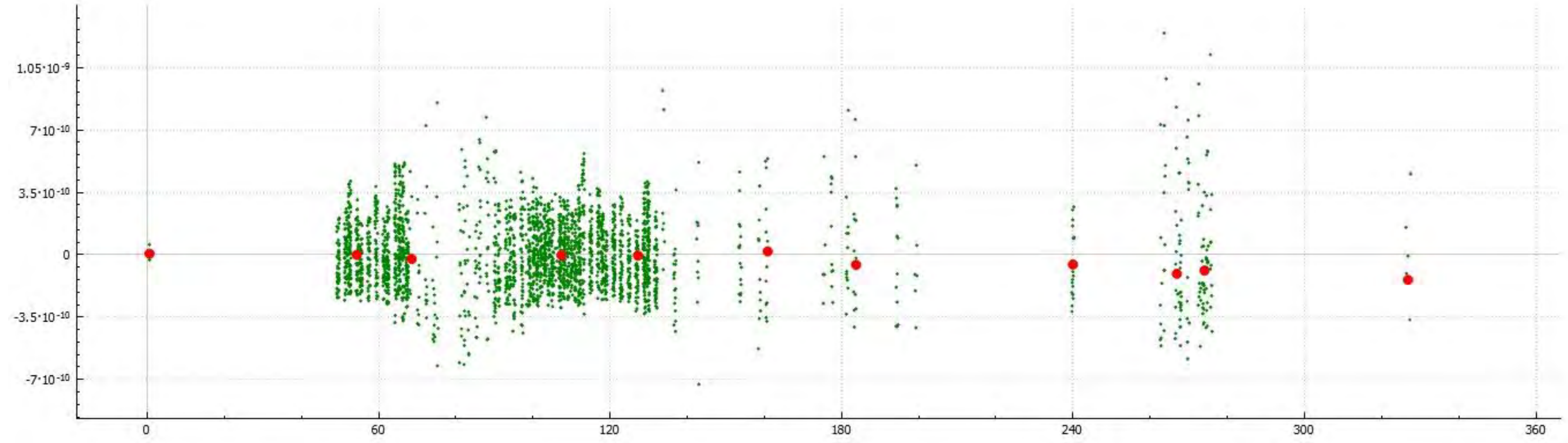
Figure 2. Graphs of calculating NPT using the same raw data

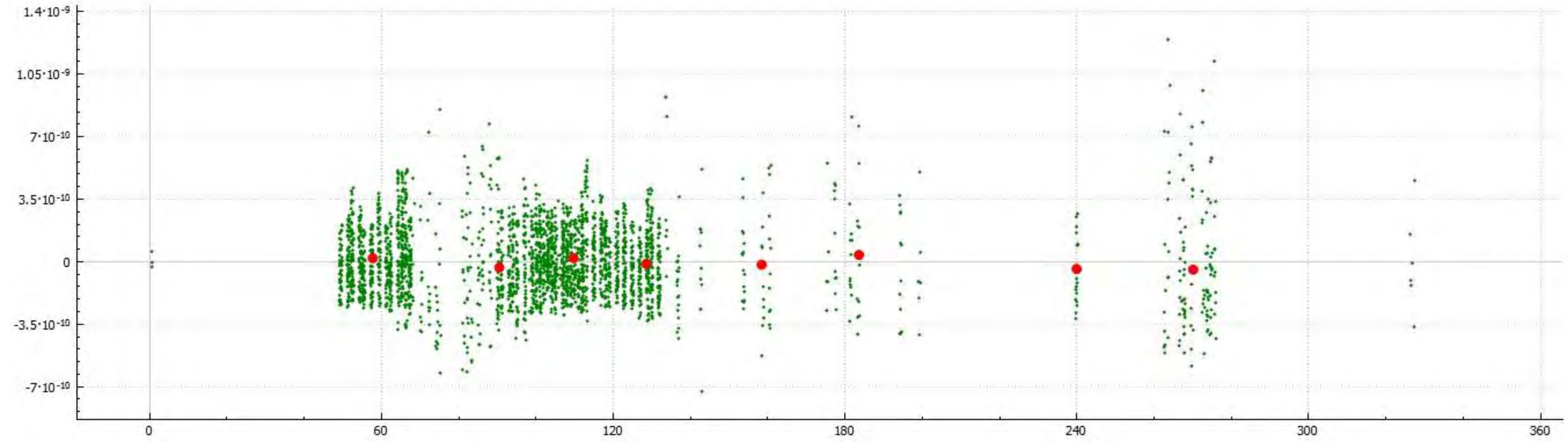
(1874_lageos1_crd_20191121_15_45)

Conclusions

1. Before calculating the NPT, we pre-process the measurement data to select sections with an acceptable density. Normal points constructed from a small number of "raw" points do not fit well on the trajectory, therefore, based on location conditions, we select the minimum sufficient number of measurements to build NPT.
2. NPTs are calculated immediately upon completion of the session and both raw data (* .frd) and the NPT array (* .npt) are saved in CRD format.

7503_ajisai_crd_20191212_09_30





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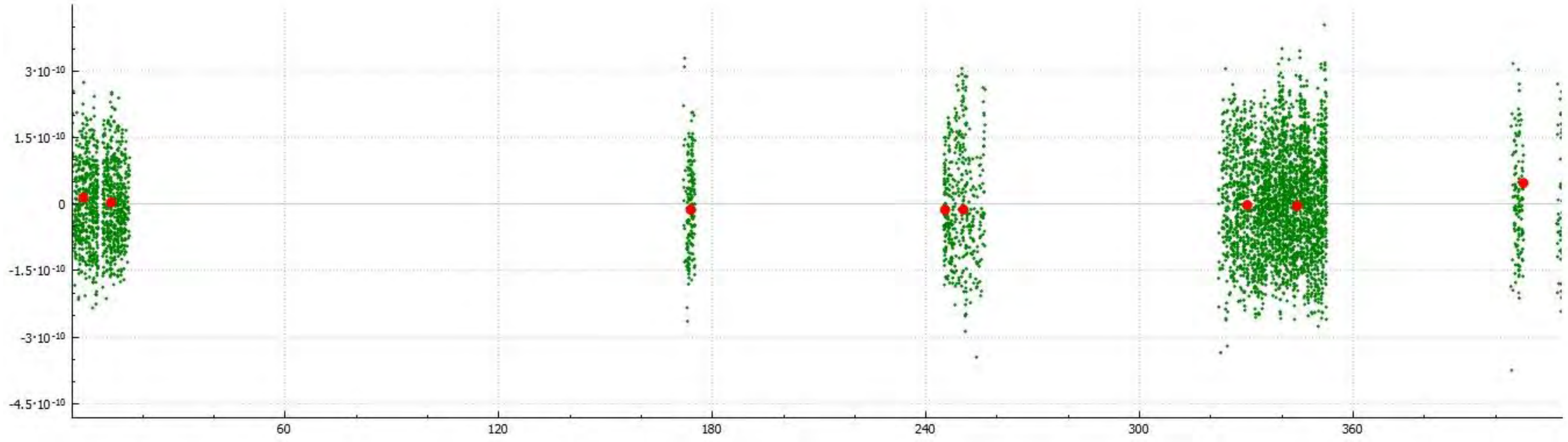
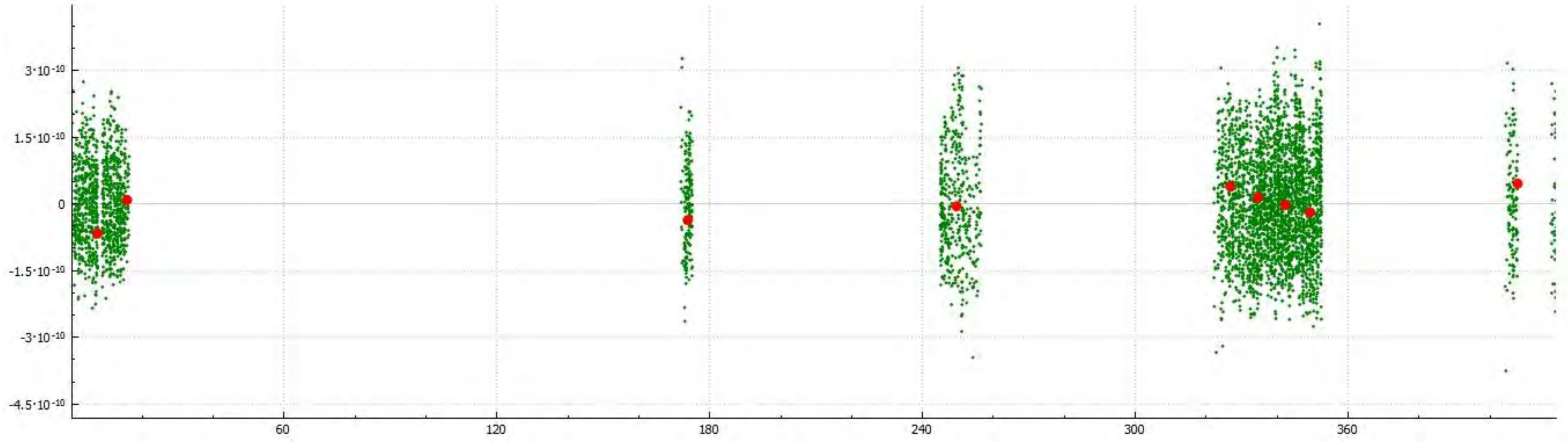
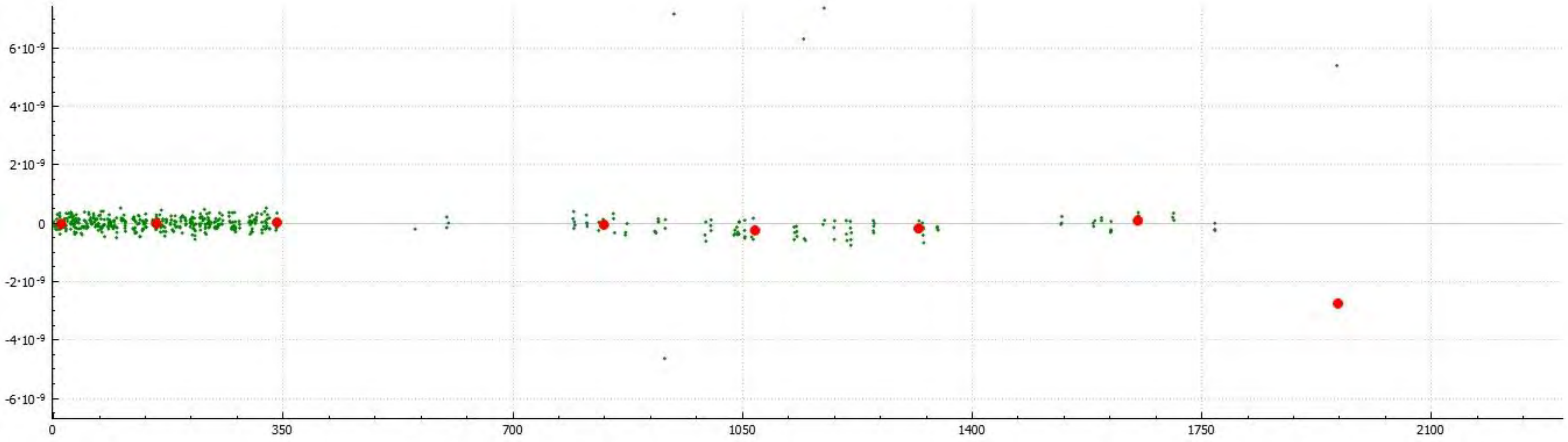
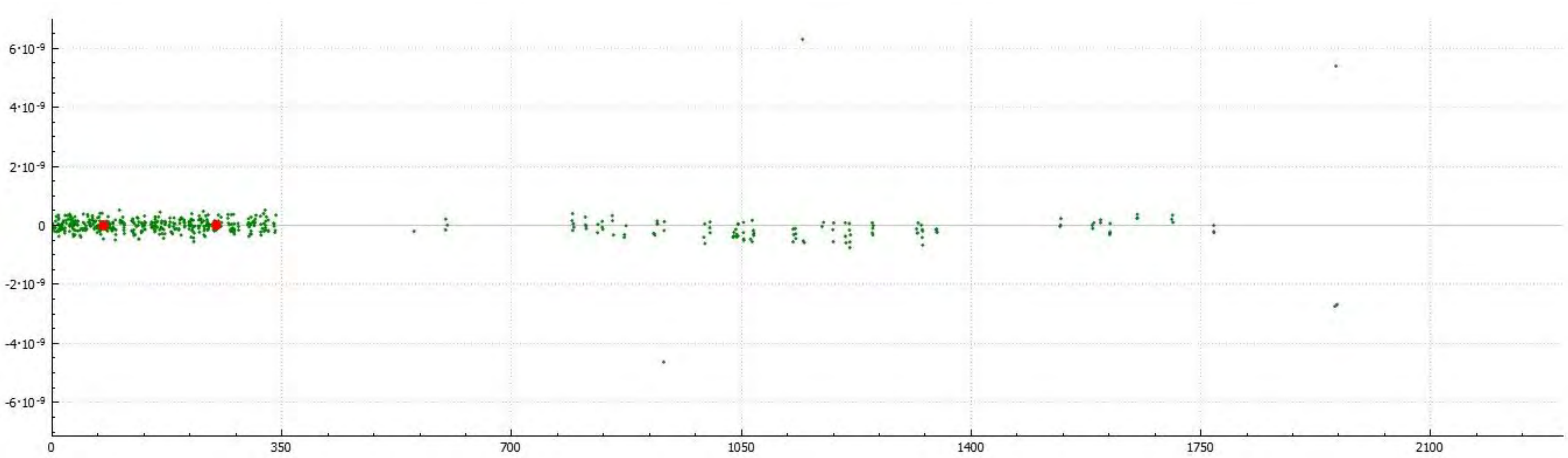


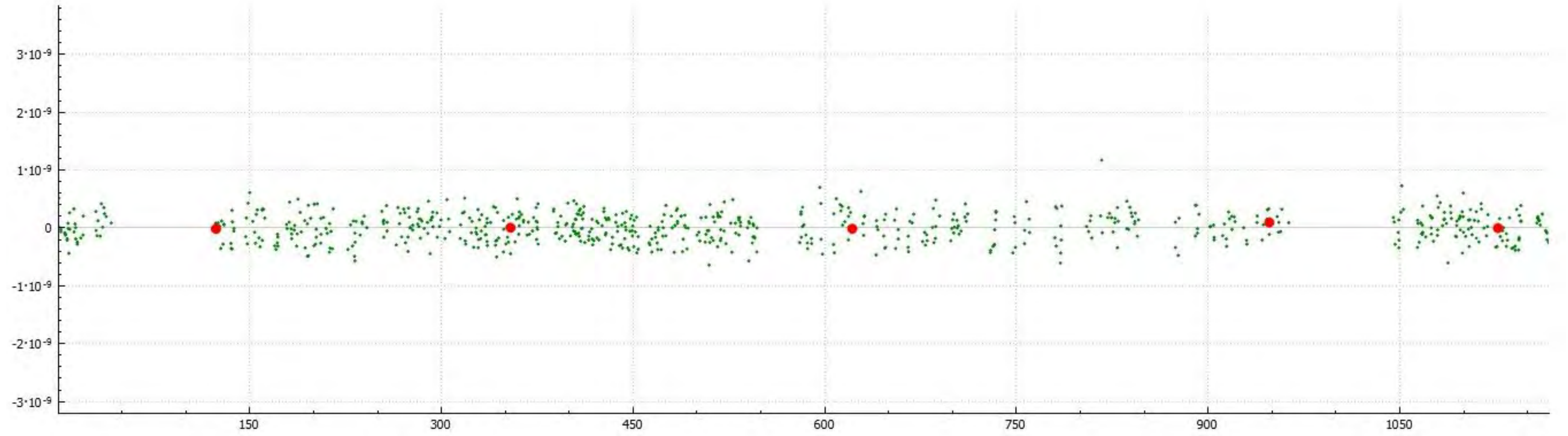


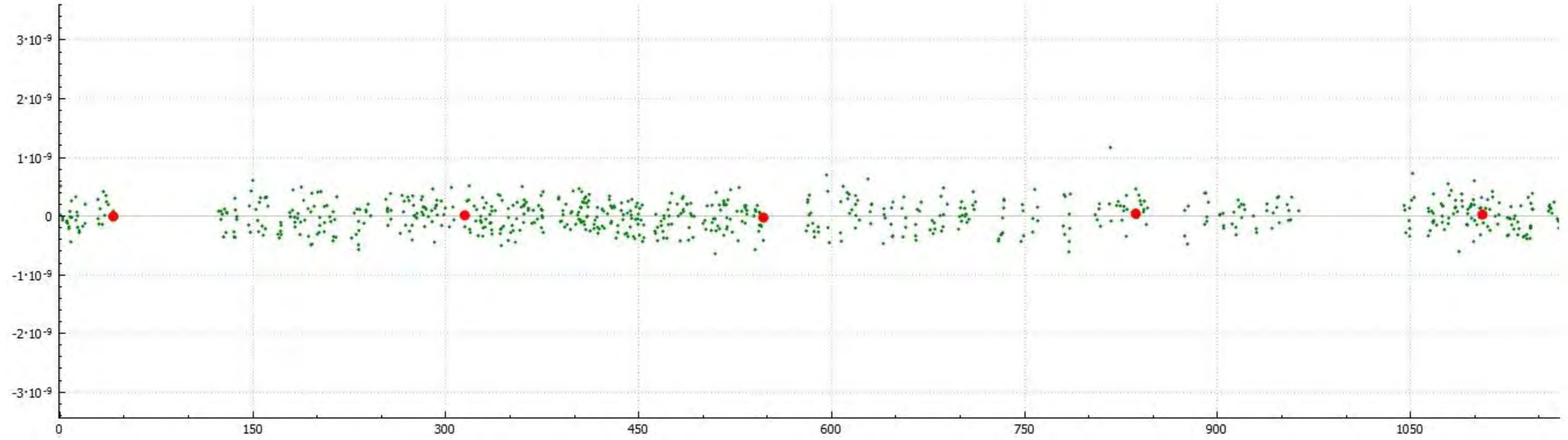
7503_glonass133_crd_20191212_19_49



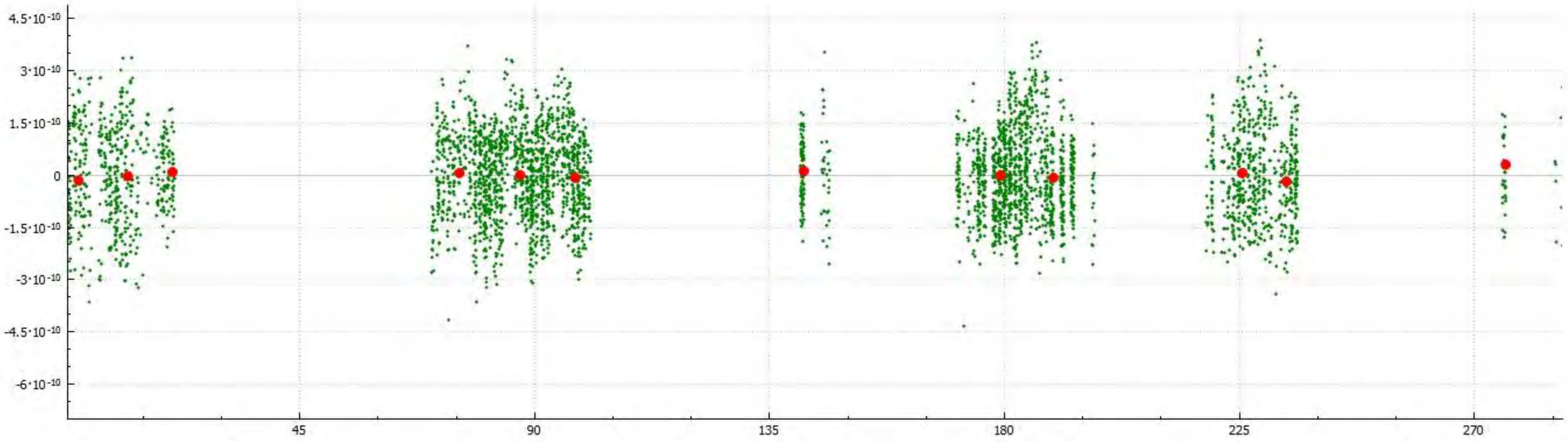


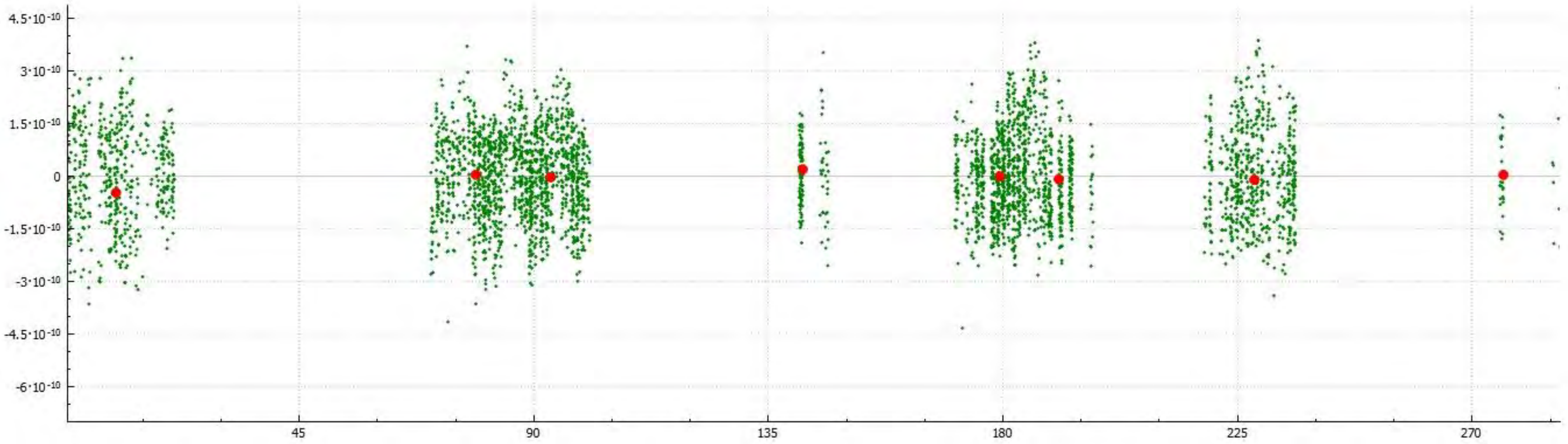
7503_glonass134_crd_20191212_22_06





7503_jason3_crd_20191212_17_28





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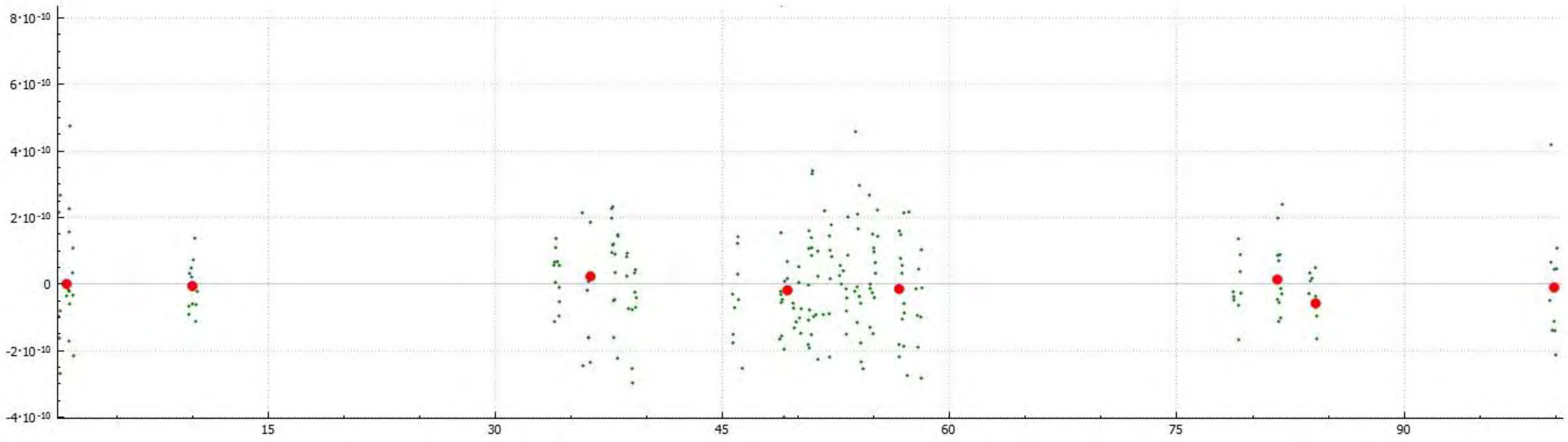
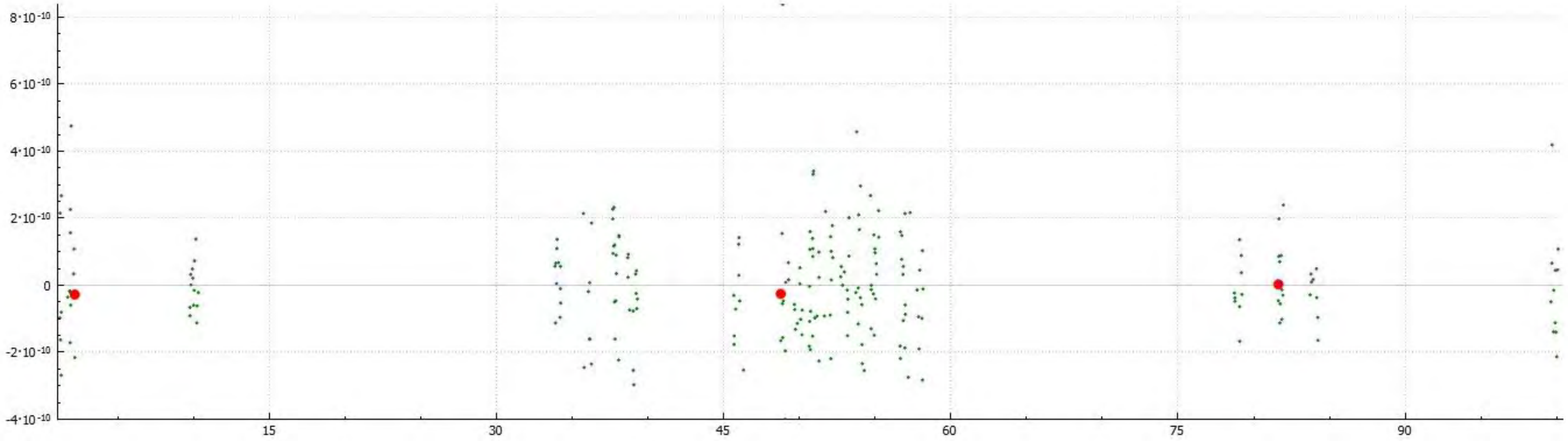
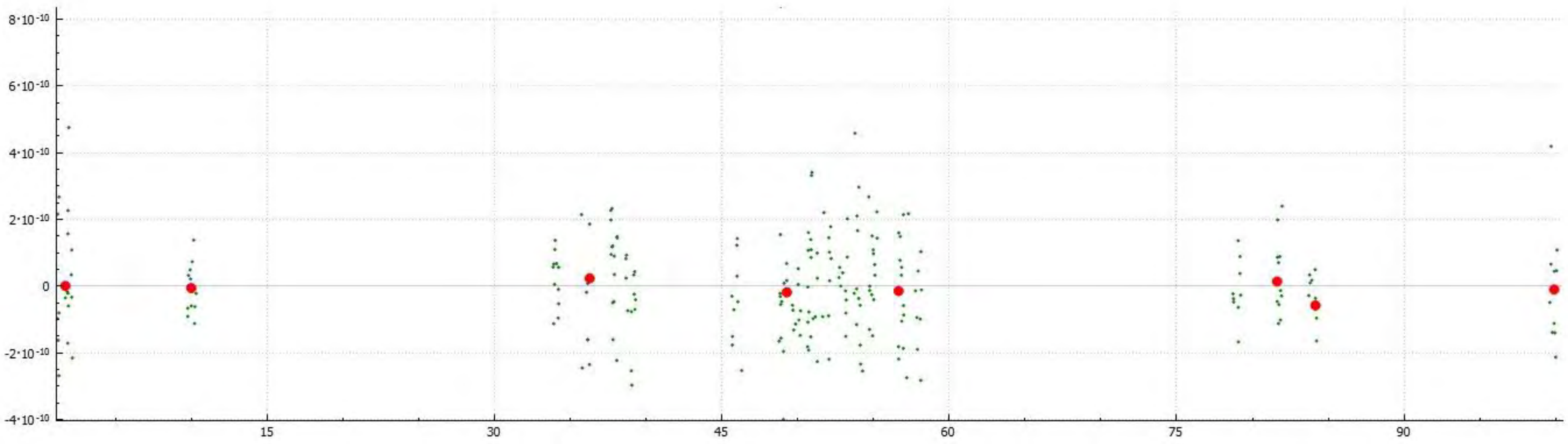
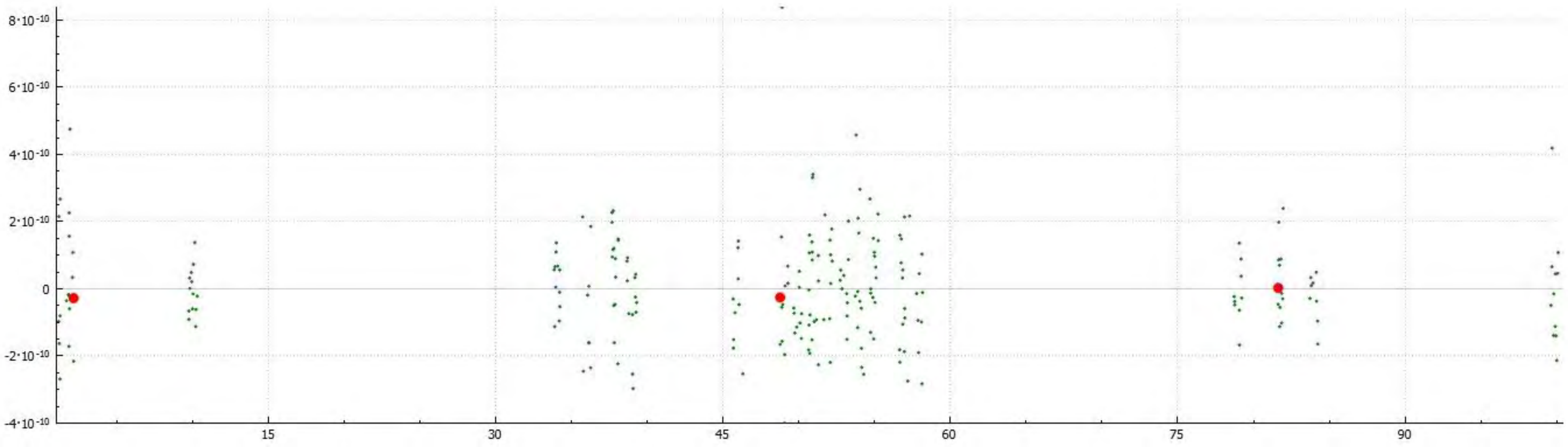




7503_jason3_crd_20191212_19_27





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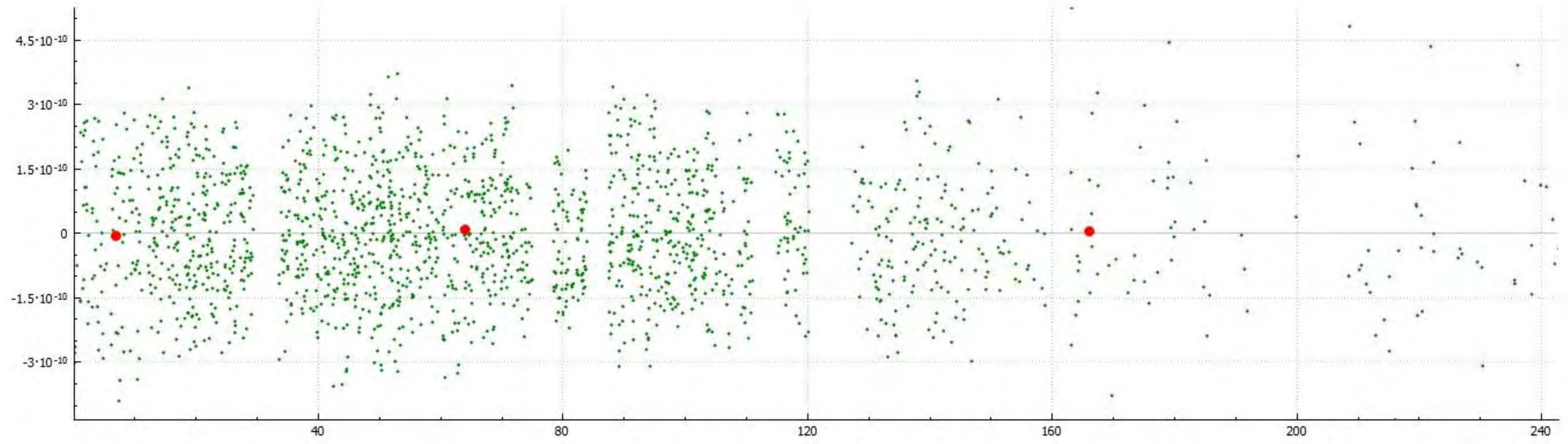
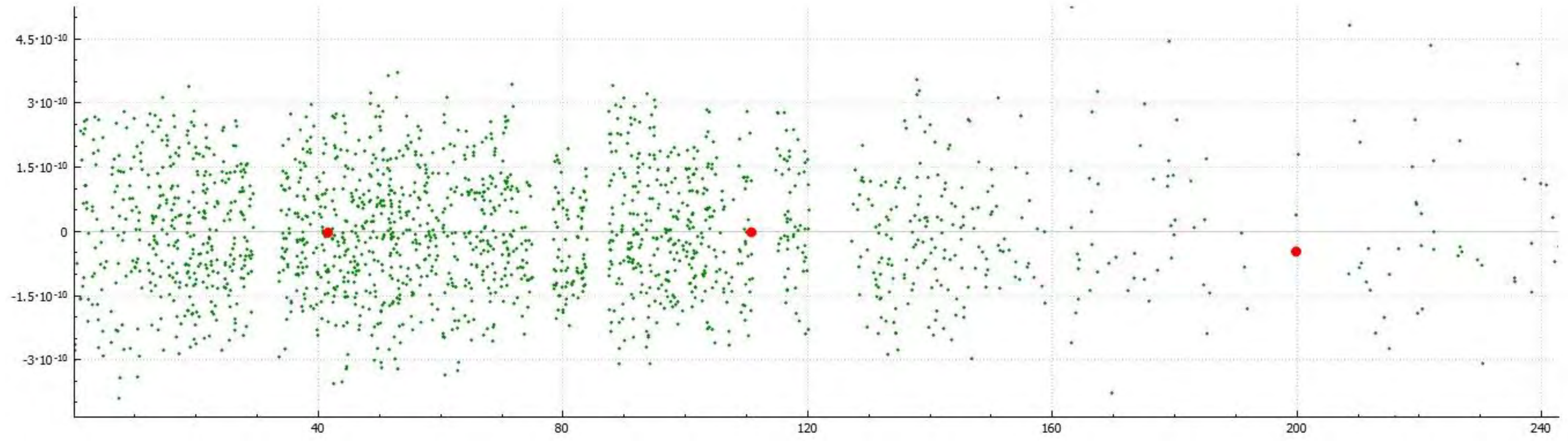
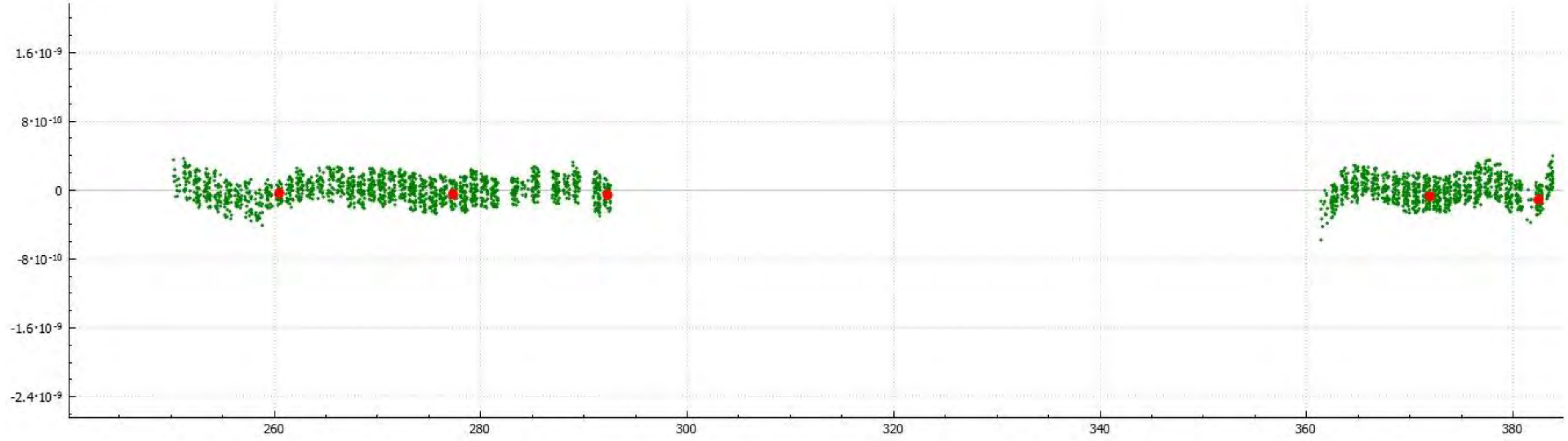
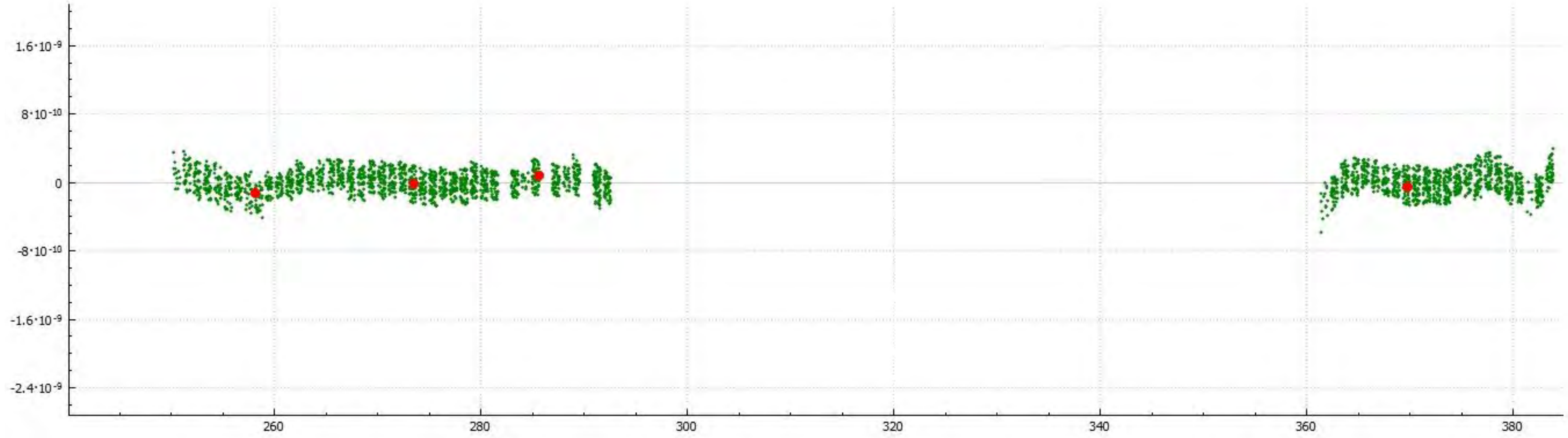


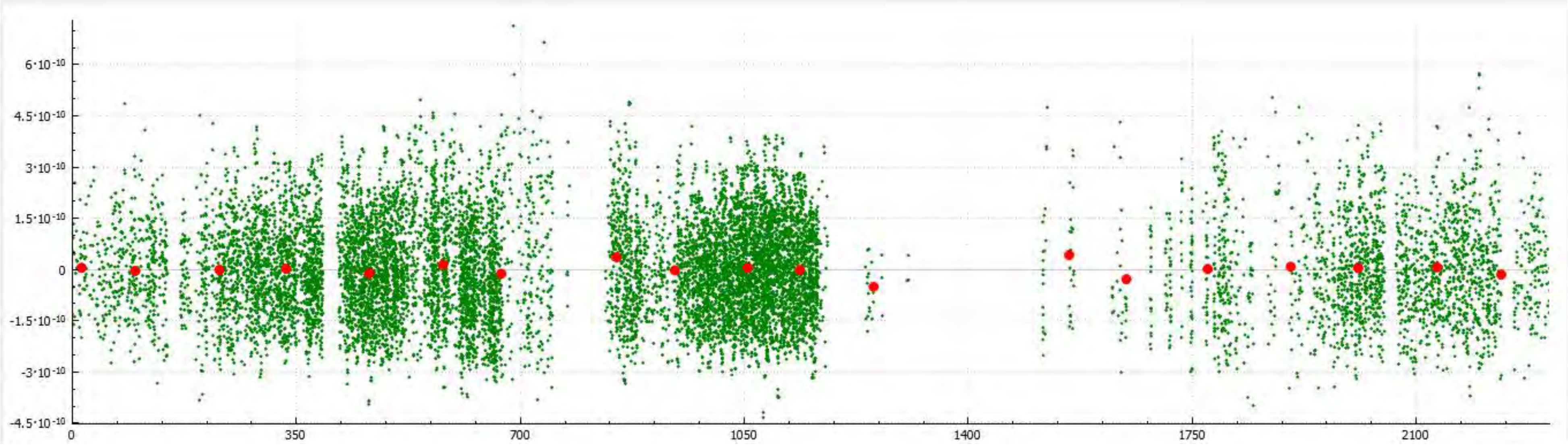


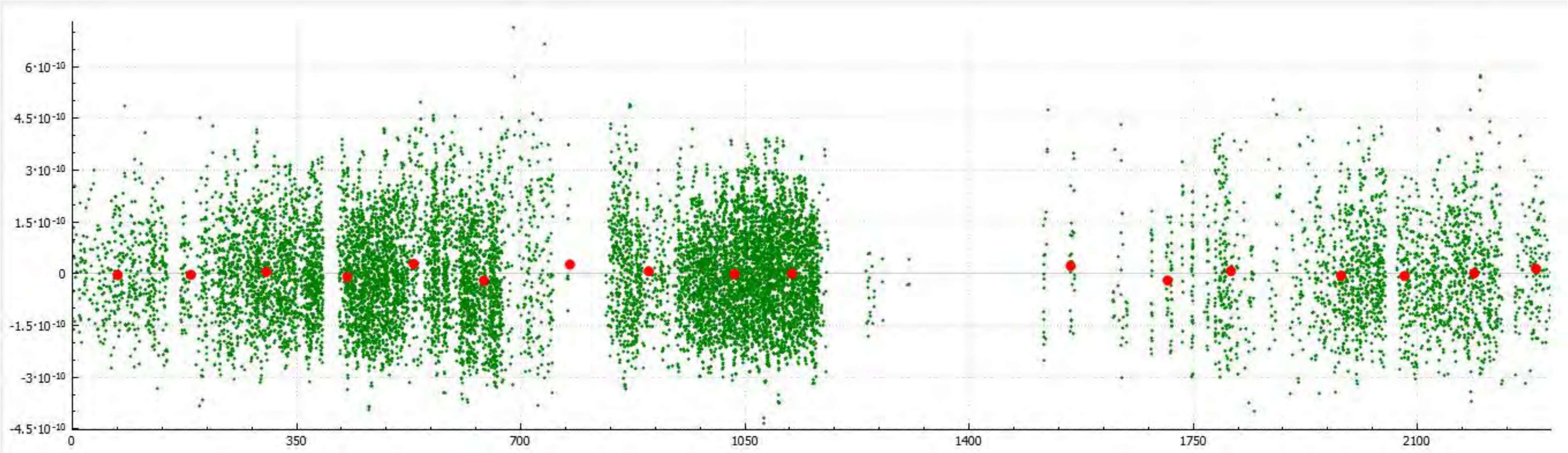
7503_starlette_crd_20191212_15_47



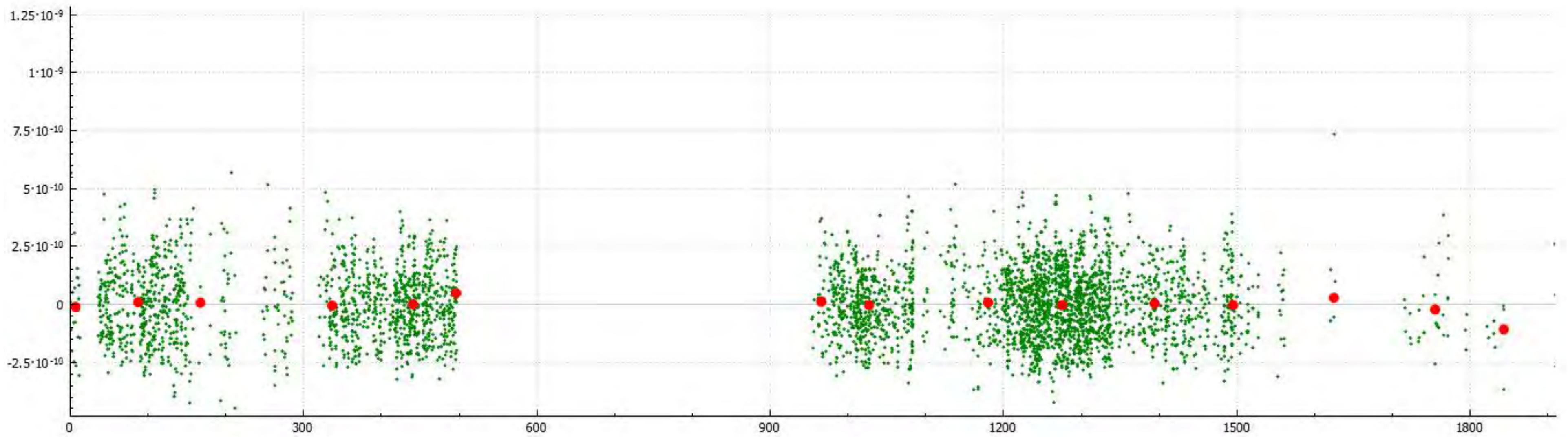


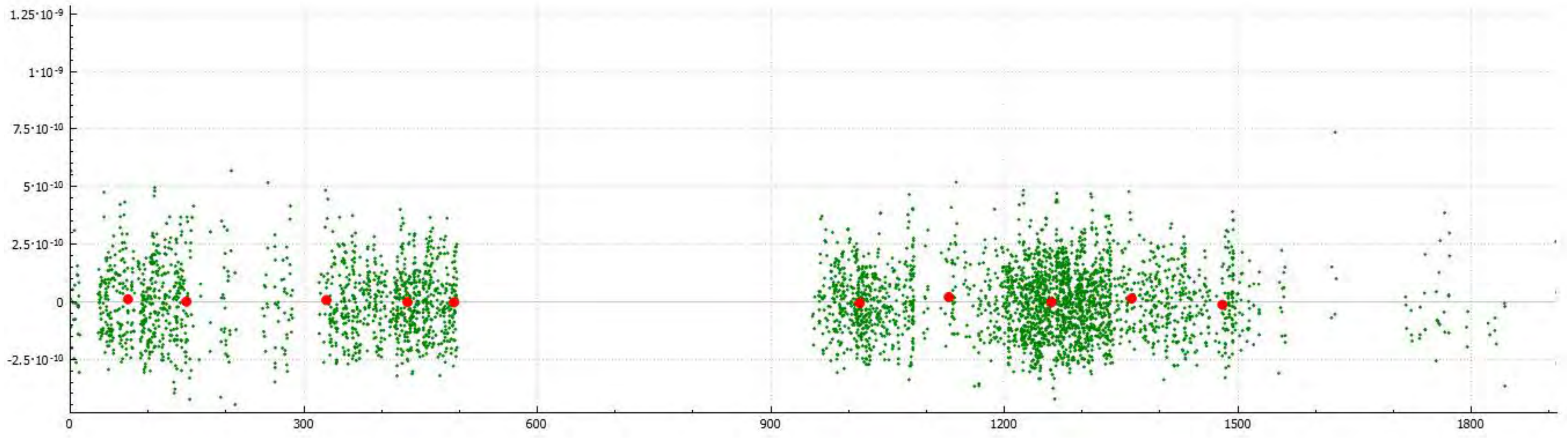
1874_lageos1_crd_20191121_19_15



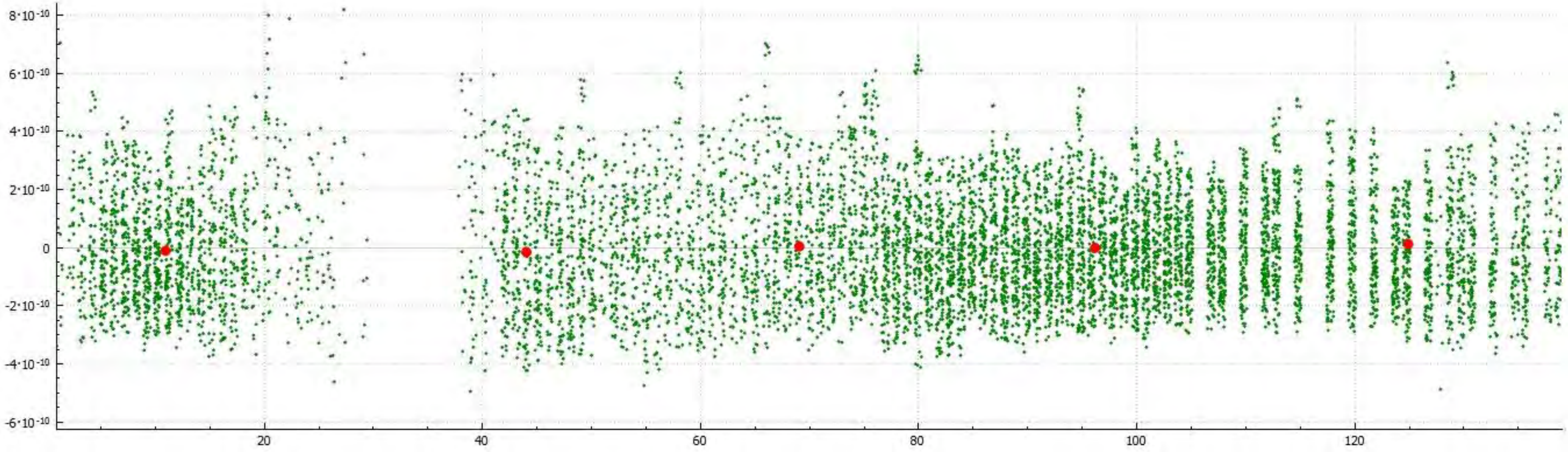


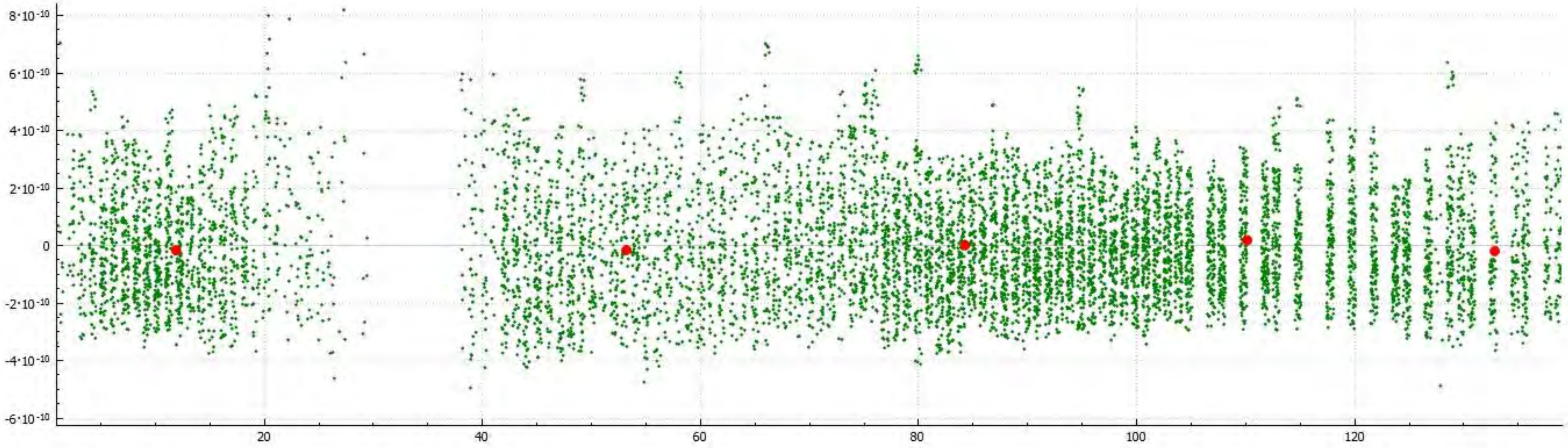
1874_lageos2_crd_20191121_18_37





7407_ajisai_crd_20191015_18_43





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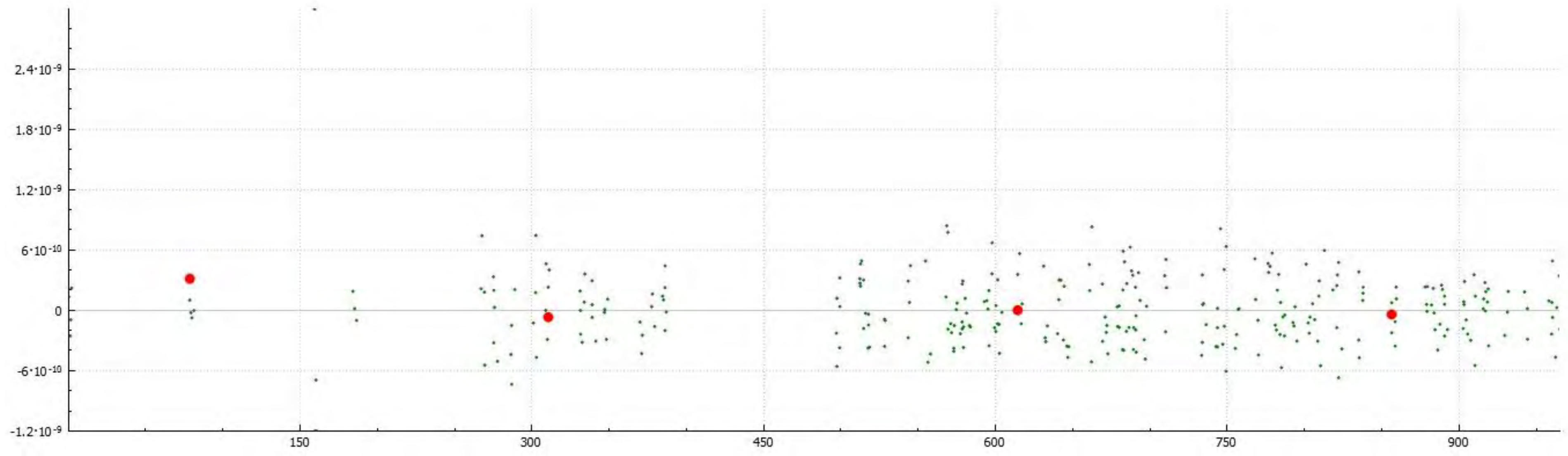
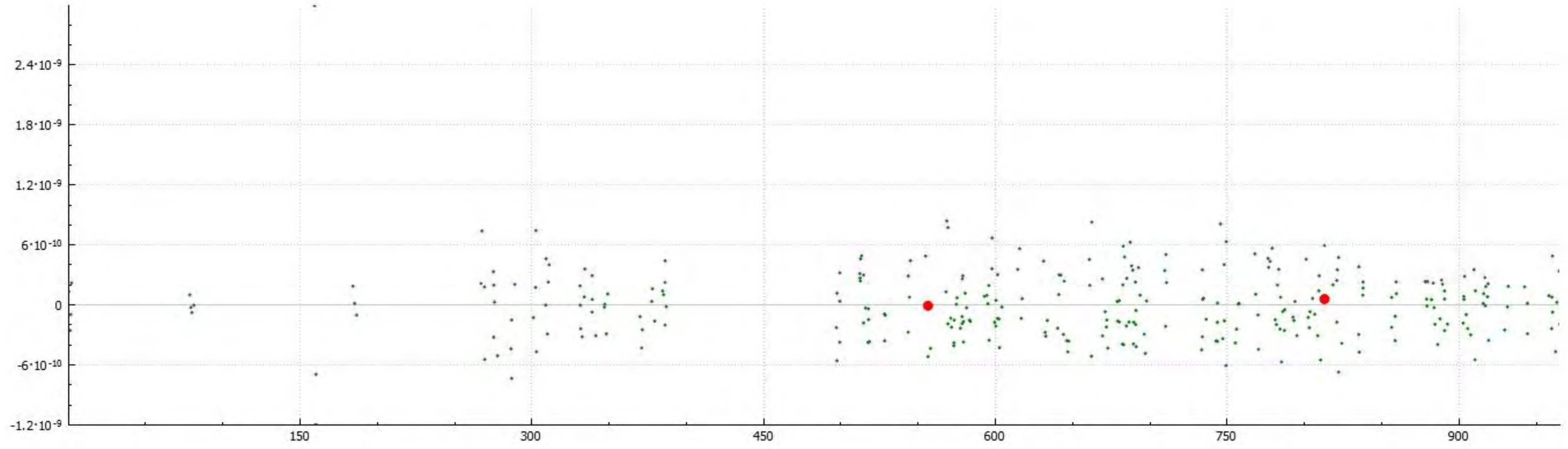
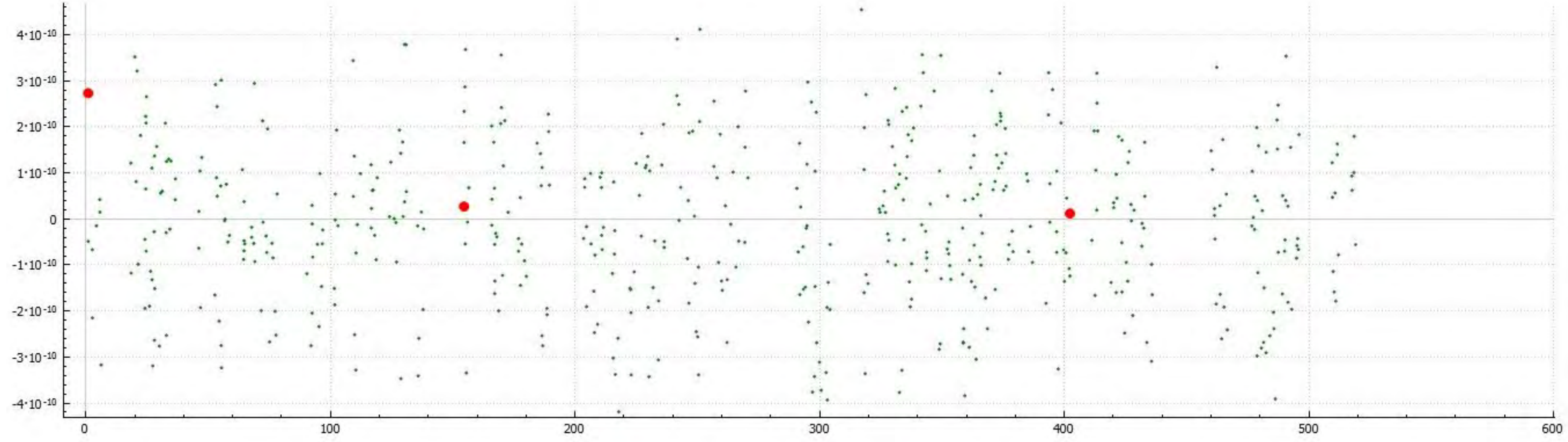
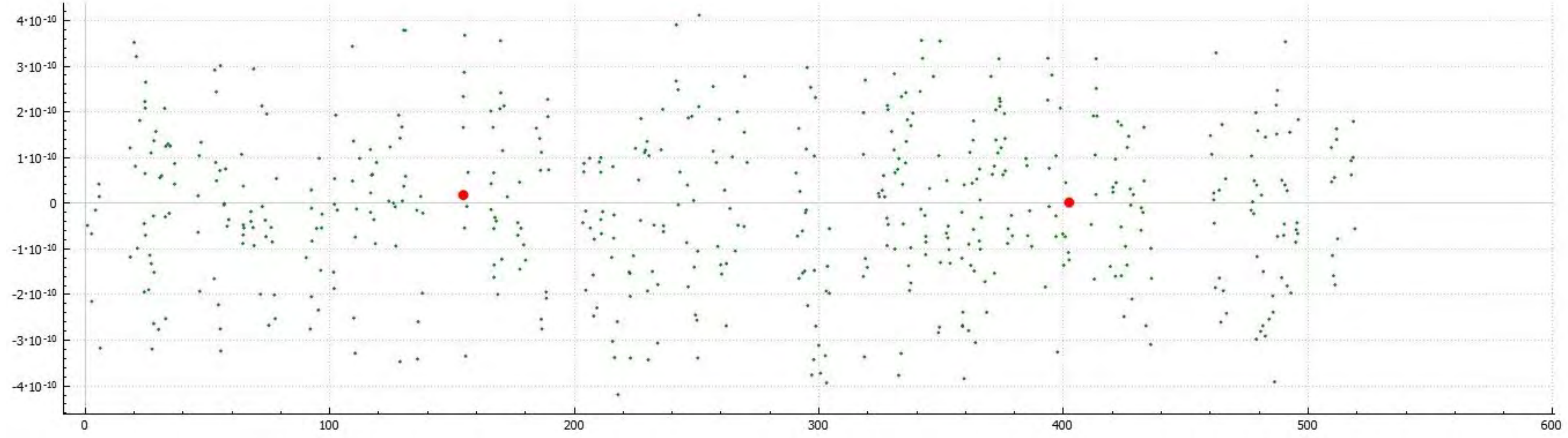


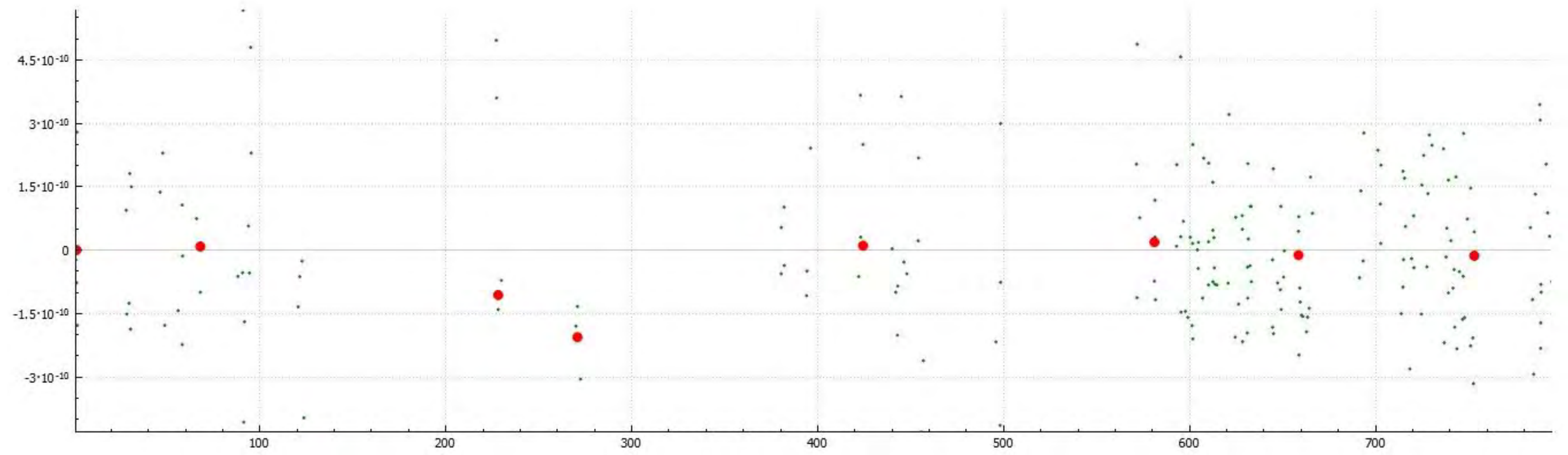


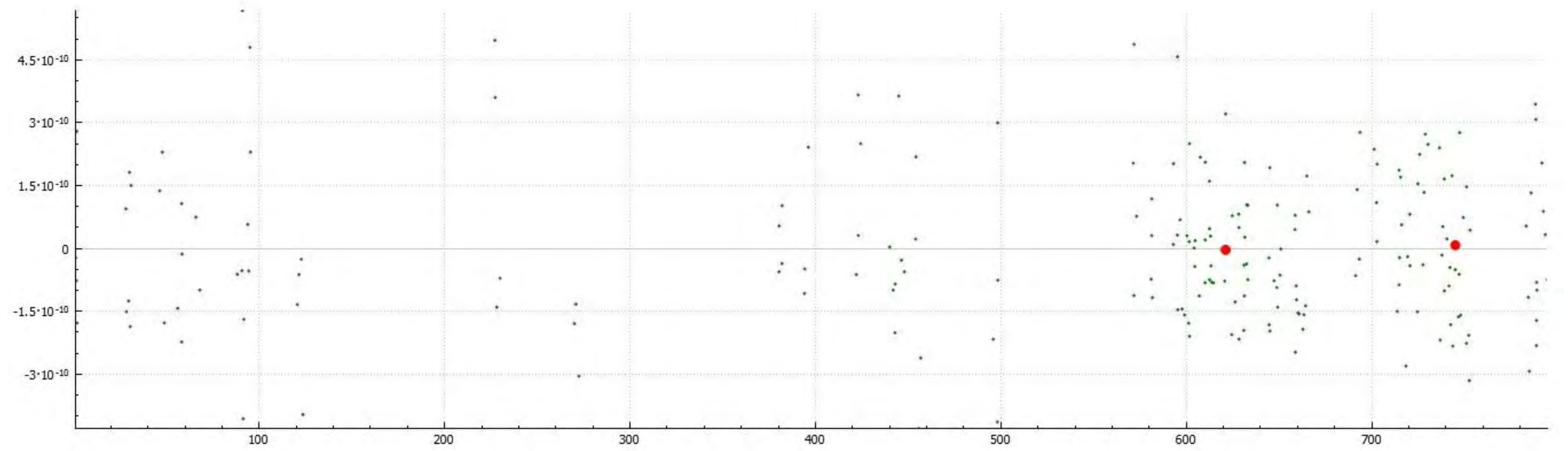
7407_glonass131_crd_20191016_11_04



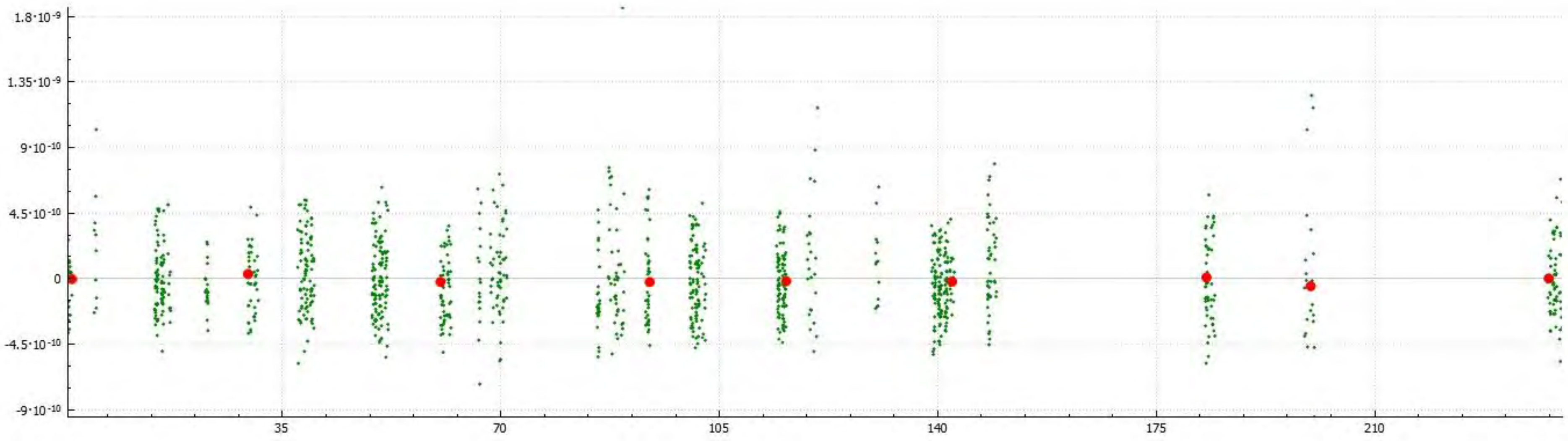


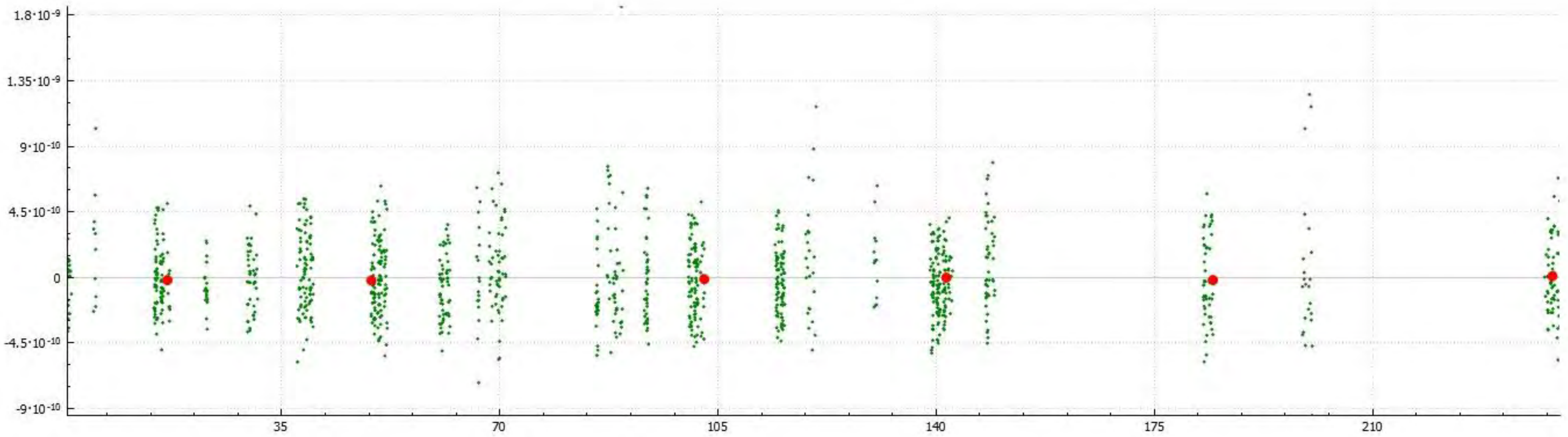
7407_lageos2_crd_20191013_23_13



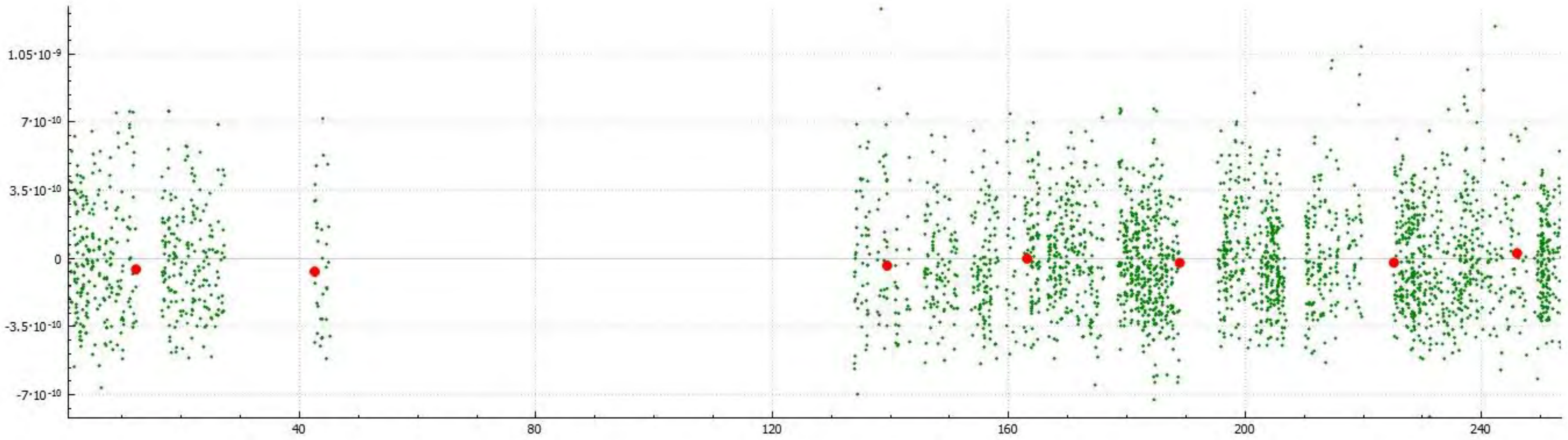


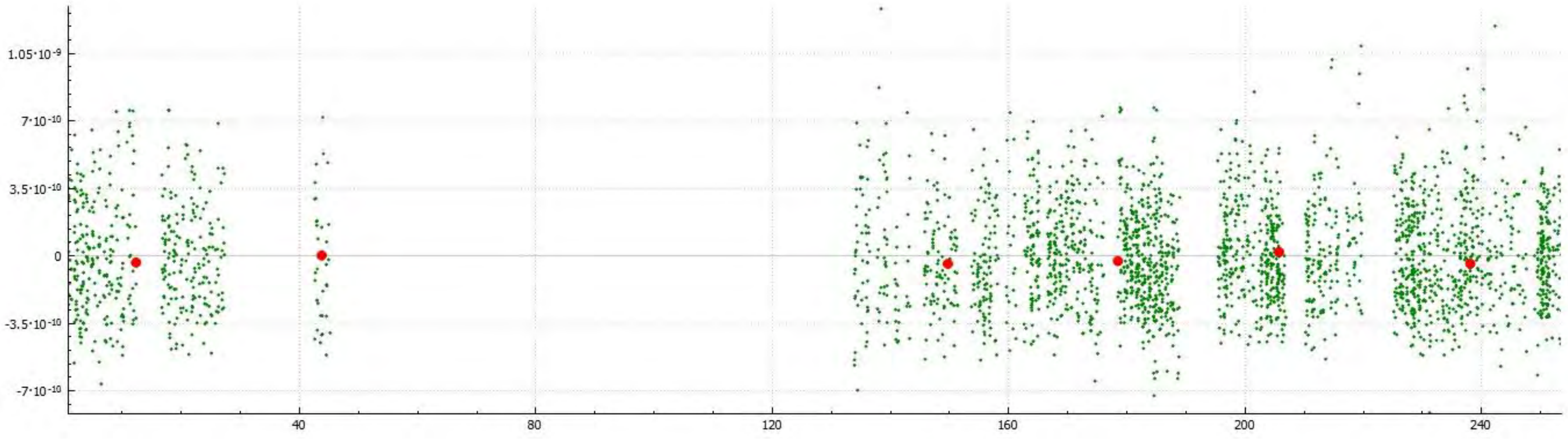
7503_ajisai_crd_20191012_17_43





7503_ajisai_crd_20191015_00_08





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

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?

Analysis of SLR normal points from new normal pointing software

John C. Ries

5/11/2020

Analysis method (V1 vs V2 for Jan 2020)

- Two variations were looked at
  - Compute residuals for V1 (nominal NPT software) and V2 (new NPT software) separately for stations that provided V2 data
    - In some cases, there were more V2 obs than V1
    - New normal point SW sometimes accepts more data for normal pointing
      - In some of those cases, the extra points were problematic
  - Process V1 and V2 data in same run (resulting in duplicates)
    - Plotted individual normal point residuals on pass-by-pass basis
    - V1 and V2 data show up side by side

Basic statistics V1 vs V2 (1)

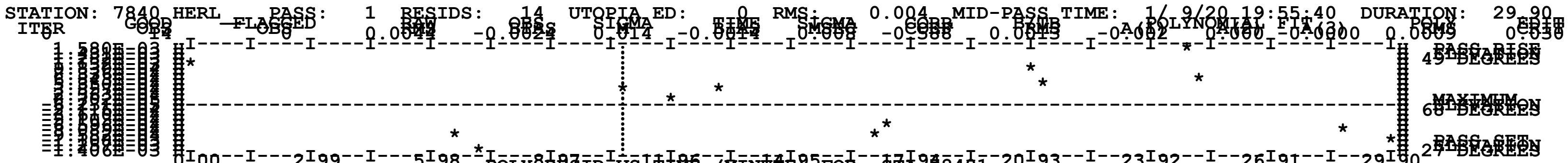
Station	V1 passes	# obs	V2 passes	# obs
1824	1	6	1	6
1873	9	48	9	48
1884	4	28	4	28
1888	7	45	7	71
1890	27	129	27	176
1891	19	86	21	105
1893	9	71	9	73
7090	108	964	108	975
7105	31	291	31	294
7110	41	324	41	325
7119	13	125	13	126
7237	43	301	43	398
7249	3	17	3	20
7501	11	103	11	104
7810	88	1042	88	1124
7811	9	98	9	98
7821	8	90	8	102
7824	4	11	4	14
7825	12	44	12	65
7827	40	218	40	383
7838	24	241	24	243
7839	48	307	48	327
7840	39	478	39	479
7841	29	144	29	145
7845	35	392	35	411
7941	62	500	62	505
8834	36	230	36	236
TOTALS	760	6333	762	6881

For example: 7840

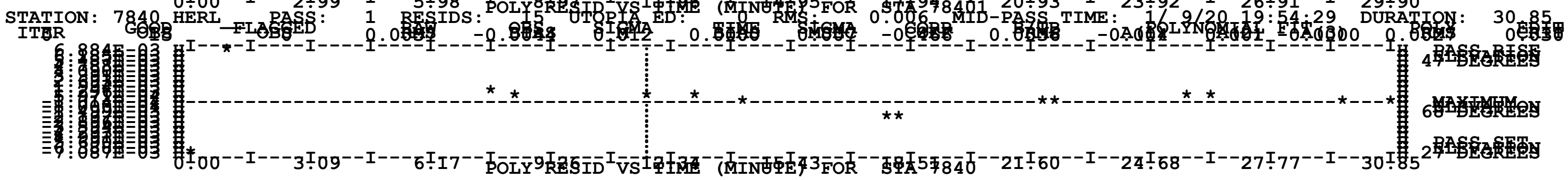
V1 = original data from CDDIS

V2 = original data but with matching V2 obs replacing V1 obs

Since there are more passes and more obs after replacing only matching obs, that implies that there are new NPTs that are not available in the original release

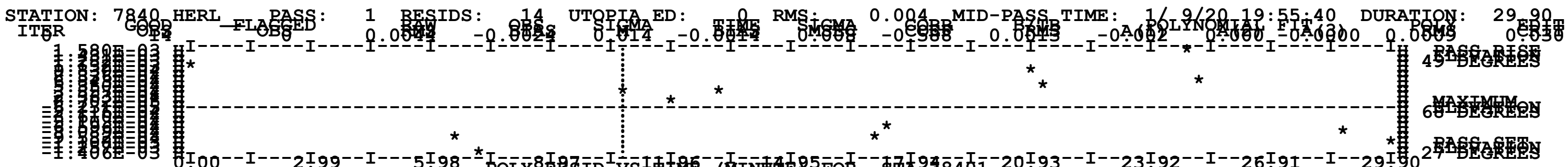


V1

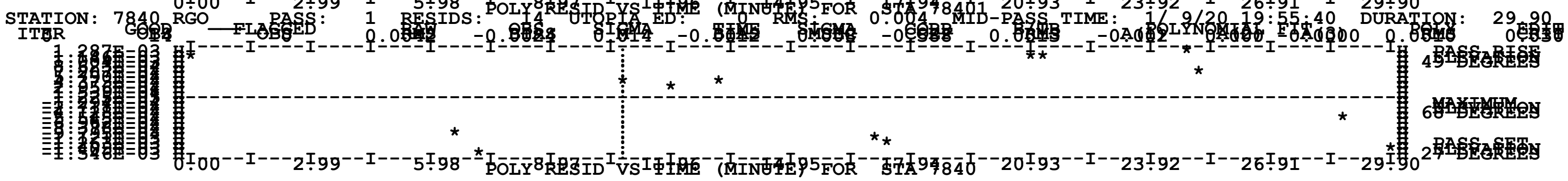


V2

This is the only pass from 7840 that had an extra point; extra point looks inconsistent with remainder of pass, which affects PolyRMS and the scale of the plot



V1



V2

Extra point removed; PolyRMS is similar now

In the following, only obs present in both data sets are compared

Using 4019 matching obs (after editing and excluding stations 1891,1824,7838,7824), the RMS was 7.02 mm for V1 and 6.89 mm for V2

Orbits were based on full original data set, then fixed

No other parameters were estimated (No EOP, biases, station coordinates, etc.)

Basic statistics V1 vs V2 (2)

STATION	PASSES	TOTAL OBS	EDITED OBS	PCT EDITED	GOOD OBS	RAW RMS	B/TB RMS	POLY RMS
1824 GLSL__	1	6	0	0.0	6	4.177	2.82	2.73
1824 GLSL__	1	6	6	100.0	0	0.000	0.00	0.00
1873 SIMEIZ	9	48	0	0.0	48	4.327	2.96	2.12
1873 SIMEIZ	9	48	0	0.0	48	4.088	2.51	1.44
1884 RIGA__	2	10	0	0.0	10	3.822	0.64	0.40
1884 RIGA__	2	10	0	0.0	10	3.843	0.63	0.34
1888 SVETLO	7	23	0	0.0	23	1.288	0.94	0.93
1888 SVETLO	7	23	0	0.0	23	1.203	0.82	0.82
1890 BADARY	26	87	7	8.0	80	1.207	0.71	0.61
1890 BADARY	26	87	7	8.0	80	1.030	0.61	0.46
1891 IRKUTS	15	39	6	15.4	33	1.621	1.01	0.69
1891 IRKUTS	15	39	15	38.5	24	1.570	1.05	0.60
1893 KATZIV	7	56	7	12.5	49	3.696	1.13	0.97
1893 KATZIV	7	56	7	12.5	49	3.667	1.13	0.98
7090 YARAG_	89	780	0	0.0	780	0.632	0.28	0.24
7090 YARAG_	89	780	0	0.0	780	0.631	0.28	0.23
7105 GRF105	31	288	0	0.0	288	0.837	0.32	0.23
7105 GRF105	31	288	0	0.0	288	0.830	0.32	0.21

First line is V1

Second line is V2

PolyRMS is estimate of NPT precision

Favorable change in green

Unfavorable change in red

No significant change in black

Basic statistics (3)

STATION	PASSES	TOTAL OBS	EDITED OBS	PCT EDITED	GOOD OBS	RAW RMS	B/TB RMS	POLY RMS
7110 MONPK1	34	282	0	0.0	282	0.778	0.42	0.26
7110 MONPK1	34	282	0	0.0	282	0.773	0.41	0.25
7119 HA4T__	11	116	4	3.4	112	0.855	0.68	0.67
7119 HA4T__	11	116	4	3.4	112	0.621	0.38	0.33
7237 CHACHU	34	159	6	3.8	153	1.571	0.84	0.54
7237 CHACHU	34	159	6	3.8	153	1.483	0.65	0.38
7249 BEIL__	3	17	0	0.0	17	0.841	0.59	0.27
7249 BEIL__	3	17	0	0.0	17	0.858	0.43	0.16
7501 HARL__	10	84	1	1.2	83	0.807	0.27	0.16
7501 HARL__	10	84	1	1.2	83	0.804	0.28	0.15
7810 ZIMMBG	40	360	1	0.3	359	0.697	0.24	0.17
7810 ZIMMBG	40	360	1	0.3	359	0.702	0.23	0.17
7811 BOROWC	4	46	0	0.0	46	0.949	0.27	0.25
7811 BOROWC	4	46	0	0.0	46	0.932	0.23	0.20
7821 SHA2__	7	67	0	0.0	67	0.841	0.21	0.14
7821 SHA2__	7	67	0	0.0	67	0.807	0.22	0.14
7824 SANF_B	2	5	0	0.0	5	1.064	0.04	0.04
7824 SANF_B	2	5	5	100.0	0	0.000	0.00	0.00

First line is V1

Second line is V2

PolyRMS is estimate of NPT precision

Favorable change in green

Unfavorable change in red

No significant change in black

Ambiguous in blue

Basic statistics (4)

STATION	PASSES	TOTAL OBS	EDITED OBS	PCT EDITED	GOOD OBS	RAW RMS	B/TB RMS	POLY RMS
7825 STROM2	12	44	4	9.1	40	0.579	0.36	0.34
7825 STROM2	12	44	4	9.1	40	0.535	0.27	0.25
7838 SISL__	21	216	40	18.5	176	1.365	0.82	0.53
7838 SISL__	21	216	29	13.4	187	1.342	0.76	0.45
7839 GRAZ__	38	248	0	0.0	248	0.535	0.20	0.11
7839 GRAZ__	38	248	0	0.0	248	0.536	0.19	0.10
7840 HERL__	26	330	0	0.0	330	0.528	0.26	0.14
7840 HERL__	26	330	0	0.0	330	0.530	0.26	0.15
7841 POTSD3	22	103	0	0.0	103	0.732	0.24	0.13
7841 POTSD3	22	103	0	0.0	103	0.731	0.24	0.12
7845 GRASSM	28	312	0	0.0	312	0.850	0.61	0.40
7845 GRASSM	28	312	0	0.0	312	0.844	0.60	0.40
7941 MLRO__	48	382	0	0.0	382	0.569	0.19	0.14
7941 MLRO__	48	382	0	0.0	382	0.572	0.20	0.13
8834 WETZL2	31	207	0	0.0	207	0.635	0.20	0.14
8834 WETZL2	31	207	0	0.0	207	0.631	0.20	0.14

First line is V1

Second line is V2

PolyRMS is estimate of NPT precision

Favorable change in green

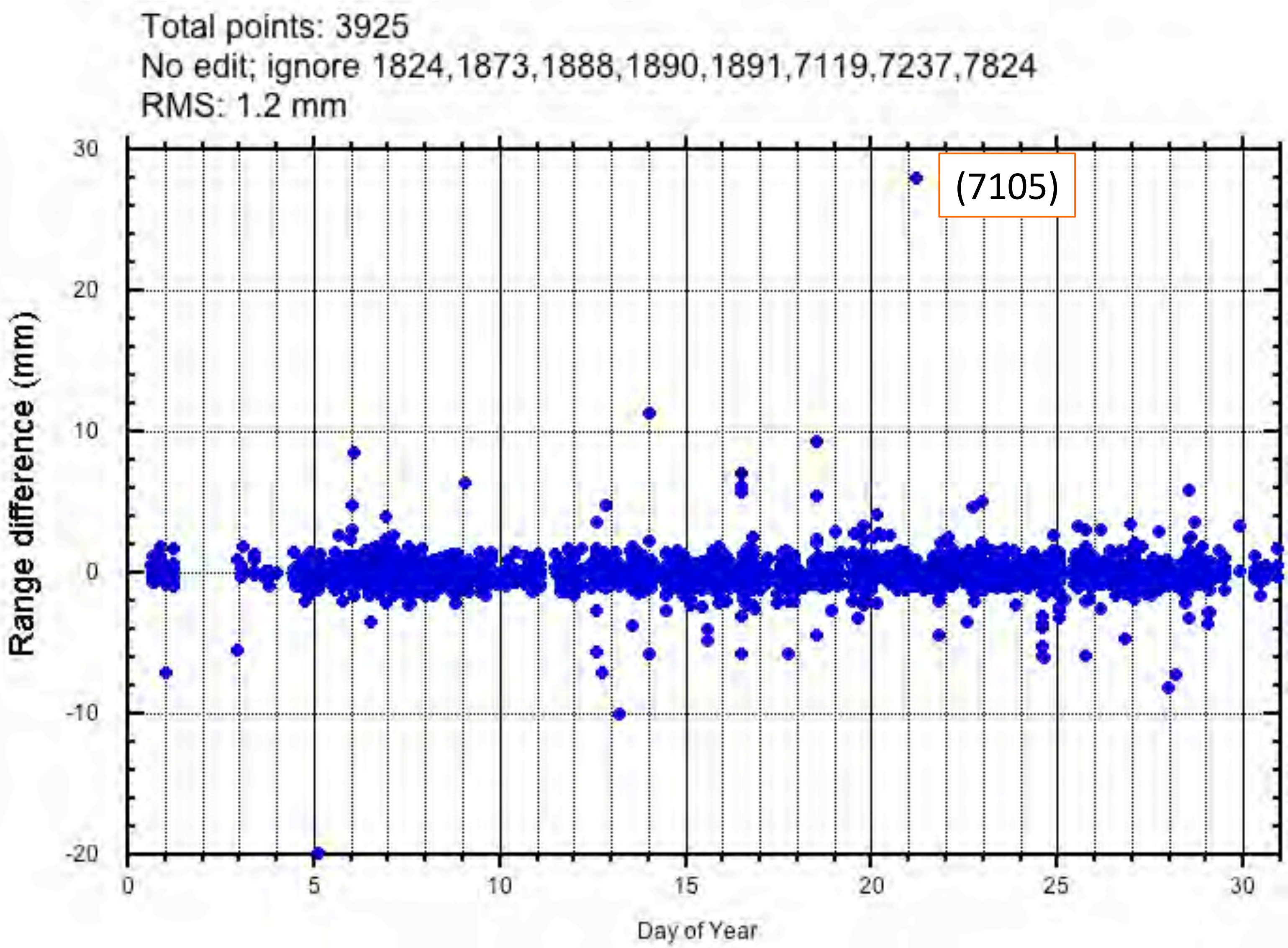
Unfavorable change in red

No significant change in black

Ambiguous in blue

Normal point range differences (each point is a NPT difference)

Normal point differences ('good' sites with sub-cm fits)



Outlier for 7105

```
760390120370710520022145416286260500000008417180728735701026270059 07    8
760390120370710520022145416286265500000008417180700704701026270059 07  187
```

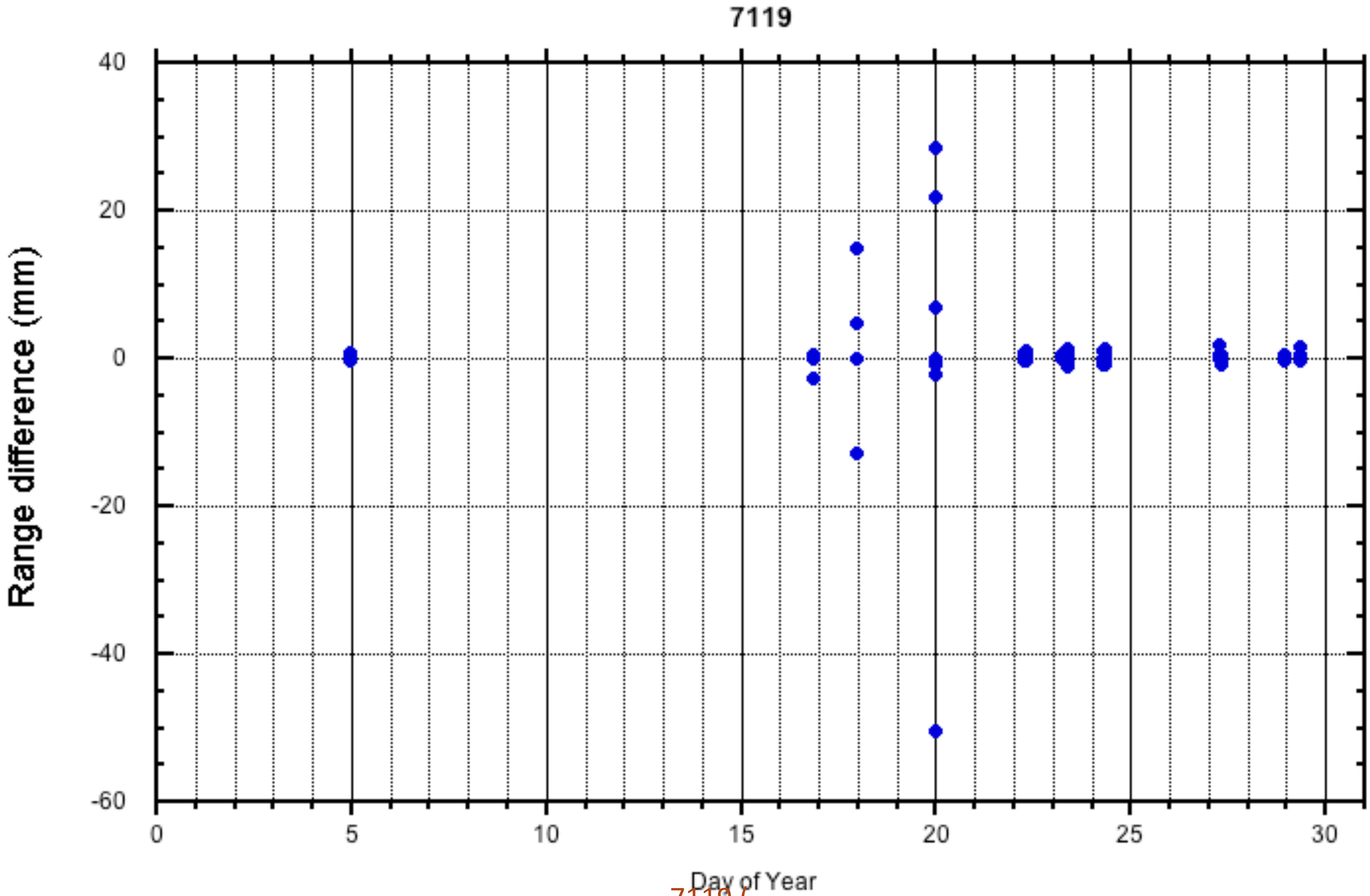
28 mm diff ^^

NPT RMS(mm) ^^^^^

Difference of 2.8 cm in range, and also a large increase in the NPT rms

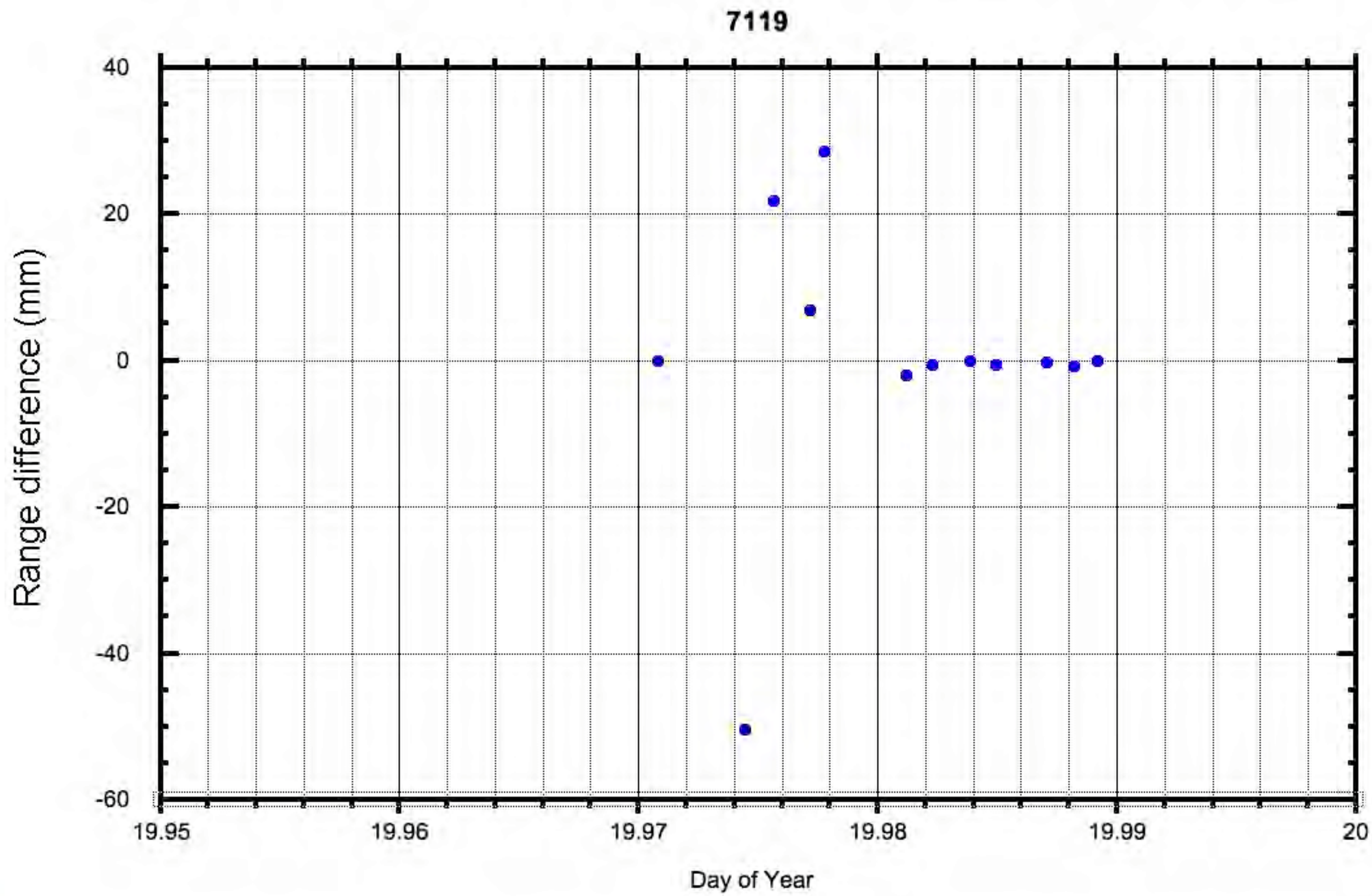
This observation had only 4 shots; old and new SW compute very different RMS values

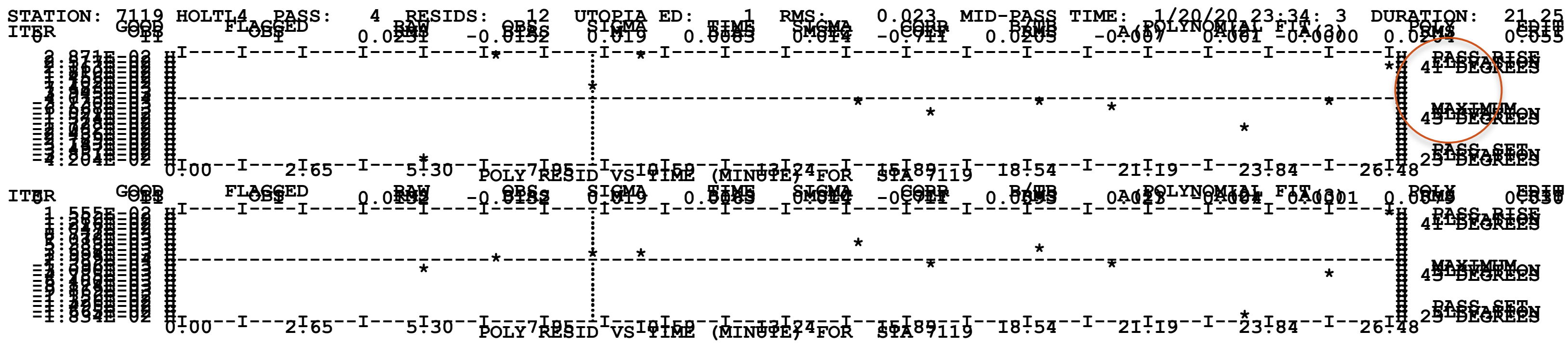
Normal point differences (7119)



7119 (

Normal point differences (7119) (Zoom in)



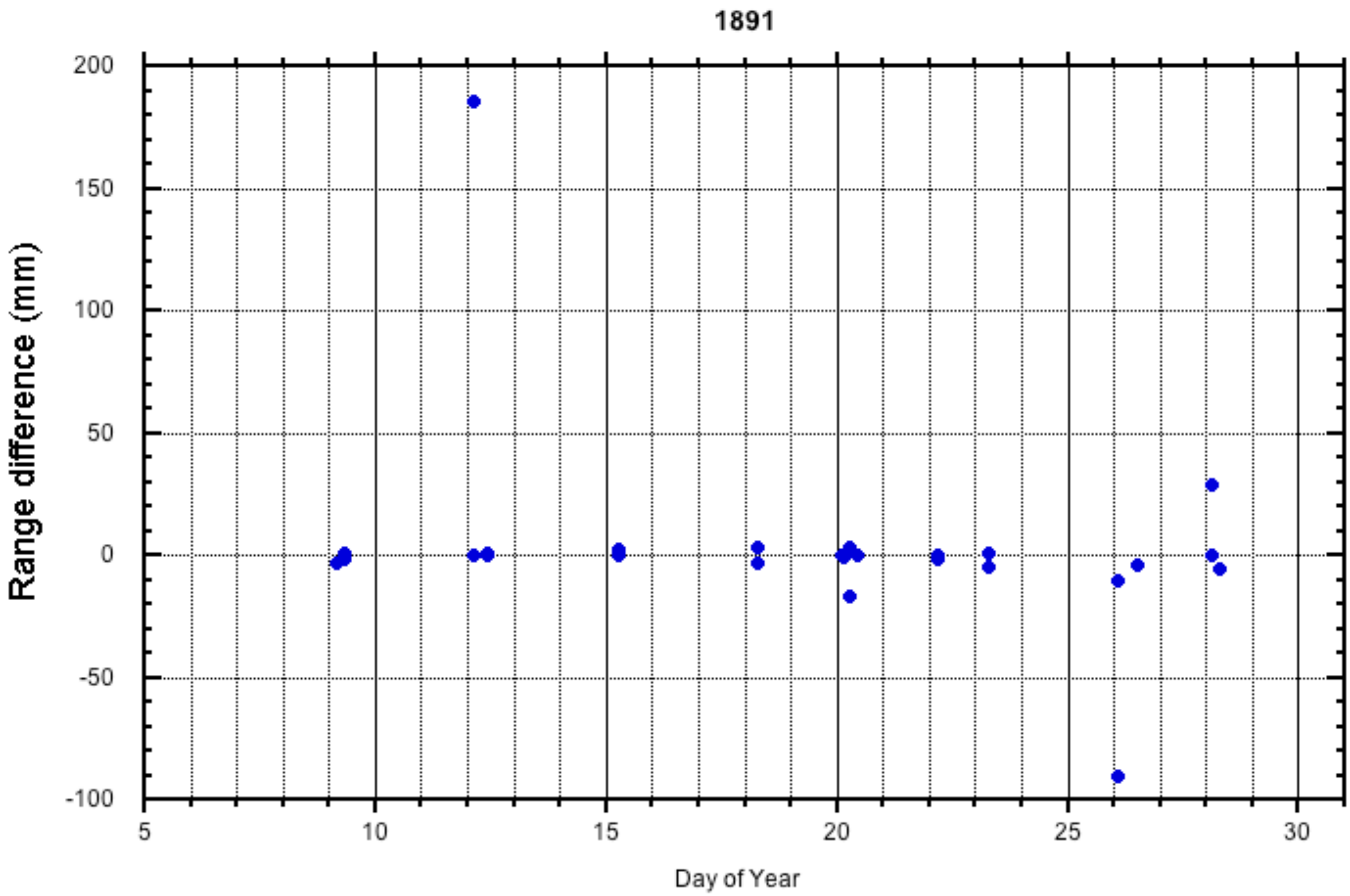


V1

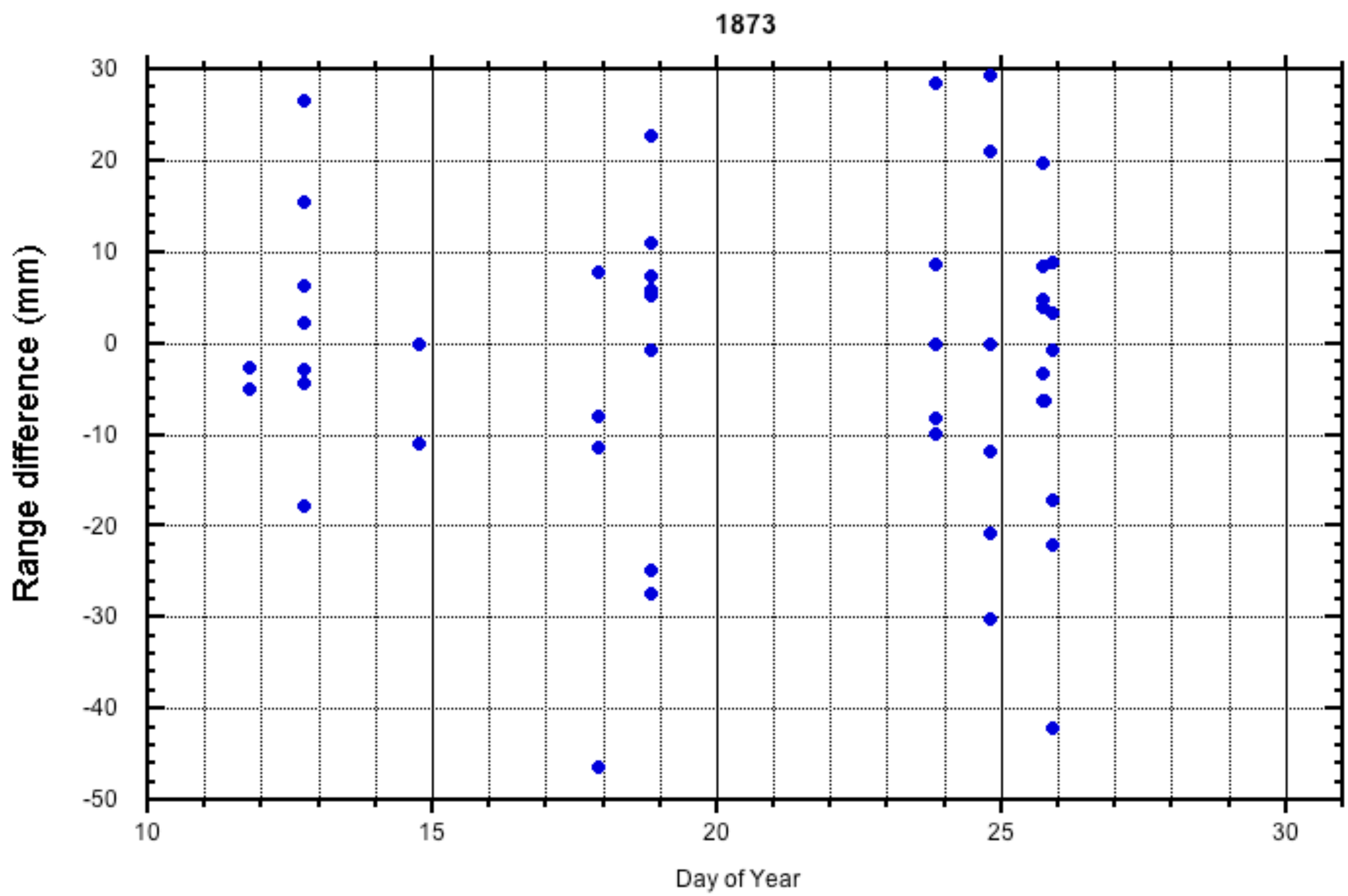
V2

In this case, the new NPTs are a clear improvement over the original (8 mm vs 20 mm)

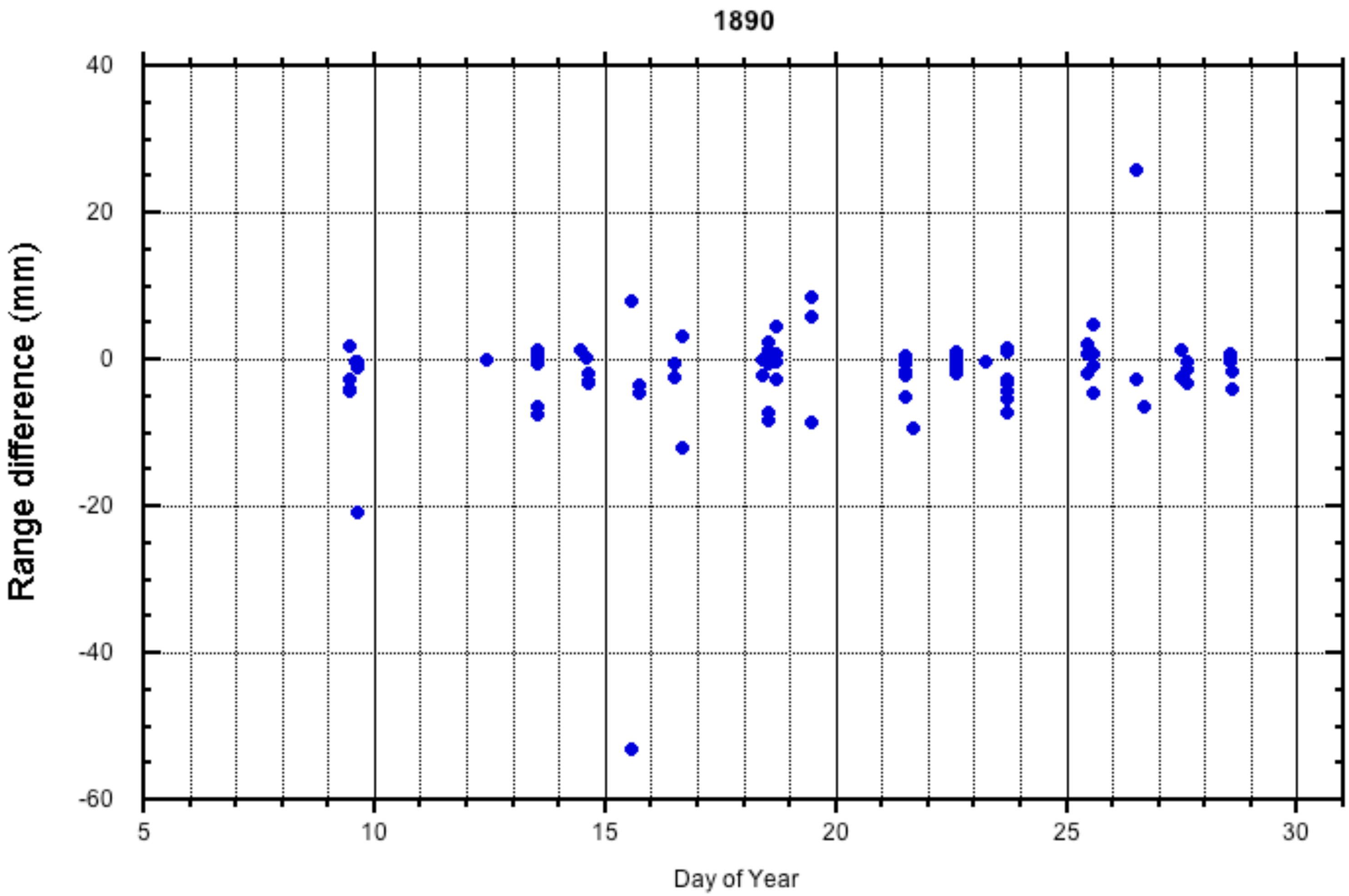
Normal point differences (1891)



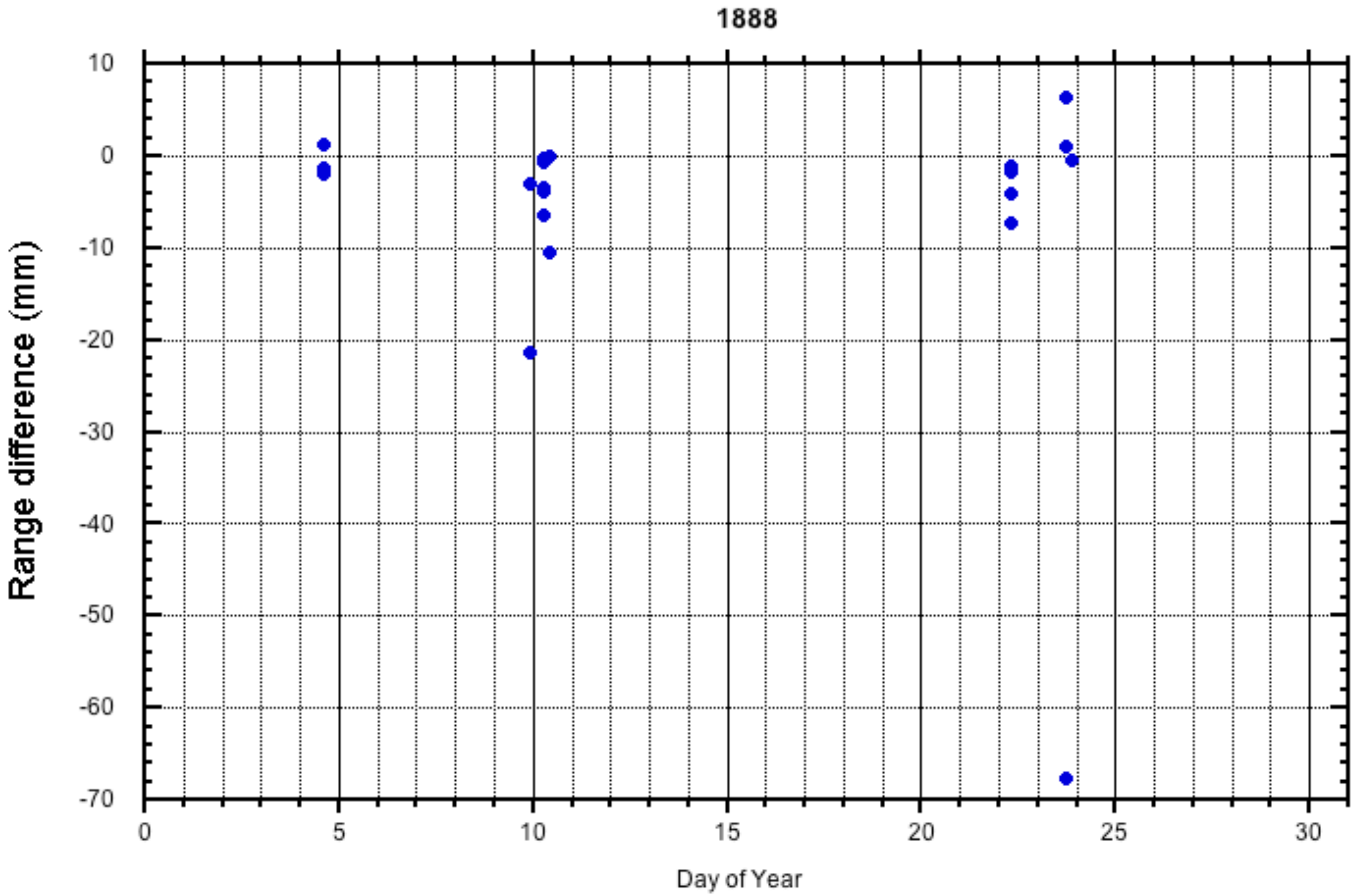
Normal point differences (1873)



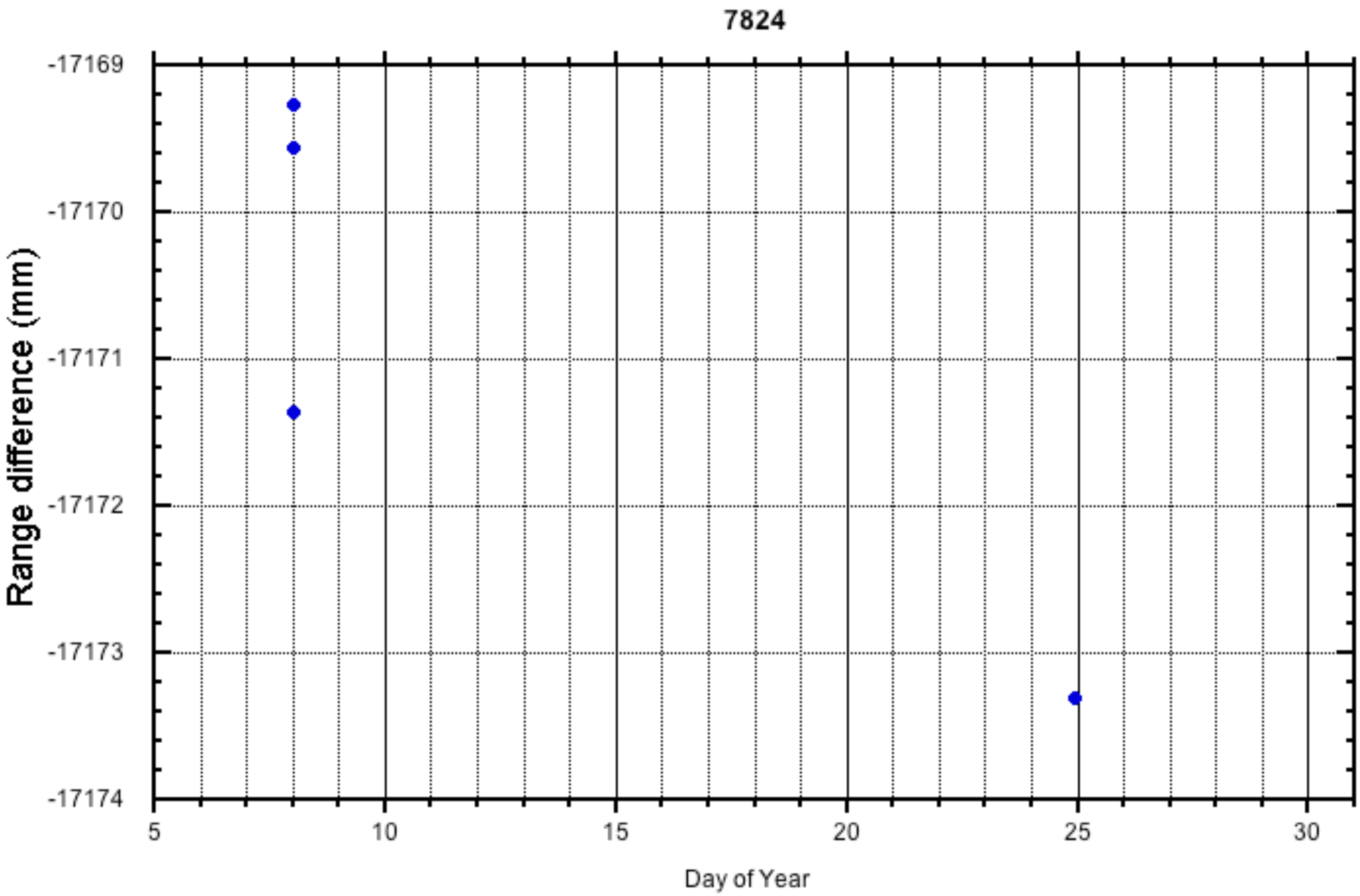
Normal point differences (1890)



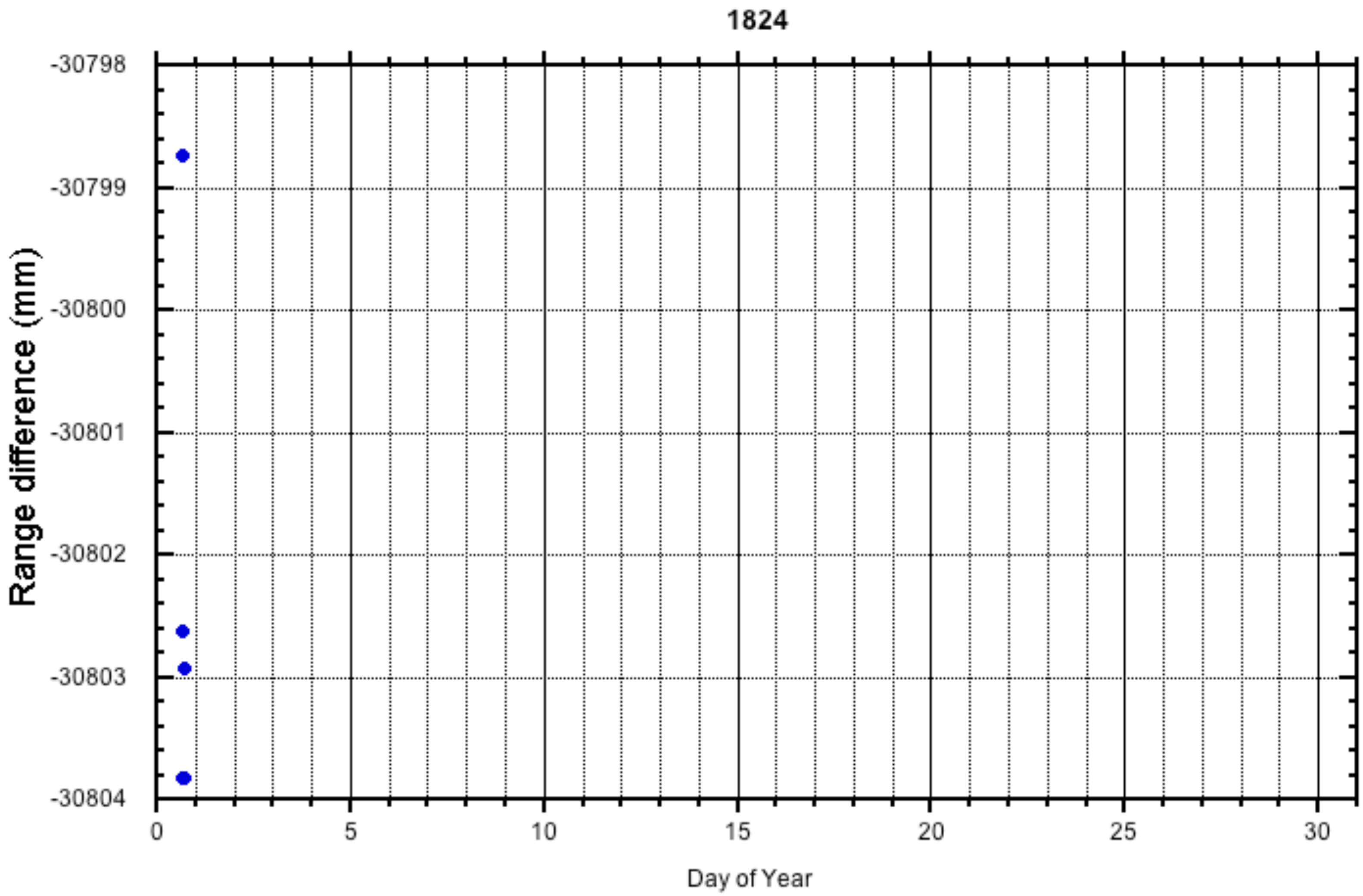
Normal point differences (1888)



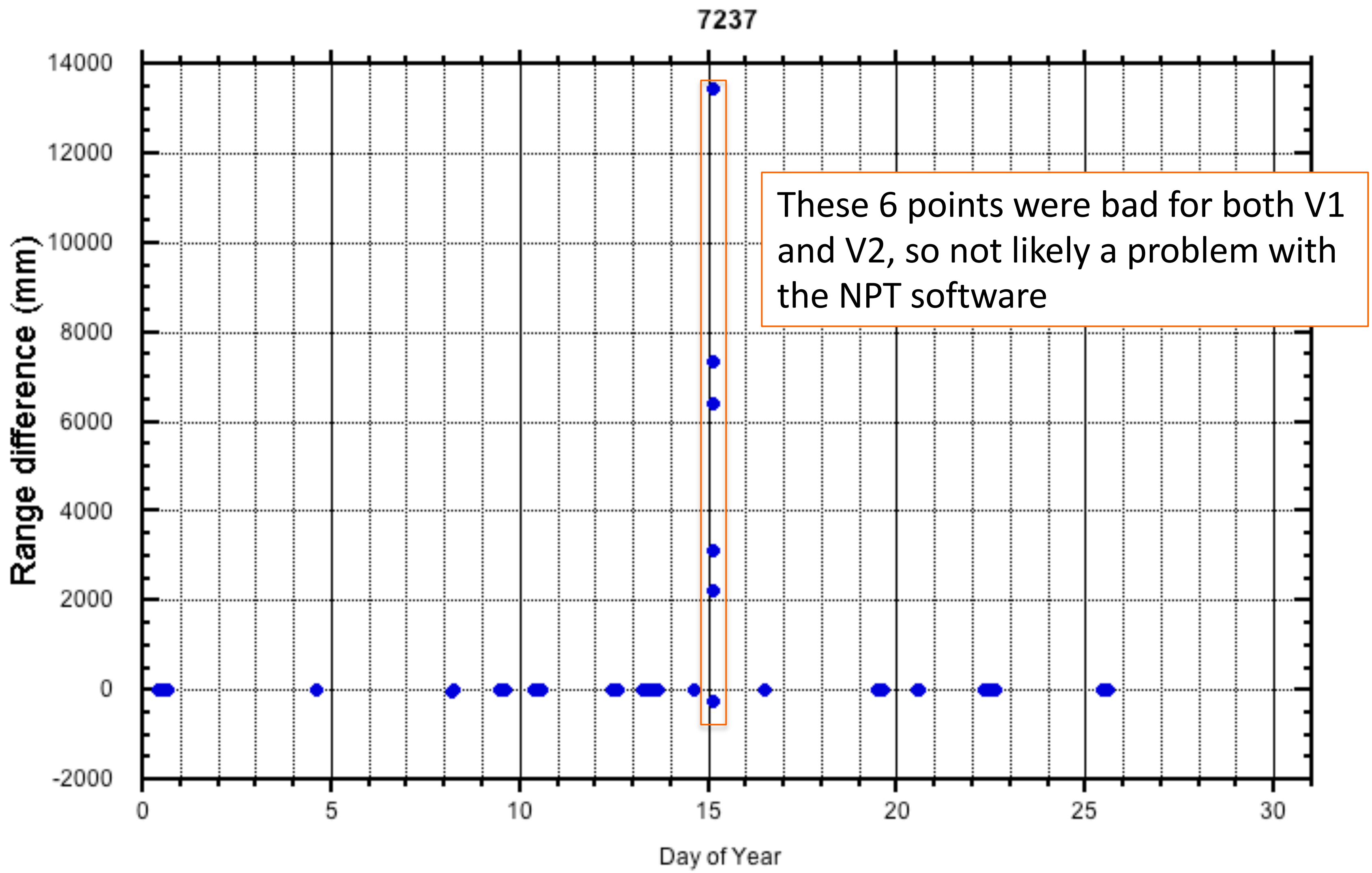
Normal point differences (7824)



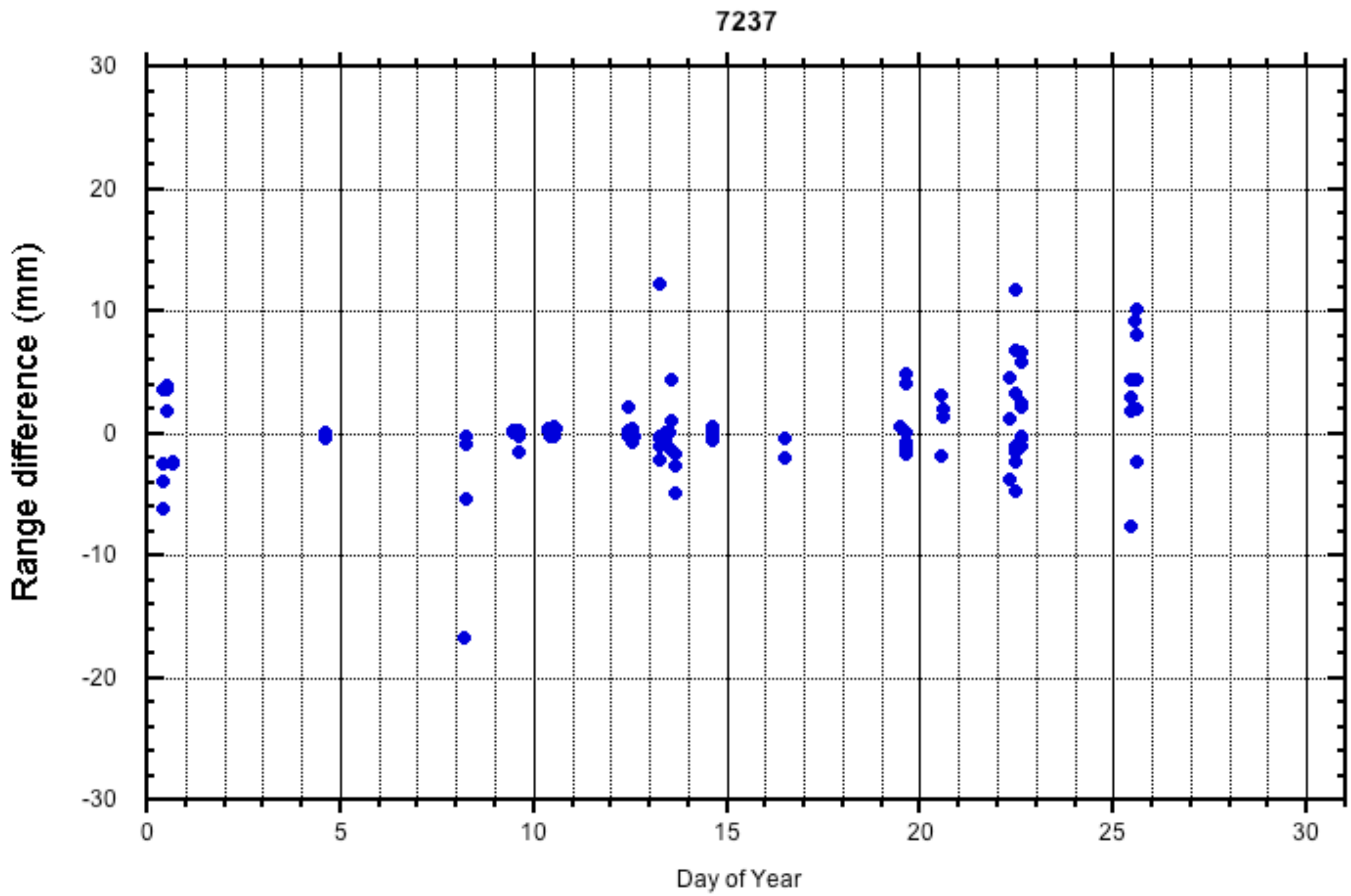
Normal point differences (1824)



Normal point differences (7237)



Normal point differences (7237; apply 30 mm editing)



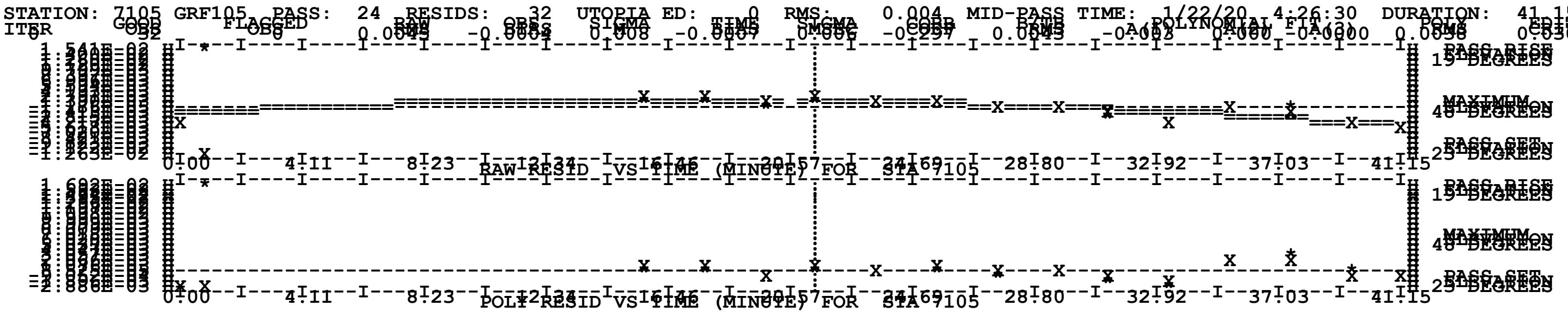
Side-by-side residual comparisons

Both versions plotted together (*=V1, X = V2)

Each plot shows the residuals before and after systematic signal has been removed

Statistics for the pass are included in the header information

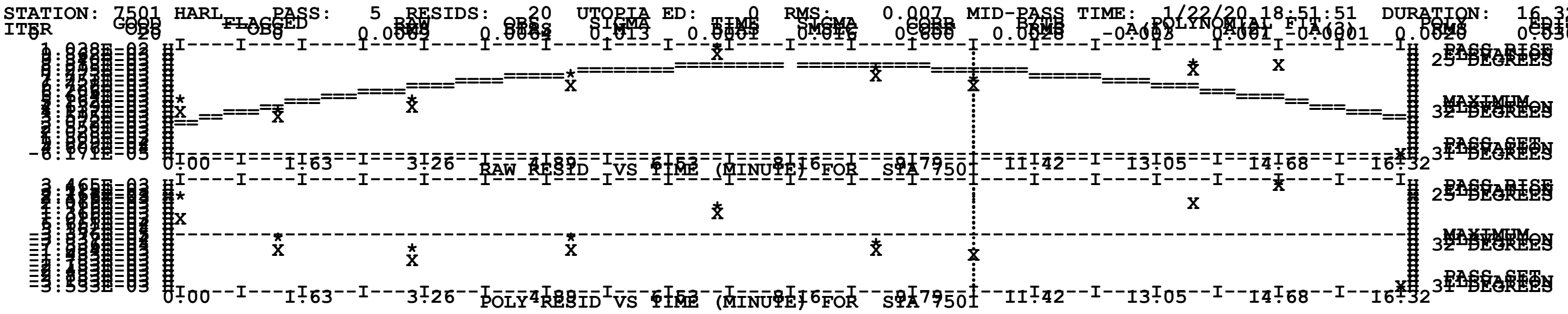
PolyRMS represents best estimate of NPT noise



Raw residuals

After removing systematics

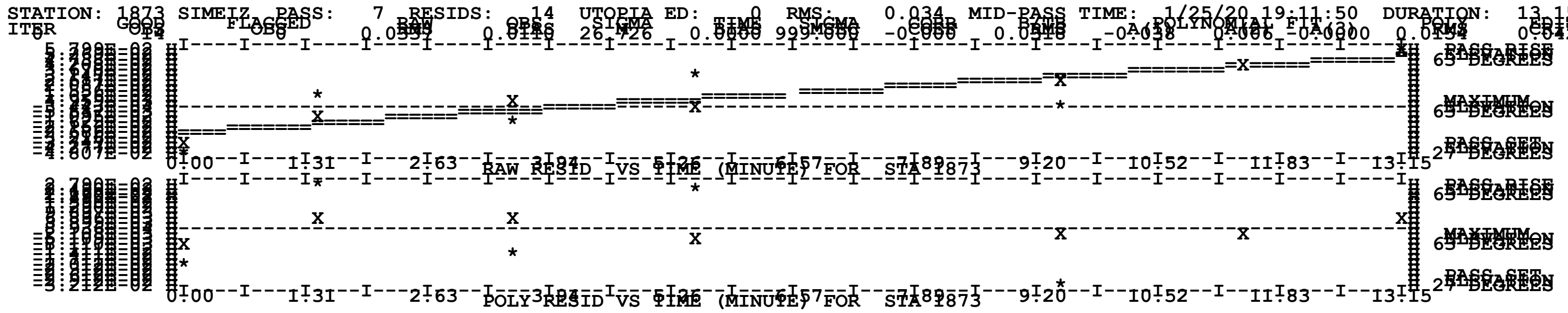
New NPT appears to be more consistent than old one



Raw residuals

After removing systematics

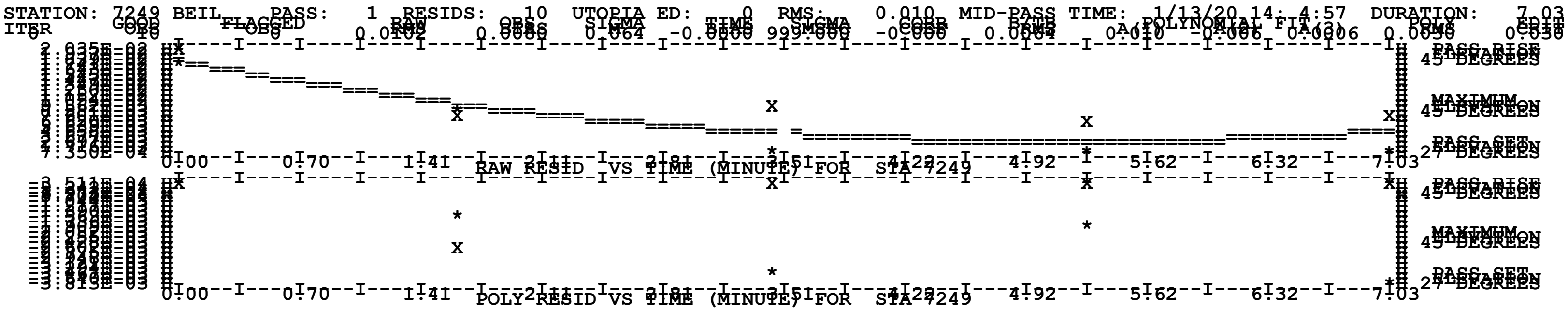
Where only one symbol is present means that the residuals are the same (within the resolution of the plot)



Raw residuals

After removing systematics

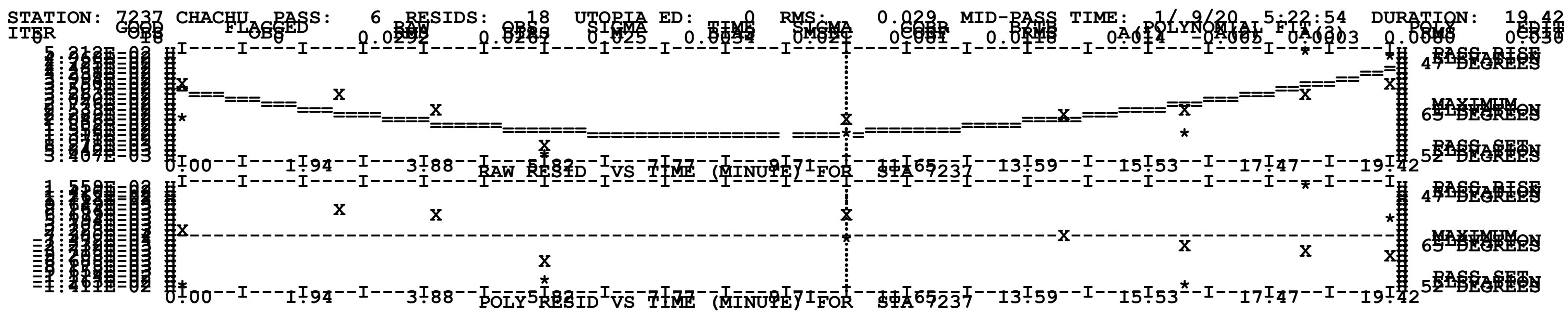
Where only one symbol is present means that the residuals are the same (within the resolution of the plot)



Raw residuals

After removing systematics

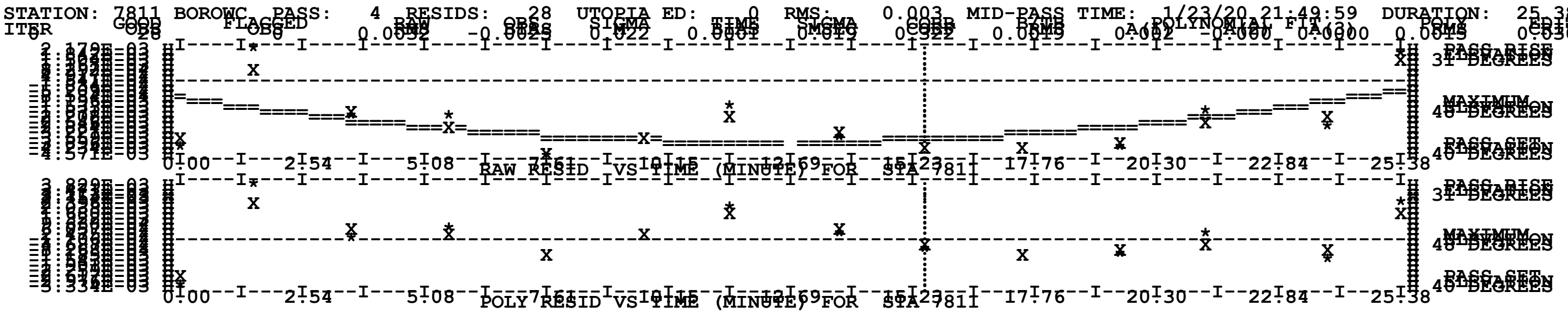
Where only one symbol is present means that the residuals are the same (within the resolution of the plot)



Raw residuals

After removing systematics

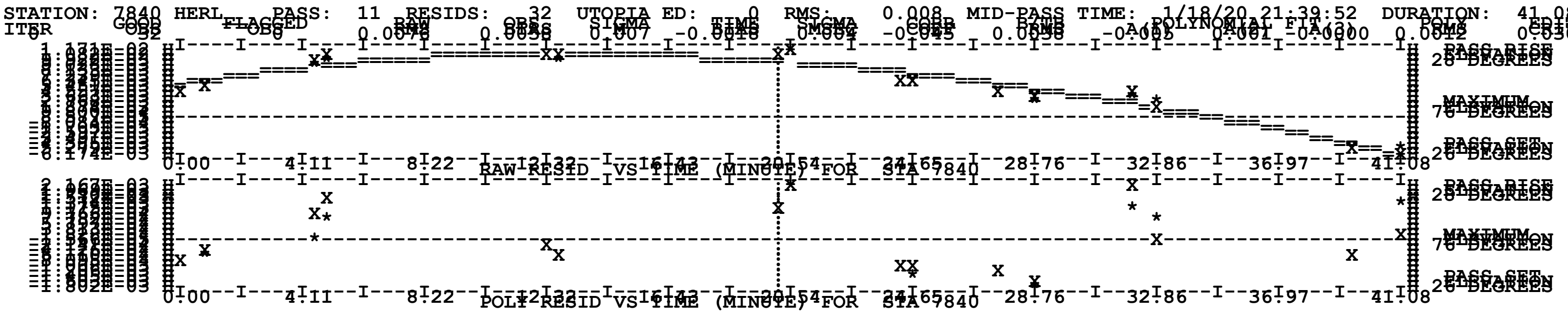
Where only one symbol is present means that the residuals are the same (within the resolution of the plot)



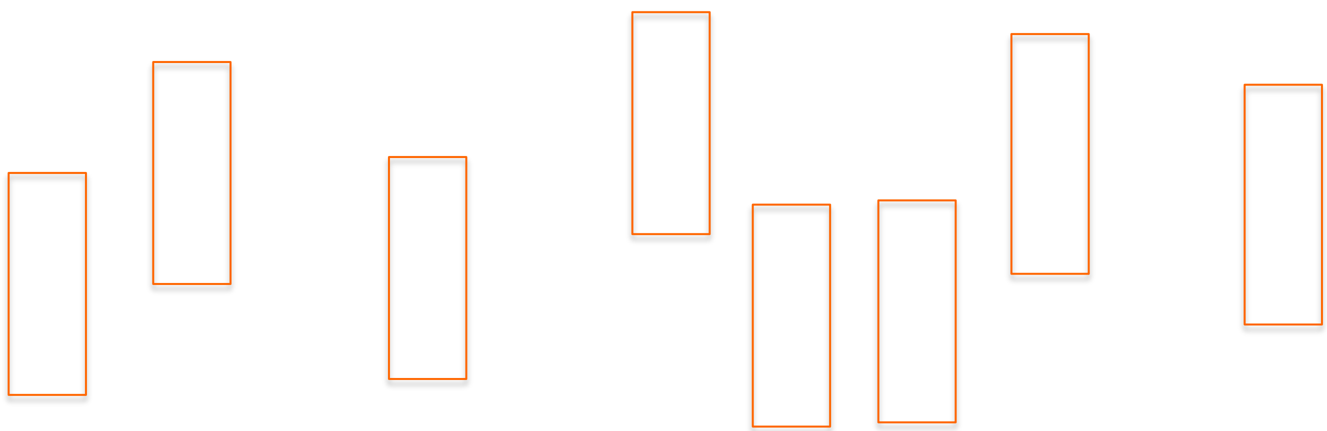
Raw residuals

After removing systematics

Where only one symbol is present means that the residuals are the same (within the resolution of the plot)



Raw residuals and fit curve



After removing systematics

7840 seems unusual in the pattern of NPTs; they seem to come in pairs
Probably a consequence of high-rate ranging

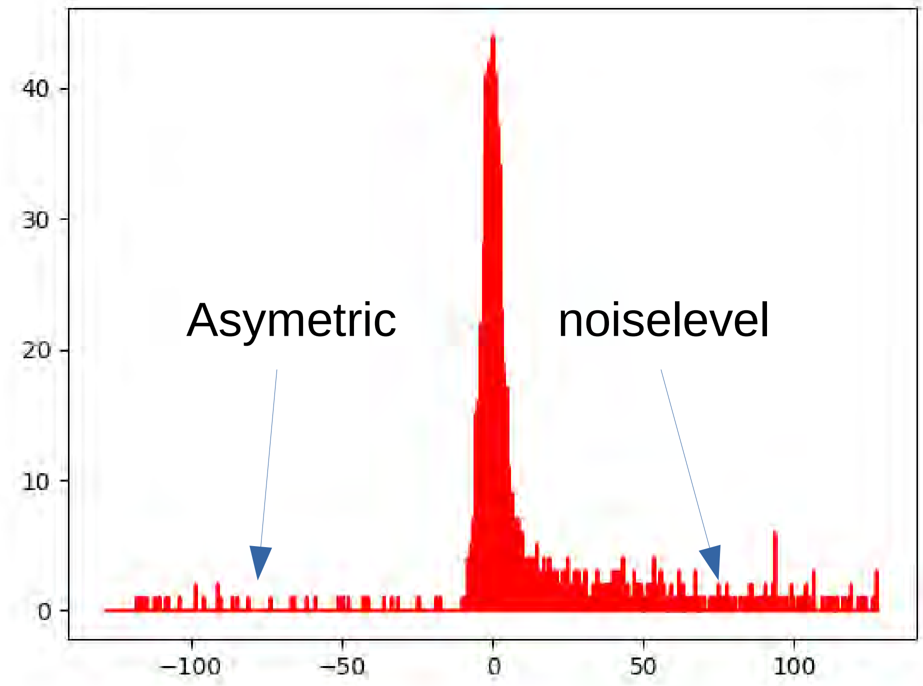
Conclusions

- In most cases, no significant difference in NPTs
  - Slight decrease in overall fit RMS
  - In a few cases, the new NPTs are clearly an improvement
  - In a few rare cases, some new NPTs (not present in V1) seem inconsistent
  - Most NPT differences under 3 mm; 1.2 mm RMS overall (considering only better precision stations)
  - Differences tend to be larger for lower precision stations
  - Observation epochs appear to be identical generally, though sub-microsecond differences sometimes occur (143 out of 4315 obs compared)
- Very large differences for 7824 and 1824
  - Possibly just a format issue
- Plots for every pass are available upon request

Wiener Normal Points from Herstmonceux Data

Instrument Function

Events

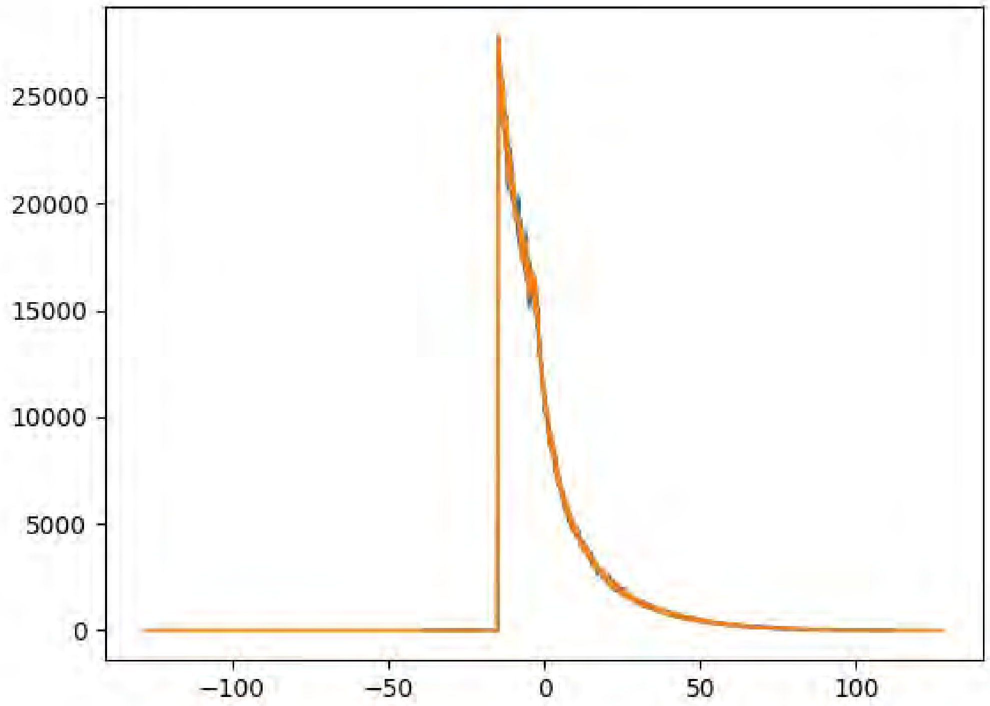


Deviation w.r.t mean / mm

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

Transfer Function

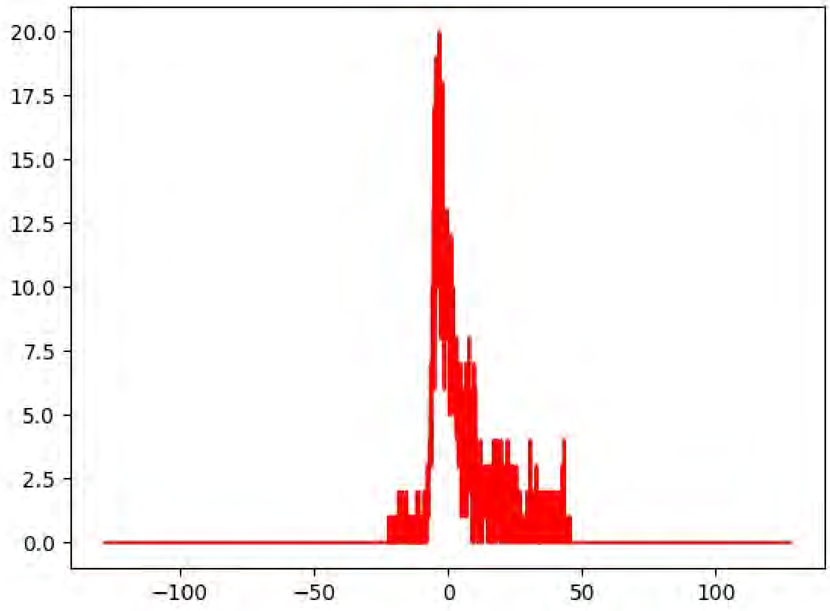
Reflectivity / a.u.

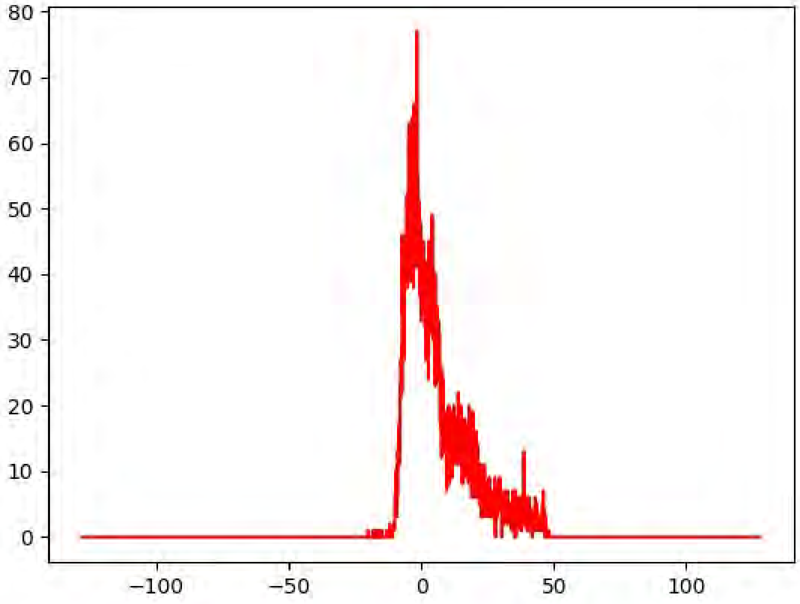


Deviation w.r.t. mean / mm

- kindly provided by J. Rodriguez (exponent 1.25)
- interpolated on a 0.125 mm grid

Lageos returns

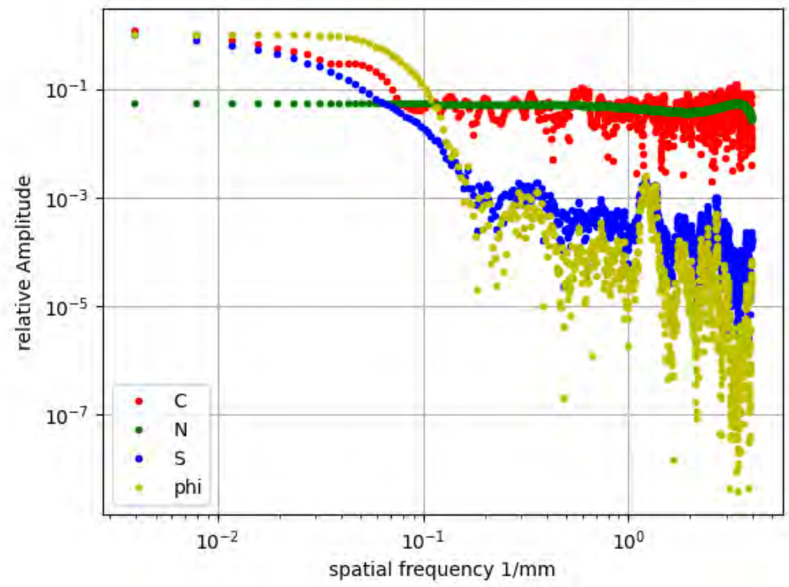


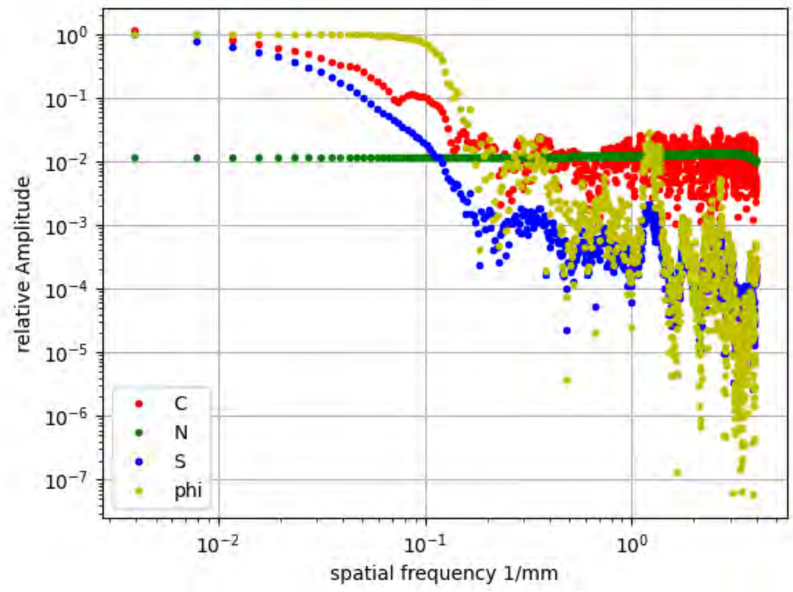


- leptokurtic multiple peaks, the usual case

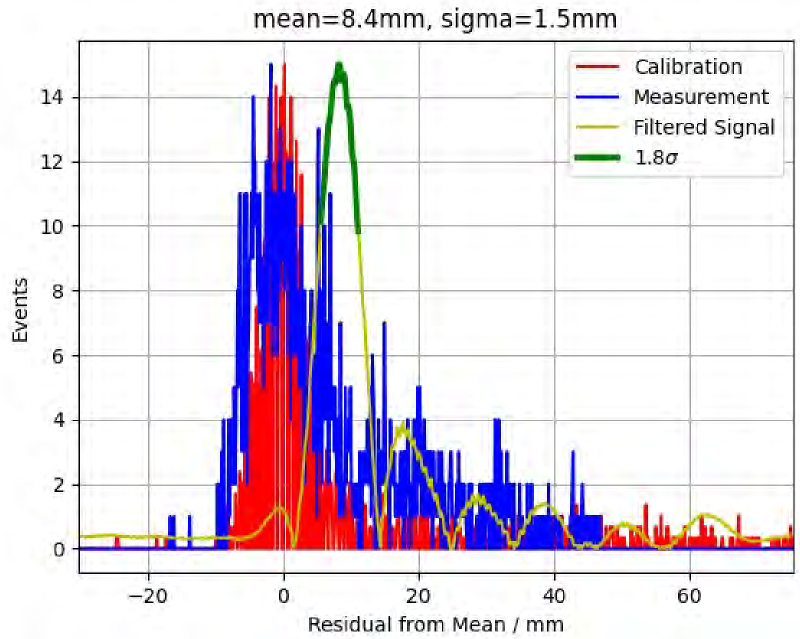
-platokurtic multiple peaks cause fringes in deconvolution

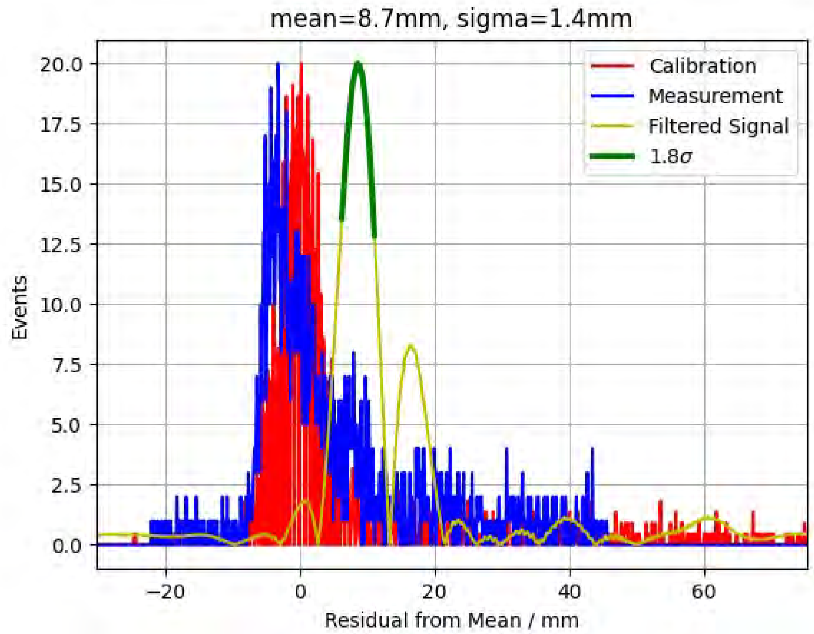
Spectral Data





Spatial Data and Deconvolution

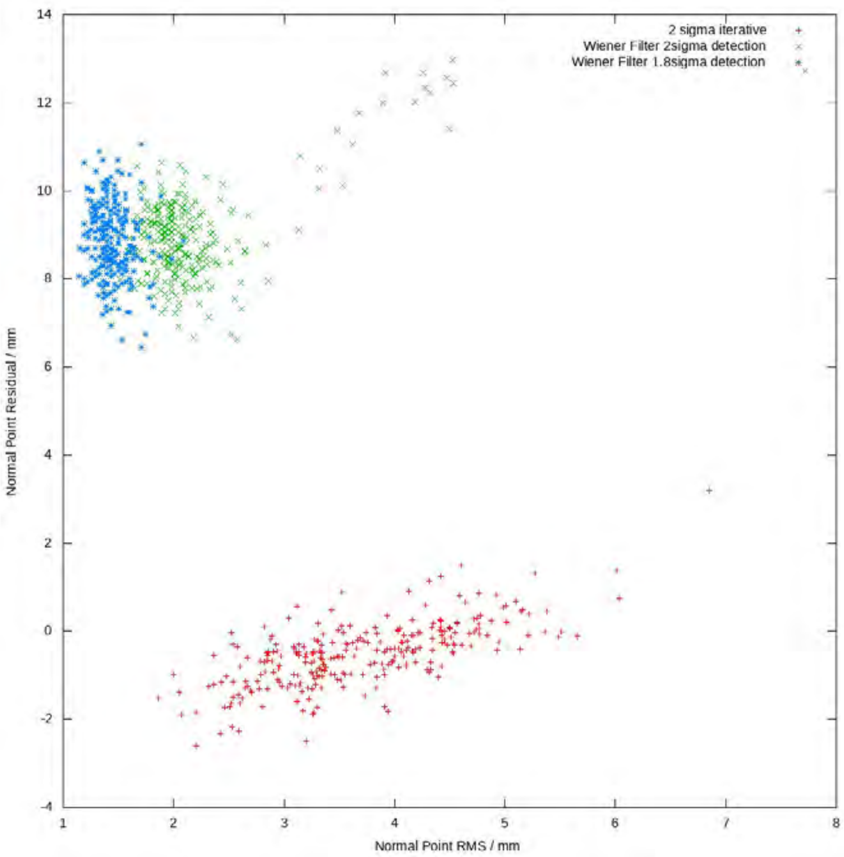




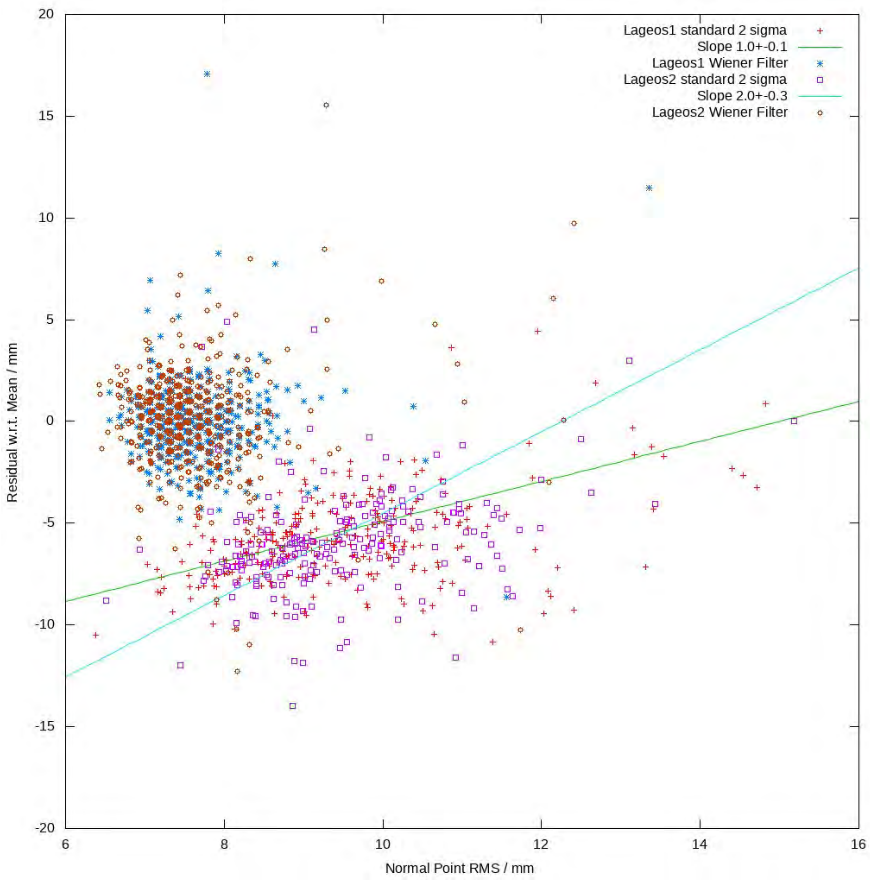
- Wiener Filter works also for sparse data
- in rare cases double peaks cause outliers when editing filtered signal with 2 sigma criterium

NP Residuals vs. NP RMS

7840



7827



Conclusion

- Herstmonceux test data set for Lageos1 has been processed to form Wiener filtered normal points

- algorithm has been tested on various linux plattforms including a miniconda python installation enabling for portability to other OS’s

- trend for NP-residual vs. NP-RMS for Lageos1 is similar to the one seen at 7827

7090, 7124, 7810, and 7839 SLR Data Analysis

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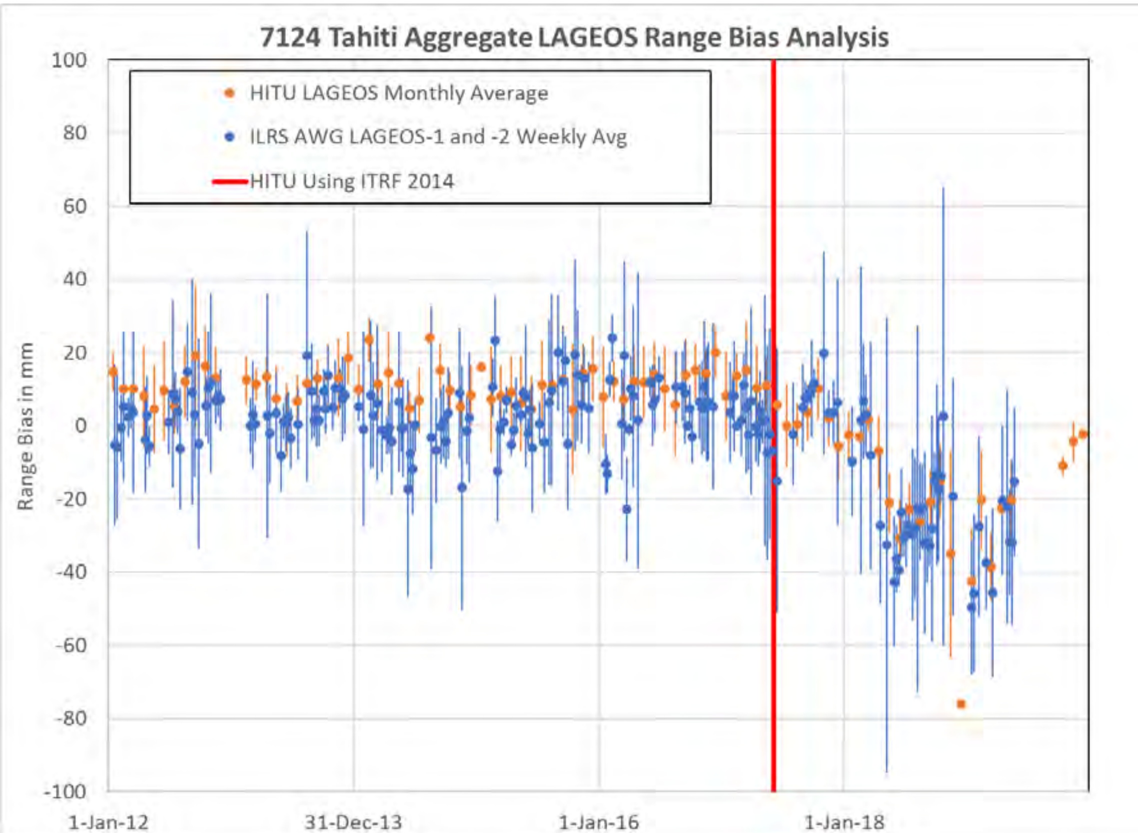
Background

- Toshi's past yearly aggregate analyses of normal points has shown mm level systematics as a function of time of day; signal strength, bin RMS, kurtosis, etc.
- Let's explore what level of biases can be detected using Toshi's 6 hour pass-by-pass analyses. We would like to answer the following question:
  - If there is an abrupt change in a station's range bias, how small a range bias can be detected and how long must it persist to be detected?

	Period of Time					
Satellite/Bias Type	Pass	Day	Week	Month	3 Months	Year
LAGEOS Range Bias (mm)						
LAGEOS Time Bias (μsec)						
Lares Range Bias (mm)						
Lares Time Bias (μsec)						
Stella/Starlette Range Bias (mm)						
Stella/Starlette Time Bias (μsec)						
Ajisai Range Bias (mm)						
Ajisai Time Bias (μsec)						
Etalon Range Bias (mm)						
Etalon Time Bias (μsec)						

7124 TAHITI ANALYSIS

7124 Tahiti LAGEOS Range Bias Analysis



In mid April 2018, there appears to have been a ~30mm change in the 7124 LAGEOS range bias which Erricos identified. Follow-on analysis reveals there was a laser diode change in mid April 2018, which coincides with the apparent change in the bias and change in system delay.

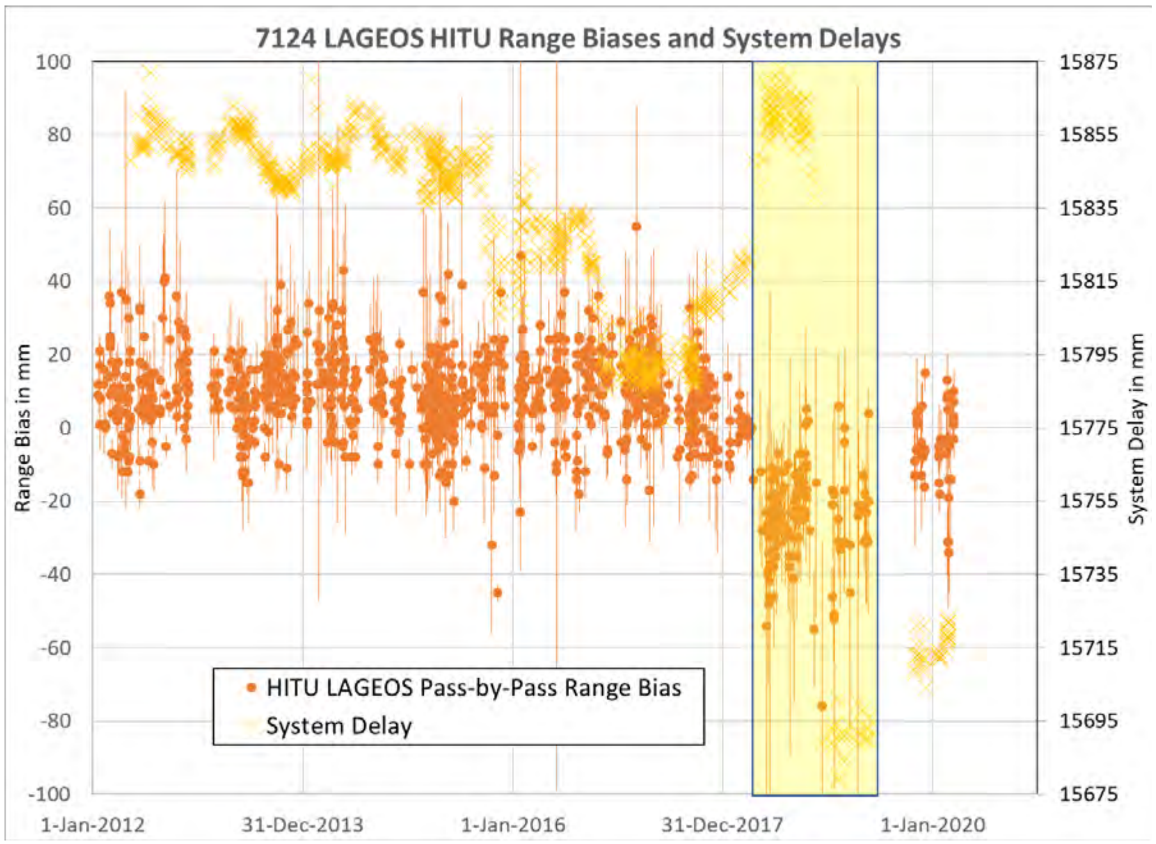
Both Erricos' weekly analysis results along with Toshi's bias results indicate this change.

There is some evidence that the LAGEOS bias may have started drifting before the laser diode change (see next slide).

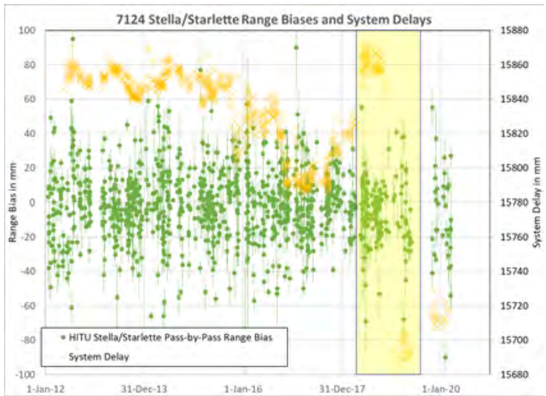
Note: The Event Timer was installed in Nov 2018, but the first ETM pass did occur until March 19, 2019.

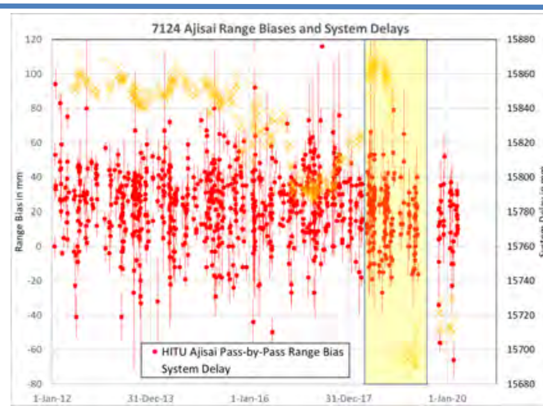
7124 Tahiti LAGEOS Range Bias Analysis

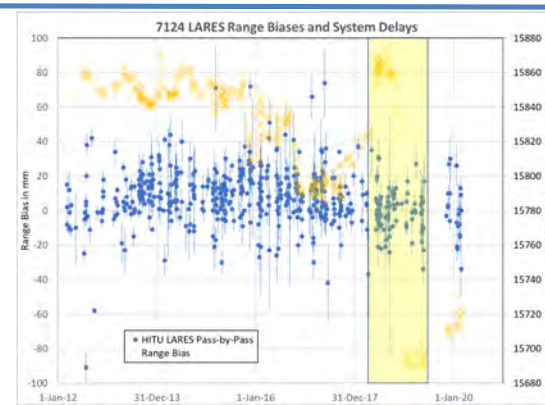
Peraton

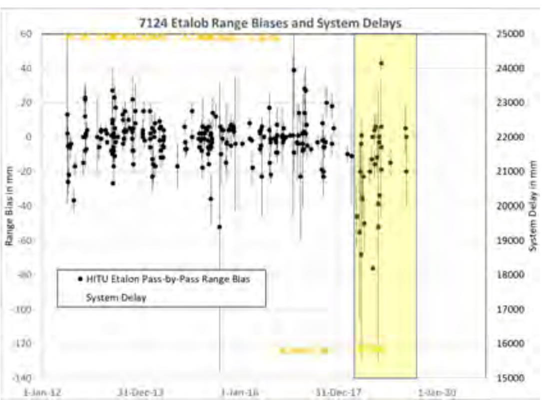


7124 Tahiti HITU Goedetic Range Bias Analysis







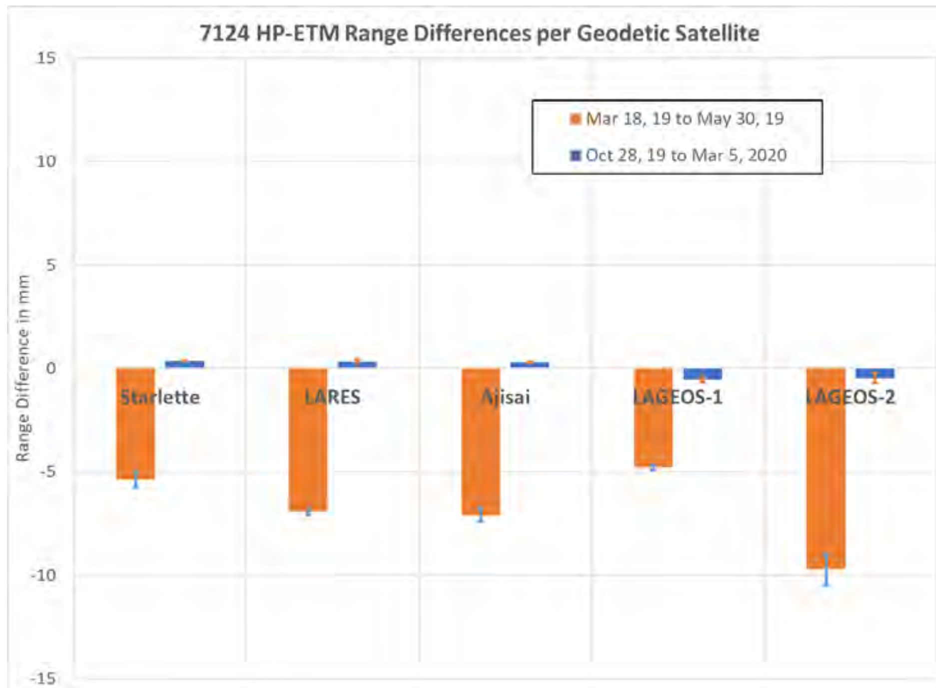


The ~30mm change in the LAGEOS bias does not appear to be as large on the LEO satellites. You can also see an initial change in the Etalon bias.

7124 Tahiti HP5370B-ETM Fullrate Bias Summary

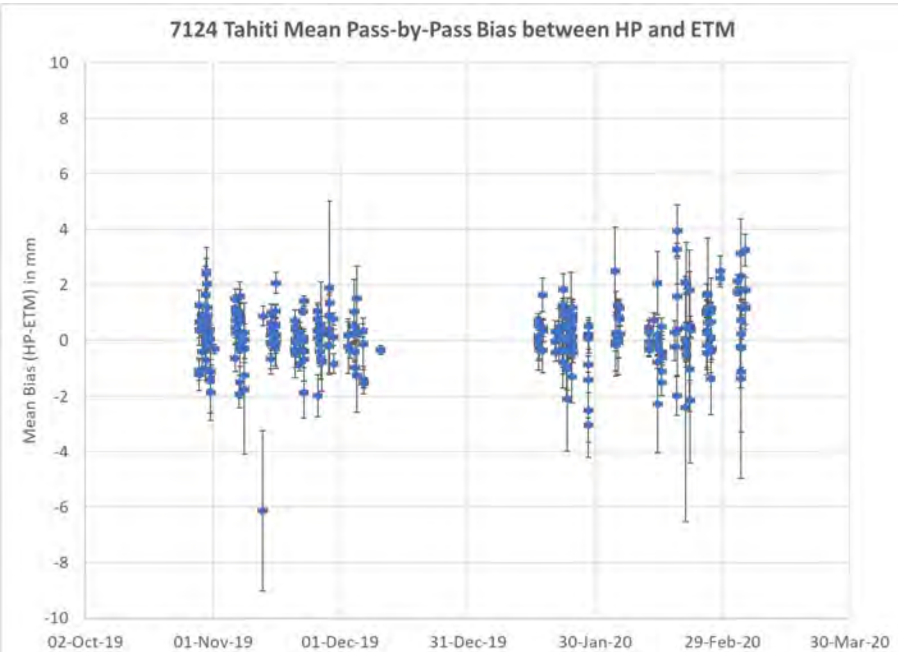
Peraton

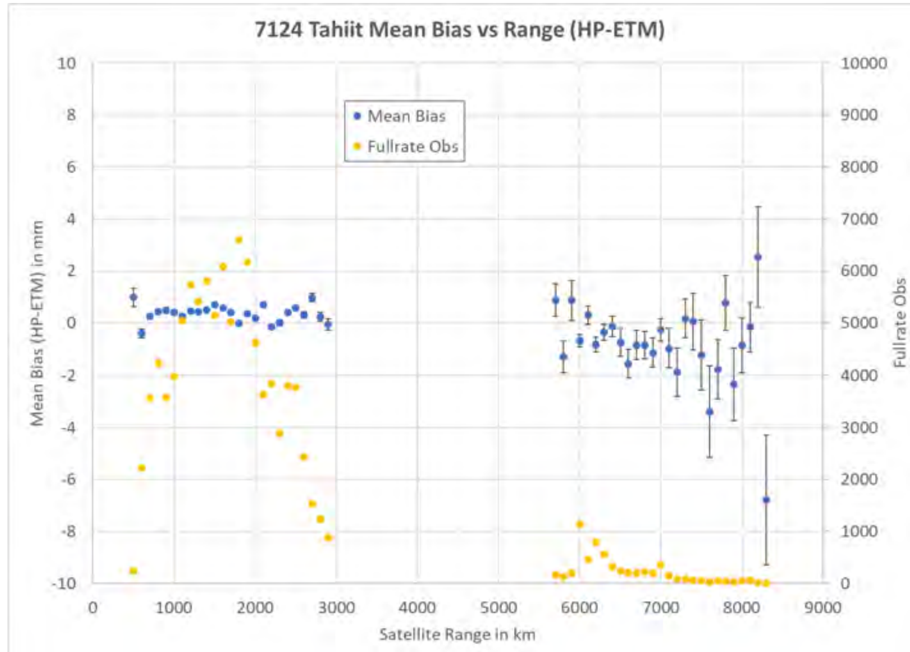
	Mar 18 to May 30, 2019				Oct 28, 2019 to March 5, 2020				JCET Analysis Oct 2019 -Mar 2020		
Satellite	Pass Count	Mean Bias in mm	Stdev in mm	Fullrate Obs	Pass Count	Mean Bias in mm	Stdev in mm	Fullrate Obs	Mean Bias in mm	Stdev in mm	Normal Points Obs
Ajisai	**15**	**-7.09**	**15.57**	**16,655**	**36**	**0.31**	**6.01**	**33,425**	**0.52**	**2.09**	**451**
BEC	1	2.22	8.32	12	3	1.63	5.44	238	1.90	2.47	17
Cryosat-2	7	-3.38	21.81	1,862	25	0.37	5.93	8,282	0.59	2.20	295
Galileo-220	1	-2.00	4.61	6							
Geo-IK-2	5	-6.80	15.41	1,721	16	0.54	5.88	6,943	0.77	2.26	112
GLONASS-131	2	-2.05	7.59	47							
GLONASS-136	1	-3.60	8.90	40							
GRACE-FO-1	6	-0.33	17.08	1,232	15	0.22	7.50	2,596	0.61	2.75	209
GRACE-FO-2	3	-4.75	13.47	492	6	0.36	6.86	1,089	1.16	3.44	81
HY-2A	4	-9.74	13.75	1,742	5	0.60	6.62	644	0.83	2.27	22
HY-2B	4	-2.10	20.07	1,590	8	0.12	5.88	1,753	0.45	3.08	50
Jason-2	2	-5.55	14.88	794							
Jason-3	7	-5.57	15.26	2,458	19	0.45	5.91	7,600	0.62	2.64	341
KOMPSAT-5	4	-4.52	22.84	958	5	0.18	7.22	1,654	0.67	3.32	109
LAGEOS-1	**4**	**-4.78**	**12.03**	**254**	**24**	**-0.54**	**7.89**	**4,892**	**-0.95**	**3.69**	**194**
LAGEOS-2	**2**	**-9.71**	**12.15**	**179**	**10**	**-0.47**	**7.38**	**1,026**	**-0.07**	**3.64**	**66**
LARES	**10**	**-6.94**	**13.81**	**1,959**	**22**	**0.34**	**5.70**	**4,389**	**0.63**	**3.20**	**161**
Larets	3	-3.80	15.44	1,705	15	0.70	5.92	5,762			
PAZ	1	2.46	22.97	600	4	-0.86	5.88	323	-0.75	3.75	38
SARAL	4	-1.65	21.74	216	2	0.46	6.08	729	0.43	2.35	24
Sentinel-3A					1	1.81	5.01	119	0.73	4.26	9
Sentinel-3B					1	1.16	6.23	66	1.28	3.01	9
SNET-4					6	0.47	5.67	285	0.38	3.24	48
Starlette	**12**	**-5.37**	**13.64**	**5,871**	**30**	**0.37**	**5.85**	**16,220**	**0.71**	**2.06**	**251**
Swarm-A	2	-6.81	10.72	57	5	-0.34	7.72	1,212	0.50	2.44	82
Swarm-B	7	-0.17	20.86	2,020	9	0.20	5.29	1,617	0.22	2.81	118
Swarm-C	2	-8.65	15.23	208	5	-0.13	7.48	1,091	0.78	2.58	68
TanDEM-X	1	-10.79	11.42	4							
TechnoSat	5	-6.59	18.15	191	8	0.53	5.61	597	-0.05	4.15	35
TerraSAR-X	4	-1.02	20.94	695	5	0.21	6.18	848			
Grand Total	**119**	**-5.50**	**16.54**	**43,568**	**285**	**0.31**	**6.17**	**103,400**	**0.61**	**0.57**	**2,790**



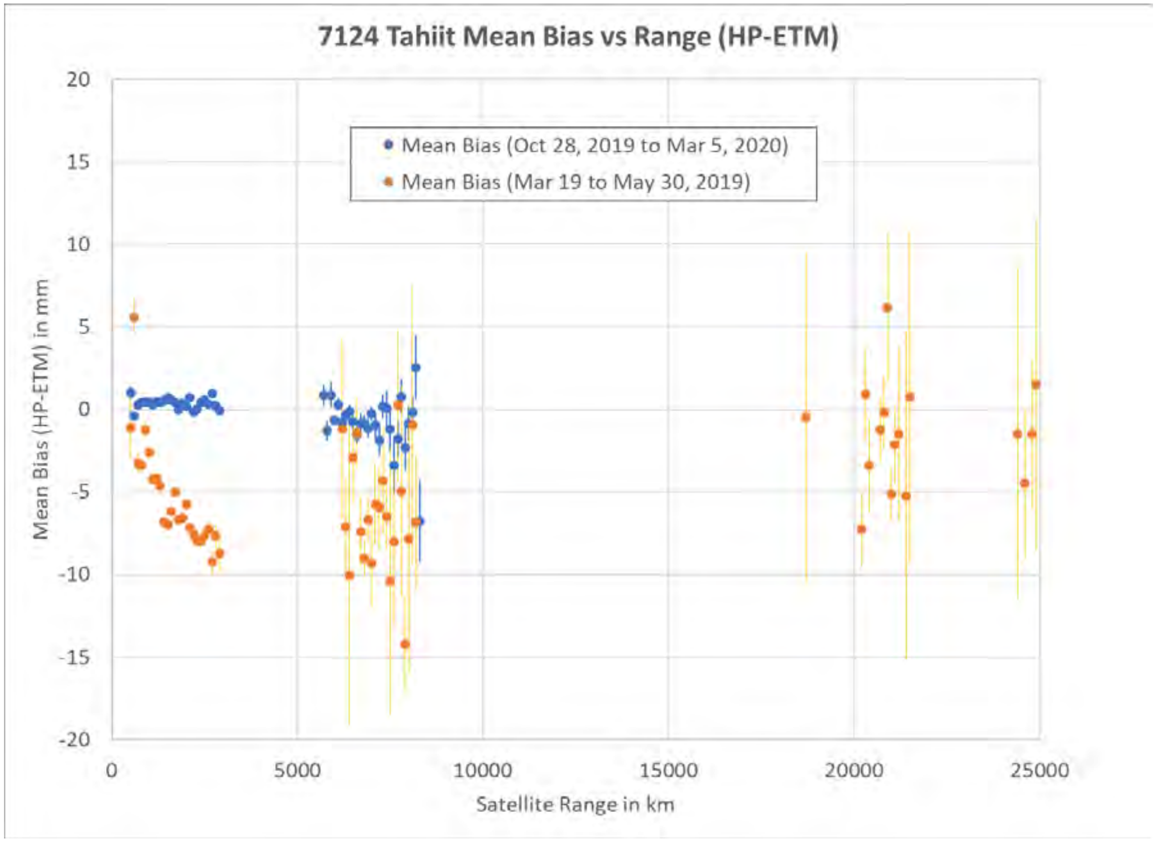
In the most recent ETM dataset, there is a 1 mm offset between LEO and LAGEOS data.

7124 Tahiti HP5370B-ETM Analysis (Oct 2019 – Mar 2020)



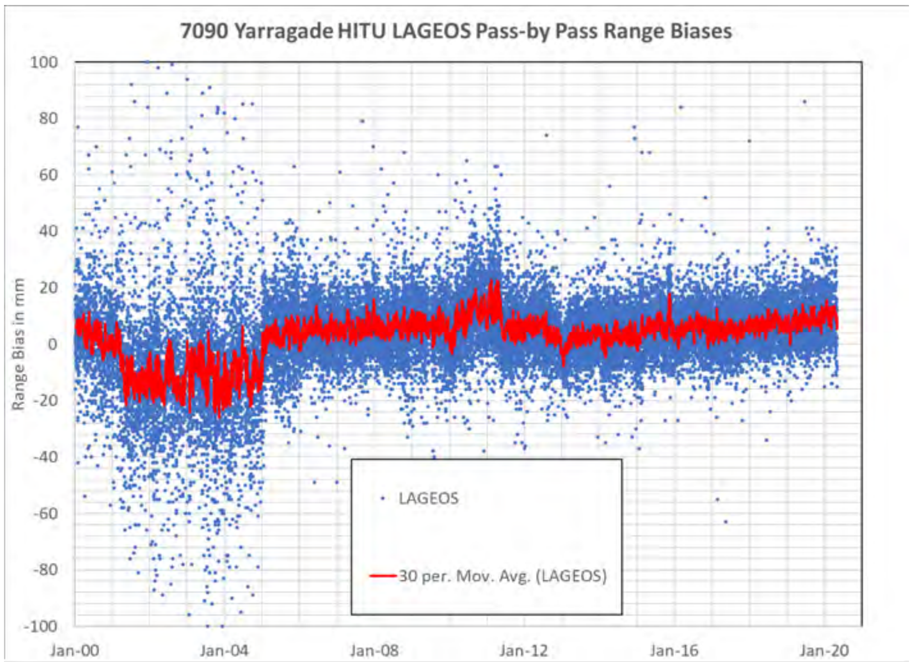


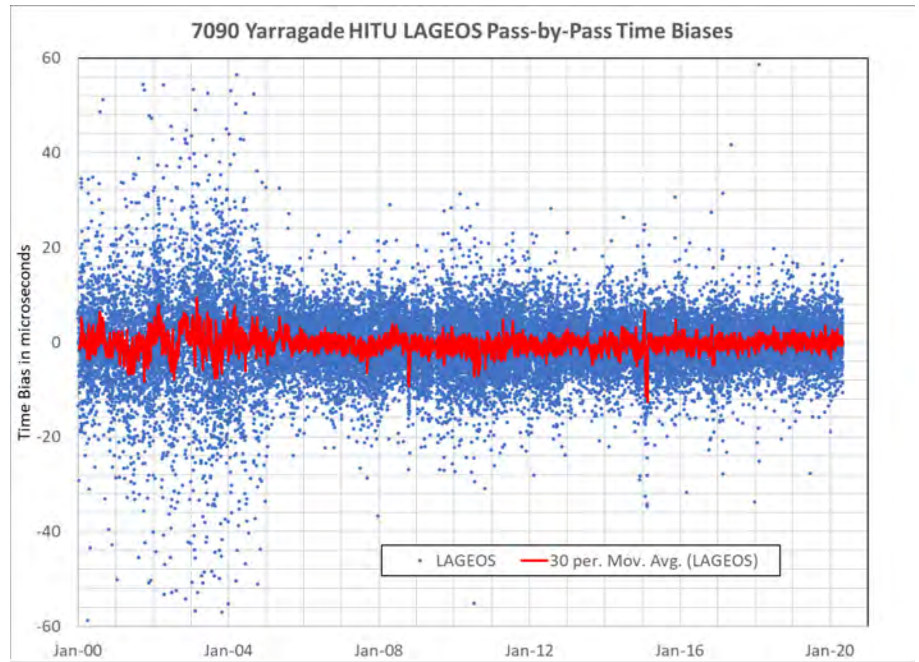
7124 Tahiti HP5370B-ETM Differences vs Range



7090 YARRAGADEE ANALYSIS

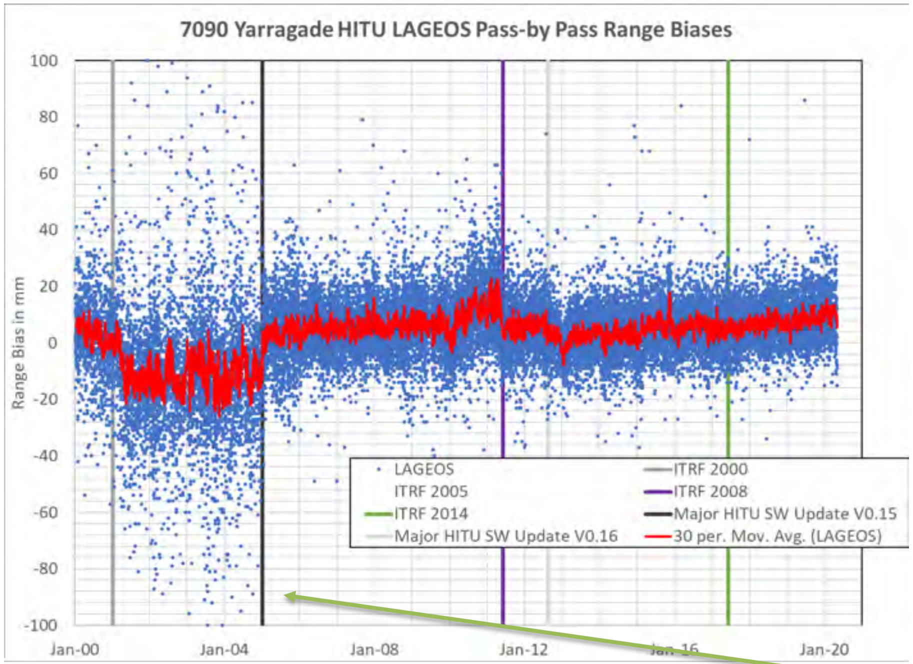
7090 Yarragadee HITU LAGEOS Pass-by-Pass Biases

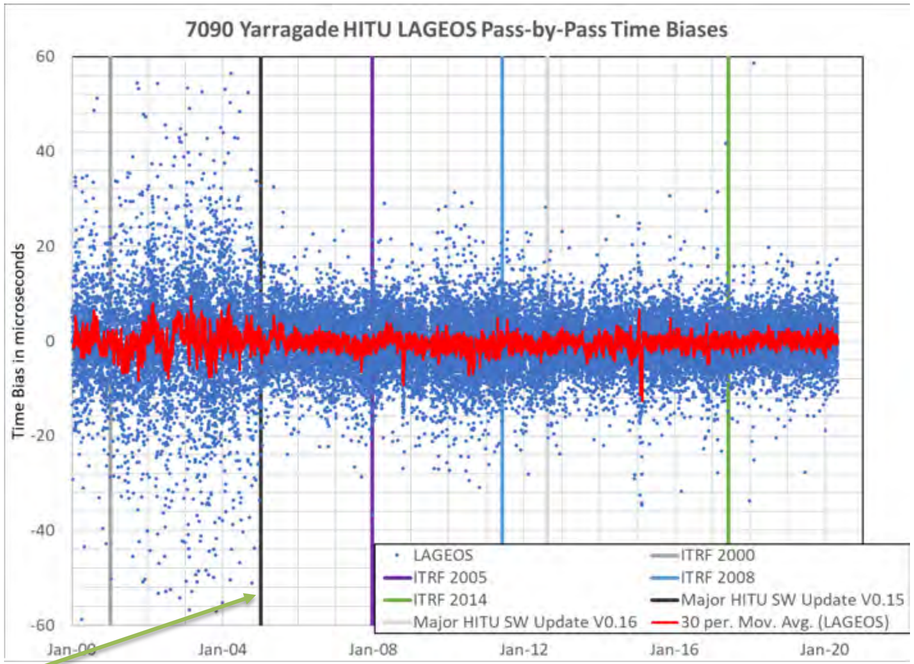




The left and right chart are 7090 HITU pass-by-pass LAGEOS range and time bias estimates; respectively, with gross outliers edited. The red line is a 30 point moving average. There appears to be some obvious changes in the bias characteristics (i.e. scatter, jumps, drifts). Over the next several slides we will explore the potential causes of these bias changes.

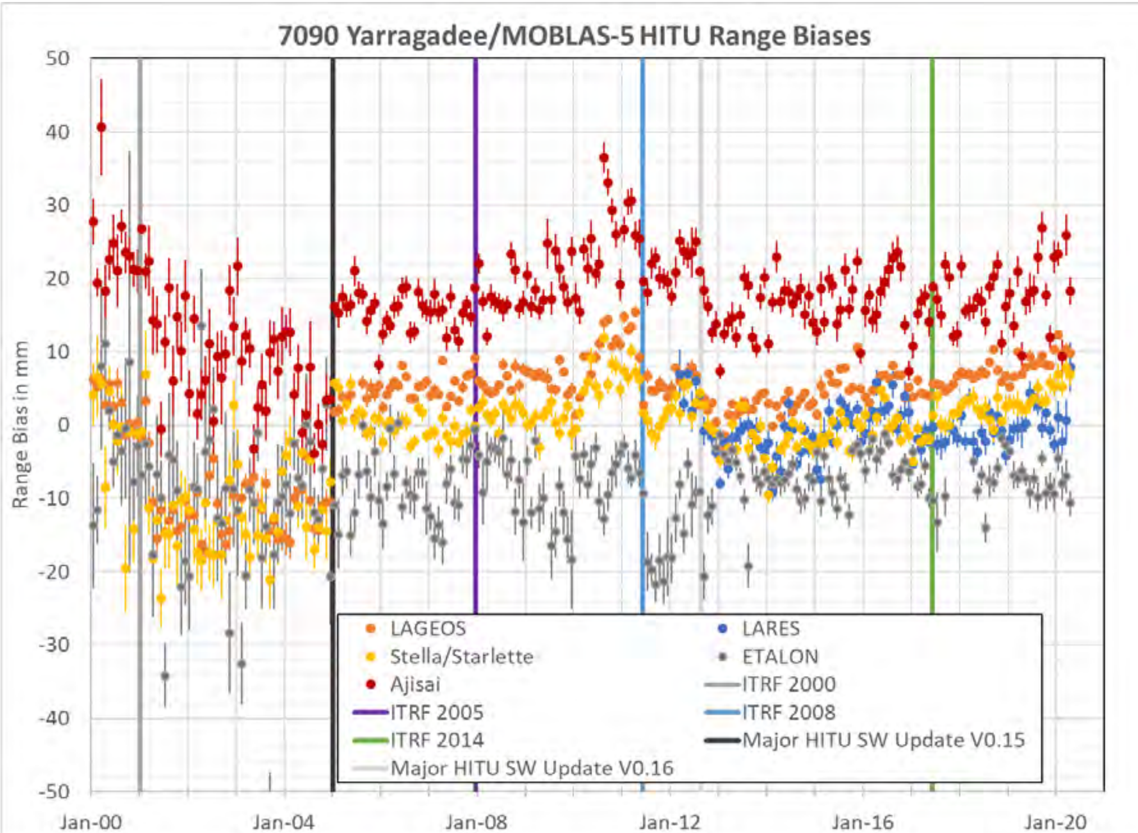
7090 Yarragadee HITU LAGEOS Biases





Now, updates to HITU ITRF station coordinates and major HITU Software (SW) updates were added to these charts.
There was a significant reduction in LAGEOS range & time bias estimates after a major HITU software update in Jan 2005.
Also, some of the apparent range bias discontinuities were a result of HITU updating the station coordinates to the latest ITRF.

7090 Yarragadee HITU Geodetic Monthly Range Biases

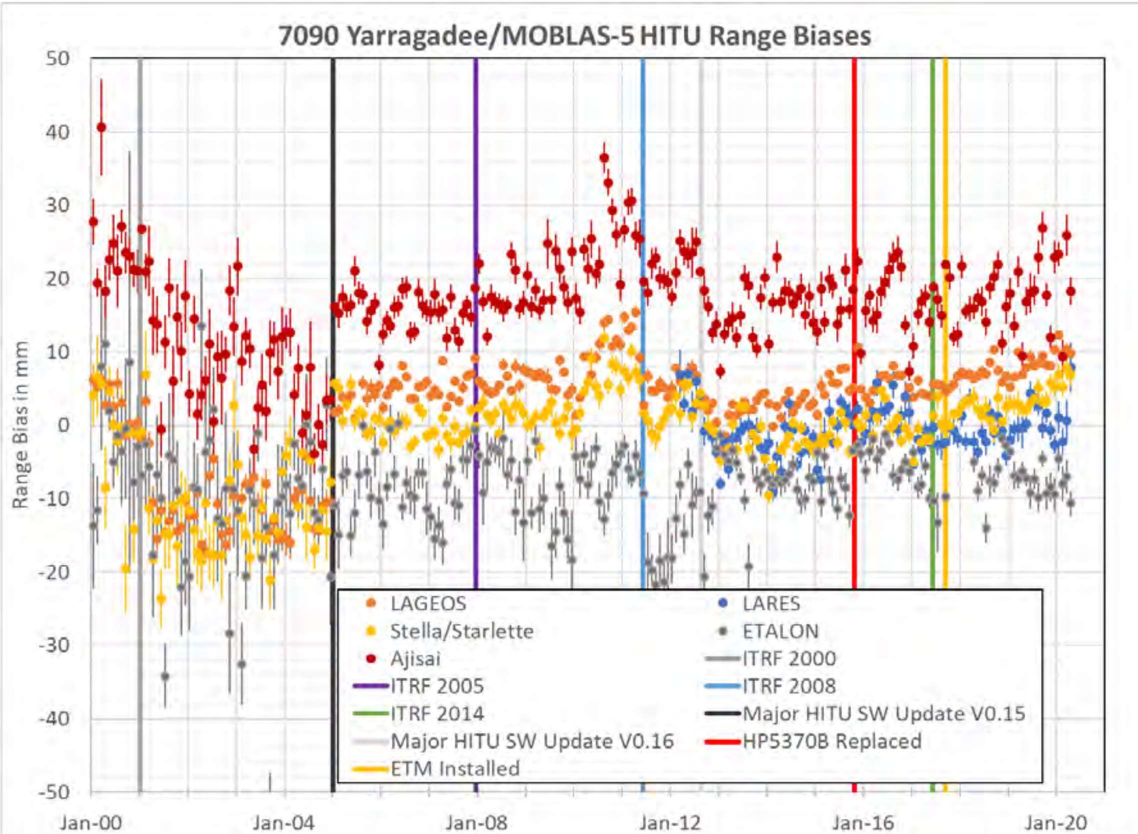


The HITU pass-by-pass range biases were aggregated by month for the geodetic satellites.

Post major HITU SW Update V0.16, these are some observed trends, but are they real or in the analysis?:

1. The LAGEOS and Starlette biases seem to be drifting positive the past few years.
2. The LARES and LAGEOS range biases appear to be diverging.
3. The Etalon bias appears to have jumped ~5 mm in October 2015.

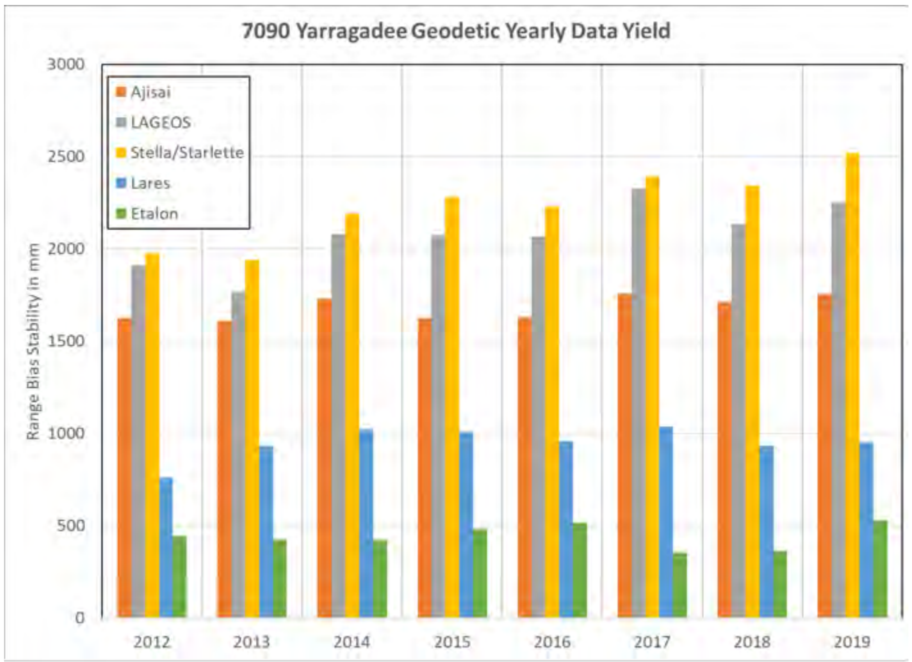
7090 Yarragadee HITU Geodetic Monthly Range Biases

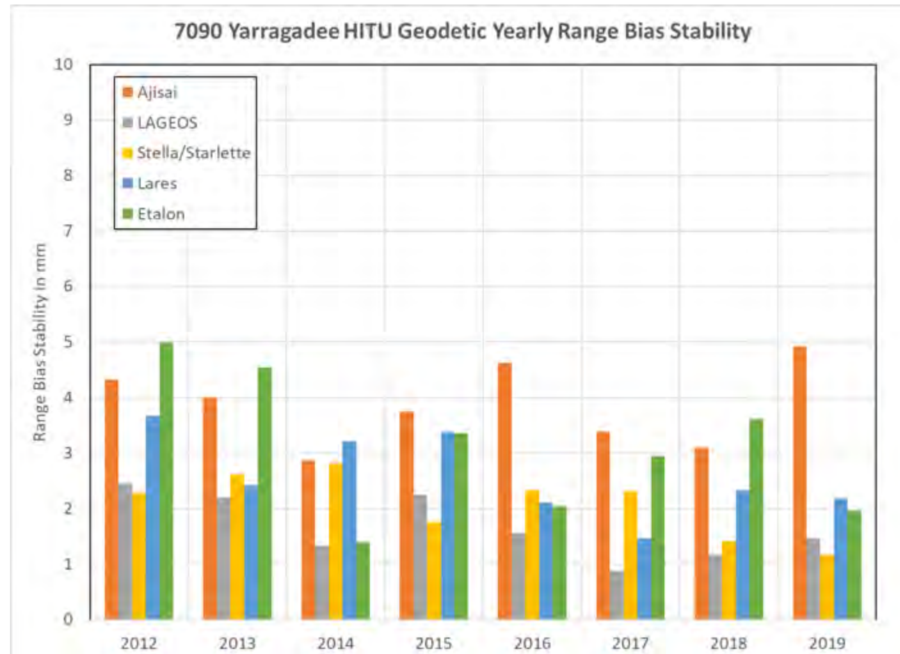


We added two new entries for changes in the time of flight device to the chart and legend.

The HP5370B was replaced with a different HP5370B on 22-Oct-2015 which appears to coincide with the ~5mm change in the Etalon bias. The ETM was installed on 11-Sep-2017.

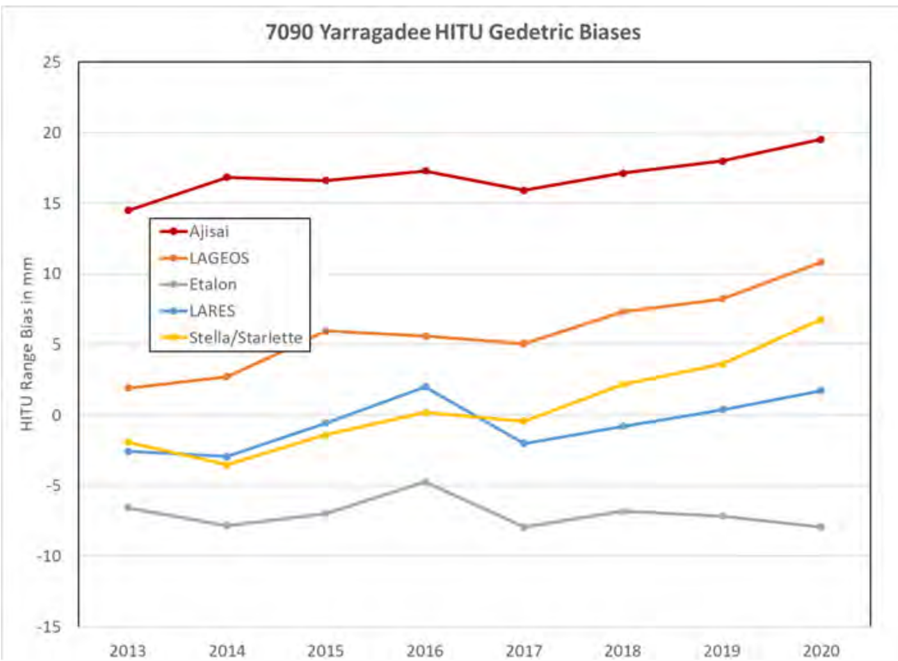
7090 Geodetic Data Yield and Range Bias Stability

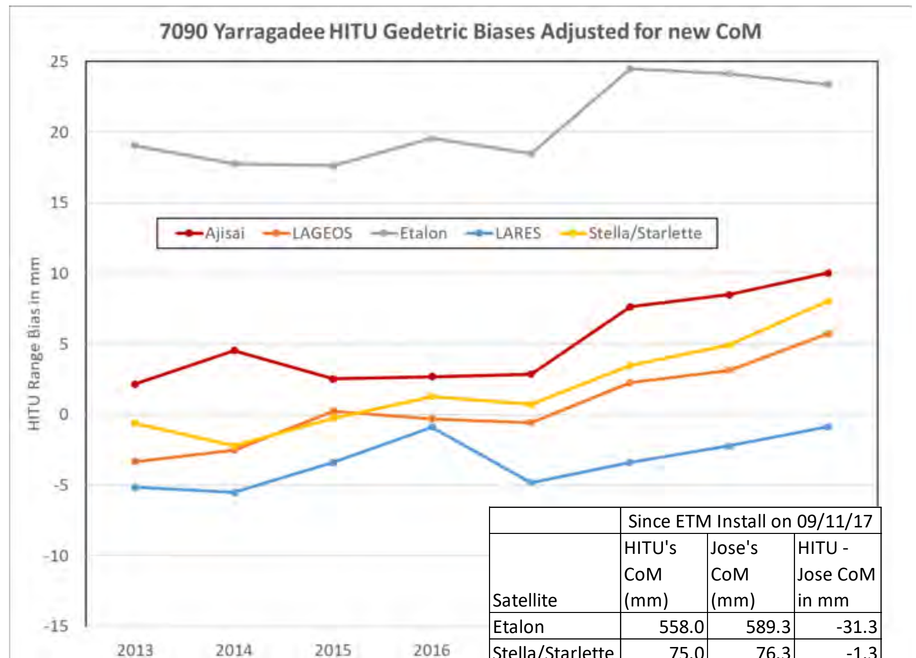




7090 Yarragadee in the perennial leader in geodetic data volume. The site is blessed with clear skies and round the clock operations. The bias stability is the standard deviation of the average monthly range biases within a month.

7090 Yarragadee Yearly Geodetic Range Biases

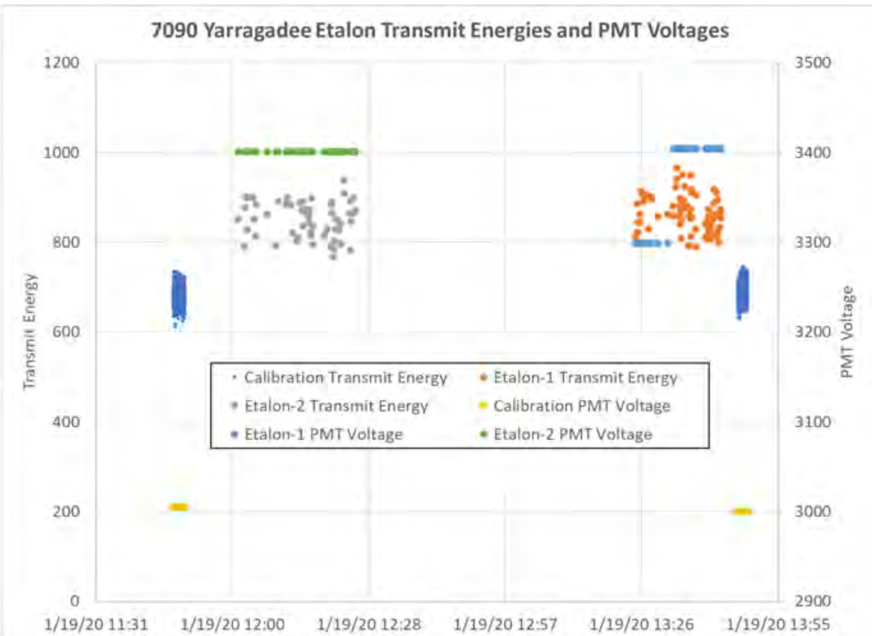


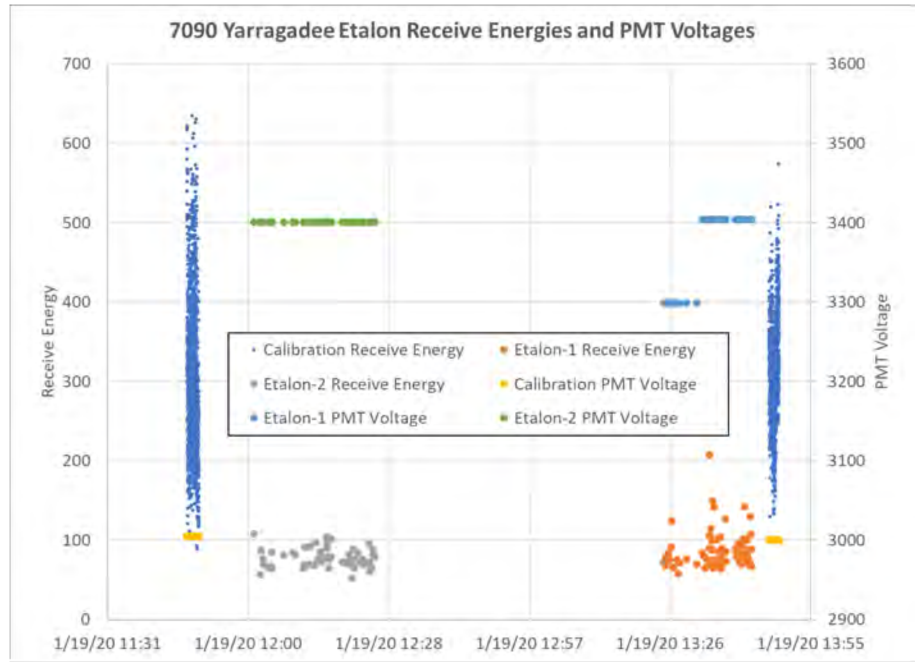


	Since ETM Install on 09/11/17		
Satellite	HITU's CoM (mm)	Jose's CoM (mm)	HITU - Jose CoM in mm
Etalon	558.0	589.3	-31.3
Stella/Starlette	75.0	76.3	-1.3
Lares	133.0	130.4	2.6
LAGEOS-1	251.0	246.2	4.8
LAGEOS-2	251.0	245.7	5.3
Ajisai	1010.0	1000.5	9.5

The right chart is adjusted for Jose's latest CoM corrections.
Are these adjusted biases on Etalon in the HITU analysis, in the new CoM, or in the system?
Starting in 2017, all the biases except Etalon are drifting positive. The several mm bias difference between LARES and LAGEOS is slowly widening over time.

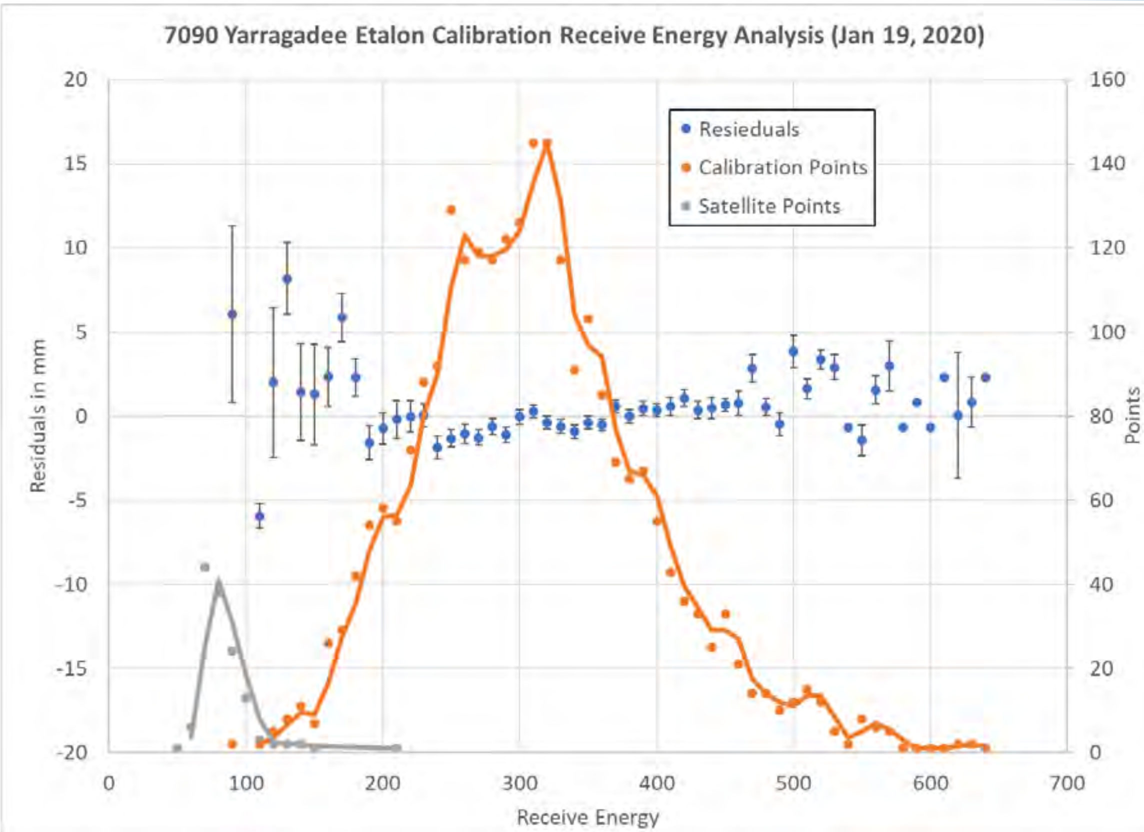
7090 Yarragadee Etalon Analysis





On Etalon, 7090 uses a different receiver configuration, the High Sensitivity Laser Ranging receiver (HSLR), which uses an amplifier to strengthen the returns. From the charts above, we can conclude the Etalon data is uncalibrated in terms of laser transmit energy, receive energy and PMT voltage. Can these items introduce a bias?

7090 Yarragadee Etalon Receive Energy Analysis

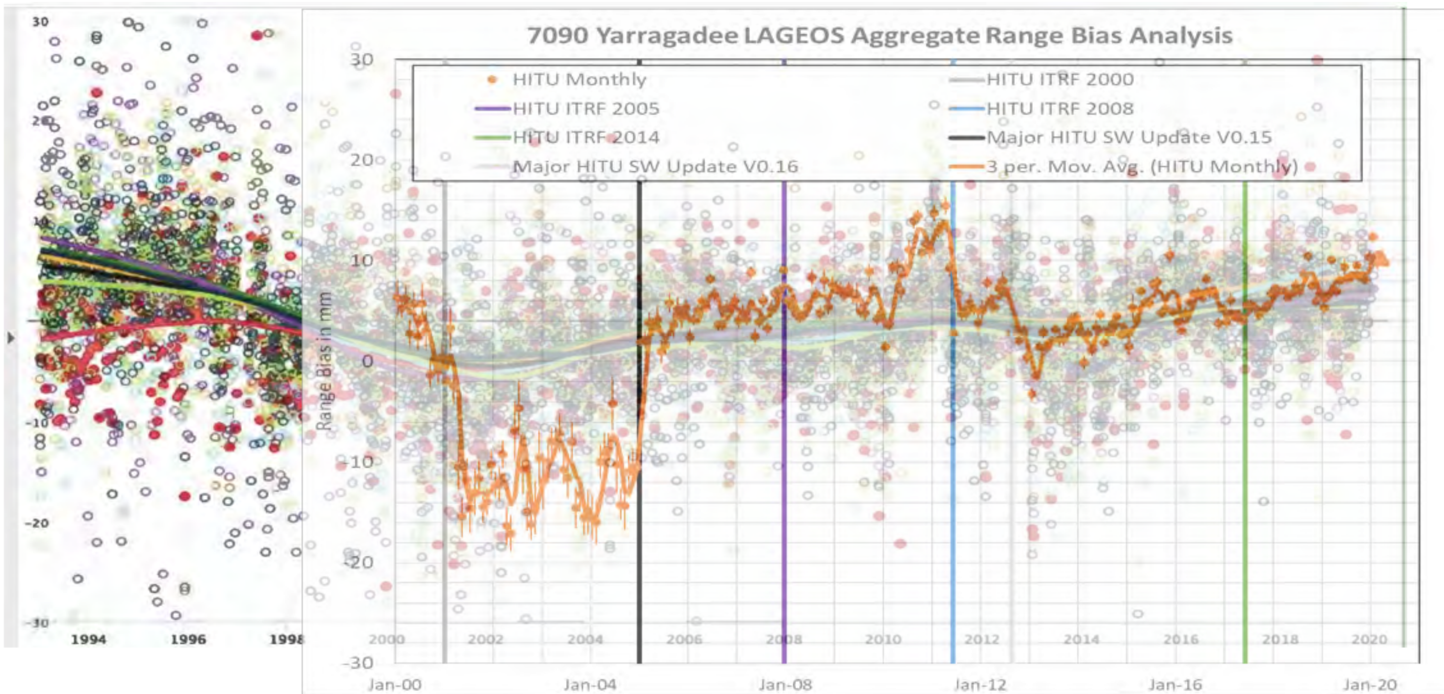


Based on the analysis of an Etalon tracking scenario from Jan 19, 2020. The calibration data was taken at much higher receive energies thus inducing a few to several mm of a positive range bias based on the calibration receive discriminator timewalk.

Based on a PMT voltage test, which is shown later, the system delay does increase at the highest PMT voltages.

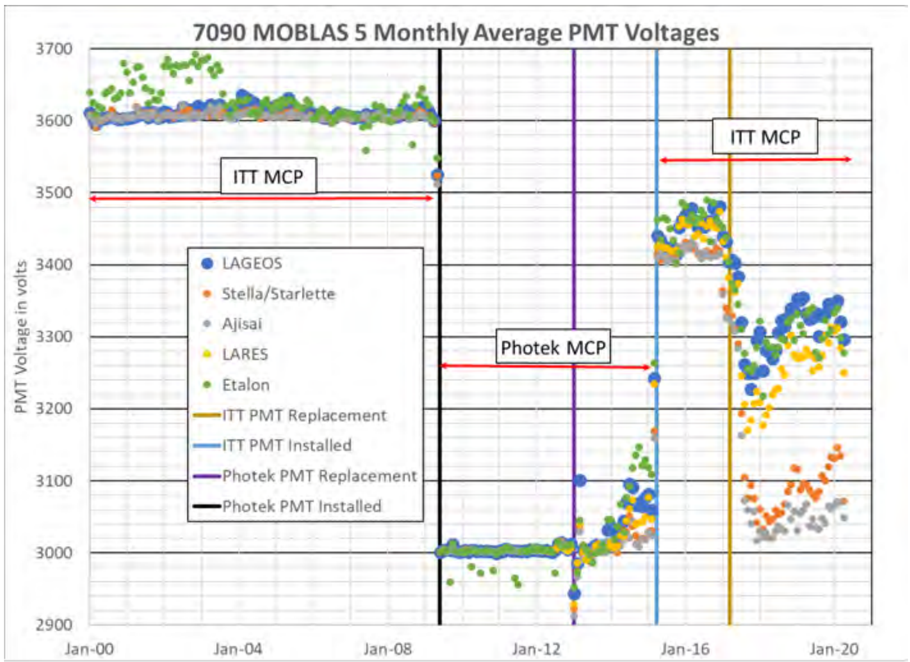
Not properly calibrating relatively weak satellite receive energies and using a lower PMT voltage settings during calibration will induce a positive range bias of more than a few mm. This may explain some of the +20 mm Etalon range bias.

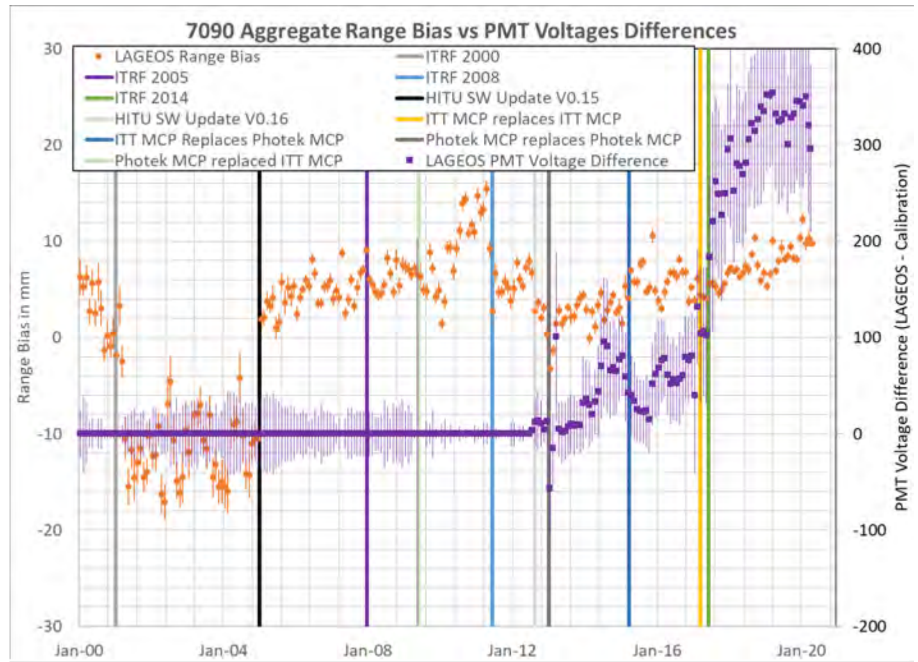
7090 Yarragadee LAGEOS Range Biases



Here are the HITU 7090 combined LAGEOS (1,2) monthly range biases overlaid on the 7090 LAGEOS-1 SSEM results presented by Erricos at the May 2020 ILRS QCB meeting. Both analyses appear to show a bias drift (~1mm/year) since 2014.

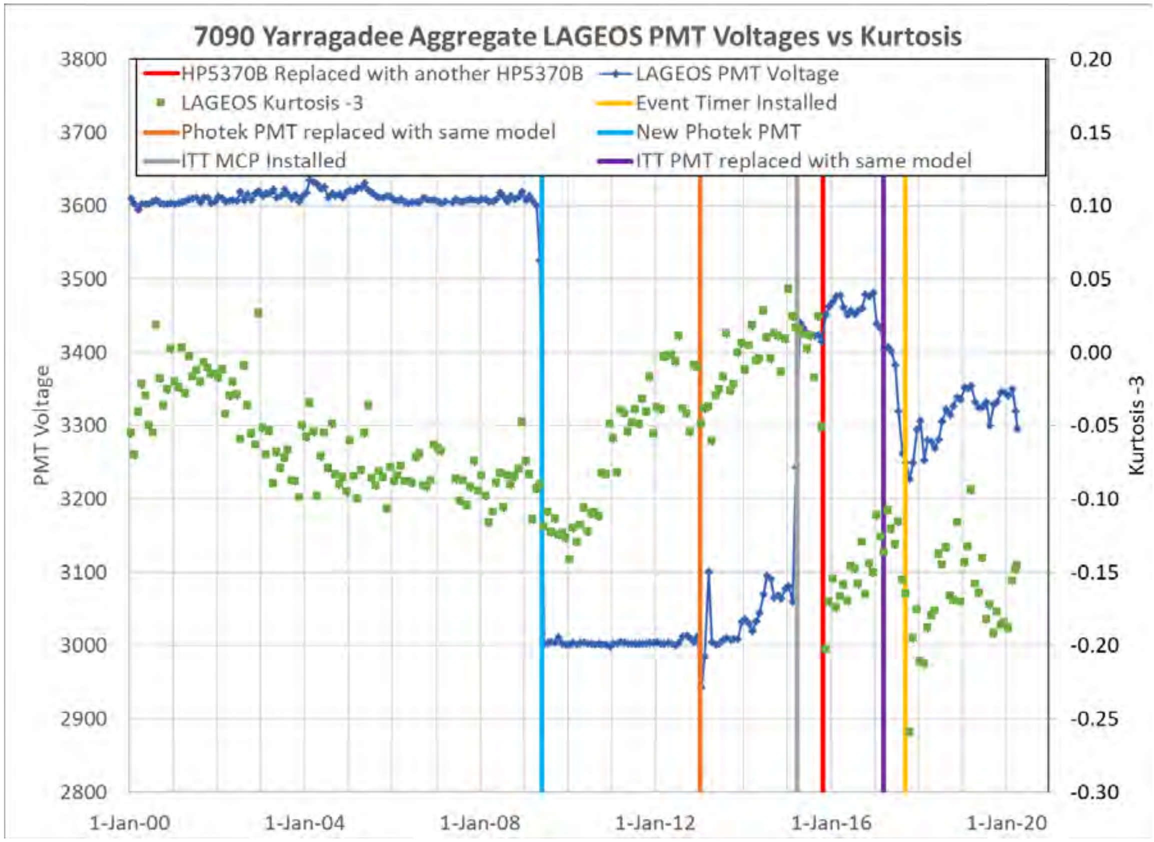
7090 Yarragadee PMT Voltages





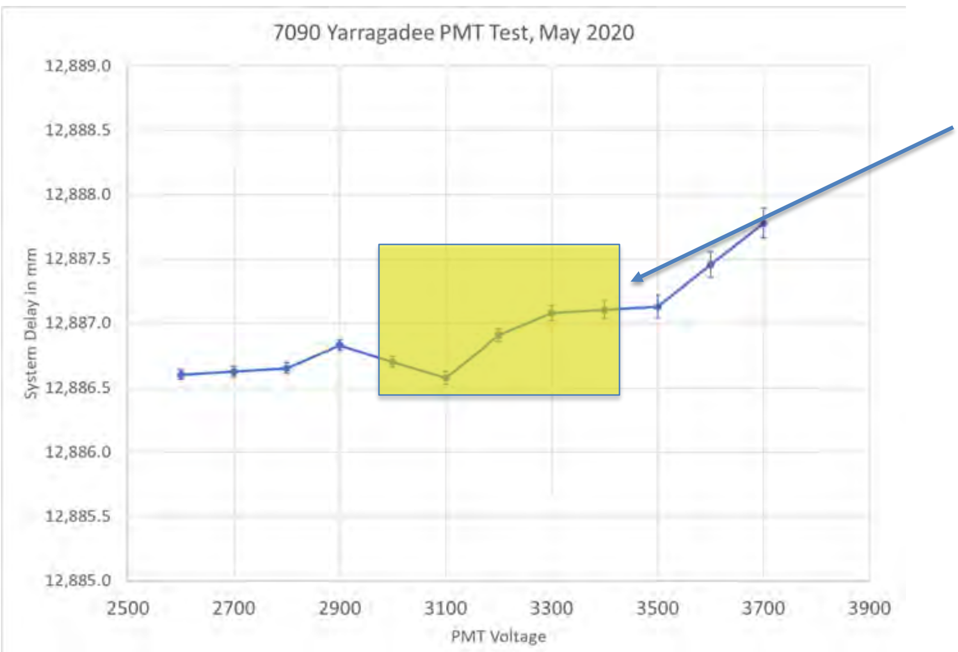
On the left chart is the monthly average PMT Voltages per satellite. Up until July 2012, a single PMT voltage (except for HEOs) was used for both calibration and satellites. On the right chart is the HITU LAGEOS range biases versus the PMT voltage difference between LAGEOS calibrations and actual LAGEOS data. Can the PMT voltage differences explain the drift?

7090 Yarragadee PMT Voltages and Kurtosis



The changes in timing devices; detectors; detector aging; and/or PMT voltages can result In changes in kurtosis.

7090 Yarragadee PMT Characterization Test

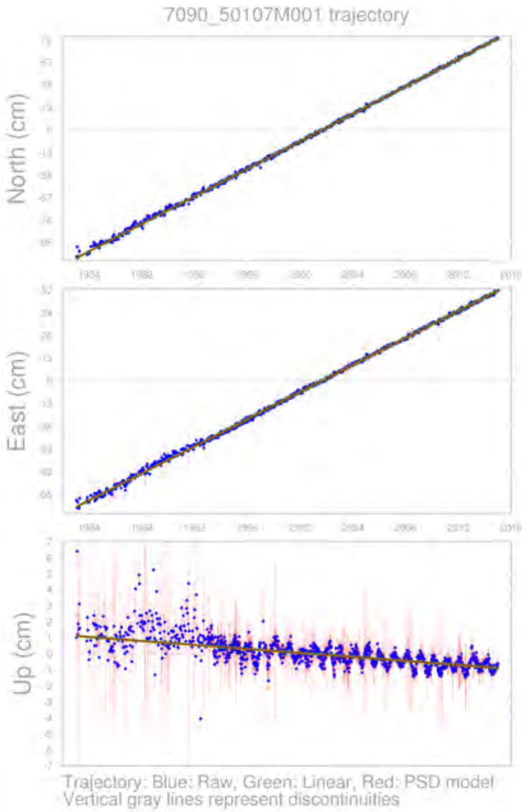


7090 LAGEOS and Etalon calibrations are taken at 3000 while LAGEOS is tracked between 3200 to 3400 volts while Etalon is tracked between 3300 to 3400 volts.

Based on this ITT MCP PMT ground test, ~0.5 mm of the recent positive mm level LAGEOS HITU range bias drift could be explained by altering PMT voltages. This is the only ITT MCP PMT test that we have, so we don't know how repeatable are these results. The other NASA systems show much larger variations at the higher PMT voltages, but the other NASA systems have 3-stage Photek MCP PMTs while Yarragadee has a 2-stage ITT MCP PMT, which is now obsolete.

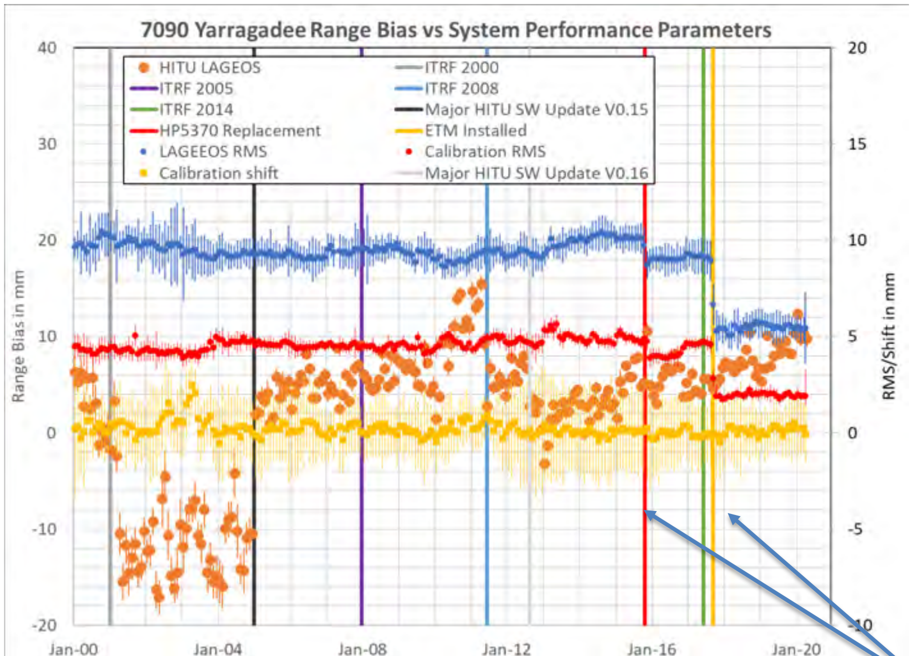
Since Ajisai, Lares and Stella/Starlette also show positive range bias drifts and are better calibrated in terms of PMT voltages, the ~+1 mm/year drift must also have another cause(s). So the question remains: Is the drift in the analysis; is it in the system; or is it geophysical?

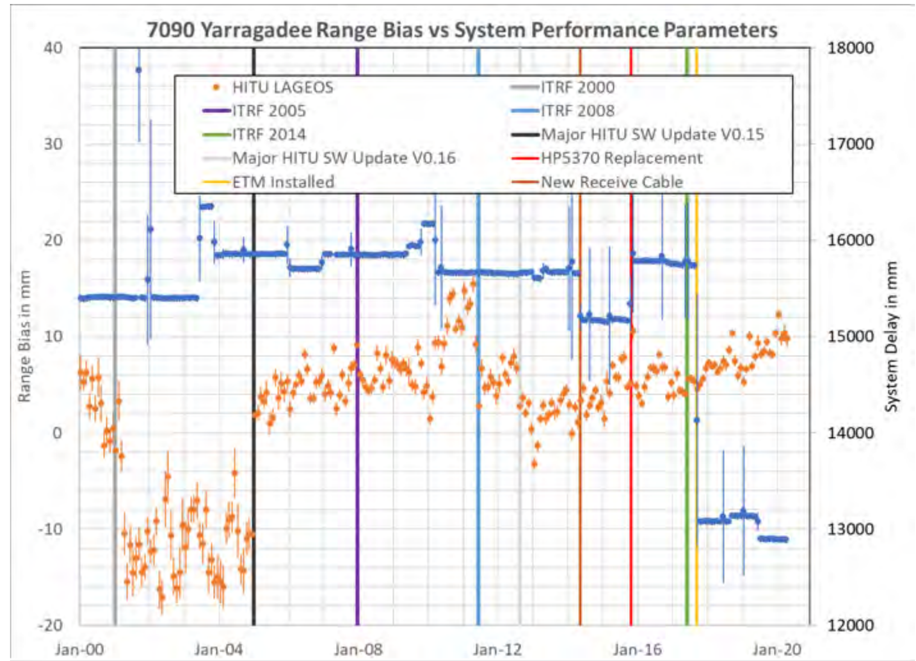
7090 Yarragadee ITRF 2014 Site Rates



In ITRF 2014, 7090 Yarragadee's height is decreasing ~0.6 mm per year.
If this drift, in reality, is closer to zero, it can explain some of the ~+1mm/year drift in Yarragadee's range biases, since an error in height would be common to all satellites.

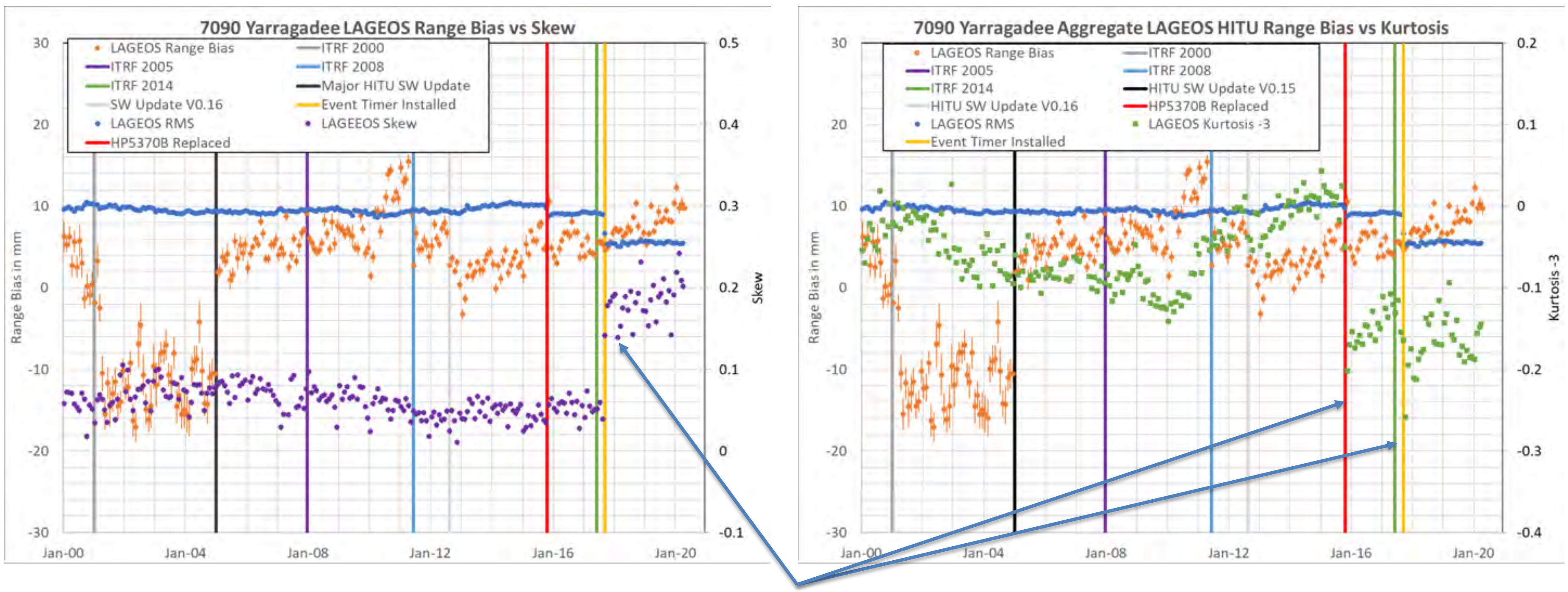
7090 Yarragadee LAGEOS Performance





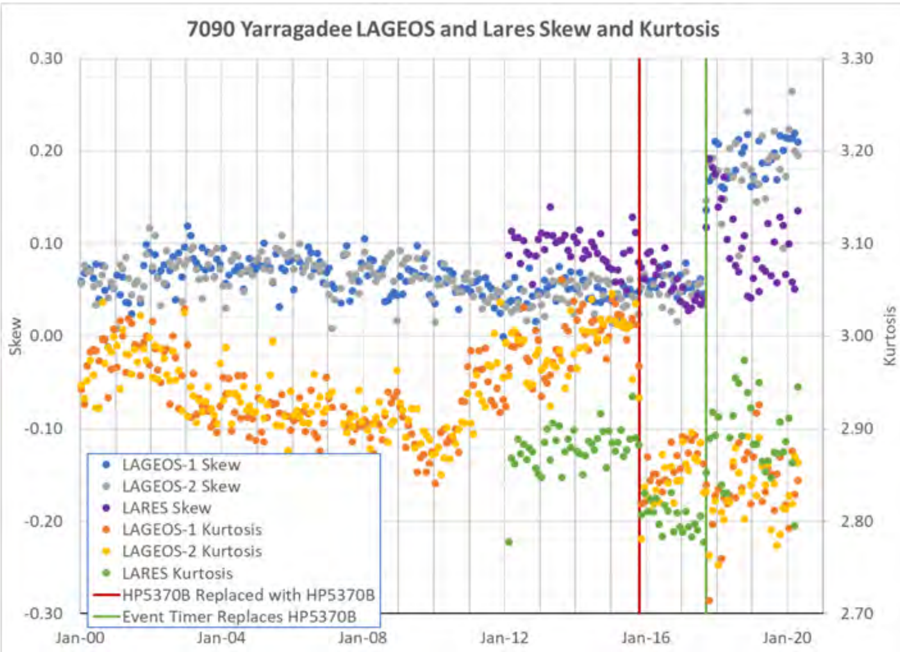
On the chart on the left, the abrupt LAGEOS and calibration RMS improvements occurred when the HP5370B was replaced with the same model and again when the event timer was installed. The chart on the right, has the LAGEOS bias along with system delay. Not all changes in system delay are documented in the change history file.

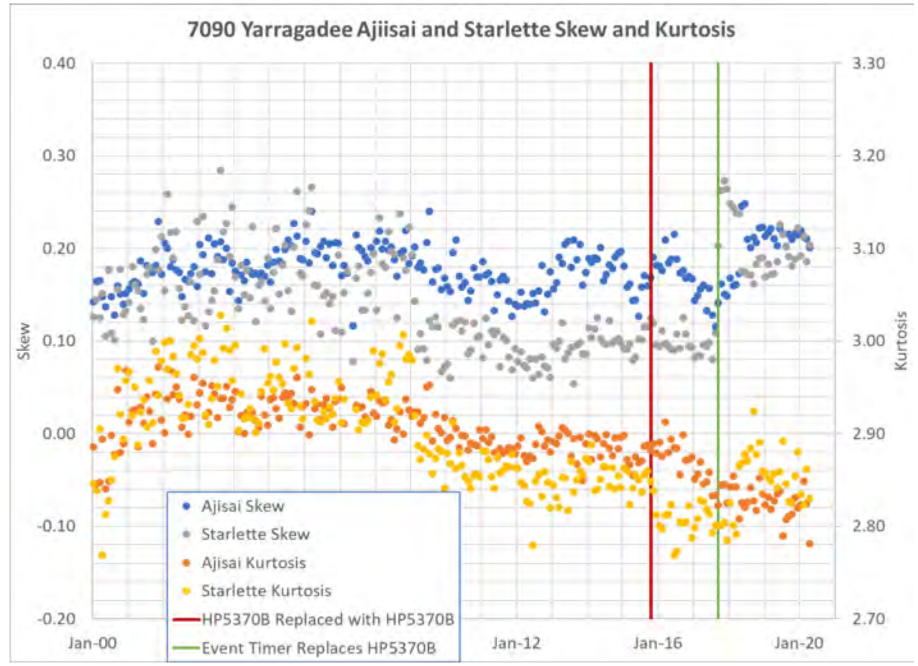
7090 Yarragadee LAGEOS Range Bias, RMS, Skew & Kurtosis



The skew and kurtosis abruptly changed when the event timer was installed on 11-Sep-2017. The kurtosis also abruptly changed when the HP5370B was replaced with another HP5370B on 22-Oct-2015.
In addition, the skew and kurtosis have more variation post Event Timer Upgrade.

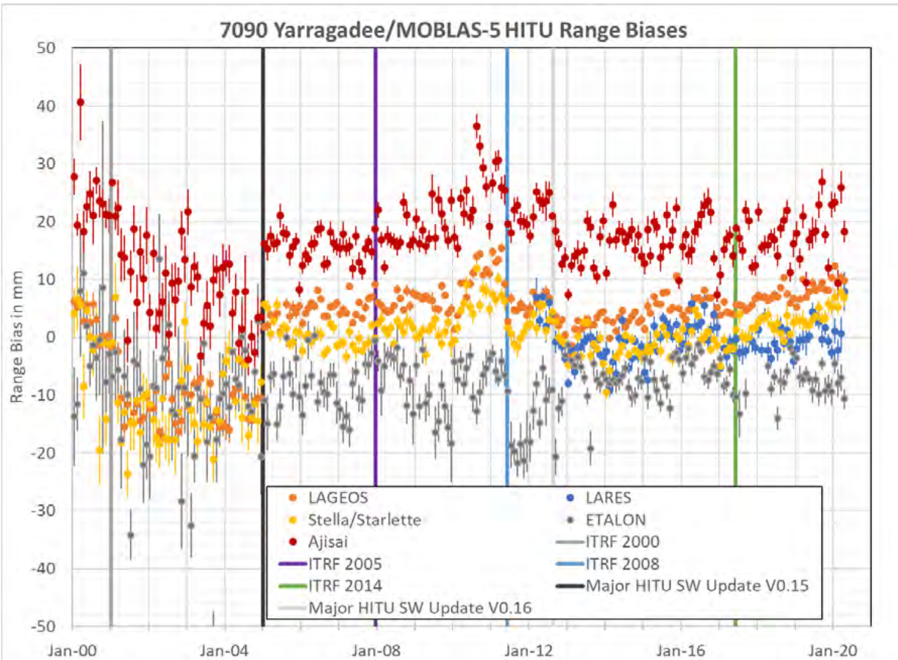
7090 Yarragadee Geodetic Satellite Skew & Kurtosis

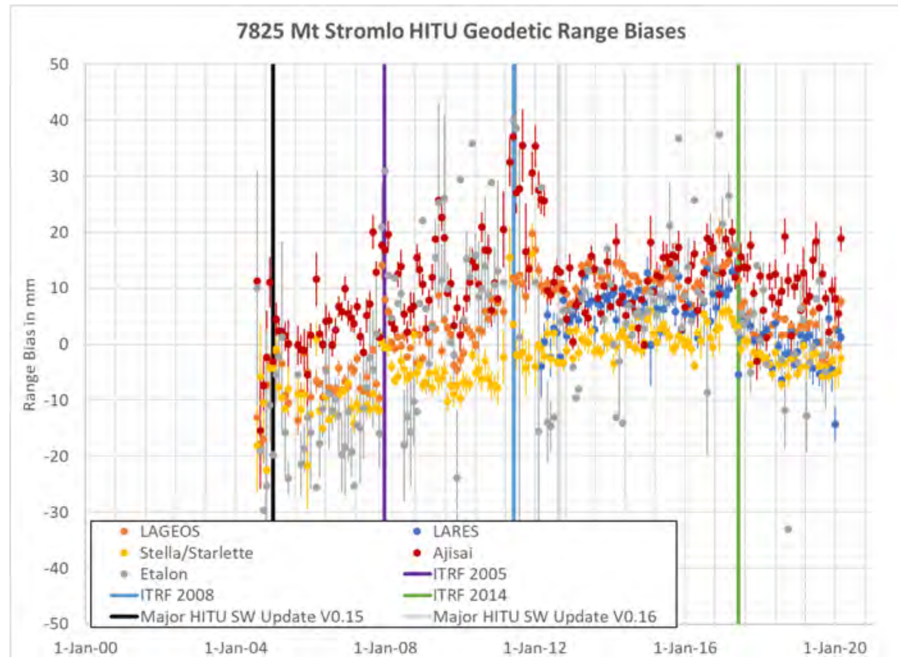




The skew and kurtosis on LAGEOS, LARES, and Starlette (but not Ajisai) changed and has more variation since the event timer was installed in 11-Sep-2017. The kurtosis on LAGEOS, Lares, and Starlette (but not Ajisai) also changed when the HP5370B was replaced with another HP5370B on 22-Oct-2015.

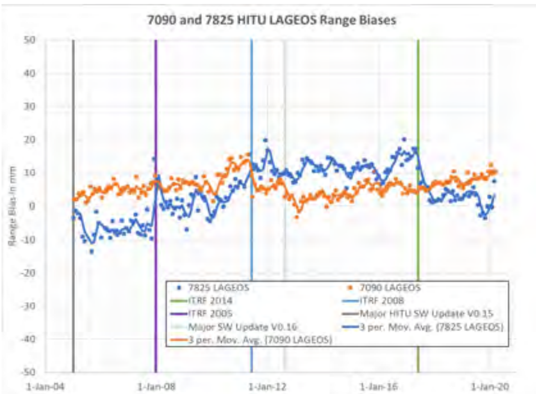
Australian (7090 and 7825) HITU Geodetic Range Biases

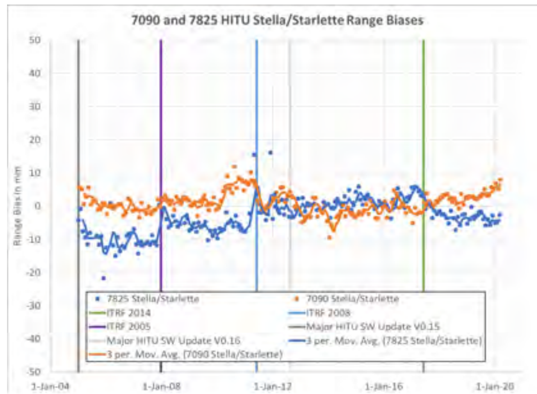


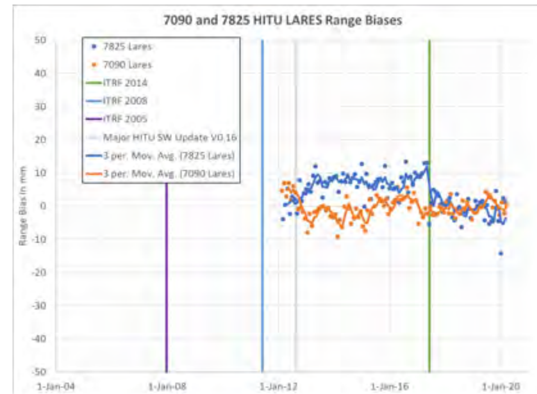


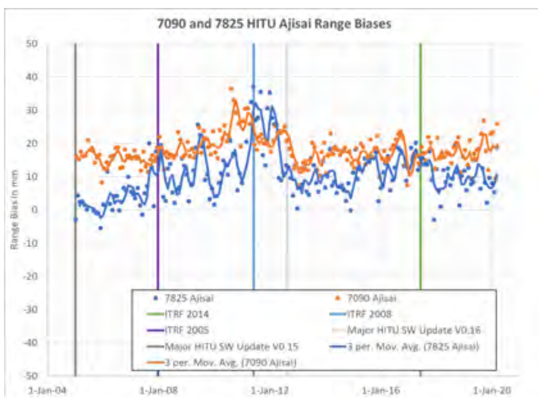
A side by side comparison of 7090 and 7825 HITU geodetic range bias estimates. The Mt Stromlo results appeared to have shifted when HITU updates its coordinates to ITRF2014.

Australian (7090 and 7825) HITU Geodetic Range Biases





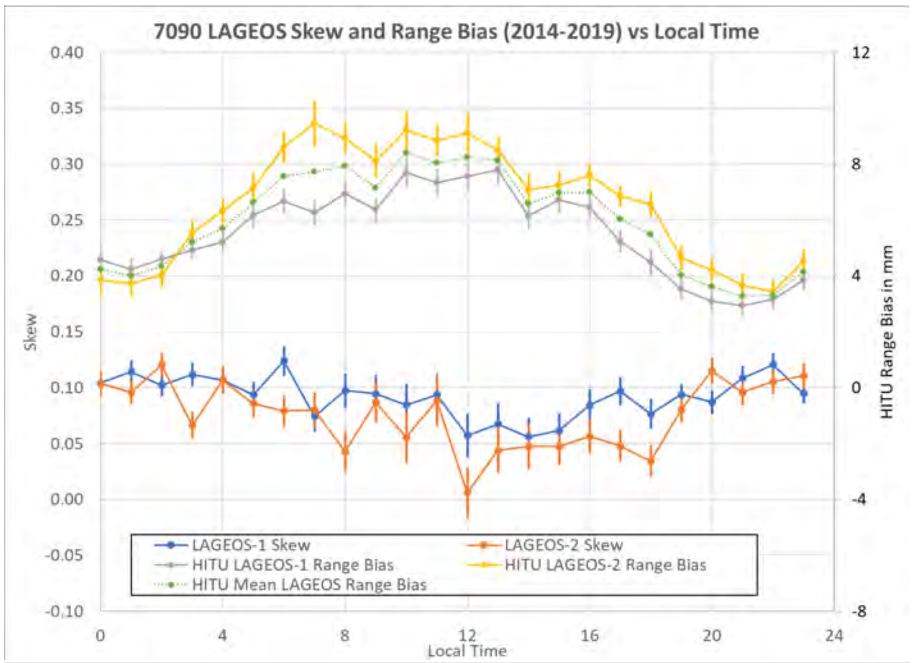


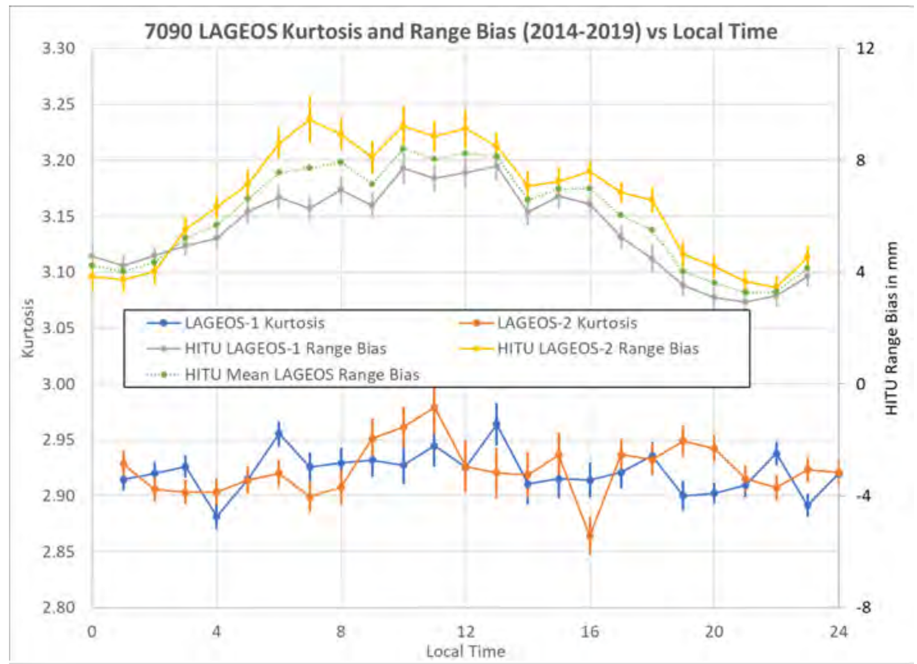


The 7090 and 7825 HITU LAGEOS and Stella/Starlette range biases flipped directions twice, when both ITRF2008 and ITRF2014 coordinates were introduced. Since ITRF 2014 coordinate have been used, the LAGEOS and Stella/Starlette HITU range biases between these 2 stations appear to be diverging, while the LARES biases appeared to have converged.

Analysis of HITU Mt. Stromlo (7825) range biases does not help explain any bias trends in its nearest neighboring station, Yarragadee (7090).

7090 Yarragadee LAGEOS Diurnal Analysis

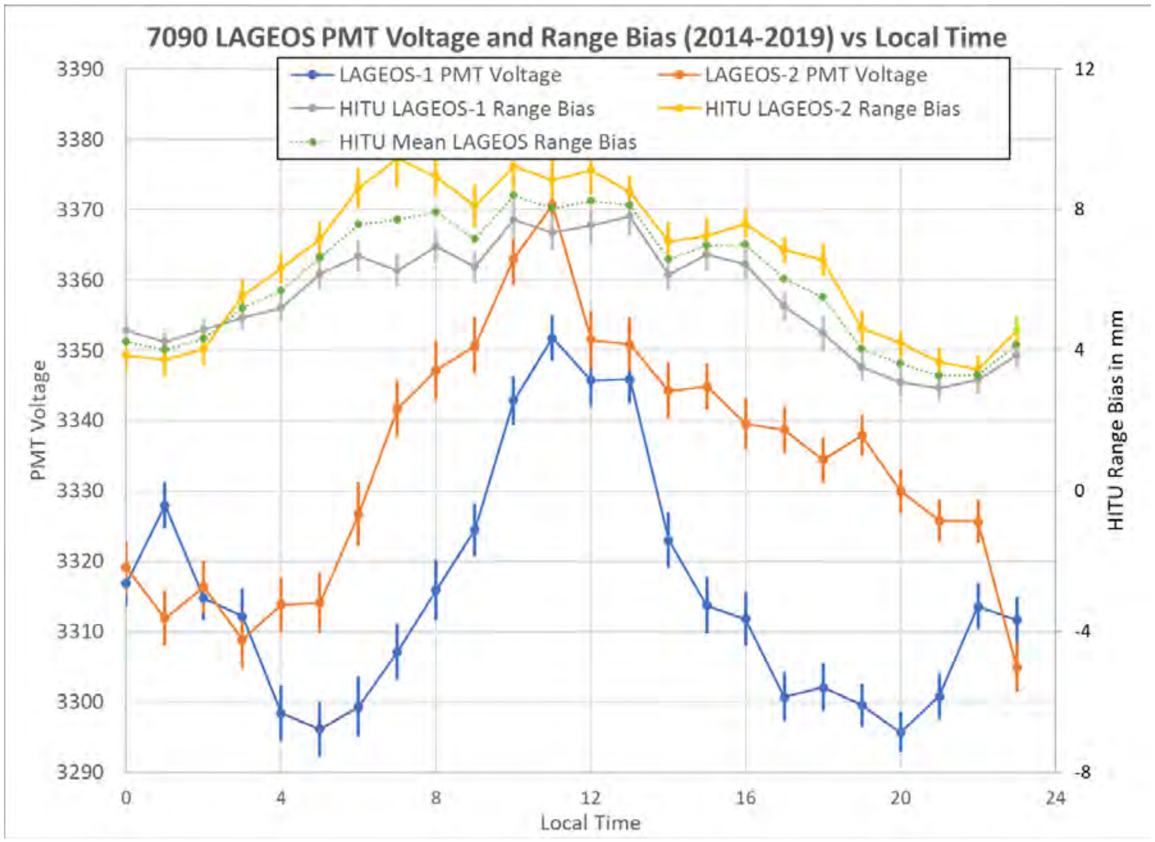




Both charts display the LAGEOS-1, 2 HITU Range Biases as a function of local time plotted versus skew and kurtosis on the left and right chart; respectively.

The 7090 LAGEOS range bias increases during the day.

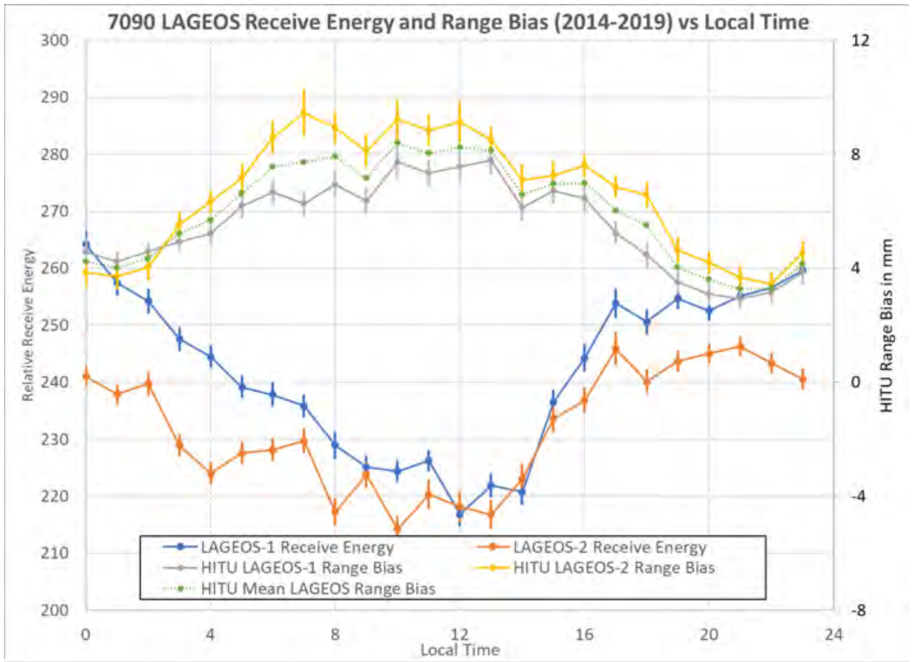
7090 Yarragadee LAGEOS Diurnal Analysis

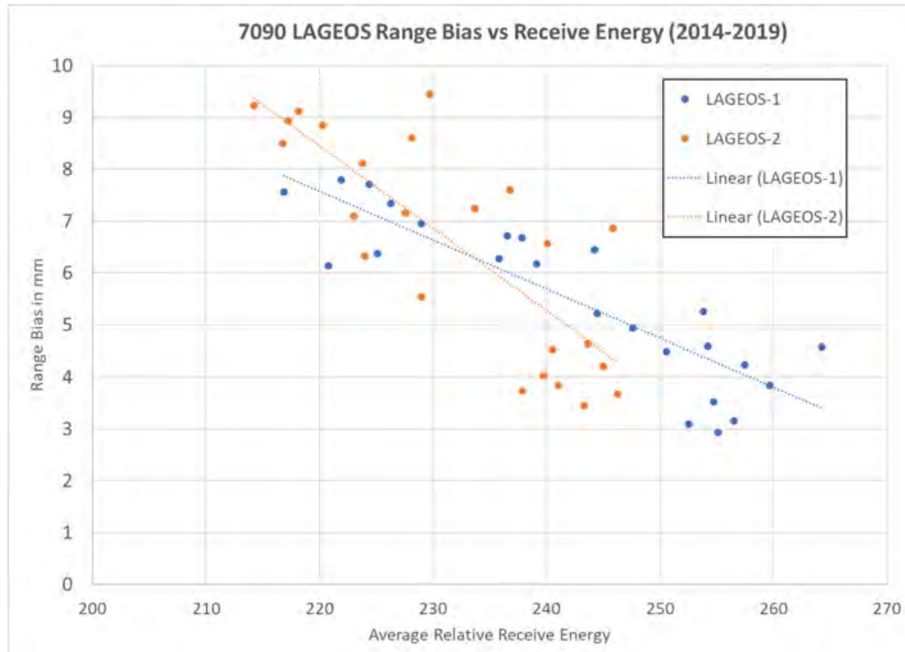


The 7090 PMT Voltage increases near local noon.

Based on the May 2020 PMT test, the diurnal range bias variations can explain perhaps ~10% of the range bias changes.

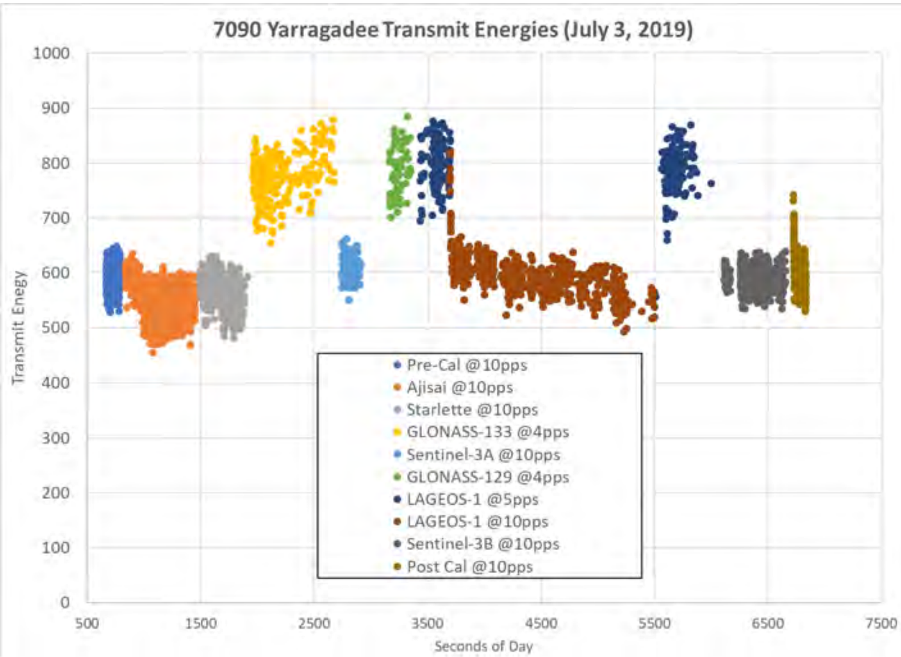
7090 Yarragadee LAGEOS Diurnal Analysis

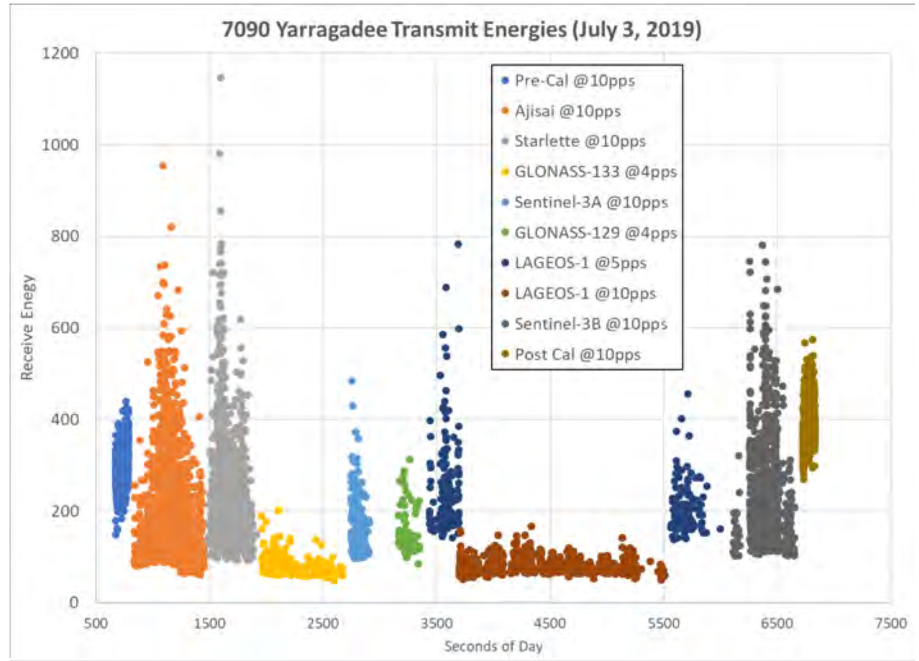




On the left chart is the LAGEOS-1, 2 HITU Range Biases as a function of local time plotted versus receive energy. The right chart shows the aggregate hourly LAGEOS biases vs mean receive energy.

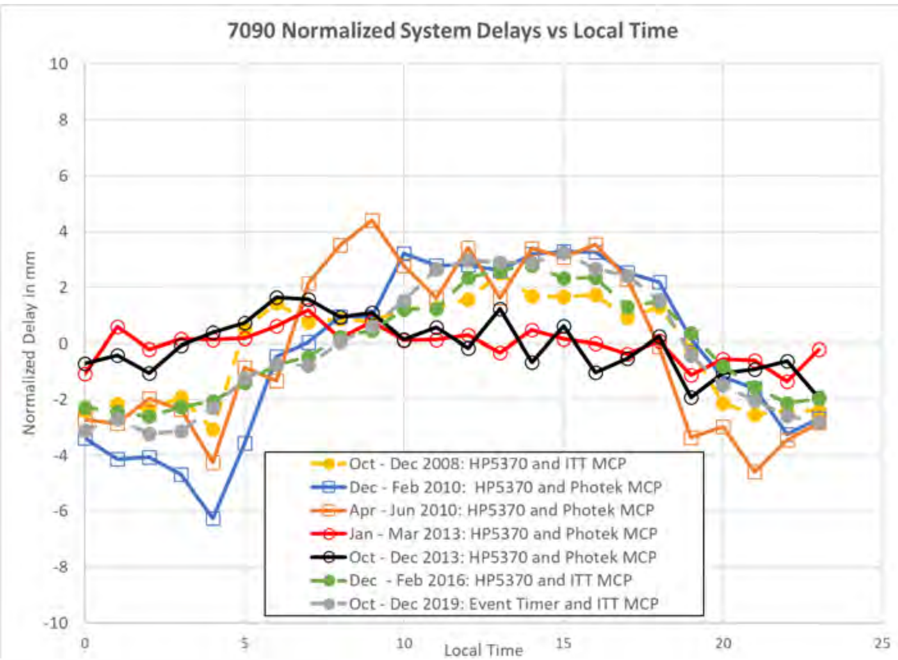
7090 Yarragadee Transmit and Receive Energies





The left and right charts are a time series of transmit and receive energies; respectively, from one 2-hour tracking scenario. The 7090 laser is optimized at 5 pps and why the transmit energies are higher on GLONASS and LAGEOS@5pps. The minimum receive energies on LAGEOS vary between 5 and 10 pps. Also, the dynamic range of calibration receive energies are much different than the satellite data. These are two barriers to modeling satellite receive energy.

7090 Yarragadee Diurnal System Delay Analysis

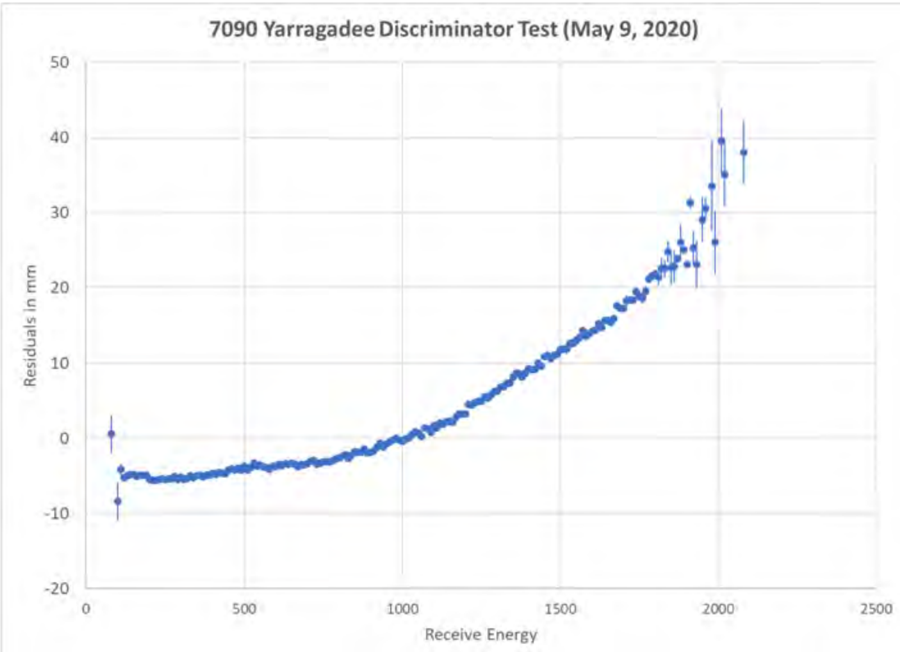


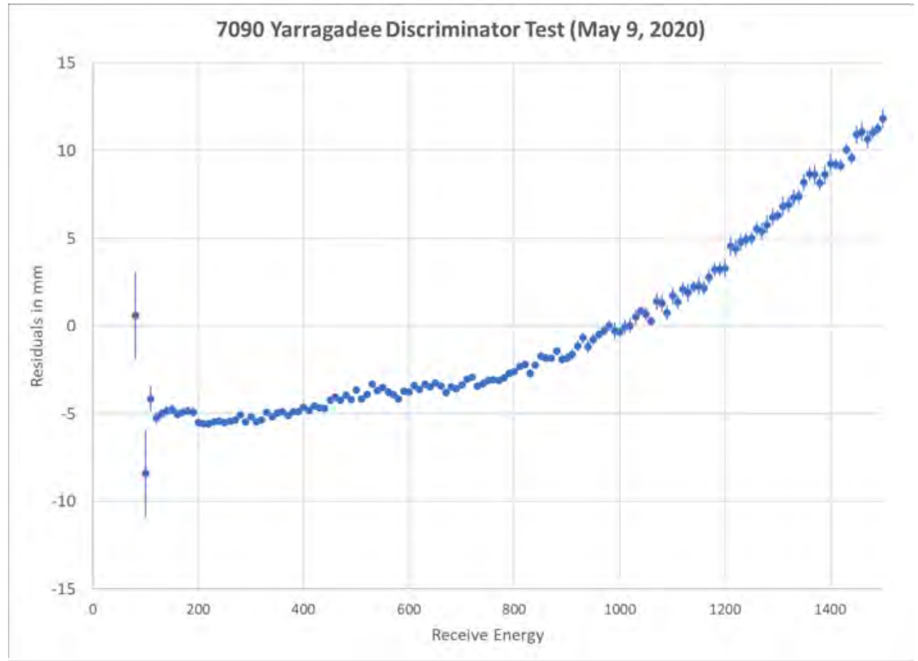
Time Span	Timer	Detector	3 Month Peak-to-Peak (mm)	Diurnal Peak-to-Peak (mm)
Oct - Dec 2008	HP5370	ITT MCP	21.0	5.6
Dec - Feb 2010	HP5370	Photek MCP	32.0	9.5
Apr - Jun 2010	HP5370	Photek MCP	34.6	9.0
Jan - Mar 2013	HP5370	Photek MCP	21.4	2.5
Oct - Dec 2013	HP5370	Photek MCP	29.7	3.6
Dec - Feb 2016	HP5370	ITT MCP	17.1	5.4
Oct - Dec 2019	Event Timer	ITT MCP	16.4	6.4

The performance of the HP5370/Photek MCP combination was much improved in 2013 vs 2010.

Both the range bias and system delay increase during the day. If the bias change is real, something is not being properly calibrated.

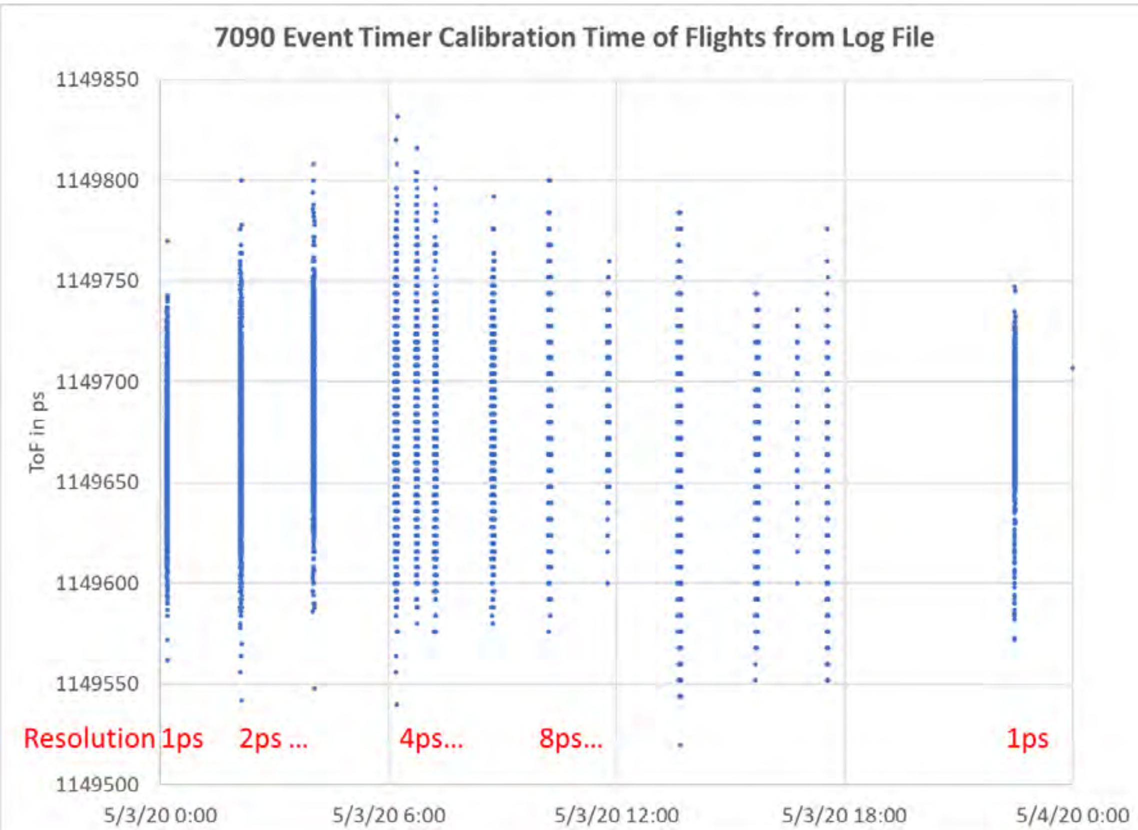
7090 Receive Discriminator Characterization Test





These charts are receive discriminator timewalk curves based on ranging to a fixed ground target. The chart on the right is a zoom in of the chart on the left. Based on the previous chart, LAGEOS is taken at the weakest receive energies, which are uncalibrated during LAGEOS calibrations. Uncalibrated LAGEOS PMT voltage and receive energy variations between day and night are in the proper direction to explain at least some of the mm level range bias diurnal variation.

7090 Yarragadee Event Timer Resolution Variation



We recently discovered that the resolution of the Yarragadee/MOBLAS-5 Event Timer (ET) can vary through the day from 1 to 8 picoseconds.

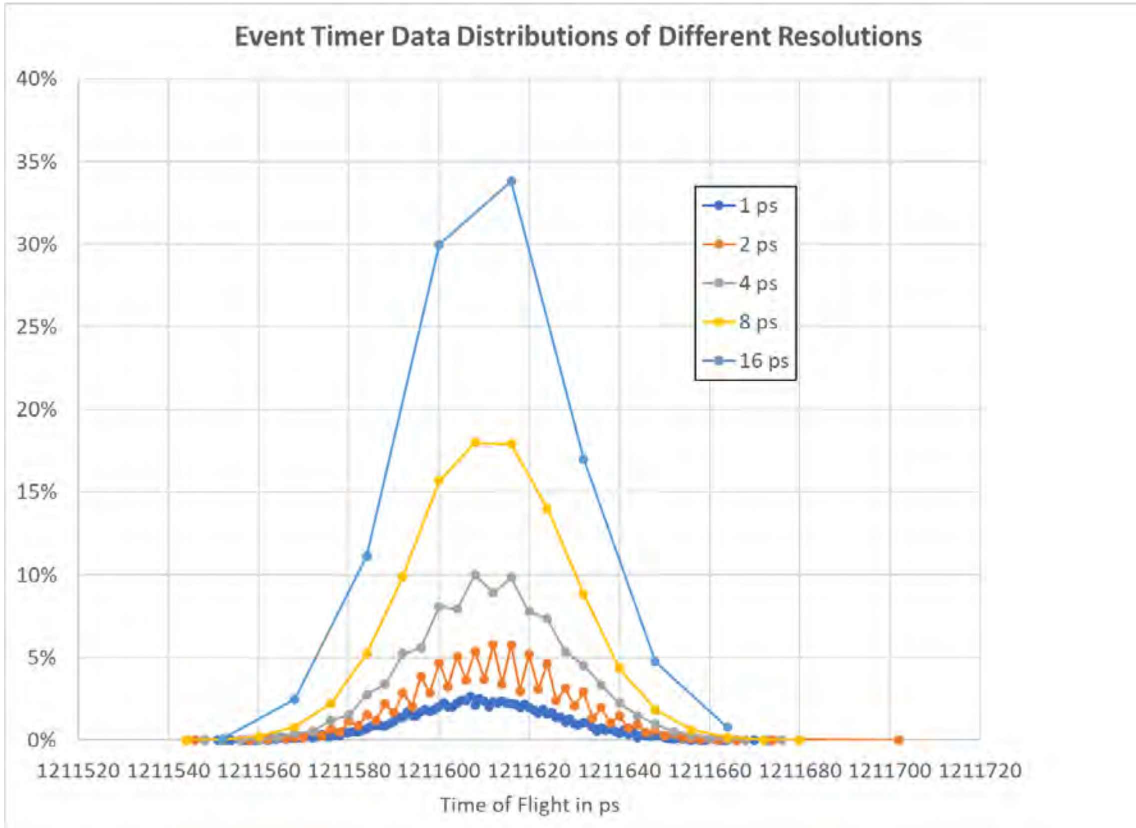
The other NASA systems (MOBLAS & TLRS) reset the ET after each 2 hour tracking scenario, but Yarragadee/MOBLAS-5 was only resetting theirs once per day.

Event Timer Lab Characterization Test

Start Time	Resolution	Elapsed time from start of test (hh:mm
5/9/20 10:41	1 ps	N/A
5/9/20 12:53	2 ps	2:12
5/9/20 15:23	4 ps	4:42
5/9/20 20:23	8 ps	9:42
5/10/20 6:24	16 ps	19:43
5/10/20 10:19	1 ps	N/A
5/10/20 11:47	2 ps	1:28
5/10/20 14:17	4 ps	3:58
5/10/20 19:18	8 ps	8:58
5/11/20 5:18	16 ps	18:58

Resolution (ps)	Mean ToF (ps)	Std Dev (ps)	Skew	Excel's Kurtosis	Points
1	1211610.48	16.89	0.0387	0.0090	6817
2	1211611.30	17.08	0.0150	0.0633	9004
4	1211611.42	16.92	0.0126	0.0002	18015
8	1211611.07	17.11	0.0091	0.0150	36025
16	1211611.02	18.34	0.0738	0.0203	1411

There was less than 1 ps change in mean ToF for the different resolutions.

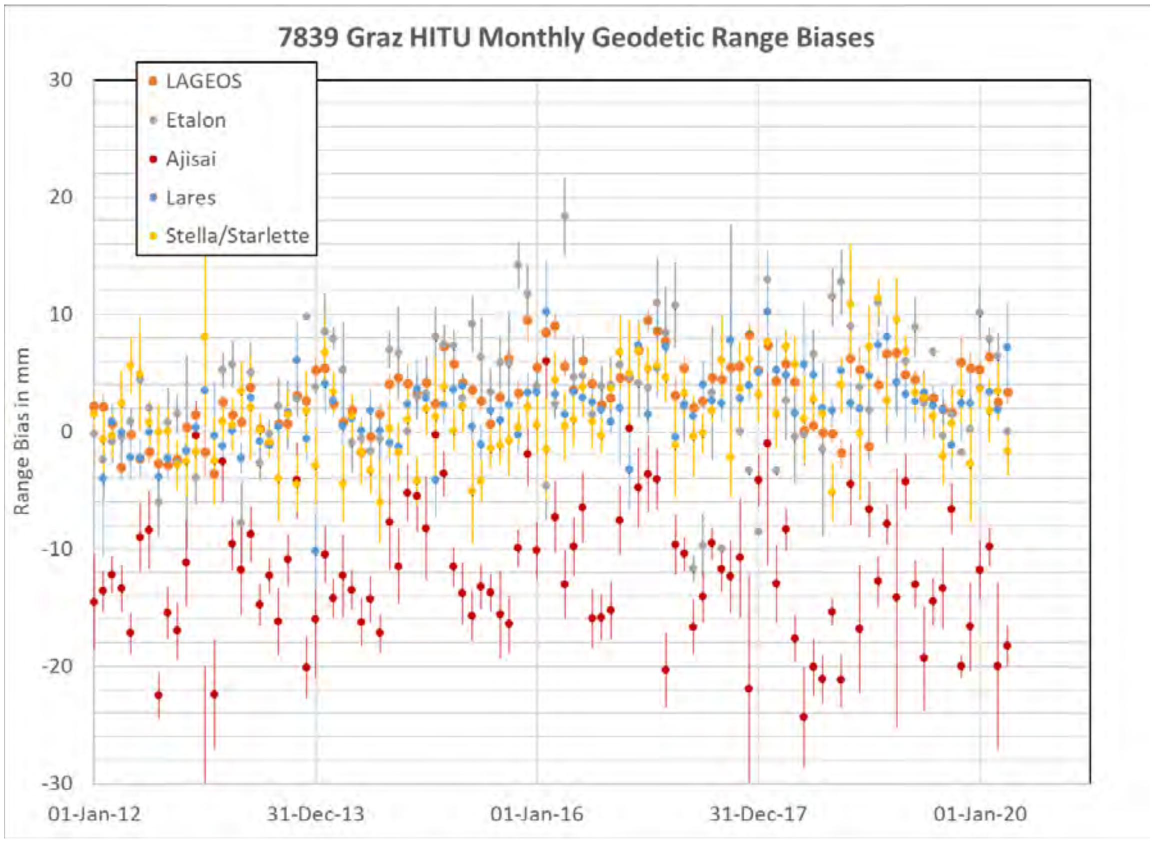


7090 Yarragadee Conclusions

- Based on our findings, 7090 has instituted the following procedural changes:
  - 5-May-2020: Reset the event timer 3-4 times per day versus once to better maintain the event timer resolution.
  - 1-Jun-2020: Standard PMT Voltage is 3200 volts.
- Some of the biases are receive energy related. Better calibration of receive energies of the geodetic satellites is needed. We will work with the station and continue to monitor their progress on this issue.
- Questions that still remain:
  - Is the HITU ~+1 mm/year bias drift in the 4 sets of the geodetic satellites (LARES, Stella/Starlette, LAGEOS, Ajisai) real or is the 7090 ITRF2014 height rate incorrect?
  - What is the real range bias difference between 7090 LAGEOS, Lares and Etalon and how accurately can we determine these offsets?

7839 GRAZ ANALYSIS

7839 Graz HITU Monthly Geodetic Range Biases



Etalon and Ajisai range bias estimates have more variation month-to-month than The other geodetic satellites.

7839 Graz Yearly HITU Geodetic Range Biases

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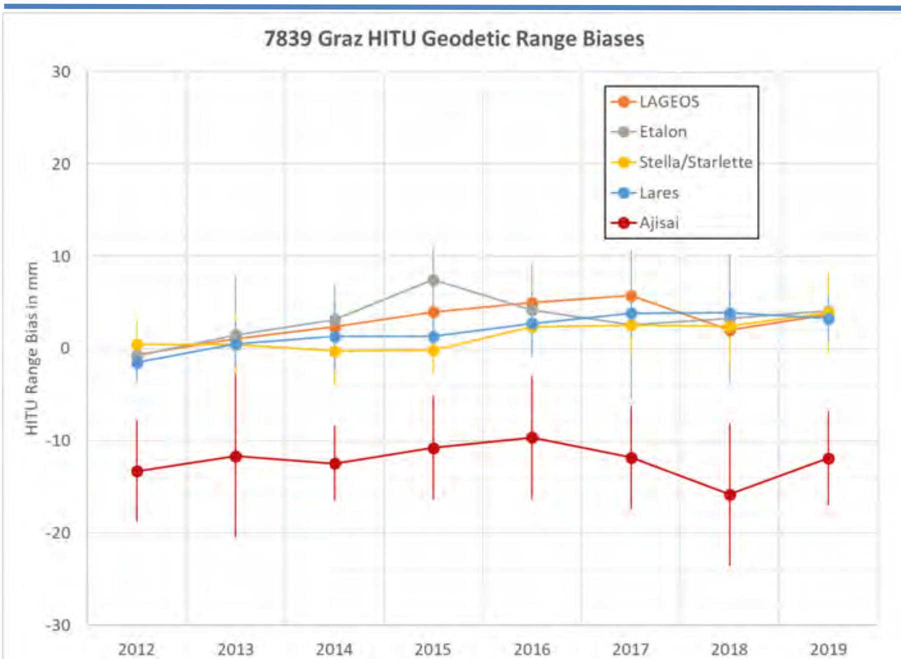
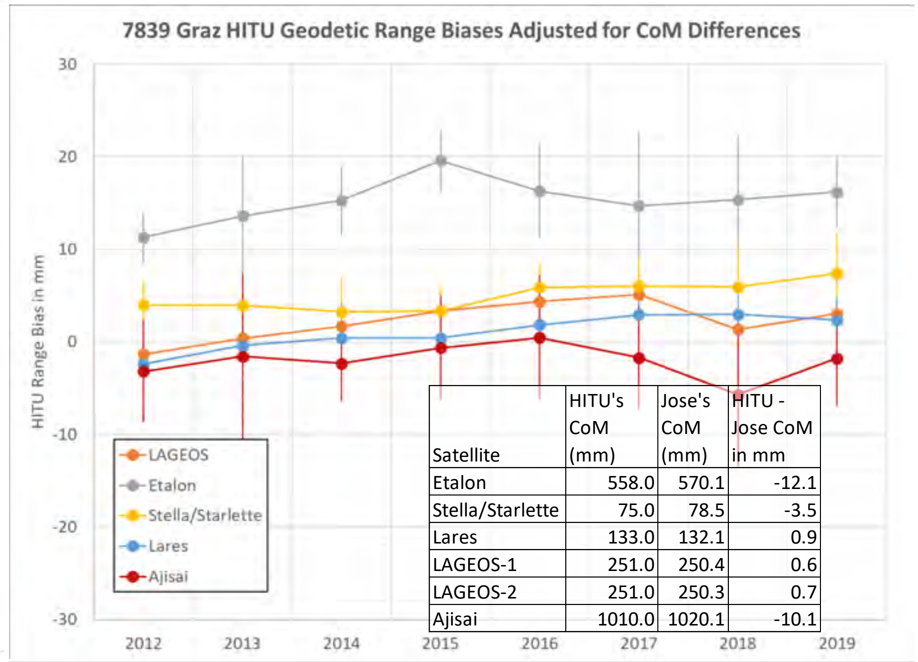
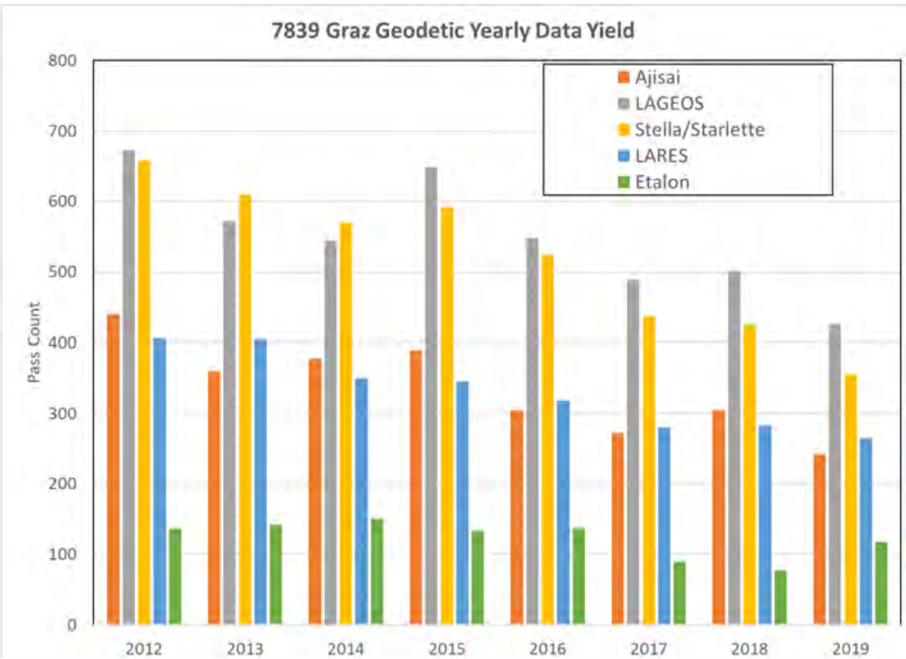


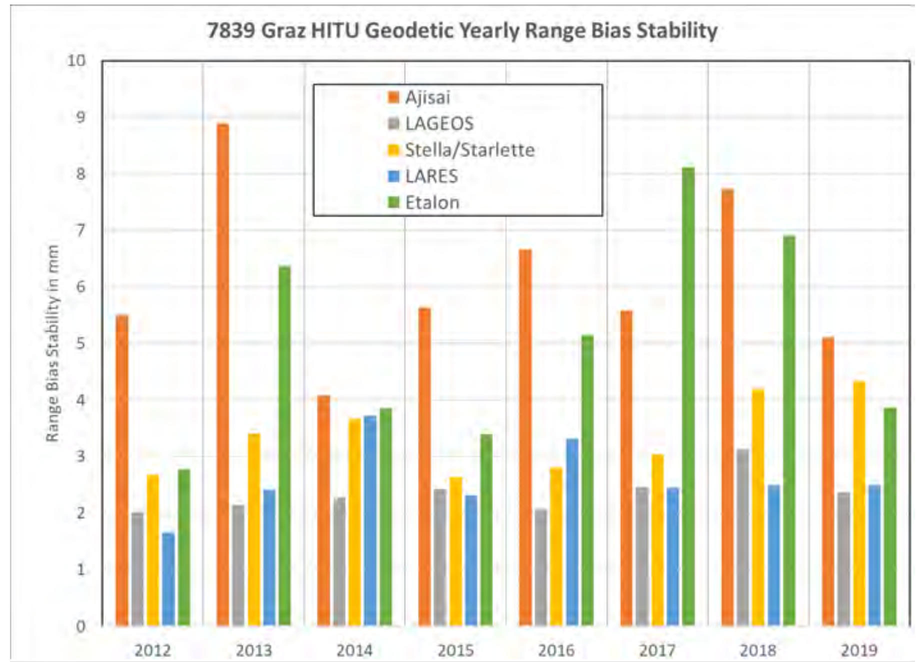


Satellite	HITU's CoM (mm)	Jose's CoM (mm)	HITU - Jose CoM in mm
Etalon	558.0	570.1	-12.1
Stella/Starlette	75.0	78.5	-3.5
Lares	133.0	132.1	0.9
LAGEOS-1	251.0	250.4	0.6
LAGEOS-2	251.0	250.3	0.7
Ajisai	1010.0	1020.1	-10.1

Does Graz have a ~+15 mm bias on Etalon?
What is the uncertainty in Jose’s Graz Etalon CoM correction?

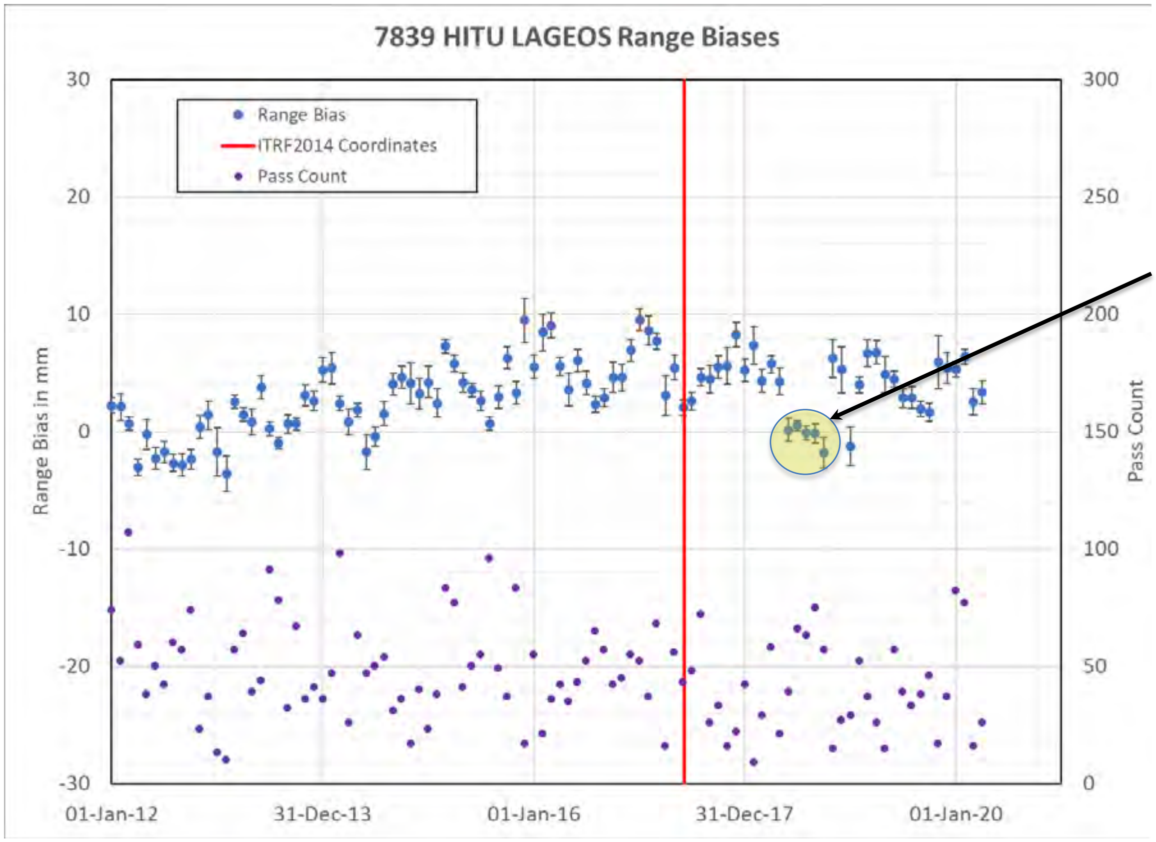
7839 Graz Geodetic Data Yield and Range Bias Stability





There is a slight downward trend in yearly 7839 geodetic data yield.
HITU 7839 LAGEOS range bias stability is consistently at the 2-3 mm level; while Stella/Starlette HITU range bias stability varies between 2.5 to 4 mm; and LARES HITU range bias stability is similar to LAGEOS.
Can a abrupt change in range bias at or near the yearly stability level be detected if it only persisted for a few months?

7839 Graz HITU LAGEOS Range Biases

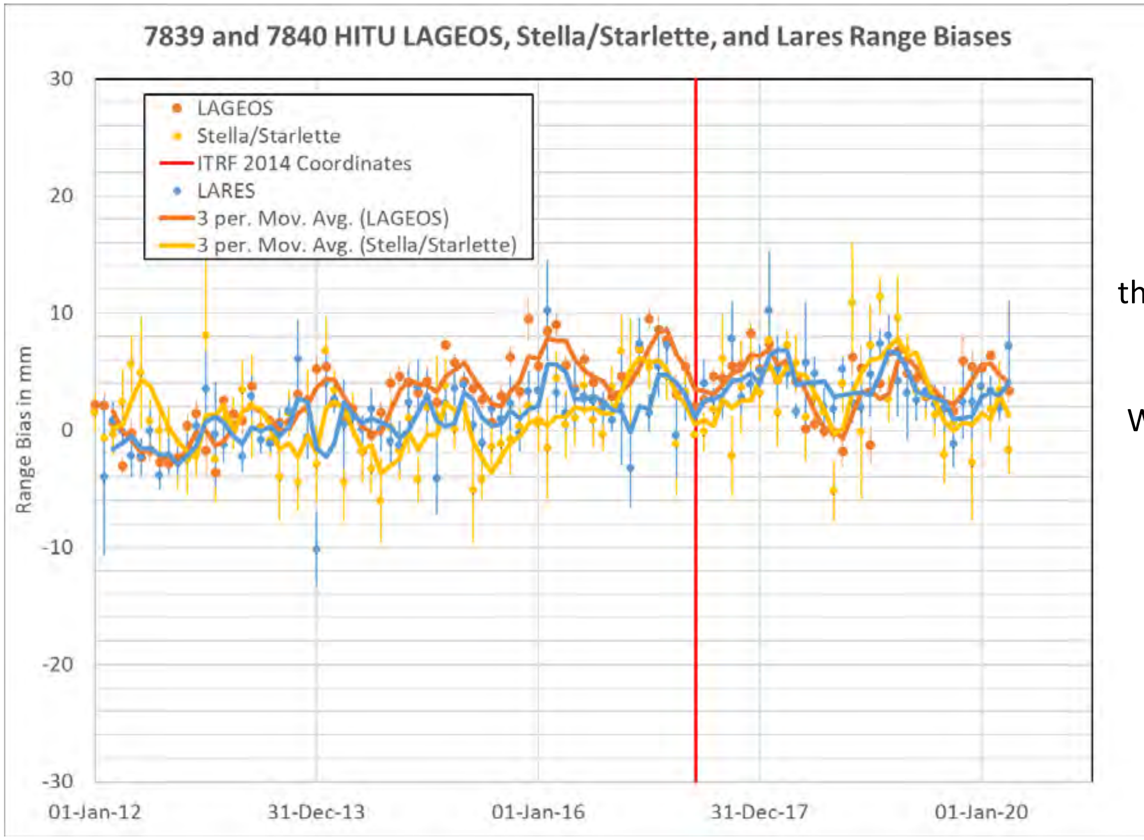


There appears to be several mm level signals in LAGEOS range biases.

Was there an abrupt actual ~5mm change in bias starting May 2018 and then did the bias return to previous levels?

Did the biases on Stella/Starlette and Lares see a similar change?

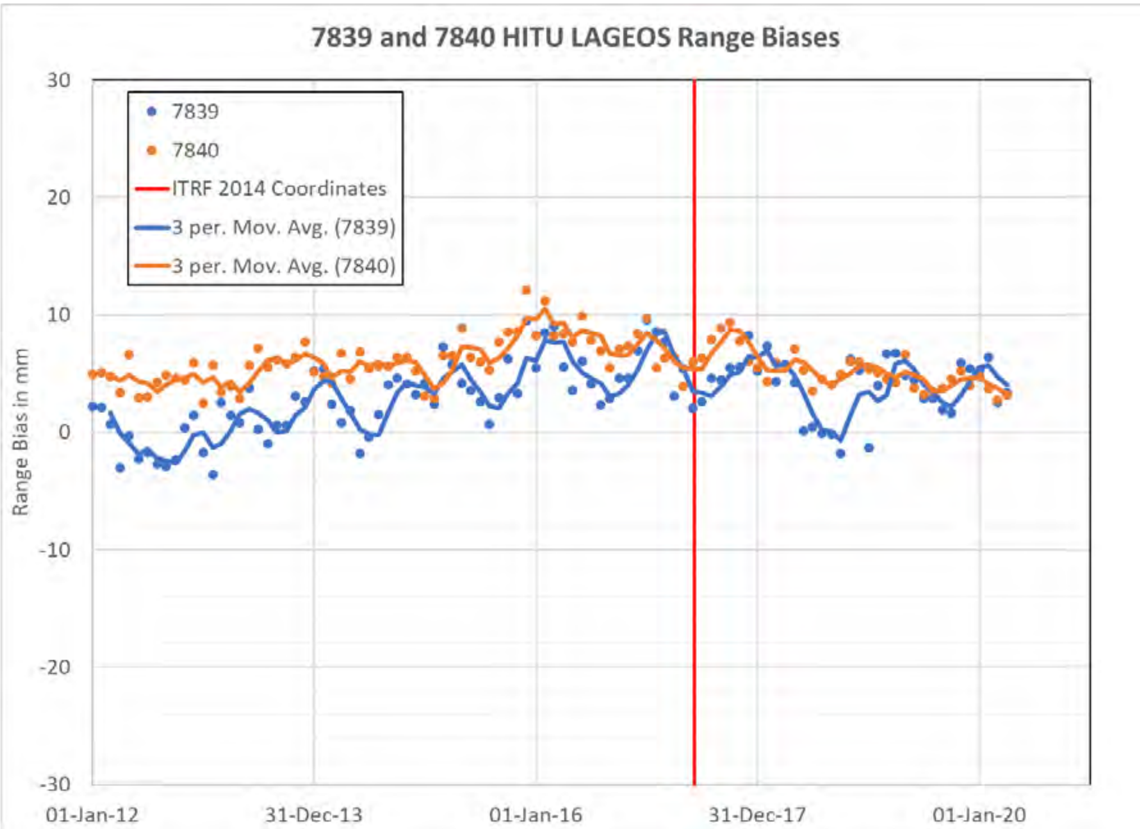
7839 Graz HITU Geodetic Range Biases



Since HITU updated their coordinates to ITRF 2014 in June 2017 (see the red line), the LAGEOS and Stella/Starlette 3-month moving averages are similar, but not for Lares.

What do the range bias trends look like in other European stations?

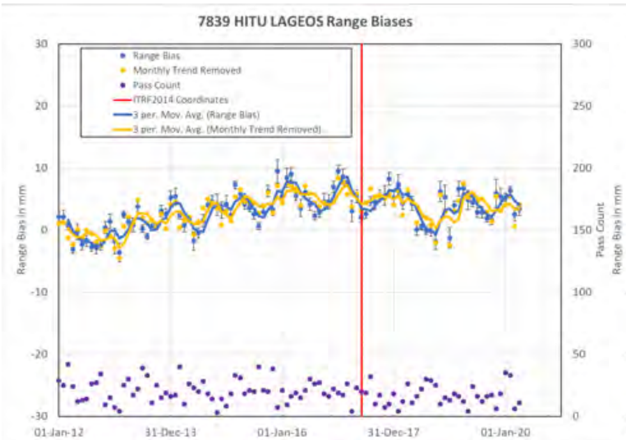
7839 and 7840 Yearly HITU LAGEOS Range Biases



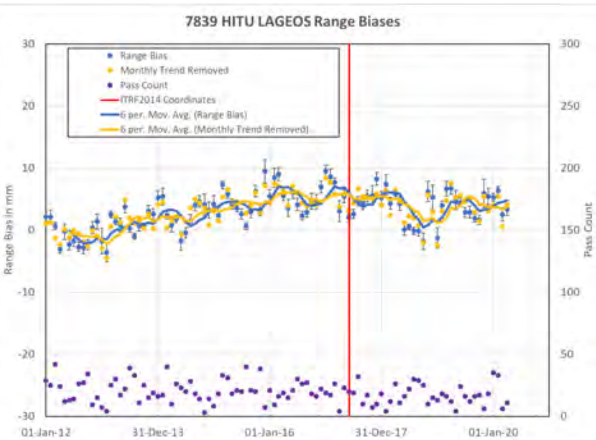
The 7839 and 7840 LAGEOS bias trends are different.

7839 Graz HITU LAGEOS Range Bias Analysis

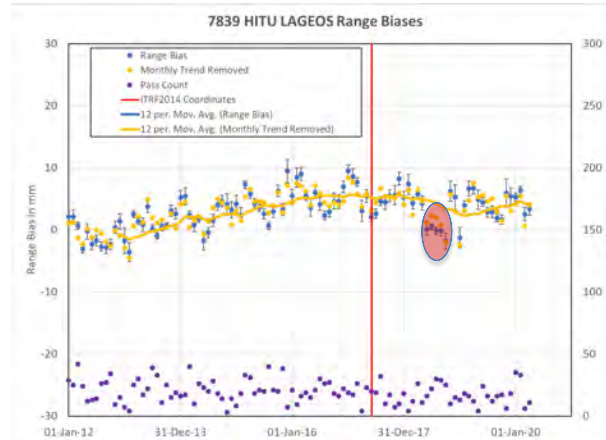
3 month range bias trend lines



6 month range bias trend lines

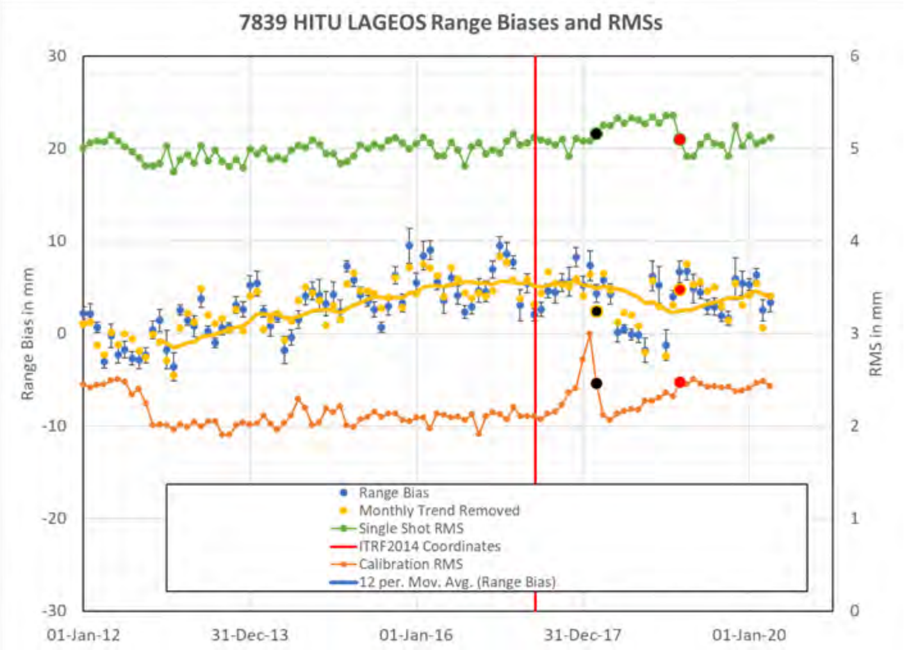


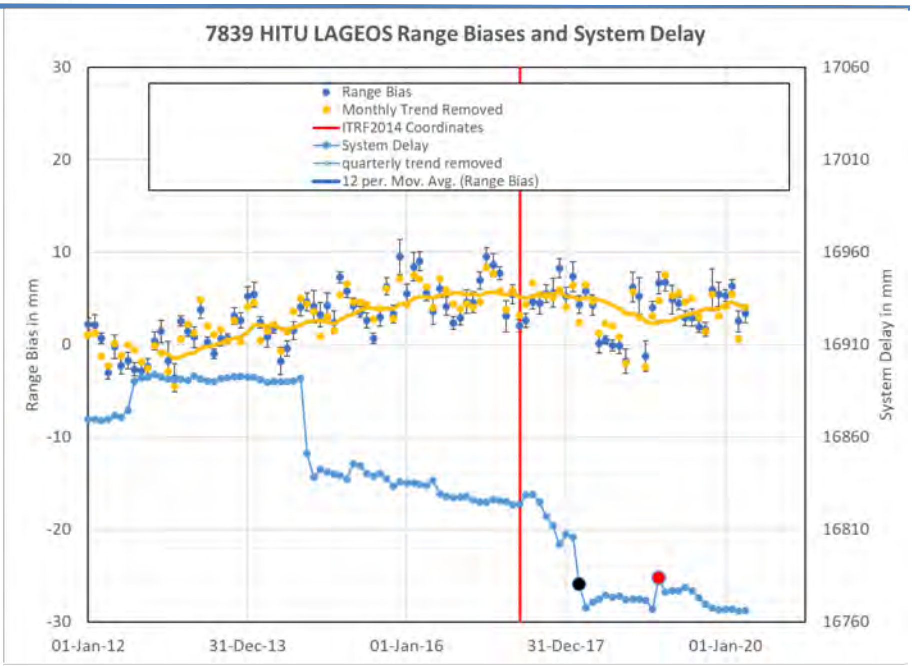
12 month range bias trend lines



The plots above are 7839 monthly HITU LAGEOS range biases estimates (blue dots), along with monthly pass counts (purple dots).
The yellow dots have a monthly mm level range bias trend removed which reduced the overall bias scatter by 10%.
Different running averages of 3, 6 and 12 months were applied to smooth the bias estimates.
The big question is are any of these bias trends real (e.g. drifts, sudden deviations) or are they in the analysis?
There appears to be ~8 mm positive drift over a few years when ITRF2008 coordinates were used, but is the drift real?
The -5 mm level jump starting in June 2018 looks suspicious, but is it real?

7839 Graz LAGEOS Analysis

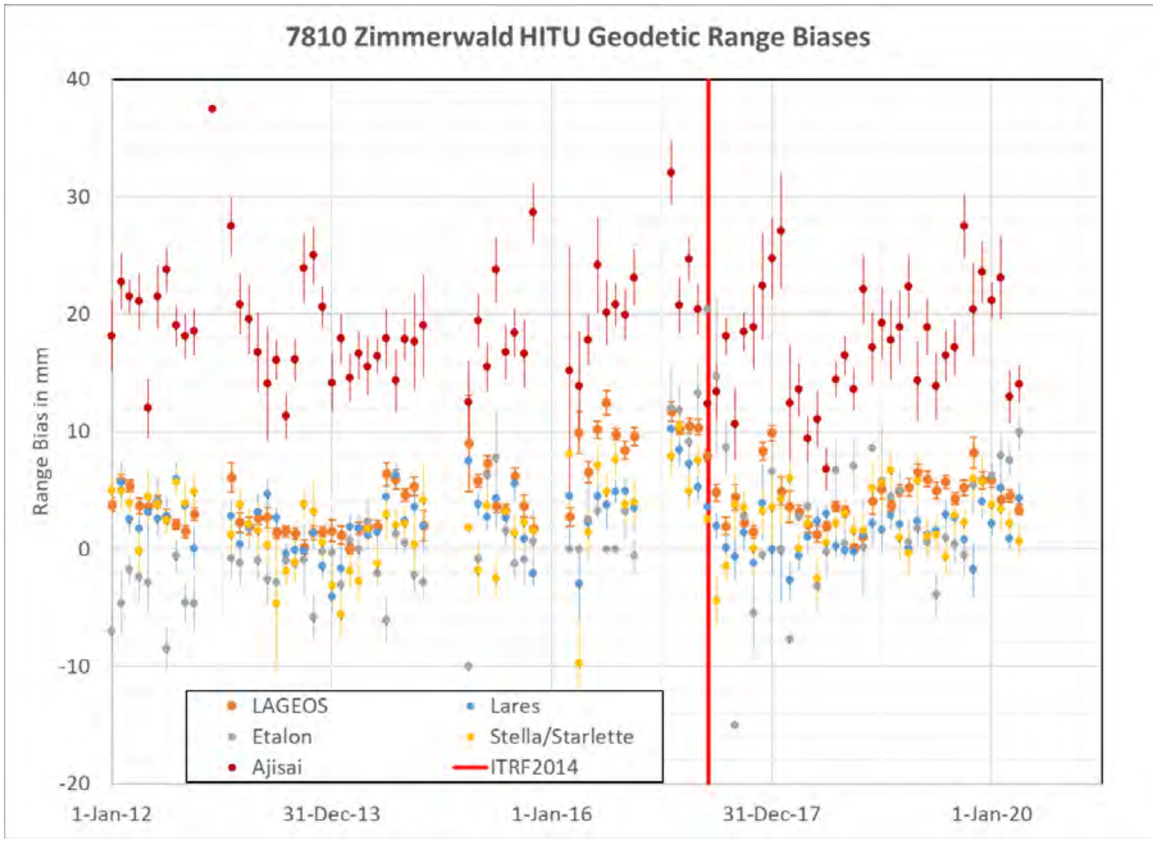




LAGEOS performance statistics (single shot RMS, calibration RMS and system delay) were added to the bias charts. Sometime between March 12 and 15, 2018, there was a sudden ~50 mm/~330 ps decrease in system delay. Since March 15, 2018 their system delay stabilized and their calibration RMSs returned to previous levels, but their calibration RMSs started drifting upwards until March 11, 2019 and then stabilized after a repair to their pulse distribution box/power supply and changed cables. There are no entries for 2018 in their system change history .

7810 ZIMMERWALD ANALYSIS

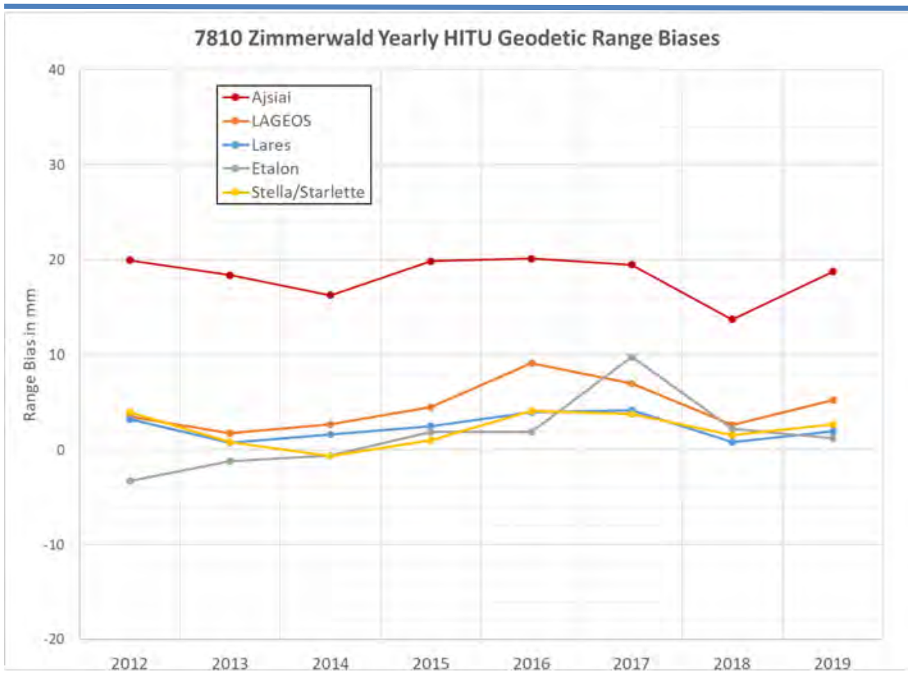
7839 Zimmwerwald HITU Monthly Geodetic Range Biases

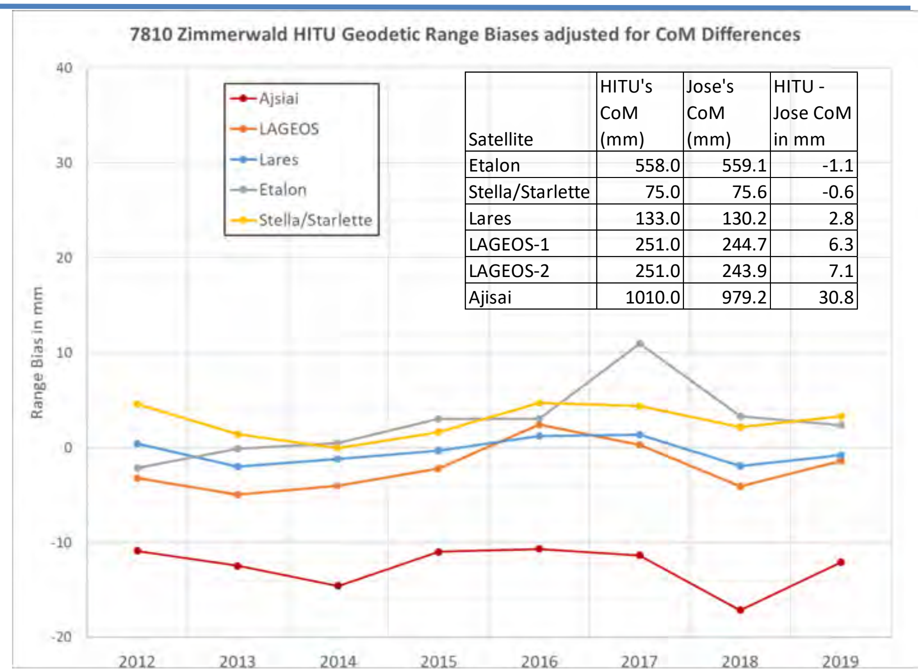


Etalon and Ajisai range bias estimates have more variation month-to-month.

Can we determine any mm level trends from this chart?

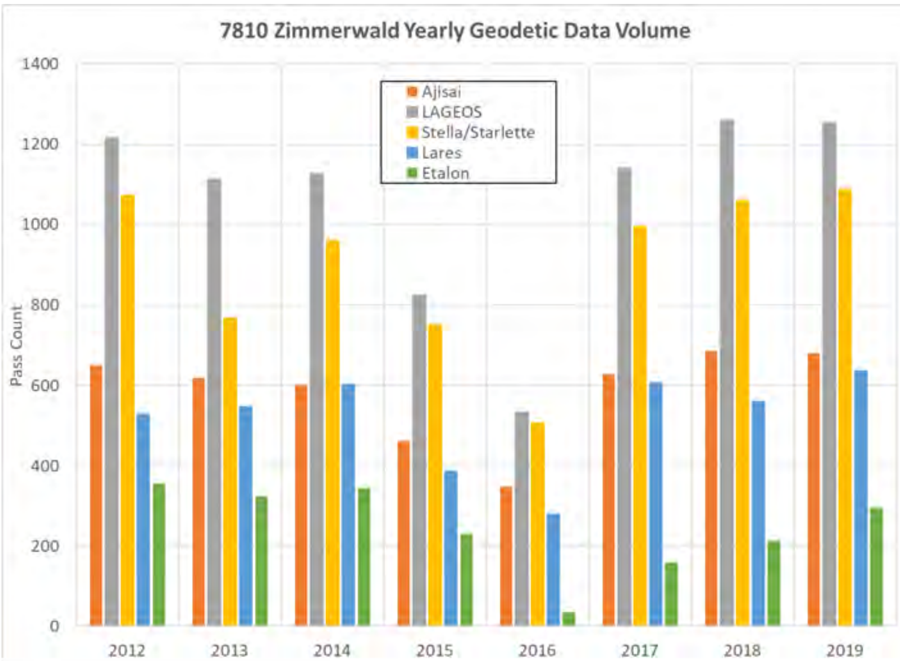
7810 Zimmerwald HITU Geodetic Yearly Biases

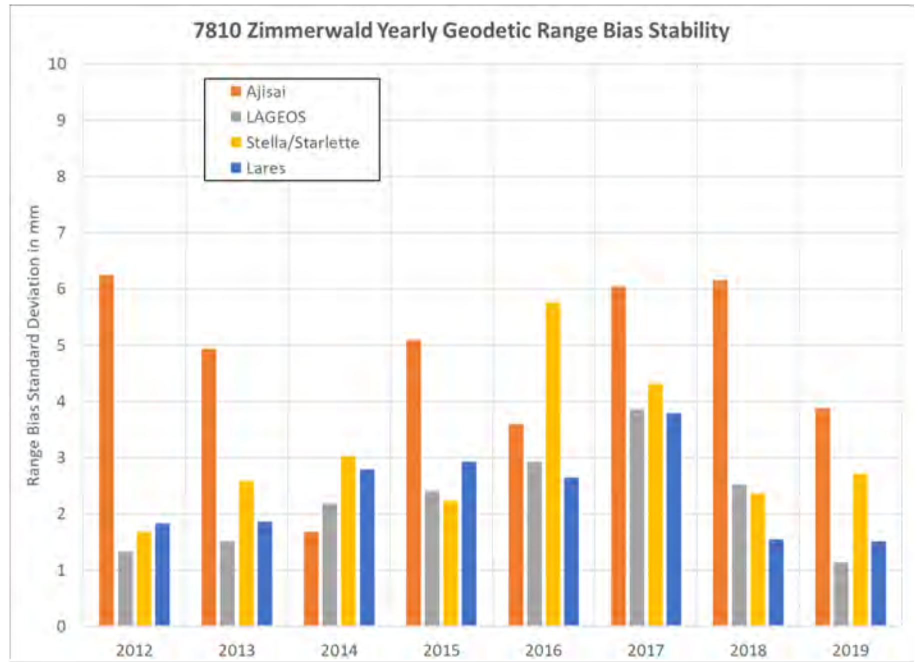




Satellite	HITU's CoM (mm)	Jose's CoM (mm)	HITU - Jose CoM in mm
Etalon	558.0	559.1	-1.1
Stella/Starlette	75.0	75.6	-0.6
Lares	133.0	130.2	2.8
LAGEOS-1	251.0	244.7	6.3
LAGEOS-2	251.0	243.9	7.1
Ajisai	1010.0	979.2	30.8

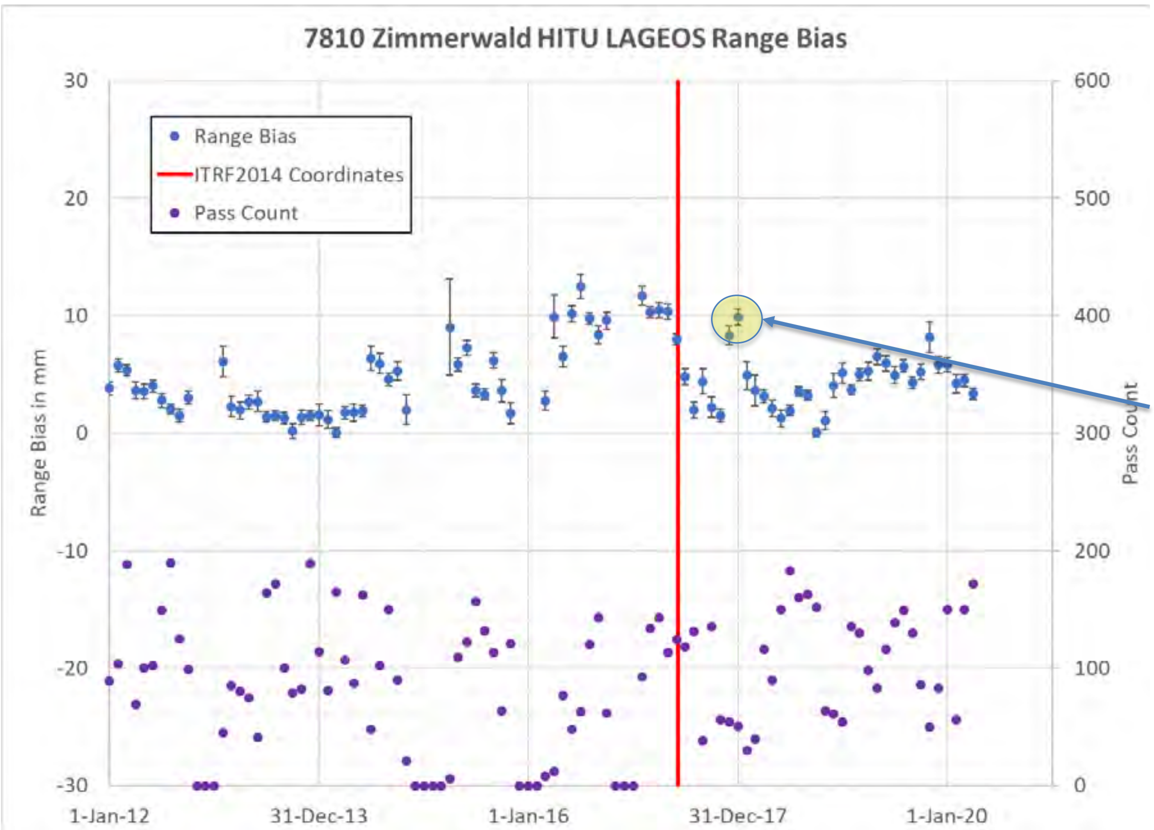
7810 Zimmerwald Geodetic Data Yield and Range Bias Stability





Zimmerwald is fully autonomous, but does not get as much data as Yarragadee since it is not blessed with clear skies.. Also when Zimmerwald goes offline it can be down for multiple months so it data volume per year can fluctuate.

7810 Zimmerwald HITU LAGEOS Range Biases



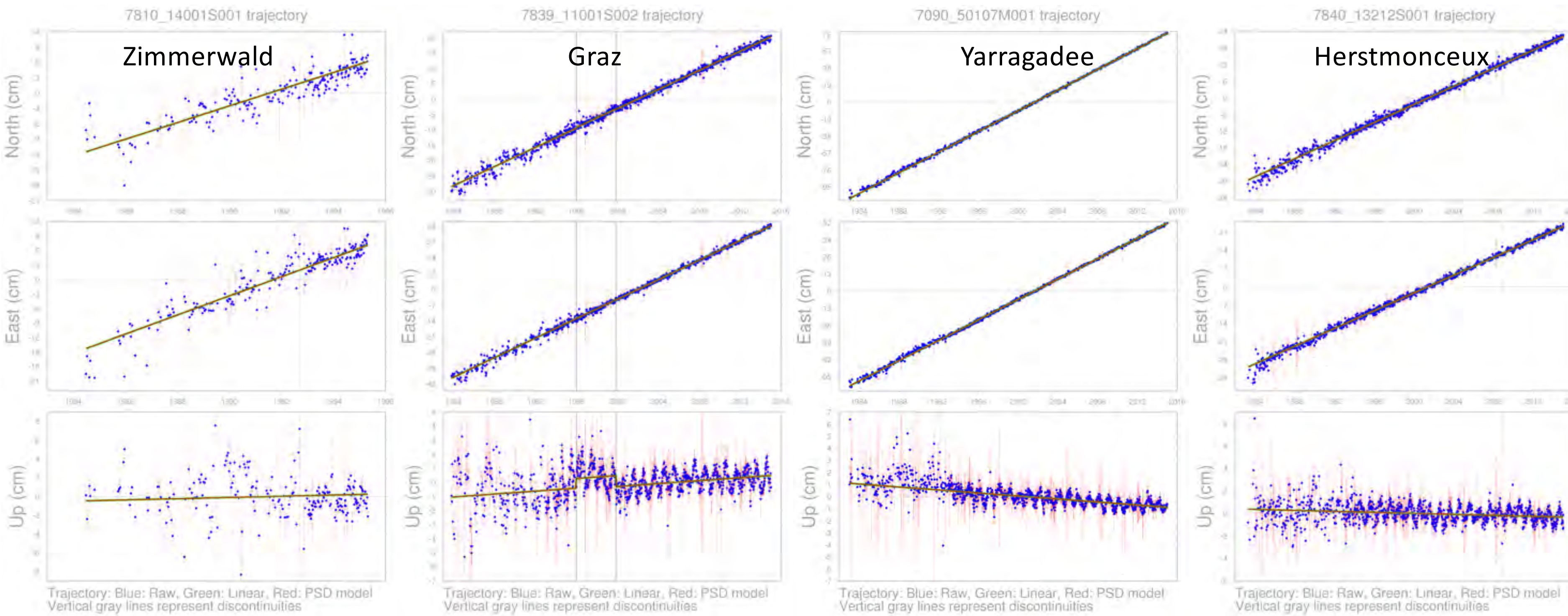
There is no obvious signal in their range bias like there was in Graz, which is a very close neighbor.

The monthly LAGEOS range bias variations are devoid of structure relative to other stations. This could be indictive of an instability in the system.

Was there an abrupt actual ~5mm change In bias starting in Dec 2017 and then did the bias return to previous levels?

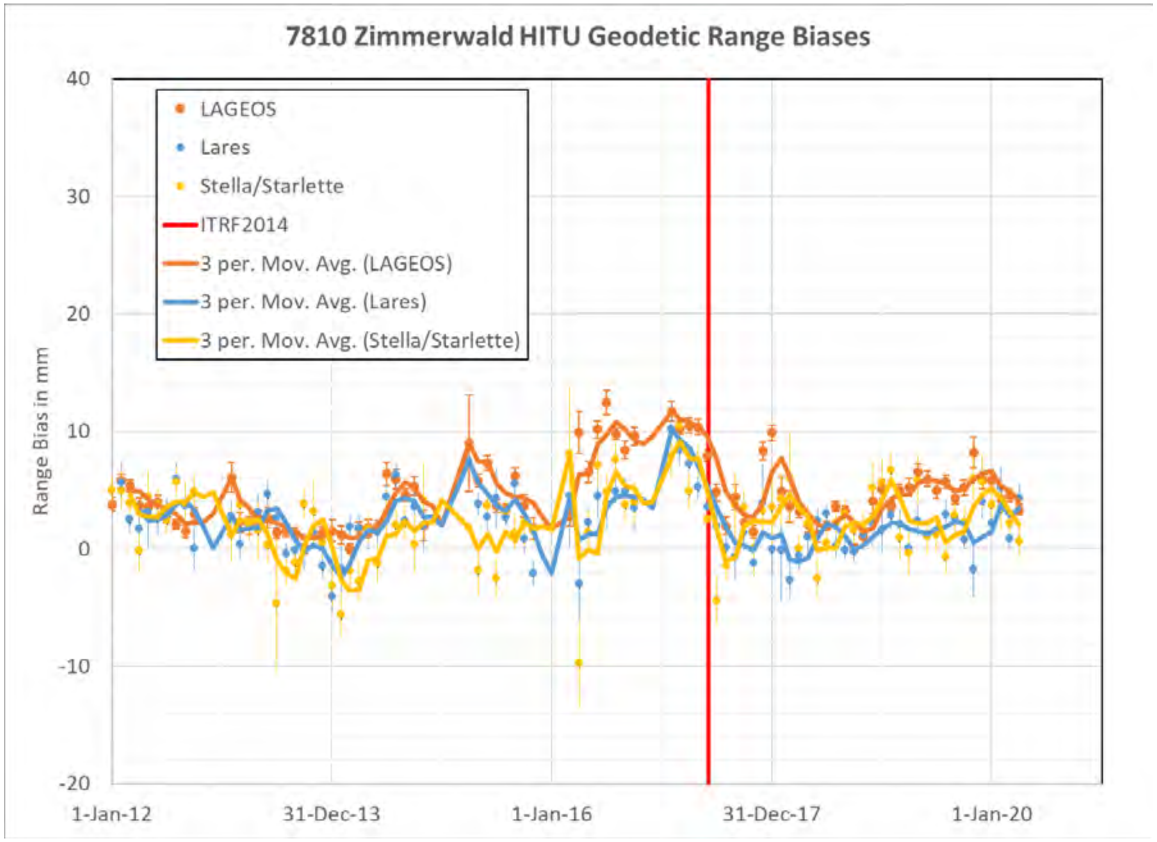
Did the biases on Stella/Starlette and Lares see a similar change?

ITRF2014 Station Result Comparisons



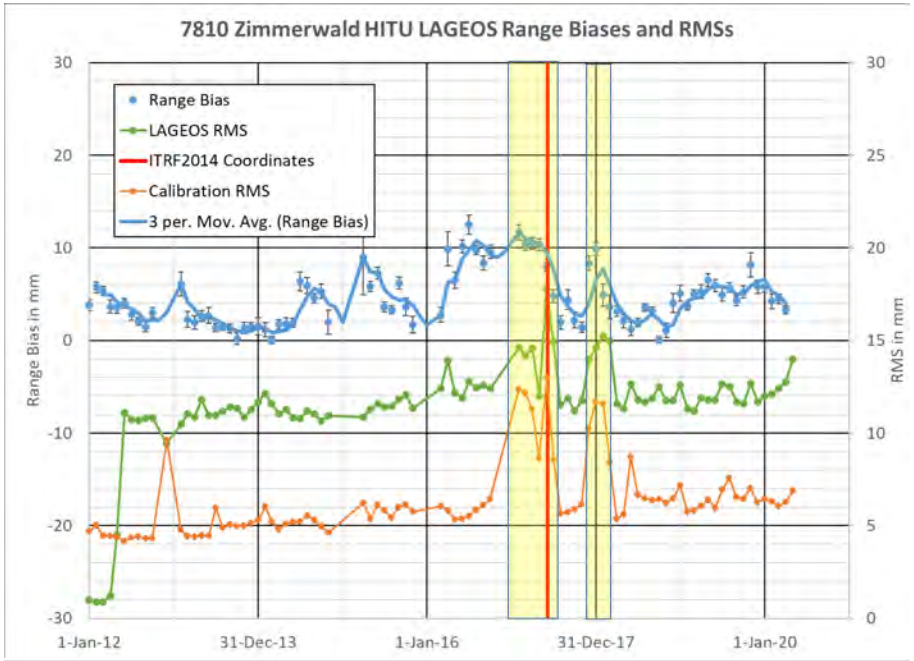
A side by side comparisons of site velocities. Notice that station heights from Graz, Yarragadee, and Herstmonceux have annual signals but Zimmerwald does not. This could be indicate of an instability in the Zimmerwald range bias.

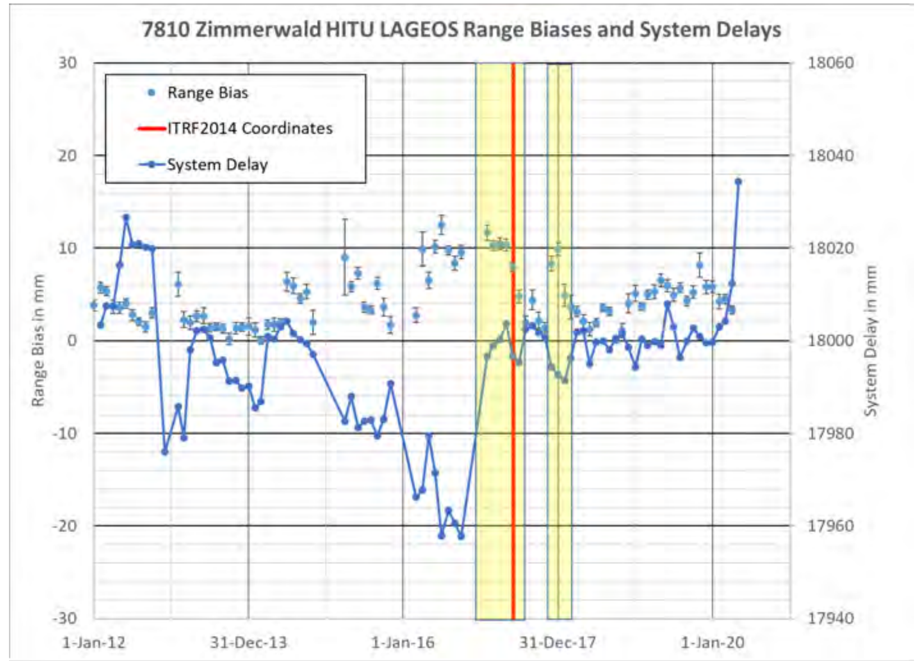
7810 Zimmerwald HITU Geodetic Range Biases



These are the 3 month trends from LAGEOS, Lares and Stella/Starlette.

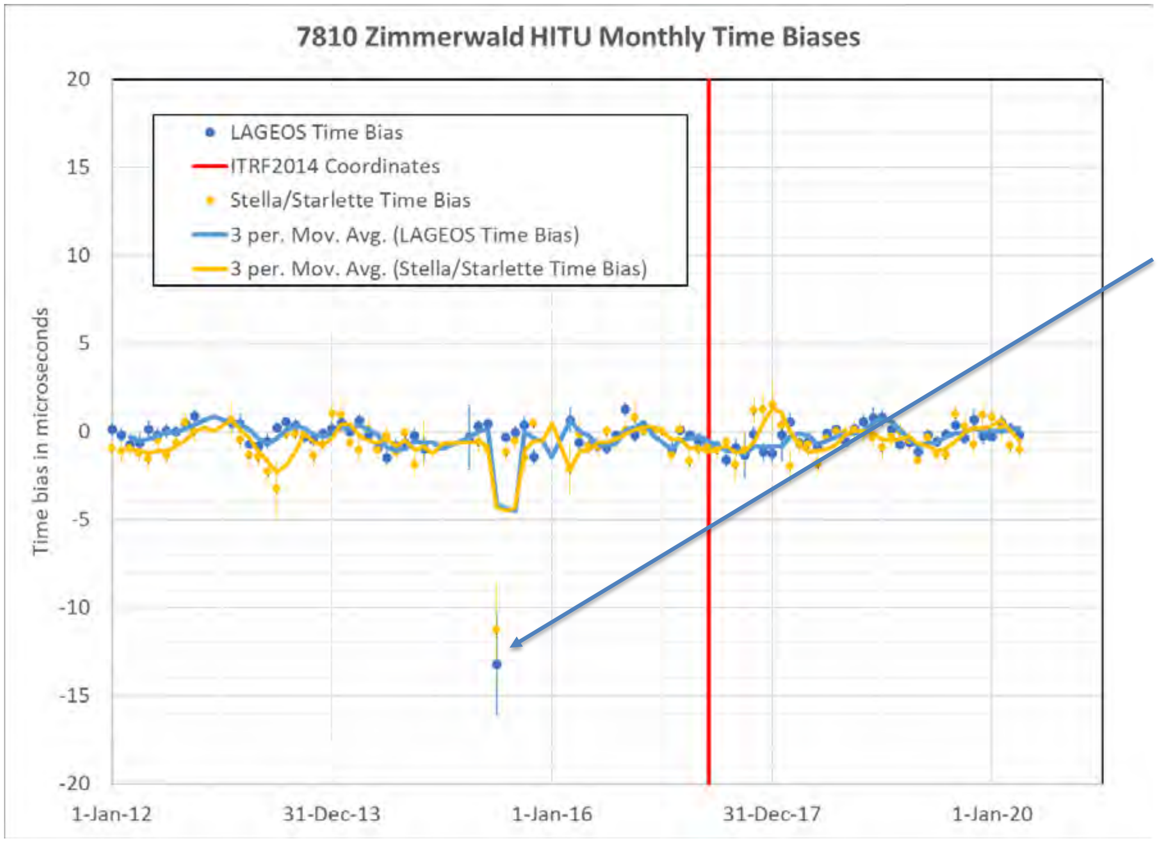
7810 Zimmerwald LAGEOS Analysis





The two areas highlighted in these charts are when there were some instabilities in the Zimmerwald system. The most notable periods are Feb through July 2017 and Dec 2017 through March 2018. In the later period the RMSs went up and the system delay went down, so the range bias change could be real.

7810 Zimmerwald HITU Monthly Time Biases



There was an ~109 microsecond time bias from July 3 to July 6, 2015 due to a problem with the GPS receiver. There is a entry in the ILRS Data Handling file to delete this data, but the data does appear to be recoverable. Also, there were no entry in the station change history about this issue.

Bias Detection Capabilities from Orbital Analysis

	Period of Time					
Satellite/Bias Type	Pass	Day	Week	Month	3 Months	Year
LAGEOS Range Bias (mm)	60-100	30-50	20-40	10-20	5-10	1-2
LAGEOS Time Bias (μsec)	30-60					
Lares Range Bias (mm)	80-120					
Lares Time Bias (μsec)	40-70					
Stella/Starlette Range Bias (mm)	100-200					
Stella/Starlette Time Bias (μsec)	40-70					
Ajisai Range Bias (mm)	120-240					
Ajisai Time Bias (μsec)	50-80					
Etalon Range Bias (mm)	80-120					
Etalon Time Bias (μsec)						

I need to complete this table and review
The numbers provided.

Questions/Comments/Conclusions

- Can Stella, Starlette and/or Ajisai data be used in future ITRF solutions?
- When range bias changes correlate to changing in system performance (i.e. RMSs, calibration shifts, skew, kurtosis); an equipment change or a procedural change; then most likely there was a real change in the bias.
- Stations needs to do a better job on maintaining their station change histories and especially documenting issues that were resolved.