7124 Tahiti minus 3 cm Range Bias Re-examination

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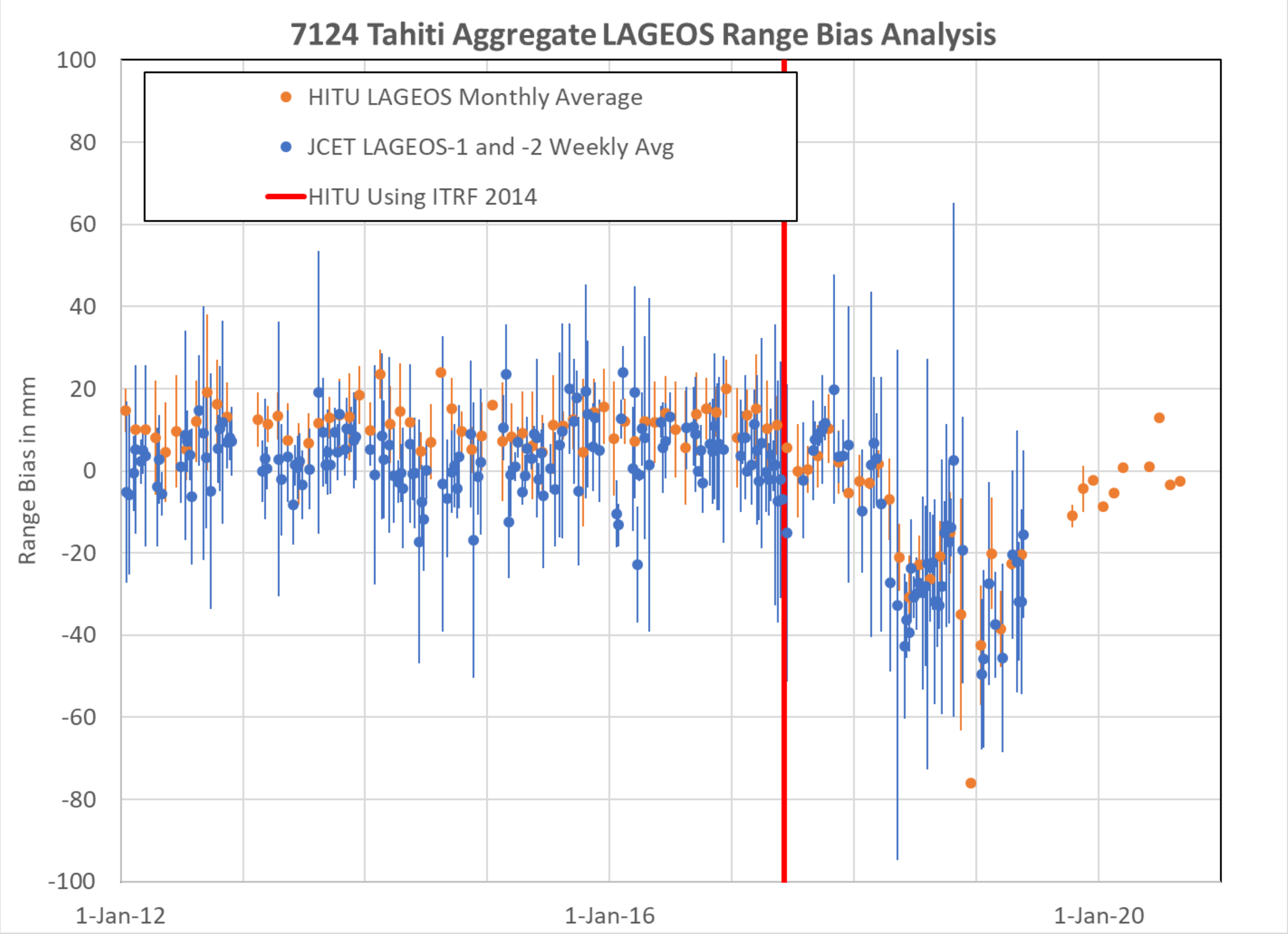
ILRS QCB

27-Jun-2022

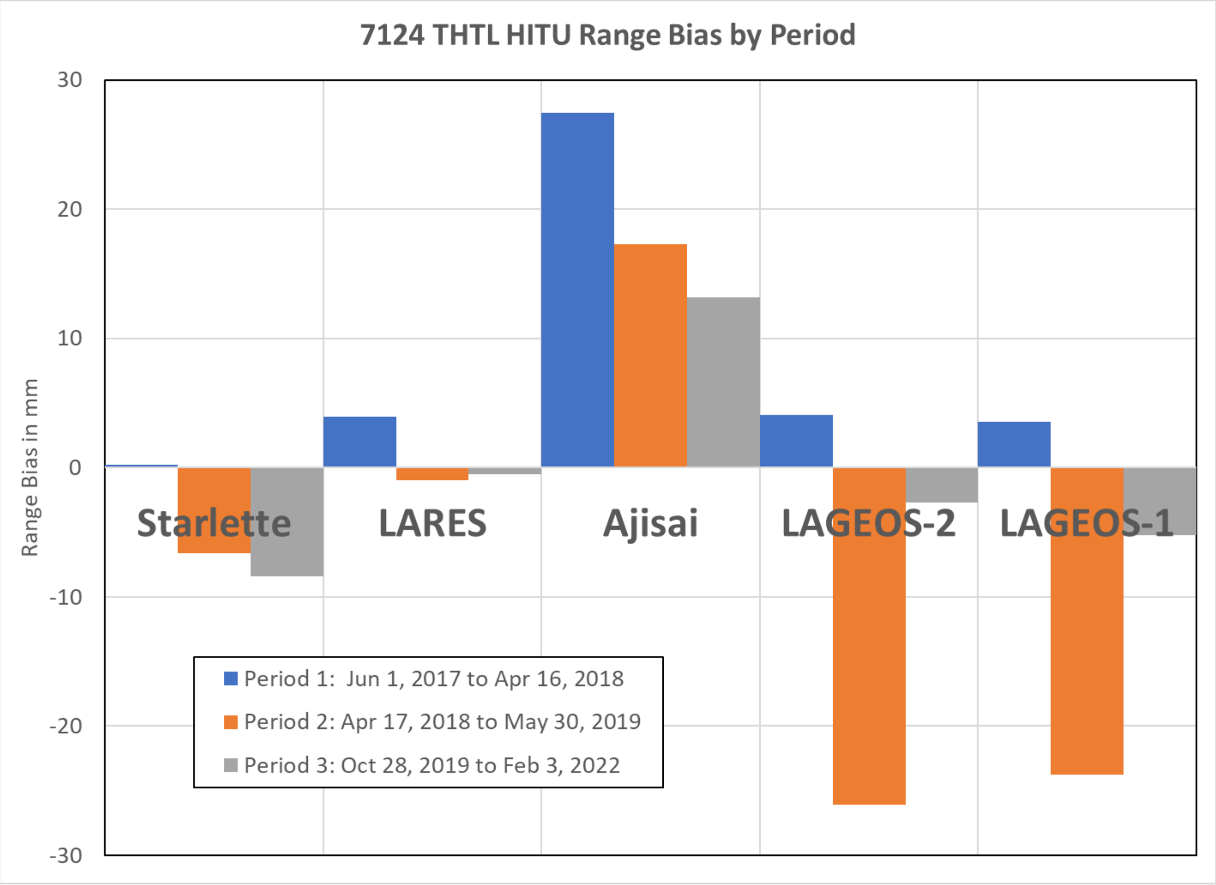
Peraton

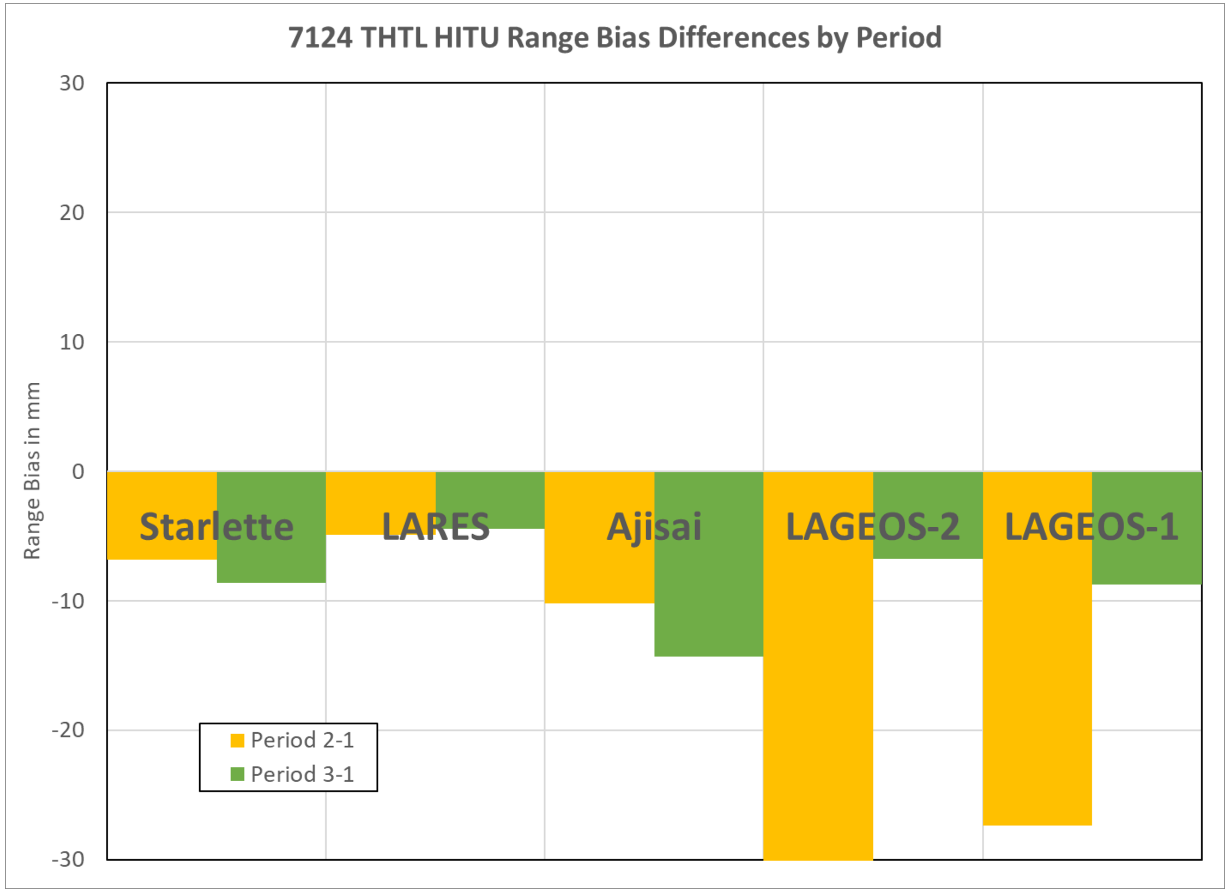
7124 THTL LAGEOS Range Bias Analysis



- ❑ **Erricos noticed a minus 30 mm change in the 7124 LAGEOS range bias starting in mid April 2018**
- ❑ **This chart was presented 2 years ago at the June 2020 ILRS QCB meeting.**
- ❑ **Both Erricos' weekly analysis results along with Toshi's bias results indicate this change.**
- ❑ **The system was down for more than 4.5 months starting in June 2019. The system returned to operation in late October 2019.**

7124 THTL HITU Range Biases by Period



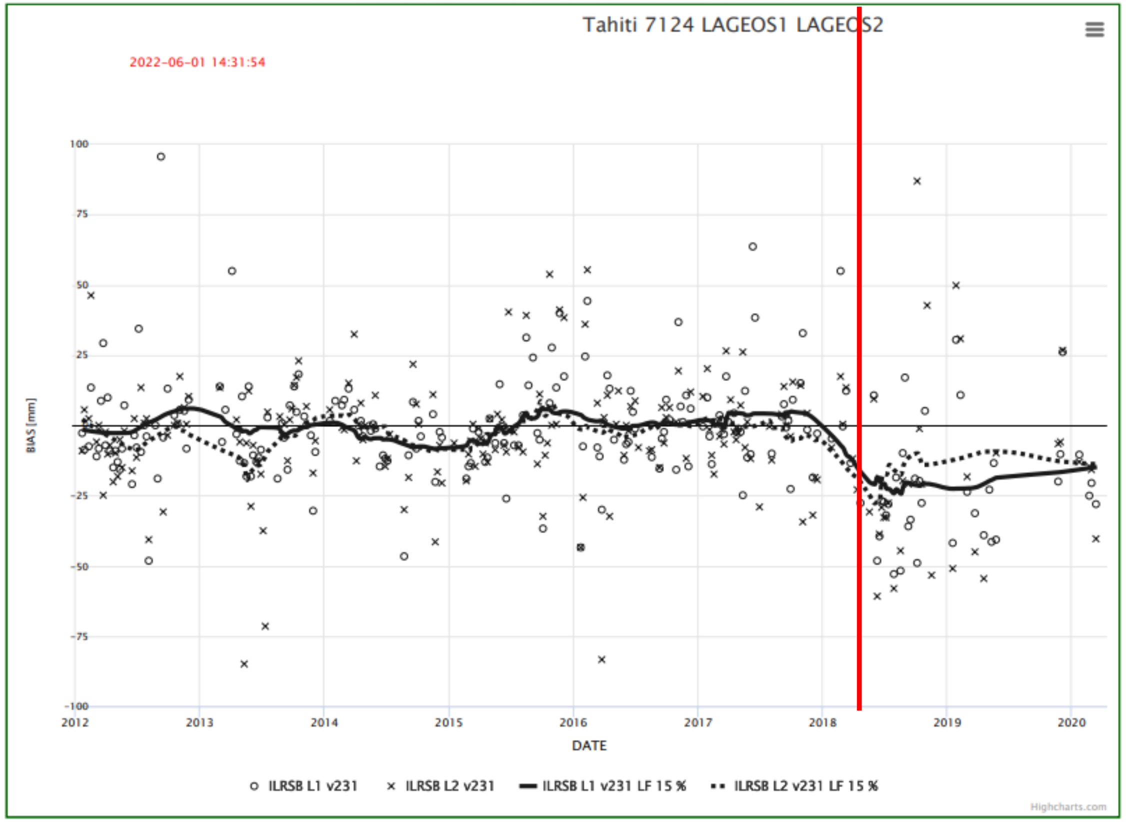


- The range biases on all satellites got more negative in Period 2 relative to Period 1 with LAGEOS-1 and -2 showing the largest change of ~30 mm.
- The range biases on all satellites are also more negative in Period 3 relative to Period 1, but the differences between satellites are more consistent.
- What caused the bias changes in Periods 2 and 3 relative to Period 1?

7124 SSEM Results

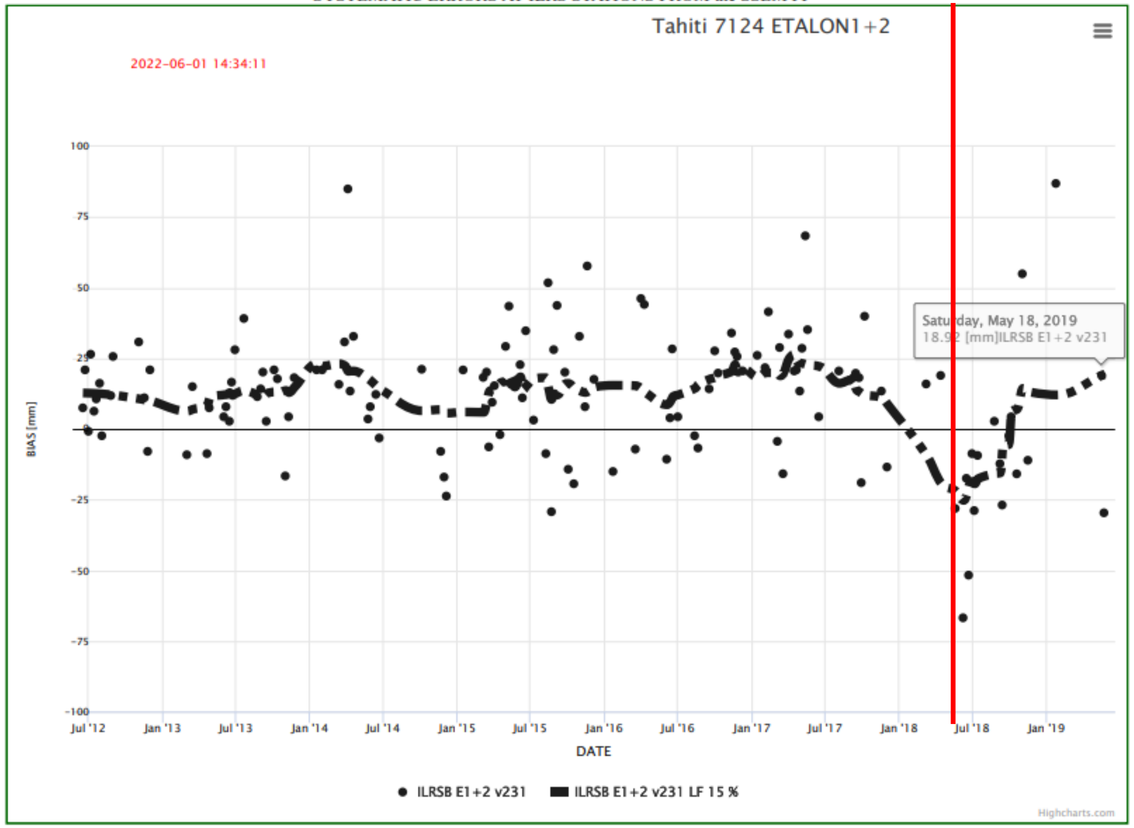
6/1/22, 2:37 PM Tahiti bias LAGEOS1 LAGEOS2

SYSTEMATIC ERRORS AT ILRS STATIONS FROM the SSEM PP



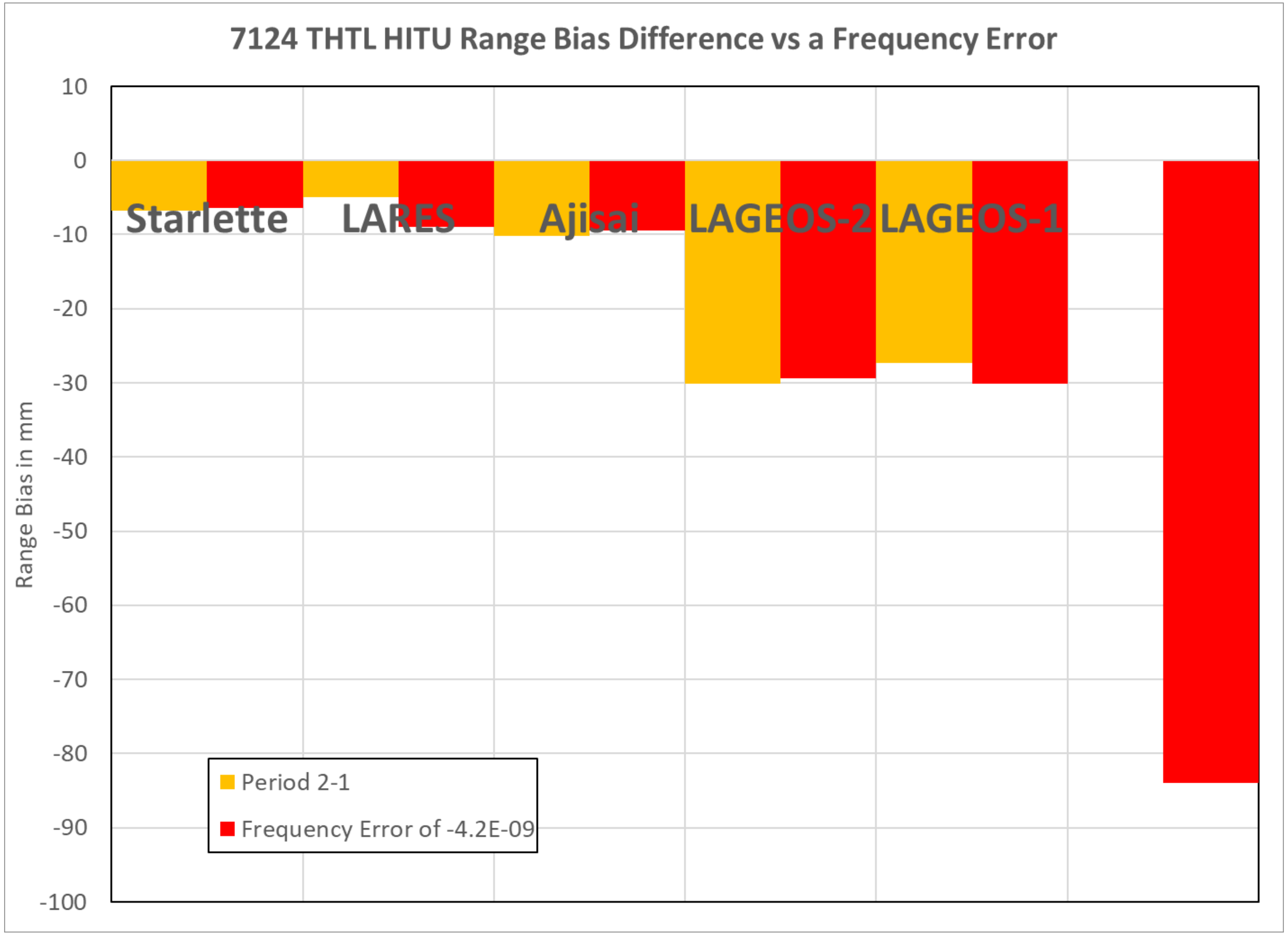
6/1/22, 2:35 PM Tahiti bias ETALON1+2

SYSTEMATIC ERRORS AT ILRS STATIONS FROM the SSEM PP



- **LAGEOS-1 and -2 results on the left chart, showing the -30 mm bias shift and then a partial bias rebound**
- **Etalon combined results on the right chart, showing a larger than -30 mm bias shift and then a bias rebound**
- **The redlines on the charts denote April 15, 2018.**
- **The LAGEOS-1 and 2 range bias in late 2019 and 2020 did not return to previous levels**

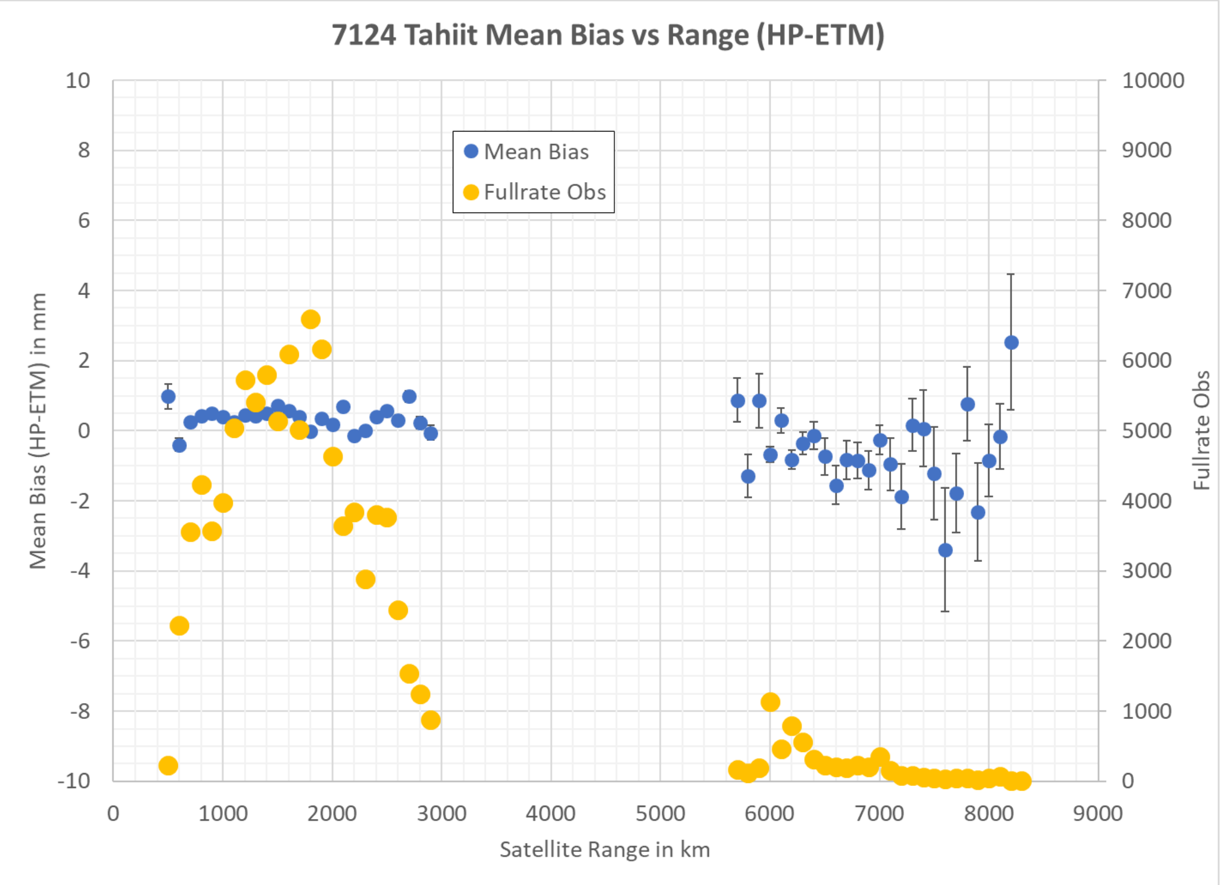
Impact of a 7124 Frequency Error on Range Bias



- ***Note: The Etalon data is sparse, so it is difficult to derive an accurate bias change estimate***
- **A frequency error of -4.2E-09 appears to explain the bias changes in Period 2.**
- **Frequency errors**
  1. will drift over time
  2. will not impact single shot or normal point precision
  3. will not impact system delay
- **If there was a frequency error, the root cause is still unknown**

7124 THTL HP-ETM Results (Oct 28, 19 to Mar 5, 20)

	Peraton Fullrate Analysis Oct 28, 2019 to March 5, 2020				JCET Normal Point Analysis Oct 2019 to Mar 2020		
Satellite	Pass Count	Mean Bias in mm	Stdev in mm	Fullrate Obs	Mean Bias in mm	Stdev in mm	Normal Points Obs
Ajisai	**36**	**0.31**	**6.01**	**33,425**	**0.52**	**2.09**	**451**
BEC	3	1.63	5.44	238	1.90	2.47	17
Cryosat-2	25	0.37	5.93	8,282	0.59	2.20	295
Galileo-220							
Geo-IK-2	16	0.54	5.88	6,943	0.77	2.26	112
GLONASS-131							
GLONASS-136							
GRACE-FO-1	15	0.22	7.50	2,596	0.61	2.75	209
GRACE-FO-2	6	0.36	6.86	1,089	1.16	3.44	81
HY-2A	5	0.60	6.62	644	0.83	2.27	22
HY-2B	8	0.12	5.88	1,753	0.45	3.08	50
Jason-2							
Jason-3	19	0.45	5.91	7,600	0.62	2.64	341
KOMPSAT-5	5	0.18	7.22	1,654	0.67	3.32	109
LAGEOS-1	**24**	**-0.54**	**7.89**	**4,892**	**-0.95**	**3.69**	**194**
LAGEOS-2	**10**	**-0.47**	**7.38**	**1,026**	**-0.07**	**3.64**	**66**
LARES	**22**	**0.34**	**5.70**	**4,389**	**0.63**	**3.20**	**161**
Larets	15	0.70	5.92	5,762			
PAZ	4	-0.86	5.88	323	-0.75	3.75	38
SARAL	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	**30**	**0.37**	**5.85**	**16,220**	**0.71**	**2.06**	**251**
Swarm-A	5	-0.34	7.72	1,212	0.50	2.44	82
Swarm-B	9	0.20	5.29	1,617	0.22	2.81	118
Swarm-C	5	-0.13	7.48	1,091	0.78	2.58	68
TanDEM-X							
TechnoSat	8	0.53	5.61	597	-0.05	4.15	35
TerraSAR-X	5	0.21	6.18	848			
Grand Total	**285**	**0.31**	**6.17**	**103,400**	**0.61**	**0.57**	**2,790**



- **Peraton and JCET range bias results on the geodetic satellites agreed to <0.5 mm.**
- **Chart on the right are based on fullrate data.**
- **The reason the 2020 LAGEOS range biases did not return to previous historical levels is still an unsolved mystery**

7821 Shanghai Analysis

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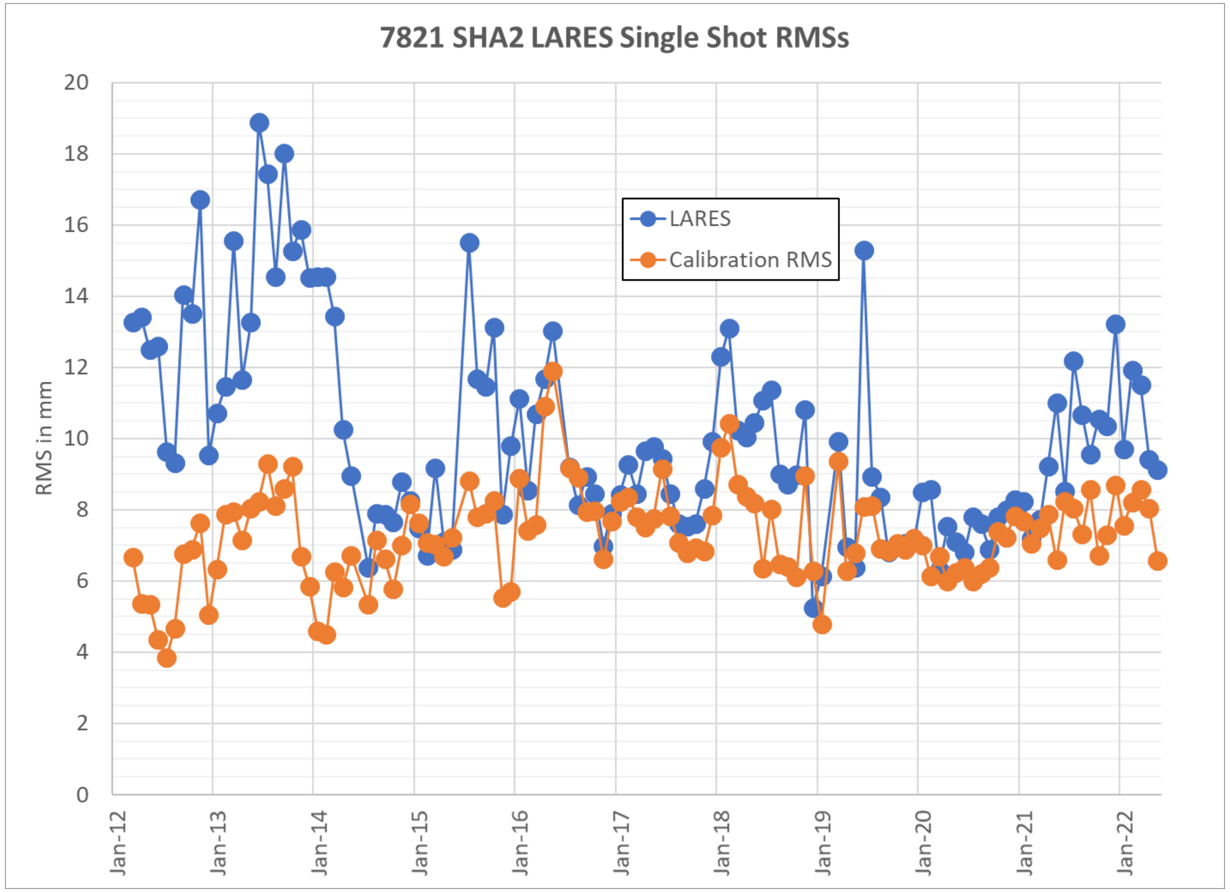
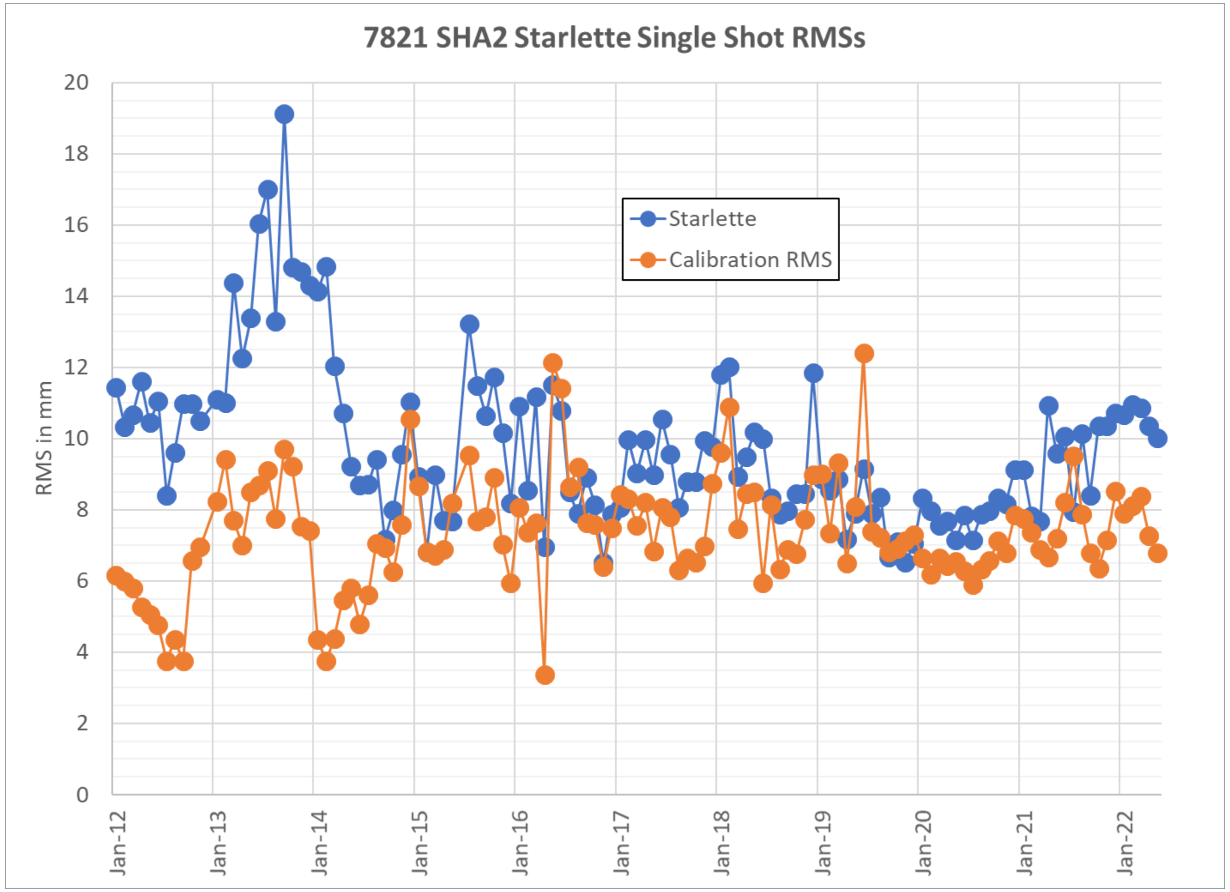
27-Jun-2022

Peraton

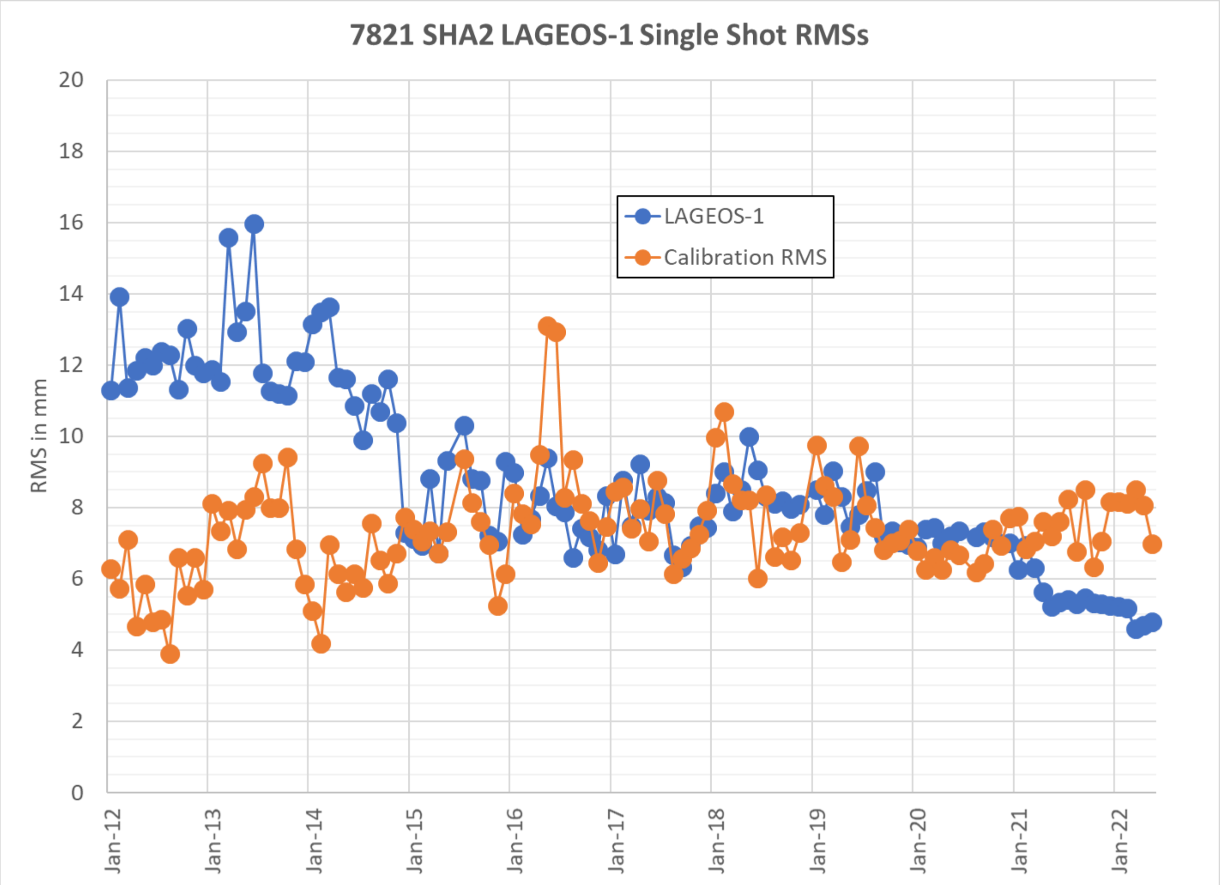
7821 SHA2 LARES and Starlette Single Shot RMSs

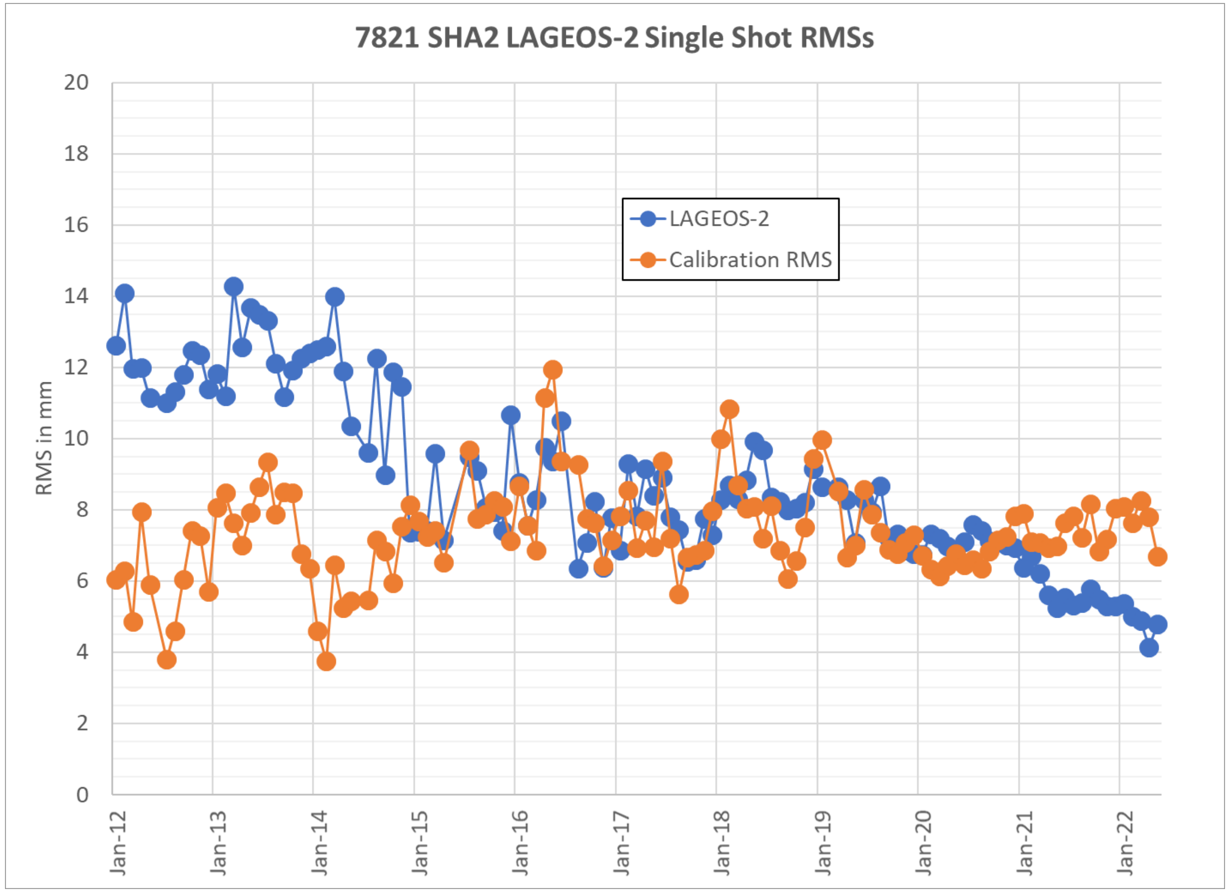




- **LARES and Starlette single shot RMSs trends are similar. Calibration single shot RMSs are lower than corresponding satellite RMSs.**

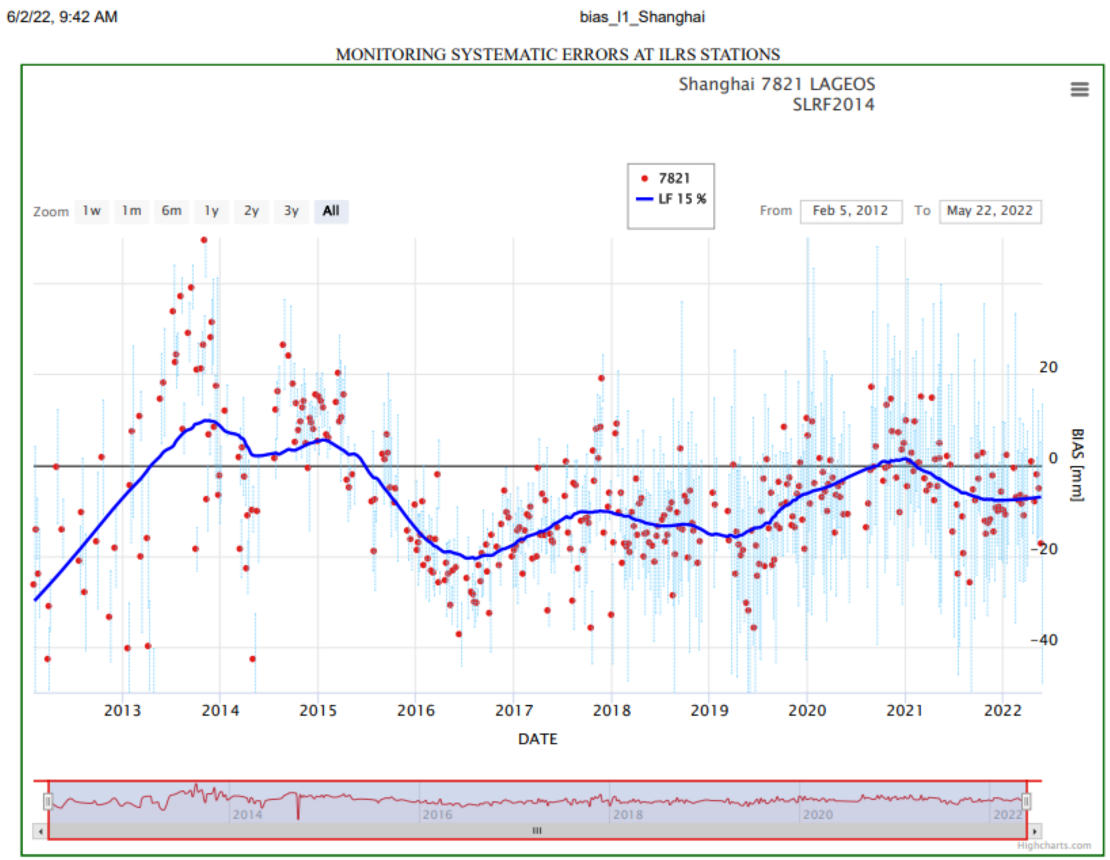
7821 SHA2 LAGEOS Single Shot RMSs

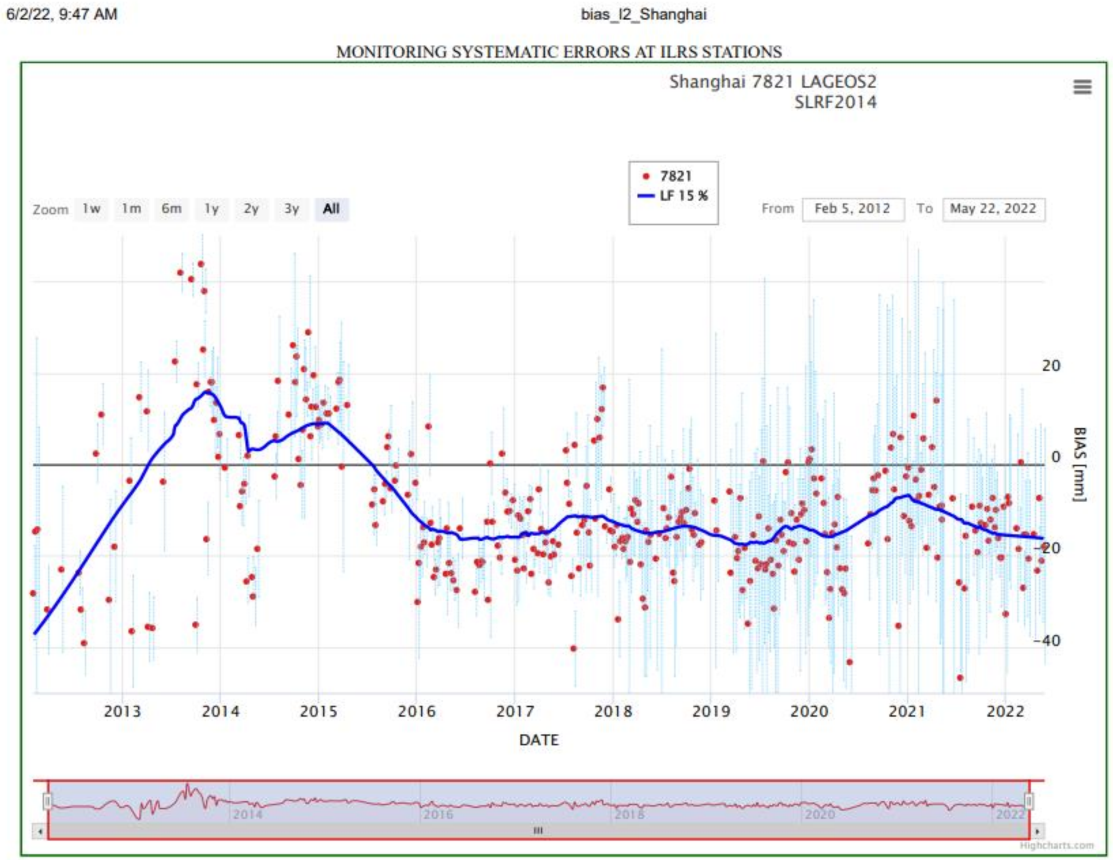




- ❑ On 27-Nov-2014, 30 mm Leading Edge (LE) was clipping applied (ref: CoM system file, +2.6 mm LAGEOS CoM change). This was NOT documented in the system change history NOR the site log. The history log mentions a data processing modification one-year earlier on 5-Nov-2013 but no detail was provided on what changed.
- ❑ LAGEOS RMSs in March, April and May 2022 are the lowest within the ILRS network, but their calibration RMSs are more than double. Have the recent LAGEOS RMS trends impacted their range bias?

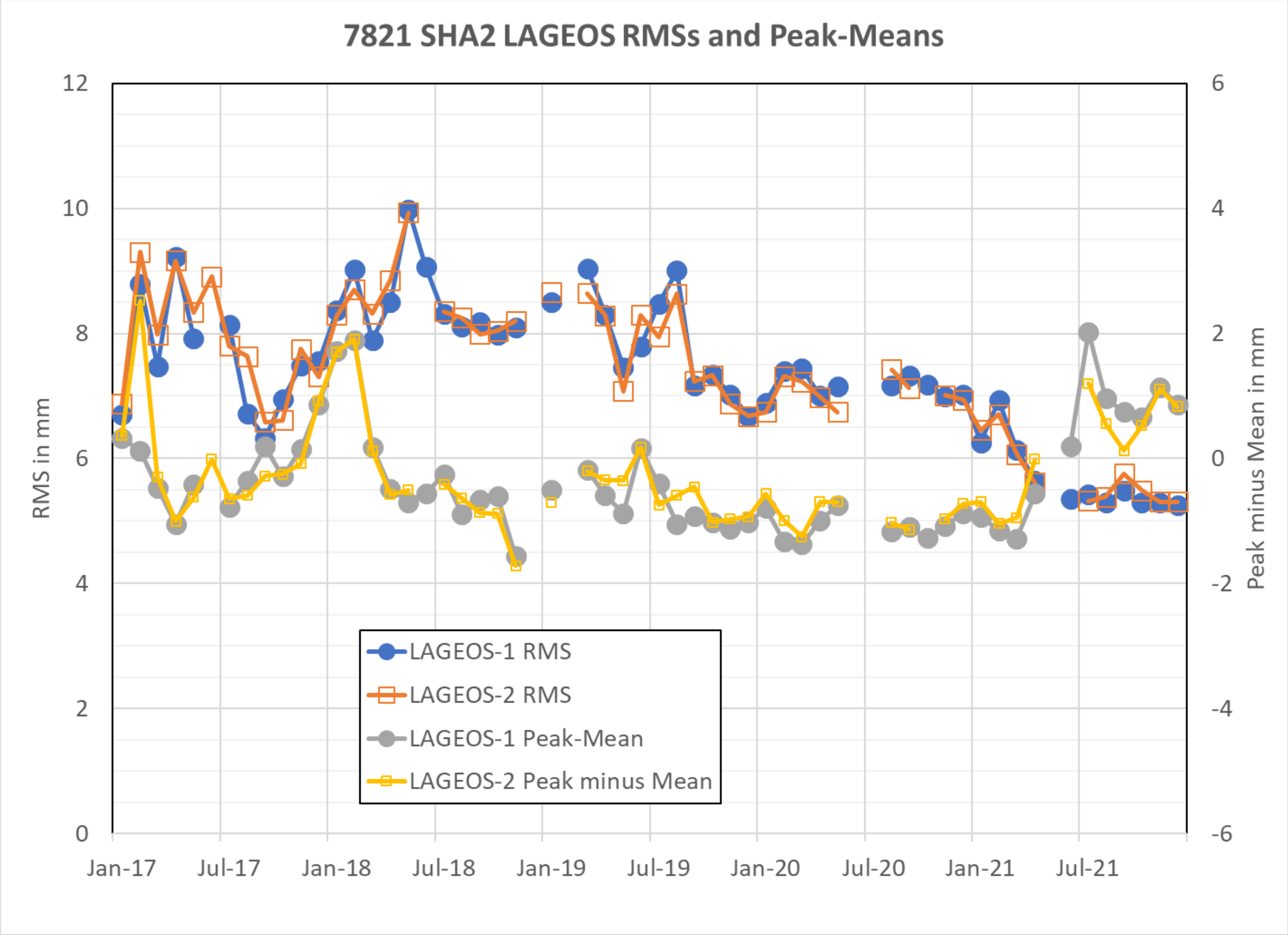
7821 SHA2 LAGEOS Range Biases





- JCET LAGEOS-1 and LAGEOS-2 Range Bias Estimates on the left and right chart; respectively.
- There is a 3-year gap in their history log from 2014 to 2017. Their site log mentions a survey of their 2.7 m calibration target on 11-Nov-2015.
- Stating in 2021, there is a downward trend in the both LAGEOSs range biases

7821 SHA2 LAGEOS RMSs and Peak-Means



- In November 2016, 7821 started to provide the higher moments plus peak-means in their CRD normal points.
- Their station history log mentions that on 22-July-2021 they updated their LAGEOS processing software to use the Leading Edge (LE) method. This is not mentioned in their site log. This change warrants a new LAGEOS Center of Mass correction.
- There are several inconsistencies between their station history log and site log (see next slide)

7821 SHA2 Station Changes

System Change	Date	Station History Log	Site Log
Data processing modification. *No details.*	05-Nov-2013	Yes	No entry
LAGEOS 30 mm LE rejection criteria applied	27-Nov-2014	No entry	No entry
Lengthen the return detector cable for Event Timer non-linear effect during calibration	22-Feb-2014	Yes	N/A
Calibration Target (2.5 m) measured. *New Target?*	15-Nov-2015	No entry	Yes
Changed laser maximum repetition rate	20-Jul-2017	Yes	No entry
Using 2 kHz laser routinely	11-Aug-2019	Yes	No entry, site log only has one laser entry (ND:YAG 1 kHz)
APD replaces C-SPAD	10-Apr-2021	Yes	No entry
Using Daheng laser	13-Jun-2021	Yes	No entry
Using LE method for LAGEOS processing	22-Jul-2021	Yes	No entry
Using SHAO Event Timer	22-Sep-2021	Yes	No entry

Optimal Wiener filter for Multiphoton systems

Outline

- Former study used semi empirical transfer function (ETF) (by J. Rodriguez) to calculate normal points for single photon systems in order to remove systematics in normal point statistics

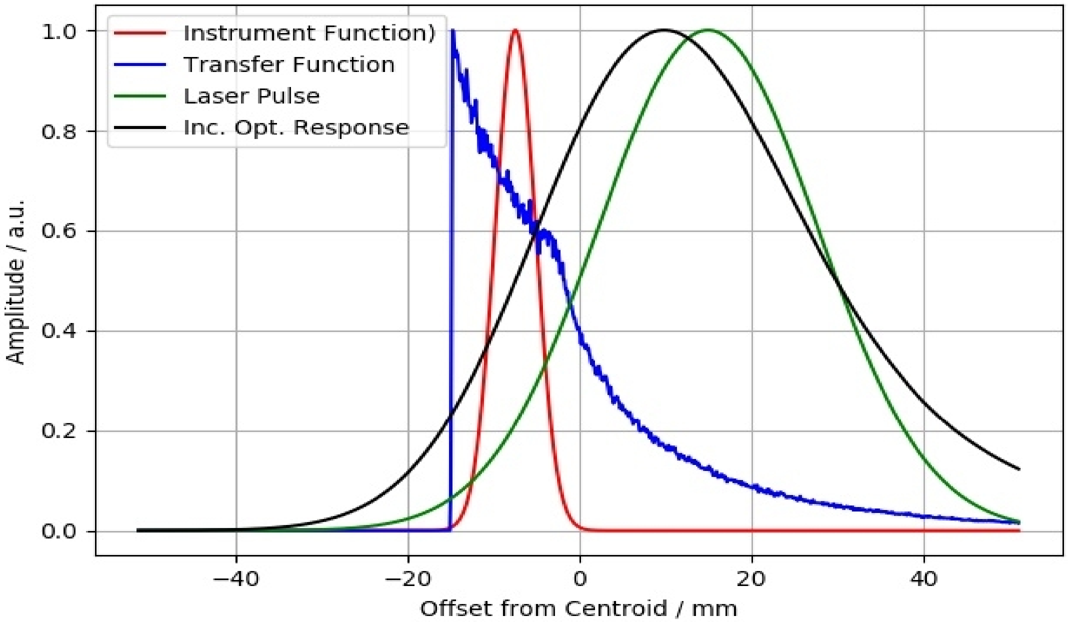
- This study: on the basis of the leading edge defined by the ETF a simplified analog signal processing model (LEHM) is used to retrieve an empirical system specific transfer function (ESSTF), which quantifies differences between calibration and satellite measurements

- Lageos fullrate data from 2019 for stations 7090,7105 and 7110 is used to compute residuals with orbitNP

- ESSTF is deconvolved passwise from the resulting histograms by unfolding the LEHM model. ESSTF is averaged over 1 month of data

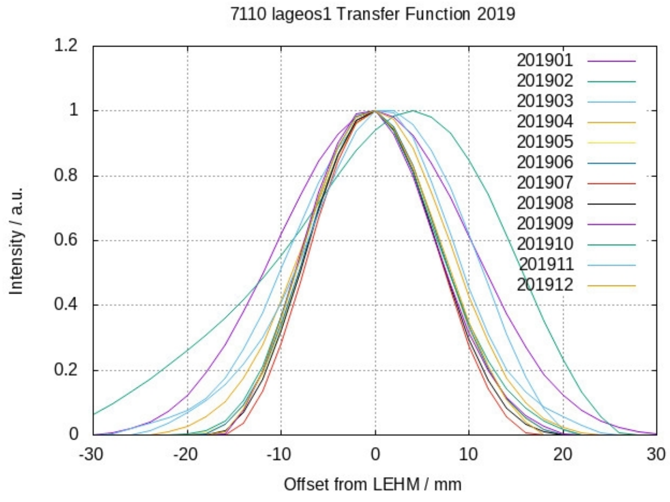
- normal points are computed using Wiener filter with ESSTF and compared to iterative 2.5 sigma normal points

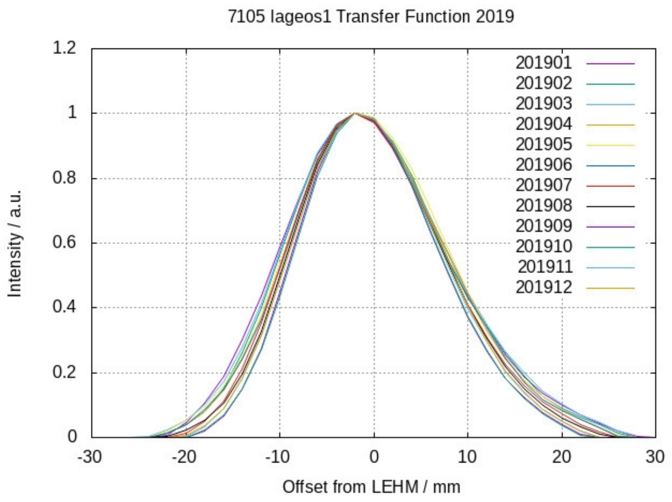
LEHM model

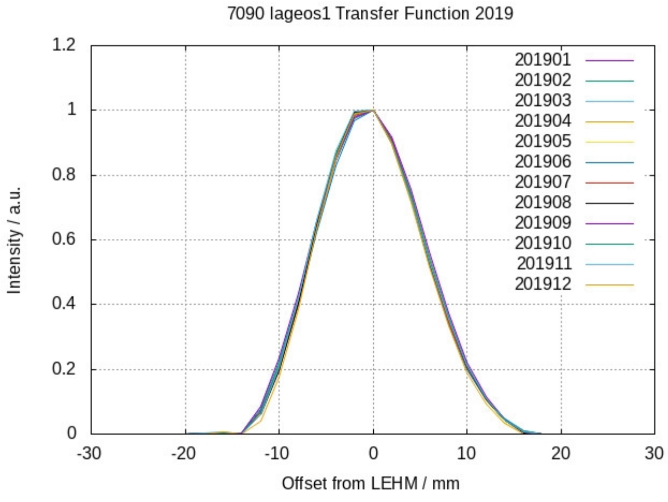


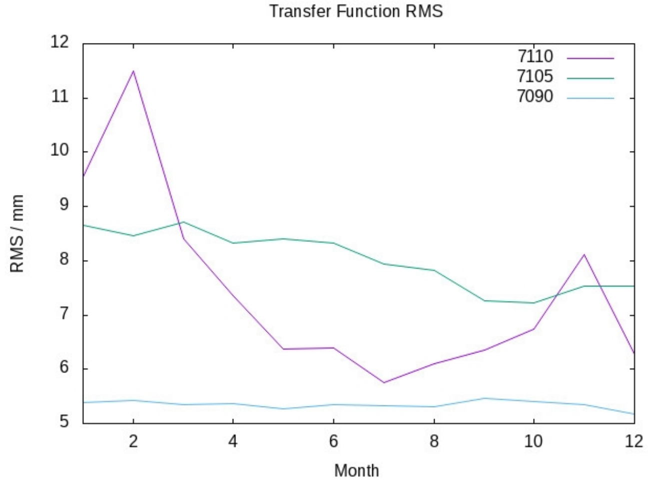
- ETF is convolved with 100ps pulsewidth laser (as used by 7090,7105,7110)
- a gaussian shape scaled with calibration rms is used as probability density function for LEHM detection (Instrument Function) of resulting incoherent optical response,
- leads to a CoM in the range of 245…249mm depending on detector risetime.
- departures from idealized detection model like residual time walk will show up in ESSTF

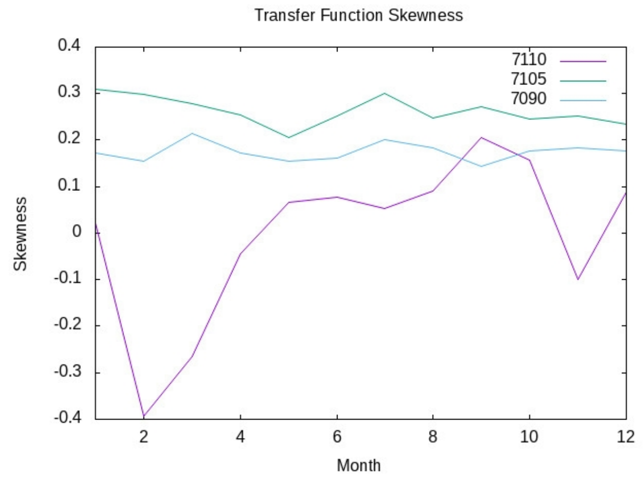
Resulting ESSTF for data from 2019





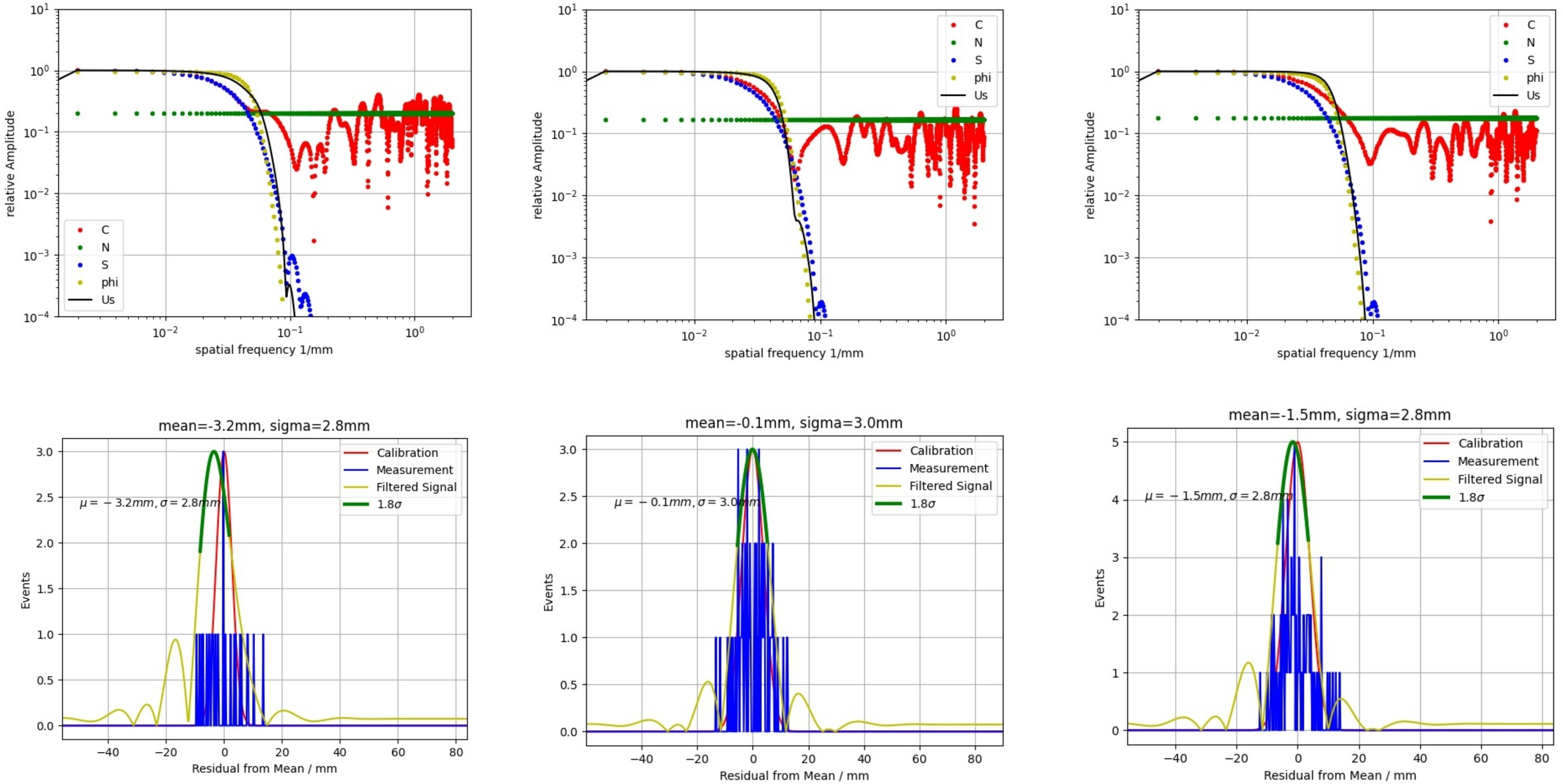




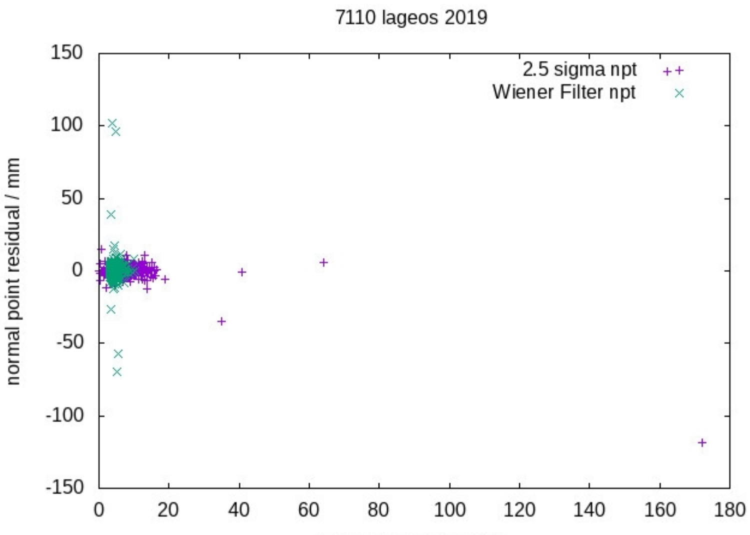


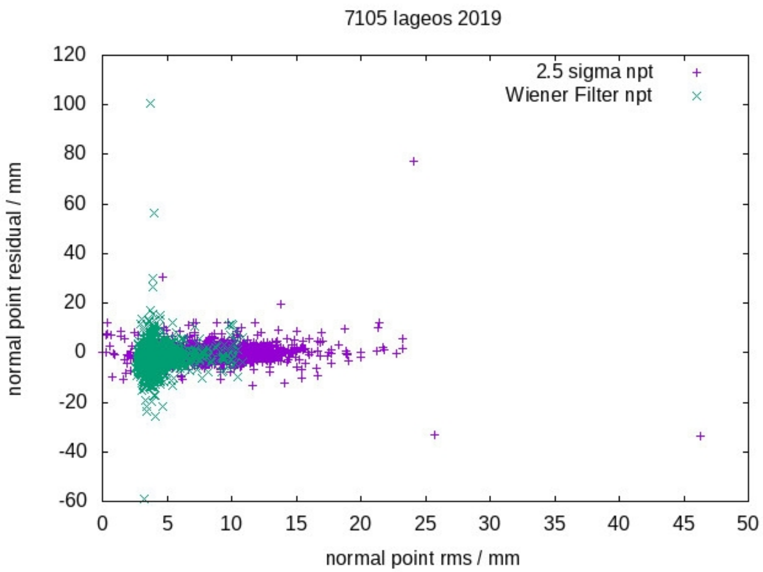
- 7105 and 7090 have stable transfer functions with significant different statistical moments
- stability of 7110 is degraded by sparse data during winter and autumn
- essential difference in setup is receiver risetime (350ps for 7090, 250ps for 7105 and 7110)

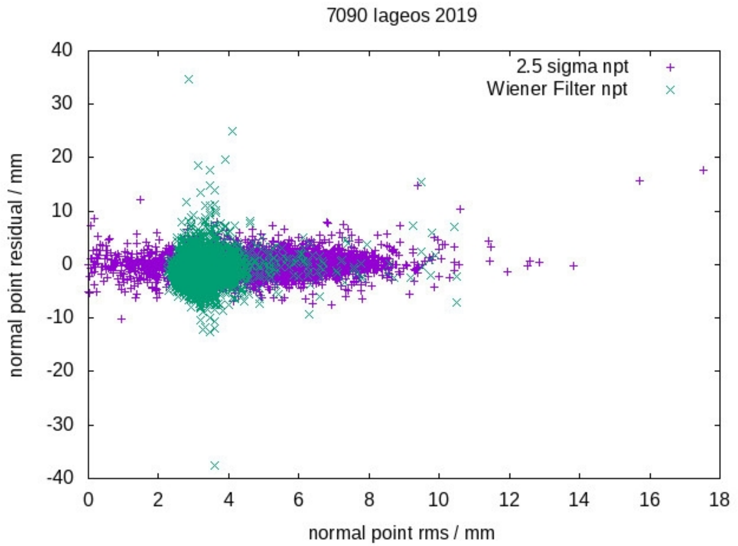
Wiener filtered normal point samples



Wiener filtered vs. 2.5 sigma normal points







- 2.5 sigma normal points show large dispersion in normal point rms
- Wiener filtered normal points are confined around a value comparable to calibration rms at the expense of larger dispersion in residual

Conclusion

- empirical system specific transfer function (ESSTF) has been retrieved for stations 7090, 7105 and 7110 from 2019 fullrate data
- high data rate ensures stable results
- even identical system setup can lead to different statistical moments in resulting ESSTF
- application of ESSTF with Wiener filter mitigates dispersion in normal point residual vs. normal point rms statistics
- Paradoxon: 7090 has got largest detector risetime and most precise ESSTF

VMF3o System Characterization using SLR Barometric Comparisons to VMF3oEl data

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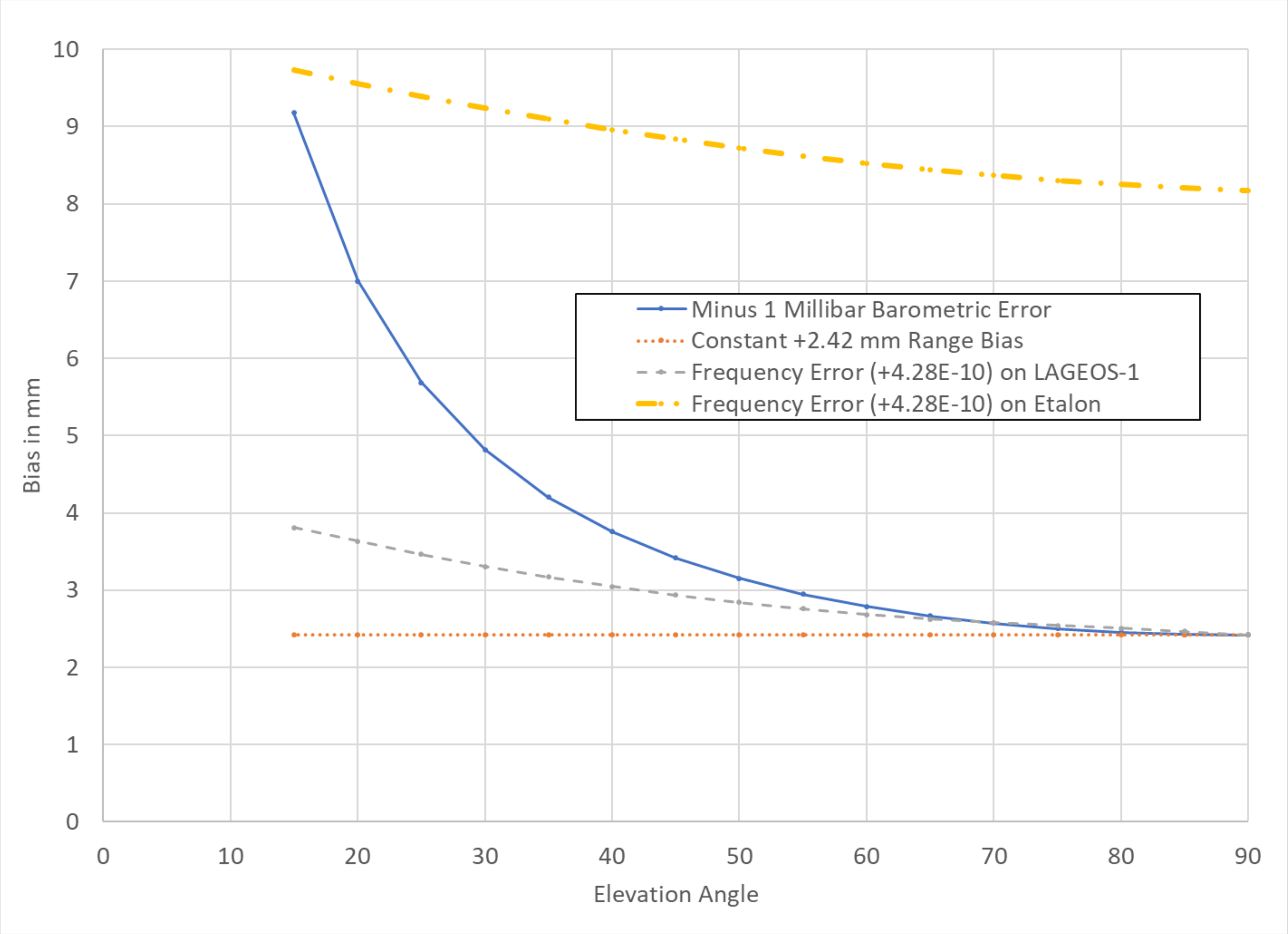
27-Jun-2022

Vienna Mapping Function (VMF)

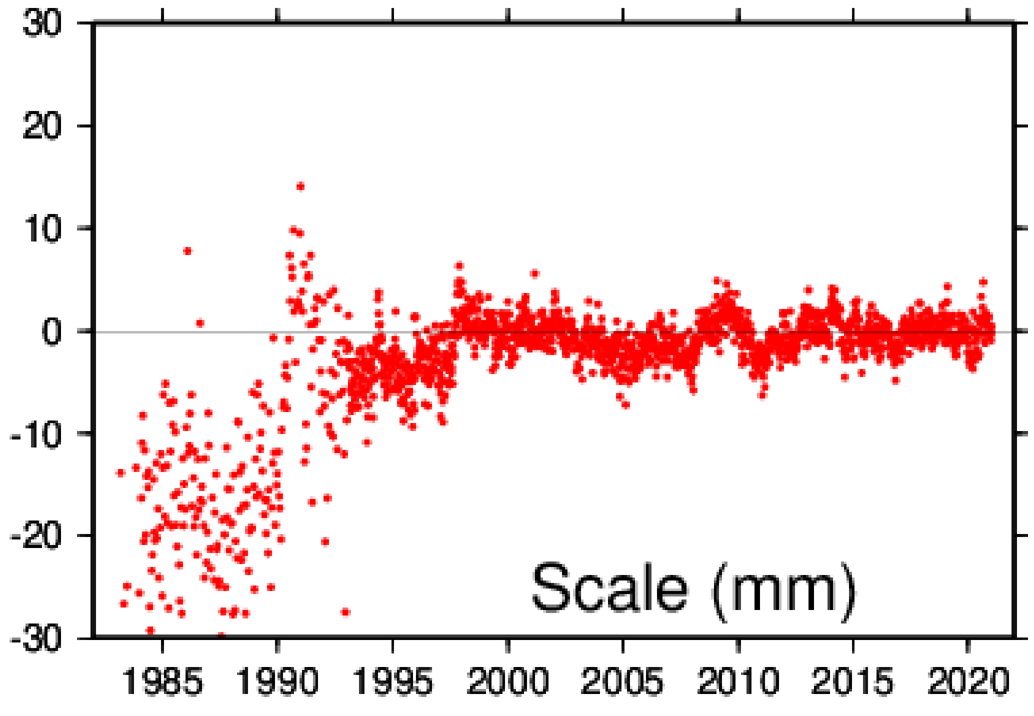
- **VMF Reference: re3data.org: VMF Data Server; editing status 2020-12-14; re3data.org - Registry of Research Data Repositories. http://doi.org/10.17616/R3RD2H**
- **VMF data is available on the VMF Data Server at https://vmf.geo.tuwien.ac.at/trop_products/SLR/VMF3o/VMF3o_EI/ and VMF Data Server (tuwien.ac.at)**
  - VMF3o: the Vienna Mapping Functions for optical frequencies. Reference: VMF3o: the Vienna Mapping Functions for optical frequencies | SpringerLink
    - There are meteorological measurements every six hours for 186 unique SLR monuments. Some sites (e.g. Greenbelt, Wettzell0 have more than one SLR monument.
    - There are semi-diurnal signals with amplitudes of a few millibars in pressure differences between the station's barometric measurements and the VMF
- **There are 3 flavors of VMF3o data**
  - VMF3o_EI: VMF3o parameters are based on ray-traced delays using European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim Numerical Weather Models (NWM) data (a climate reanalysis). Time Span: January 1, 1990, to August 31, 2019.
  - VMF3o_FC: ECMWF forecasted NWM
  - VMF3o_OP: ECMWF operational NWM. Data is available next day. Time Span: January 1, 2008 to present.

SLR Error Signatures as a Function of Elevation



- **At zenith the following errors would have the same magnitude but would have different magnitudes at 15 degrees**
  - Minus 1 millibar barometric error
  - +4.28E-10 Frequency Error
- **The same frequency error on LAGEOS would cause a much larger error on Etalon**
- **Elevation and/or range dependent errors are the worst types of SLR systematic errors.**
- **Frequency and barometric errors are silent killers of SLR data quality since these systematic errors do not impact data precision (single shot RMS, normal point RMS, calibration RMS)**

SLR Scale from ITRF2020

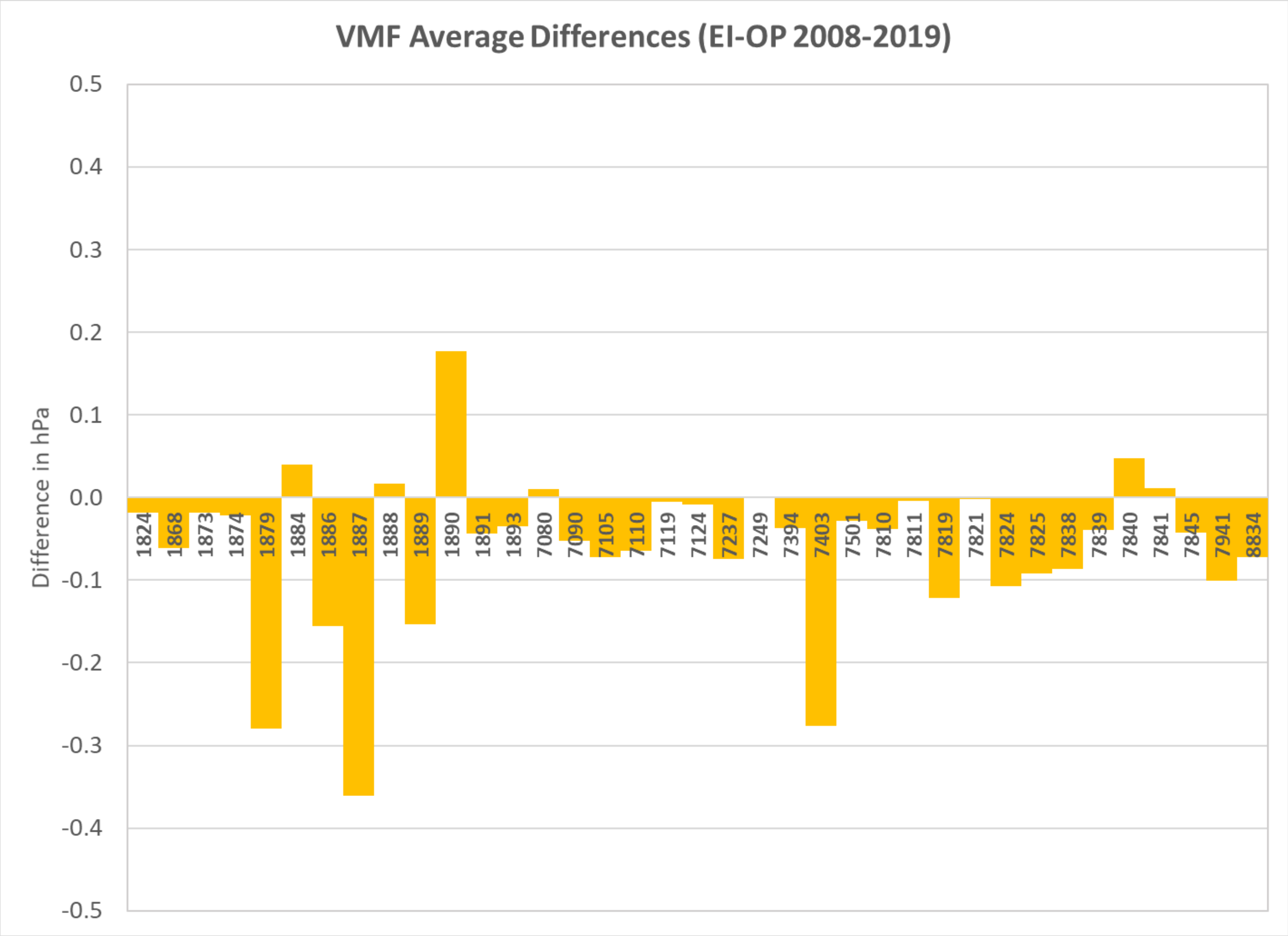


- Adding a second LAGEOS satellite in 24-Oct-1992 improved the ITRF scale derived from SLR
- The SLR scale from 1993 to 1997 appears to be biased short. Were barometric and/or frequency errors within the SLR network a root cause?
- To achieve one mm absolute ranging accuracies, the ILRS need to reduce systematic errors to <1 mm [Prochazka, ILRS Technical Workshop 2015]
- Based on this, the following SLR barometric and frequency requirements can be derived:
  - Absolute barometric accuracies better than 0.10 to 0.15 millibars dependent upon the site's minimum tracking elevation angle
  - Absolute frequency accuracies of less than 4.28E-11

Historical SLR Barometric Measurement Issues

- No data integrity checks were preformed on SLR barometric measurements prior to 08-Sep-2021
- Meteorological measurements do not always update
- Barometric sensors can drift over time
- Changing a barometric sensor or a recalibration may induce a discontinuity
- Infrequent barometric calibrations
- Height differences between the barometric sensor and the System Reference Point (SRP) are not modelled in the onsite data processing

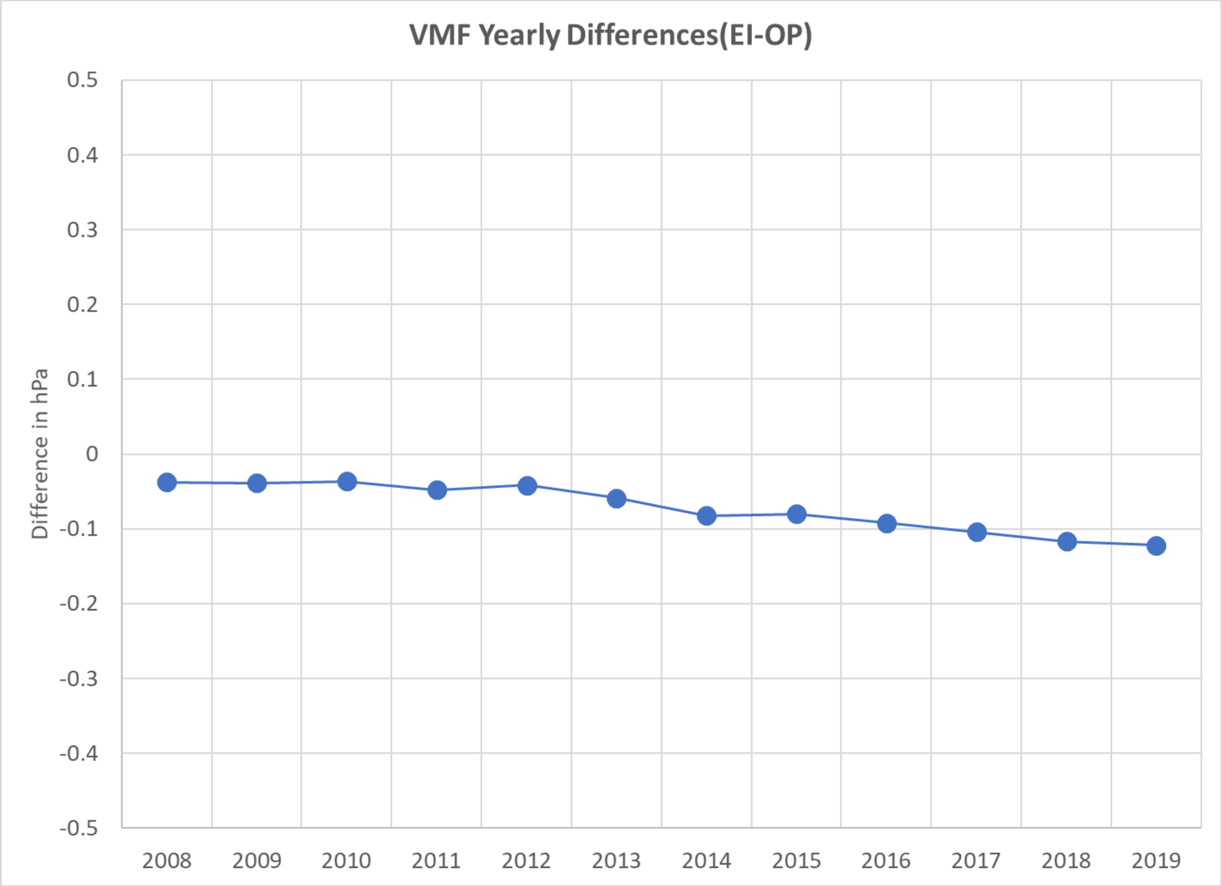
VMF System Characterization (EI versus OP)



Mark	Location
1824	Golosiiv, Russia
1868	Komsomolsk-na-Amure, Russia
1873	Simeiz, Ukraine
1874	Mendeleevo, Russia
1879	Altay, Russia
1884	Riga, Latvia
1886	Arkhyz, Russia
1887	Baikonur, Kazakhstan
1888	Svetloe, Russia
1889	Zelenchukskya, Russia
1890	Badary, Russia
1891	Irkutsk, Russia
1893	Katzively, Ukraine
7080	McDonald, TX, USA
7090	Yarragadee, Australia
7105	Greenbelt, MD, USA
7110	Monument Peak, CA, USA
7119	Haleakala, HI, USA
7124	Tahiti, French Polynesia
7237	Changchun, China
7249	Bejing, China
7394	Sejong City, Republic of Korea
7403	Arequipa, Peru
7501	Hartebeesthoek, South Africa
7810	Zimmerwald, Switzerland
7811	Borowiec, Poland
7819	Kunming, China
7821	Shanghai, China
7824	San Fernando, Spain
7825	Mt Stromlo, Australia
7838	Simosato, Japan
7839	Graz, Austria
7840	Herstmonceux, United Kingdom
7841	Potsdam, Germany
7845	Grasse, France
7941	Matera, Italy
8834	Wettzell, Germany

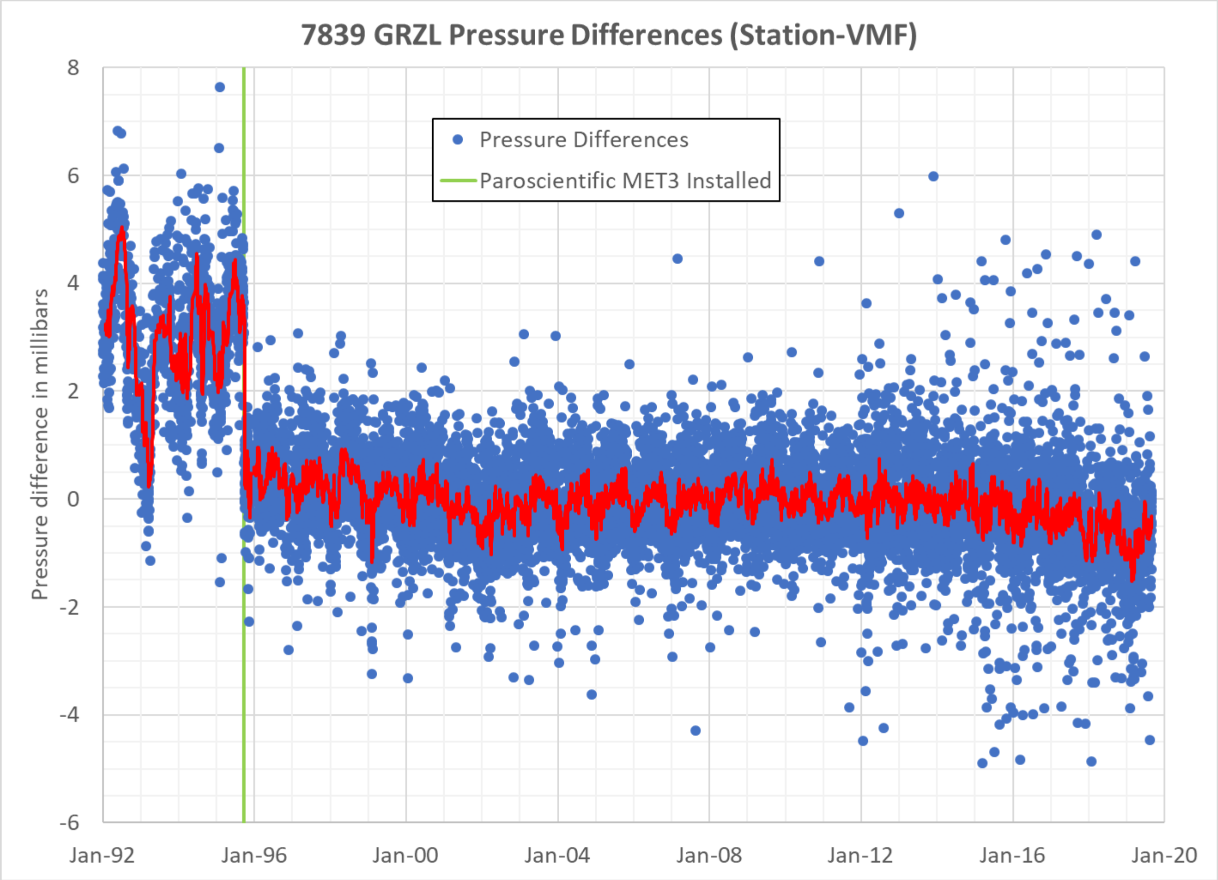
- **The mean difference between VMF3oEI and VMF3oOP for all 186 SLR monuments for the 12 years is minus 0.07 hPa (EI-OP).**
- **Listed here are most of the current active sites.**

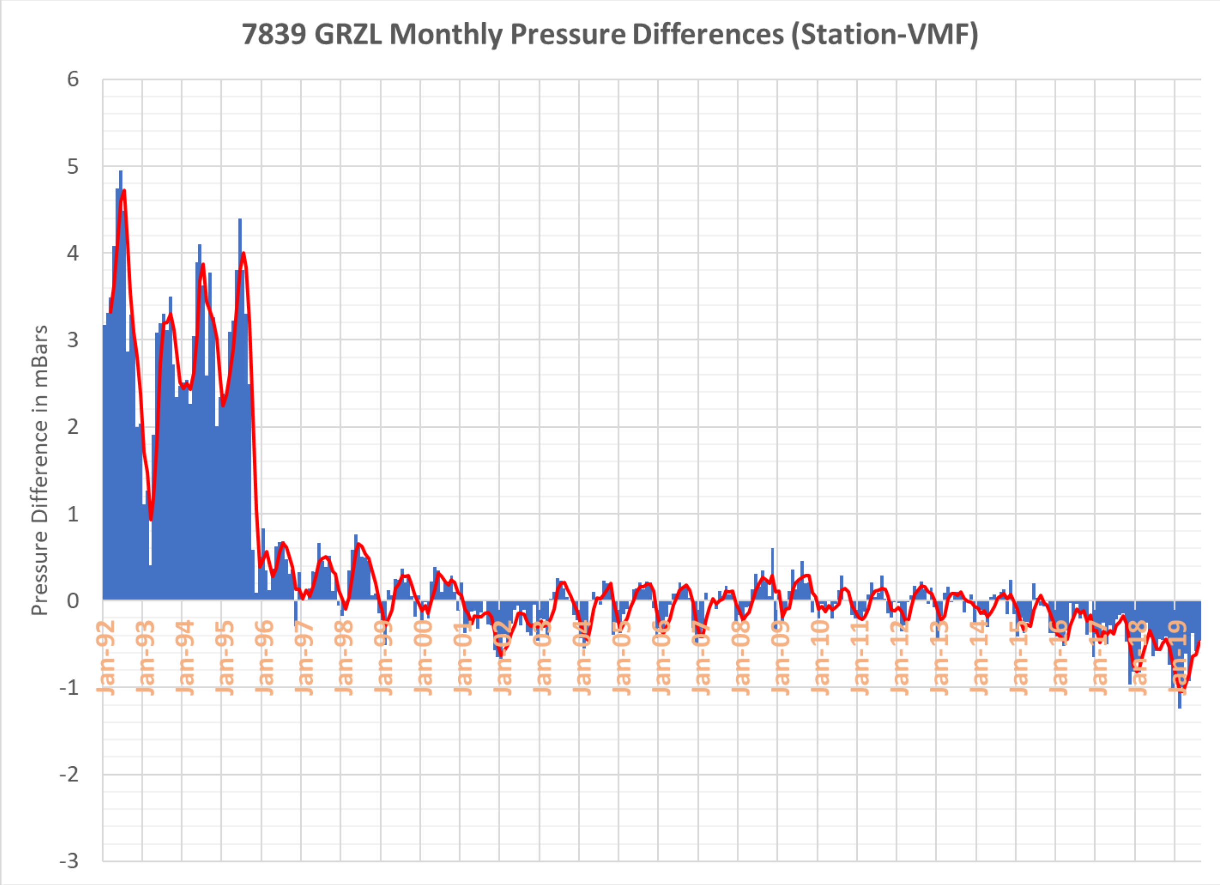
VMF System Characterization (EI versus OP)



- **There is a small minus 0.09 hPa drift in the VMF differences (EI-OP), for all sites, over the twelve years.**

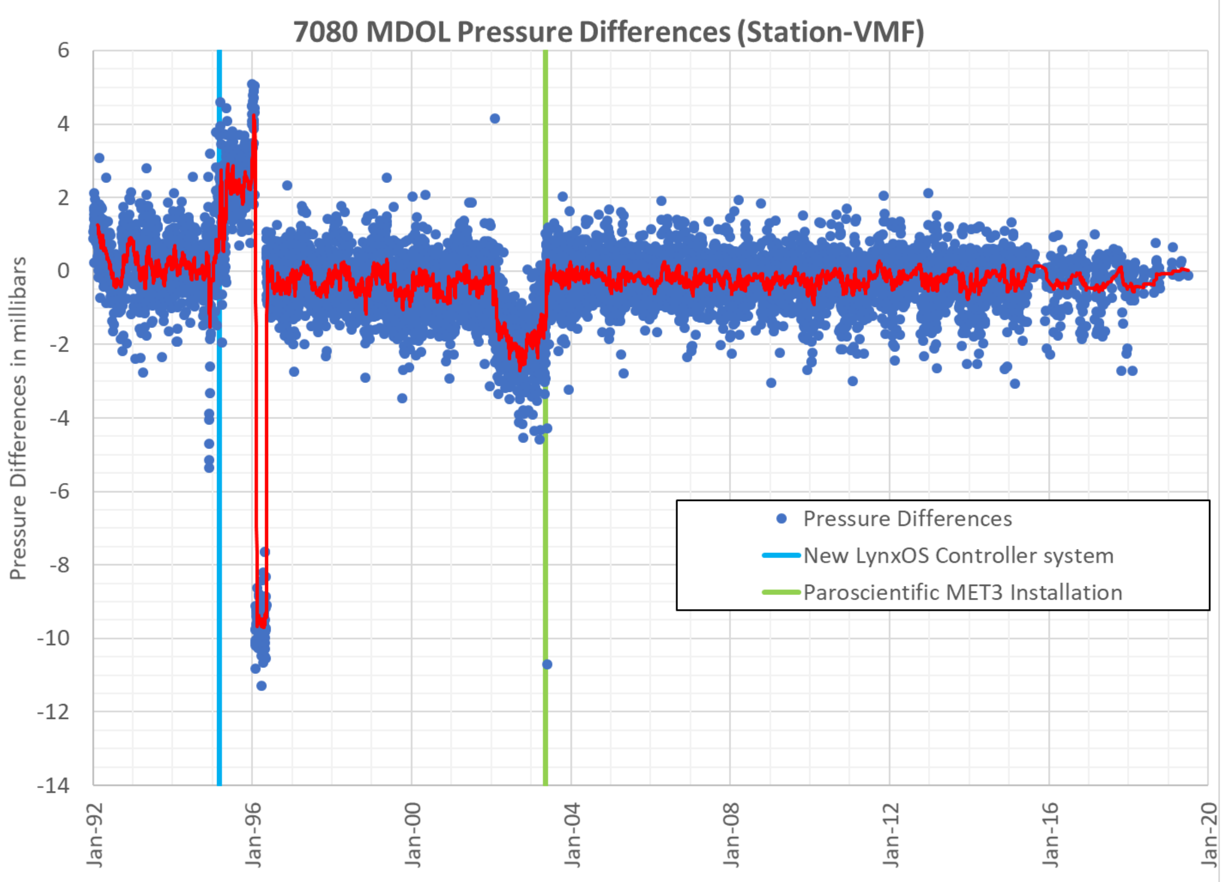
7839 GRZL Pressure Analysis

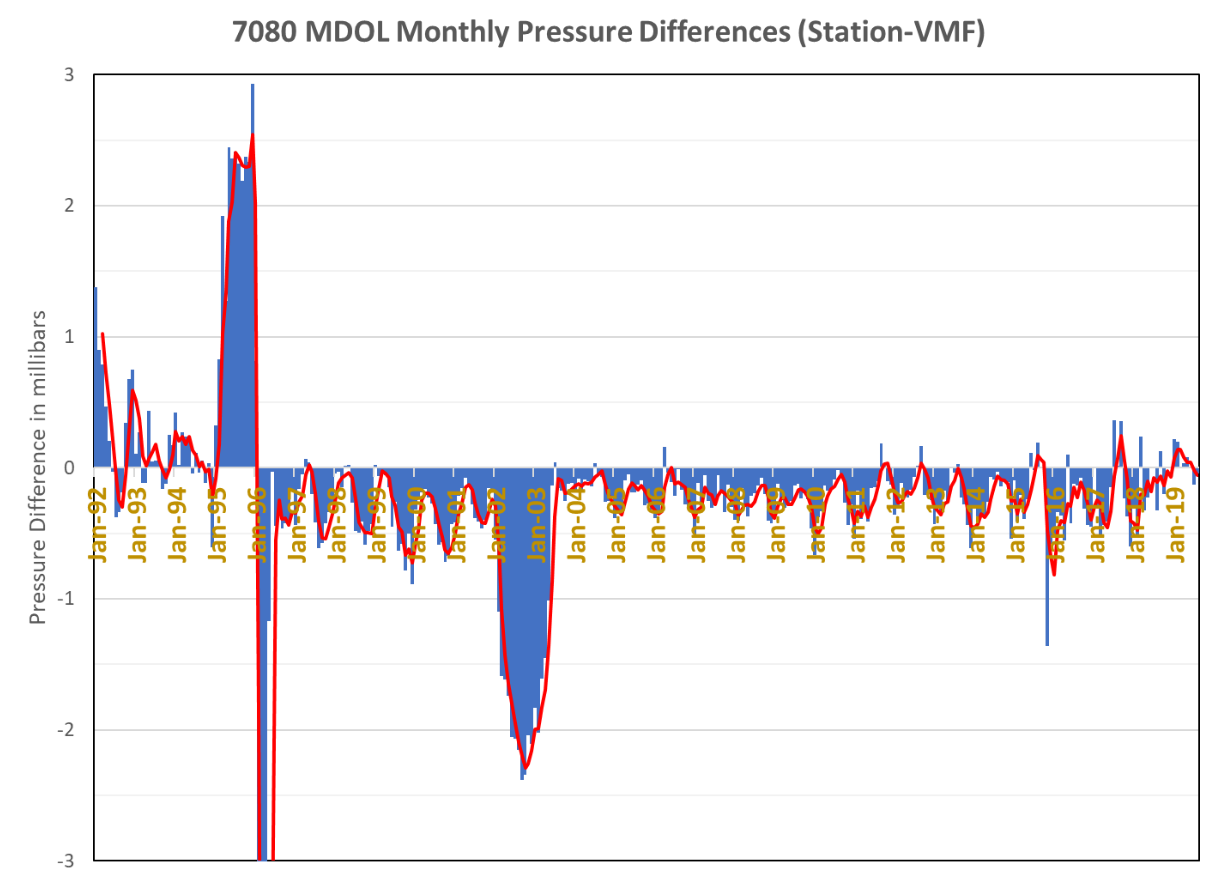




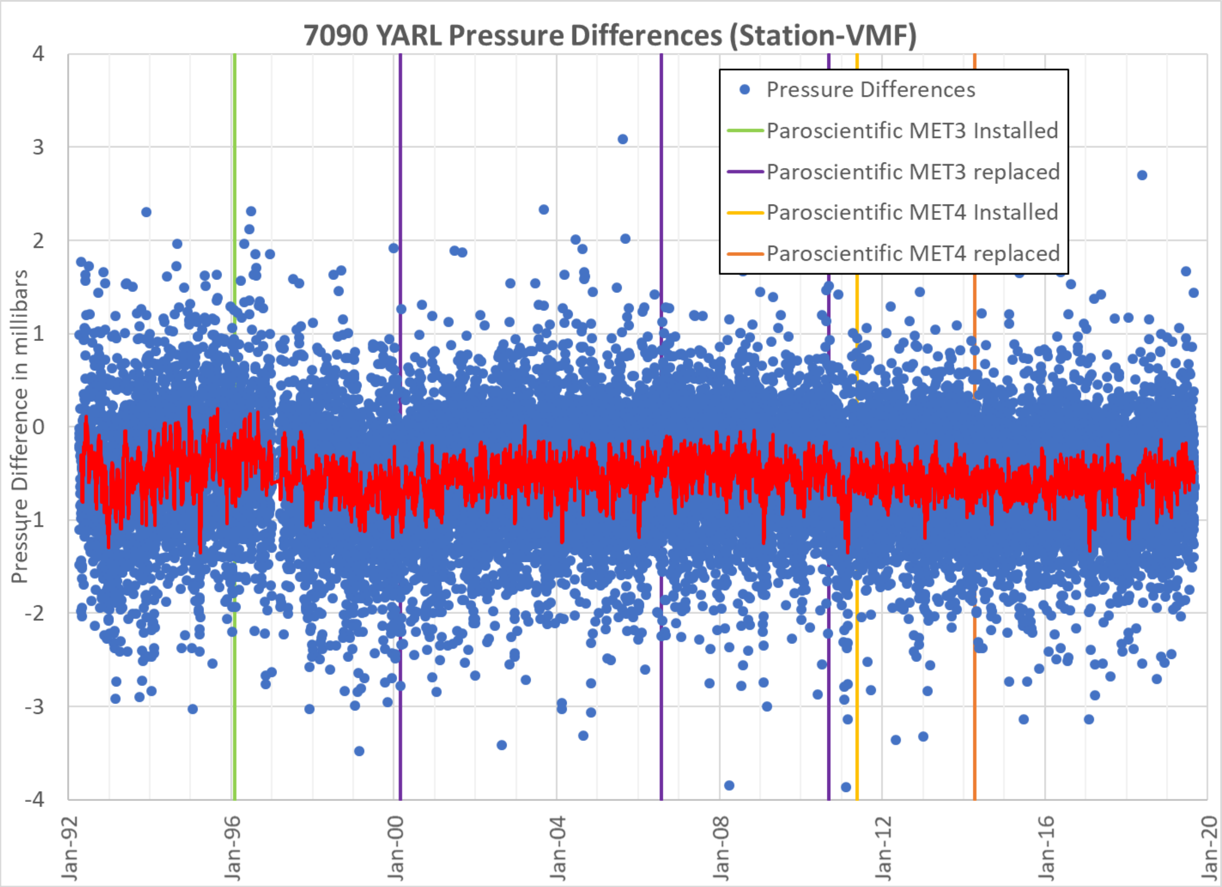
- ❑ Left & right charts are pressure differences (Station-VMF3oEI) aggregated every 6 hours and monthly; respectively.
- ❑ Red lines on the left & right chart are a 20-point running average and a 3-month running average; respectively.
- ❑ On the left chart, there is sudden discontinuity when the Paroscientific MET3 was installed on 22-Sep-1995.
- ❑ *Note: All Graz site pressures are from the original release of data (release 0).*

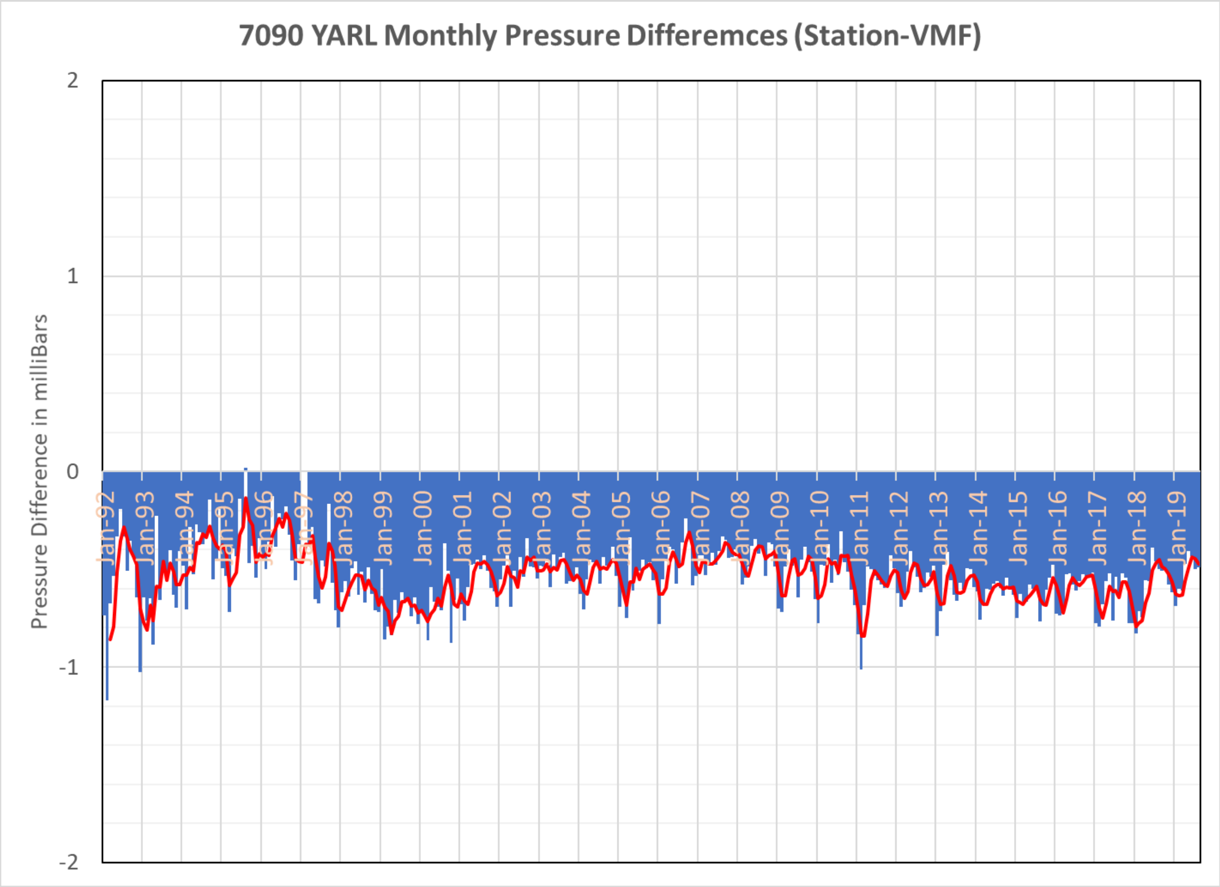
7080 MDOL Pressure Analysis





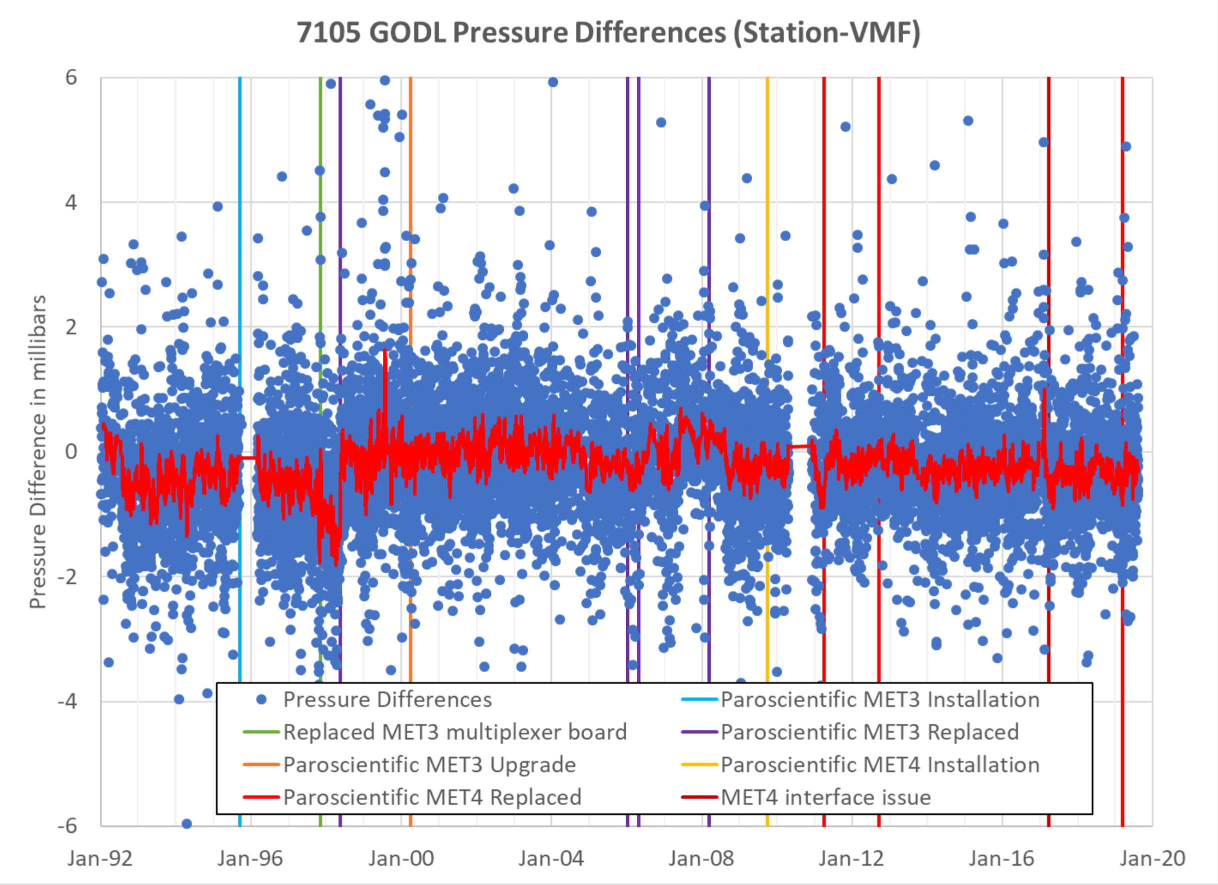
7090 YARL Pressure Analysis

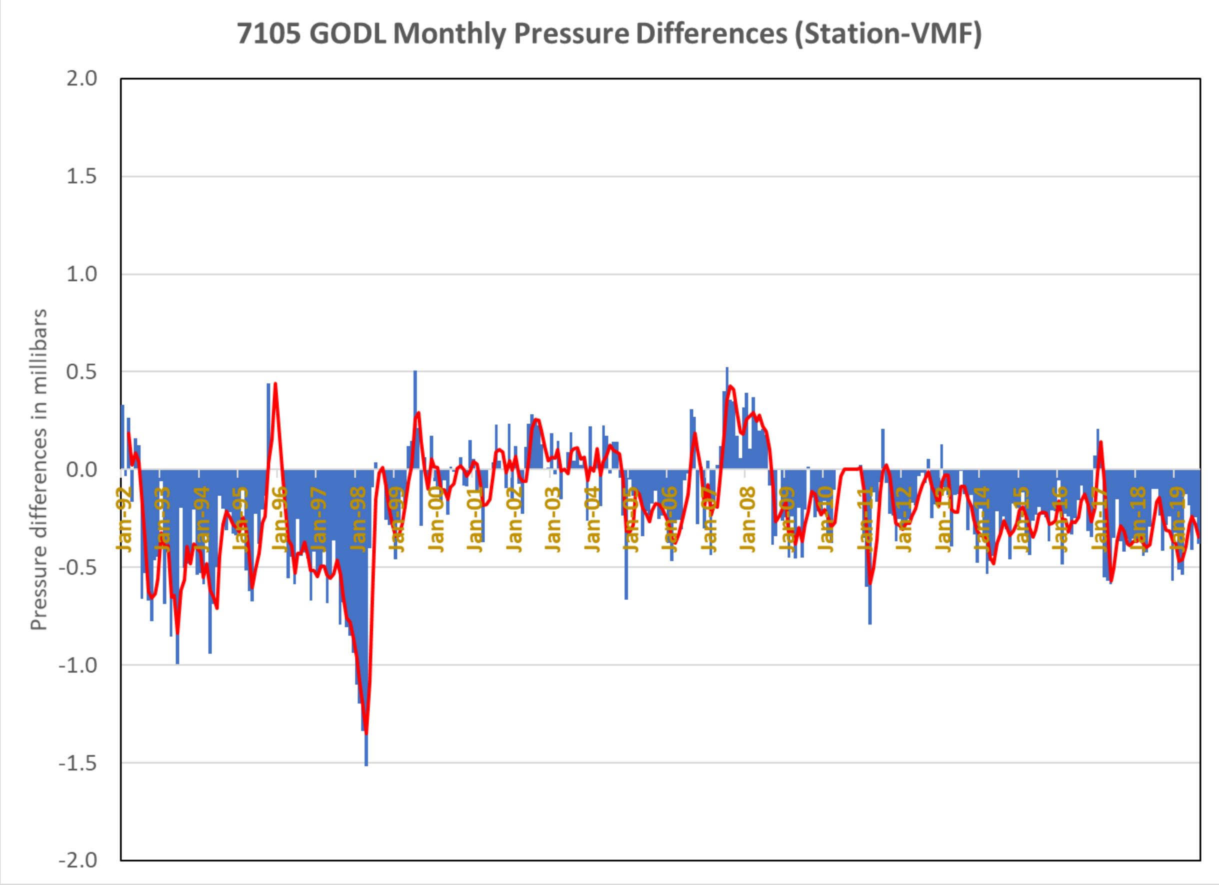




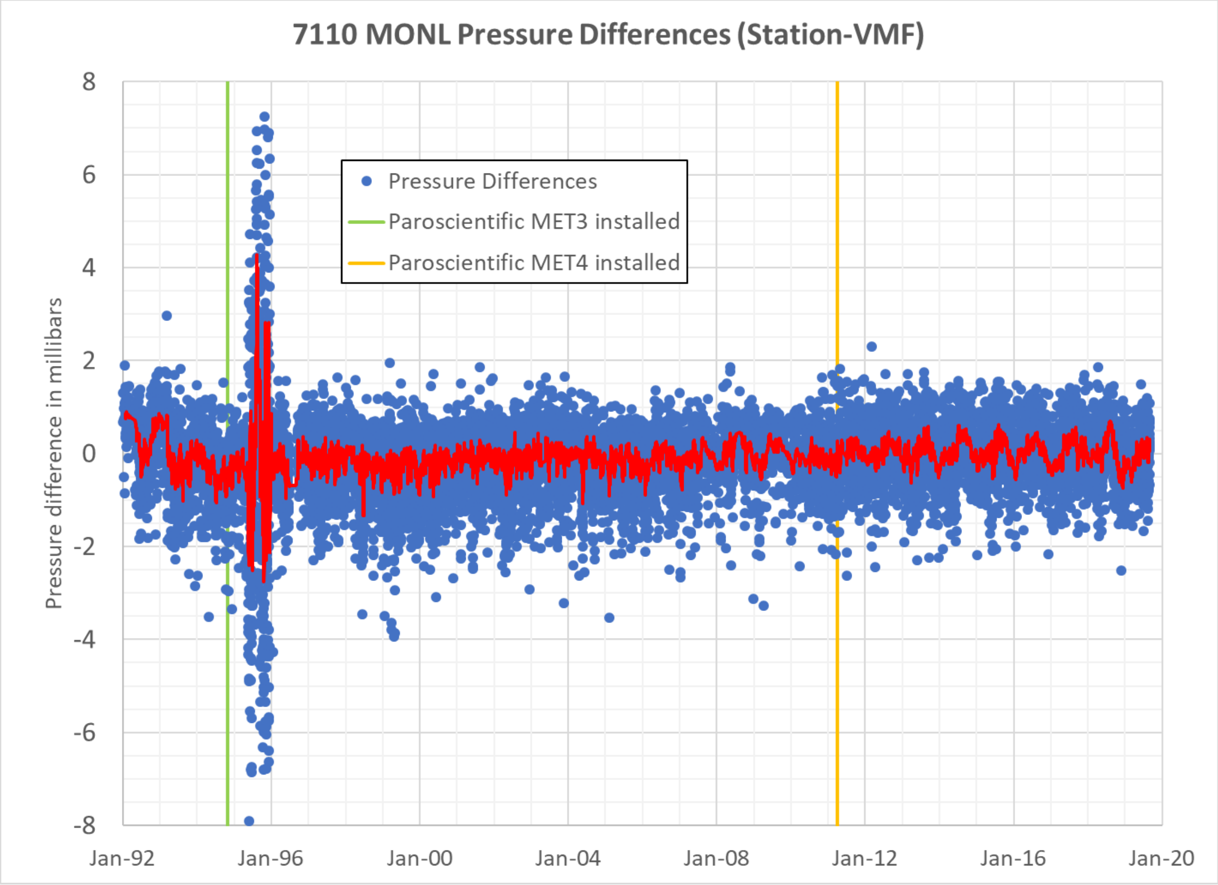
- ❑ There is -0.54 millibar offset between the Station and the VMF. Based on the left chart the 7090 meteorological sensors were calibrated/replaced every few years. This begs the question, which data is more accurate?

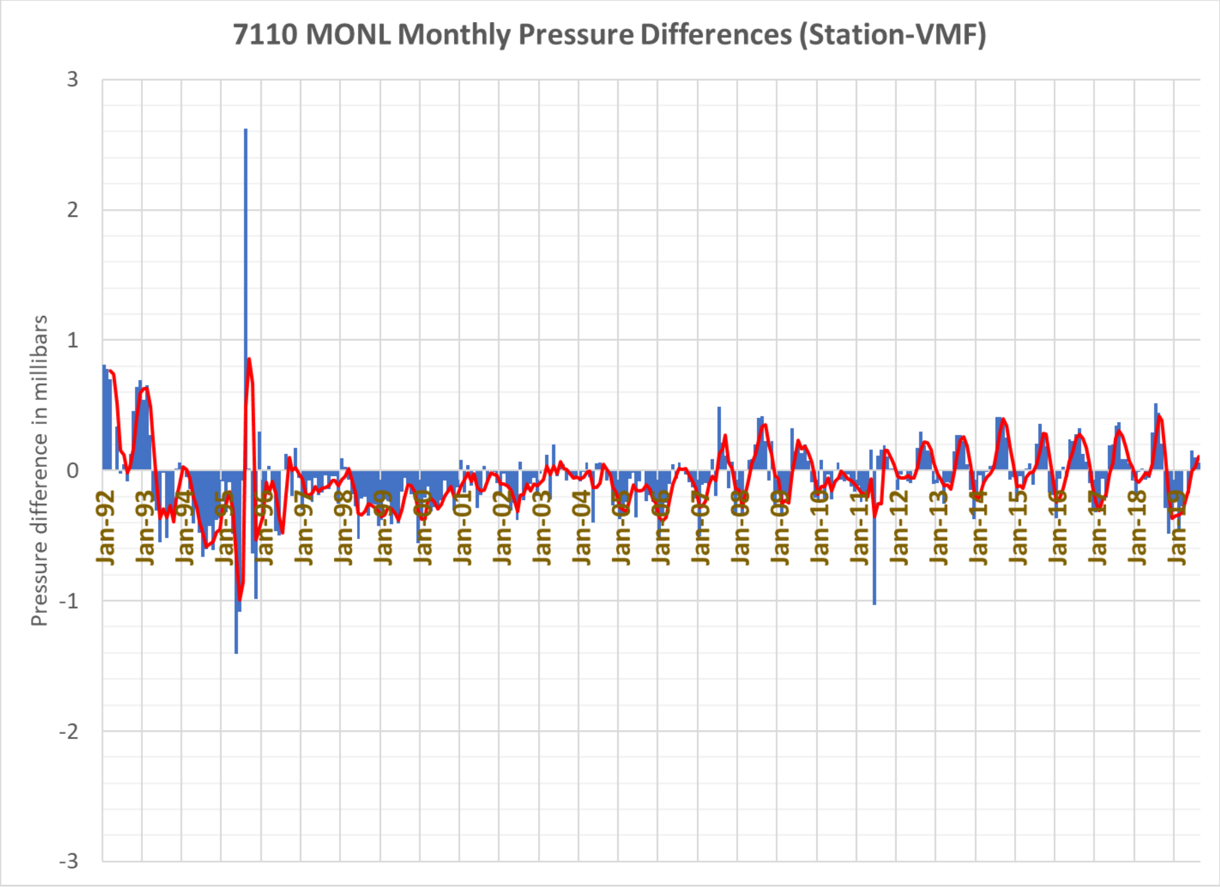
7105 GODL Pressure Analysis





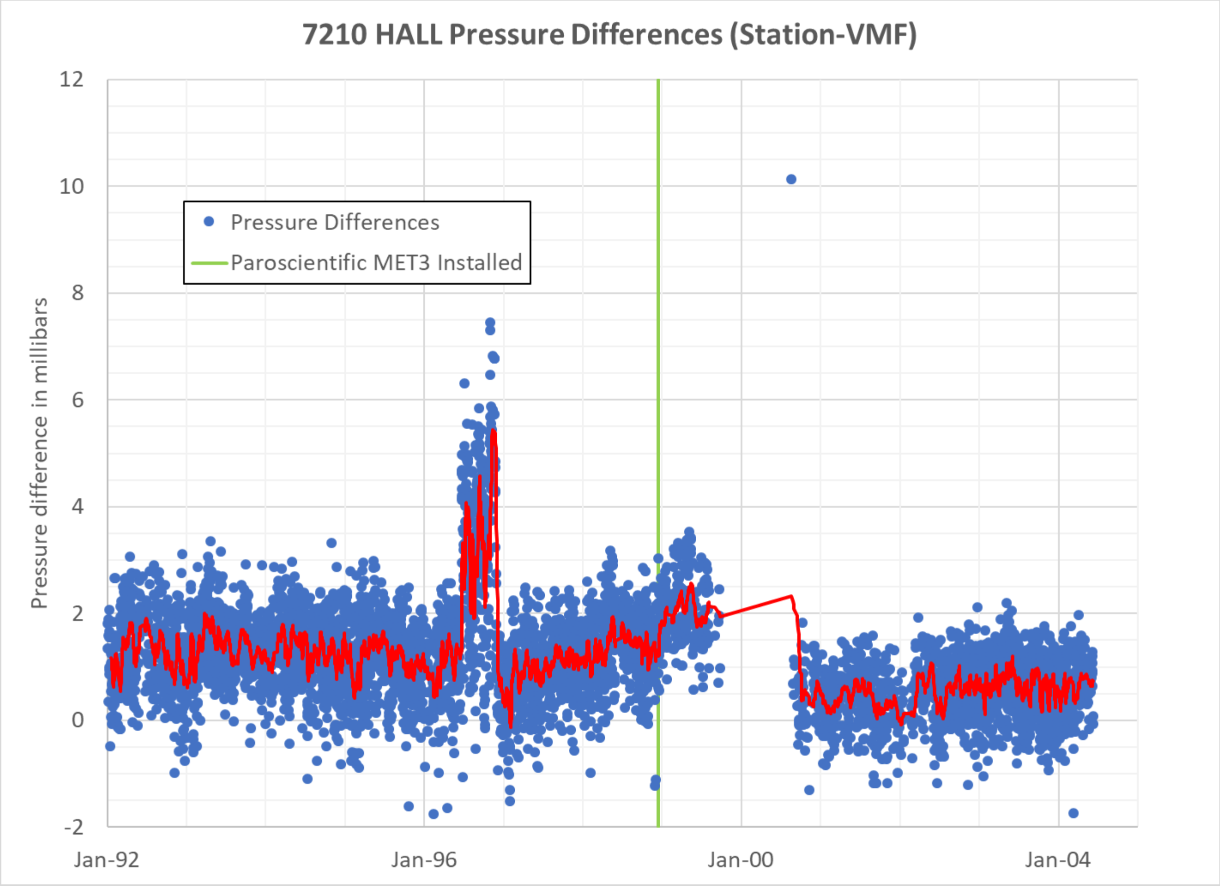
7110 MONL Pressure Analysis

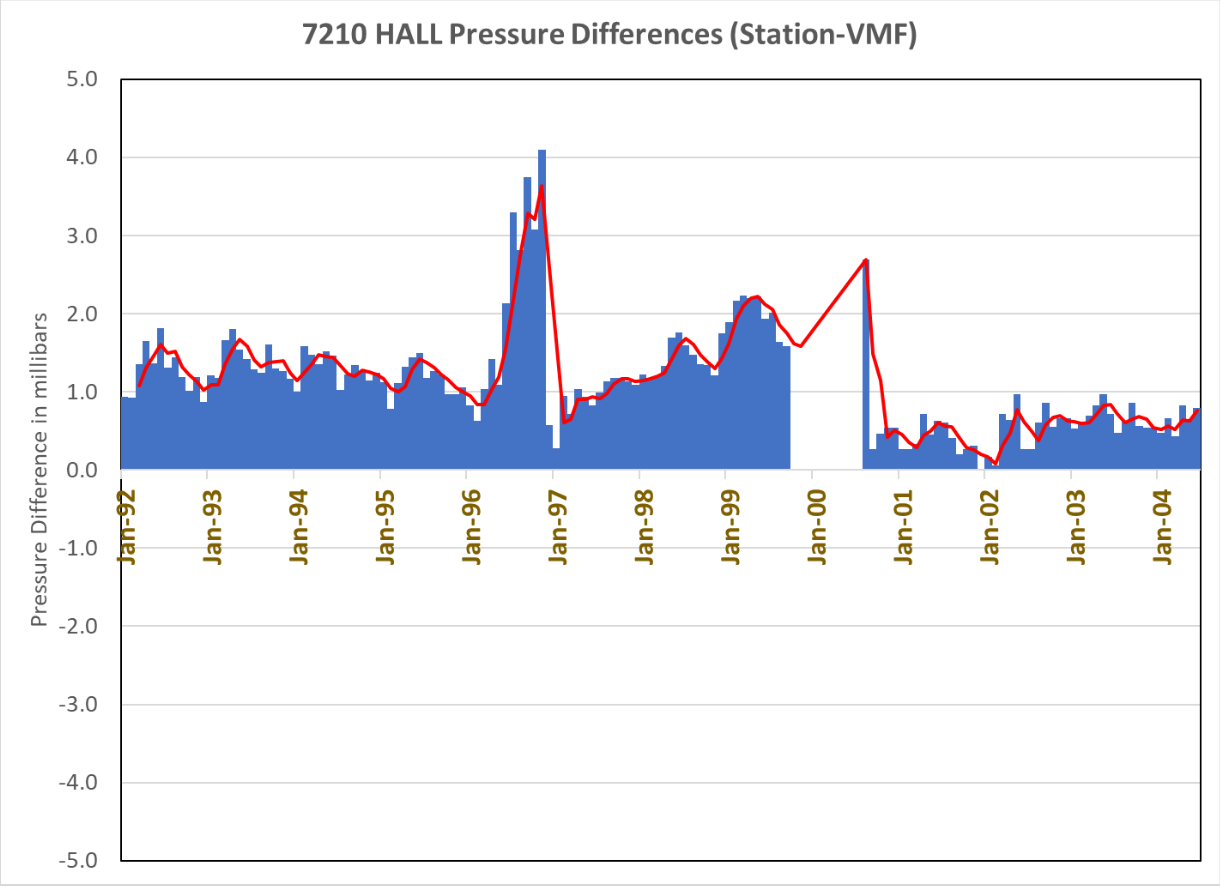




- ❑ **There was an issue with the 7110 barometer in 1995 causing an increase in the scatter and a possible bias.**

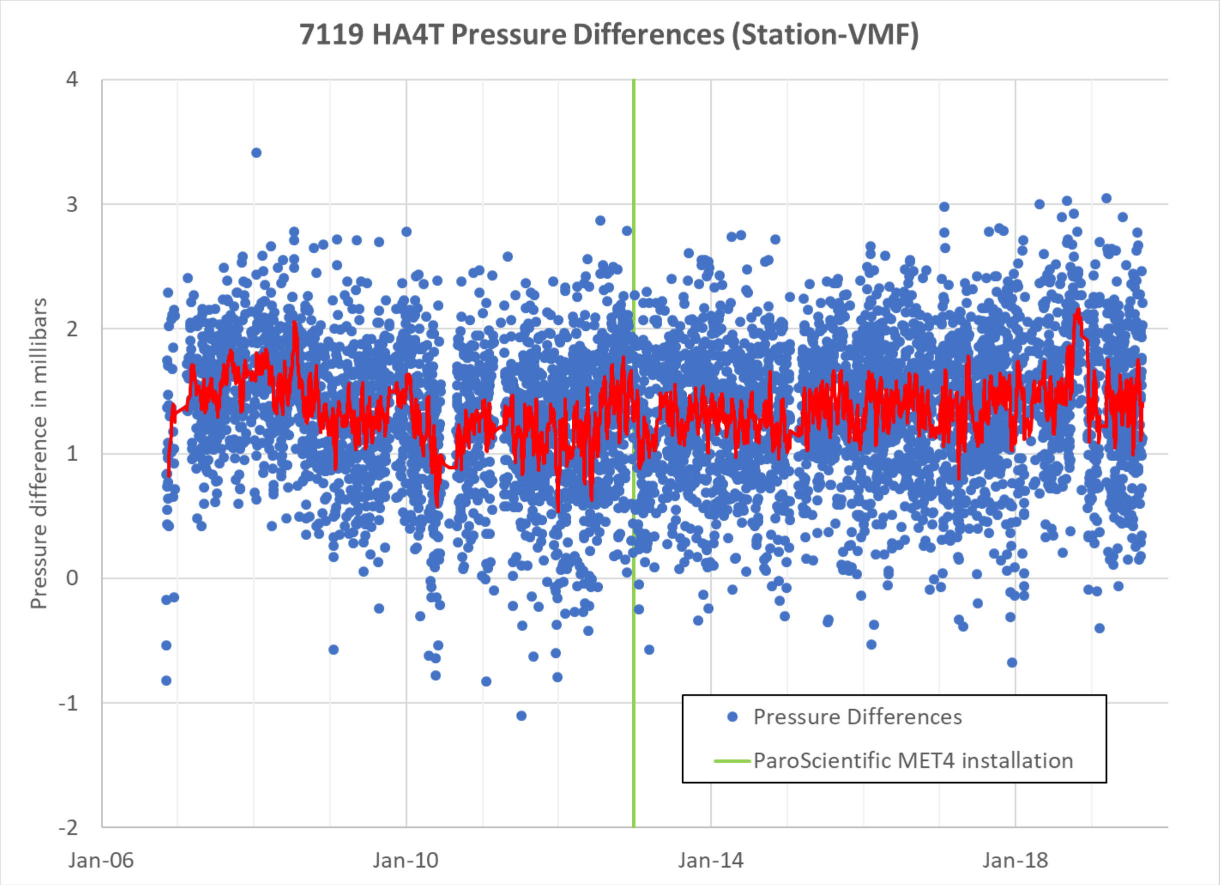
7210 HALL Pressure Analysis

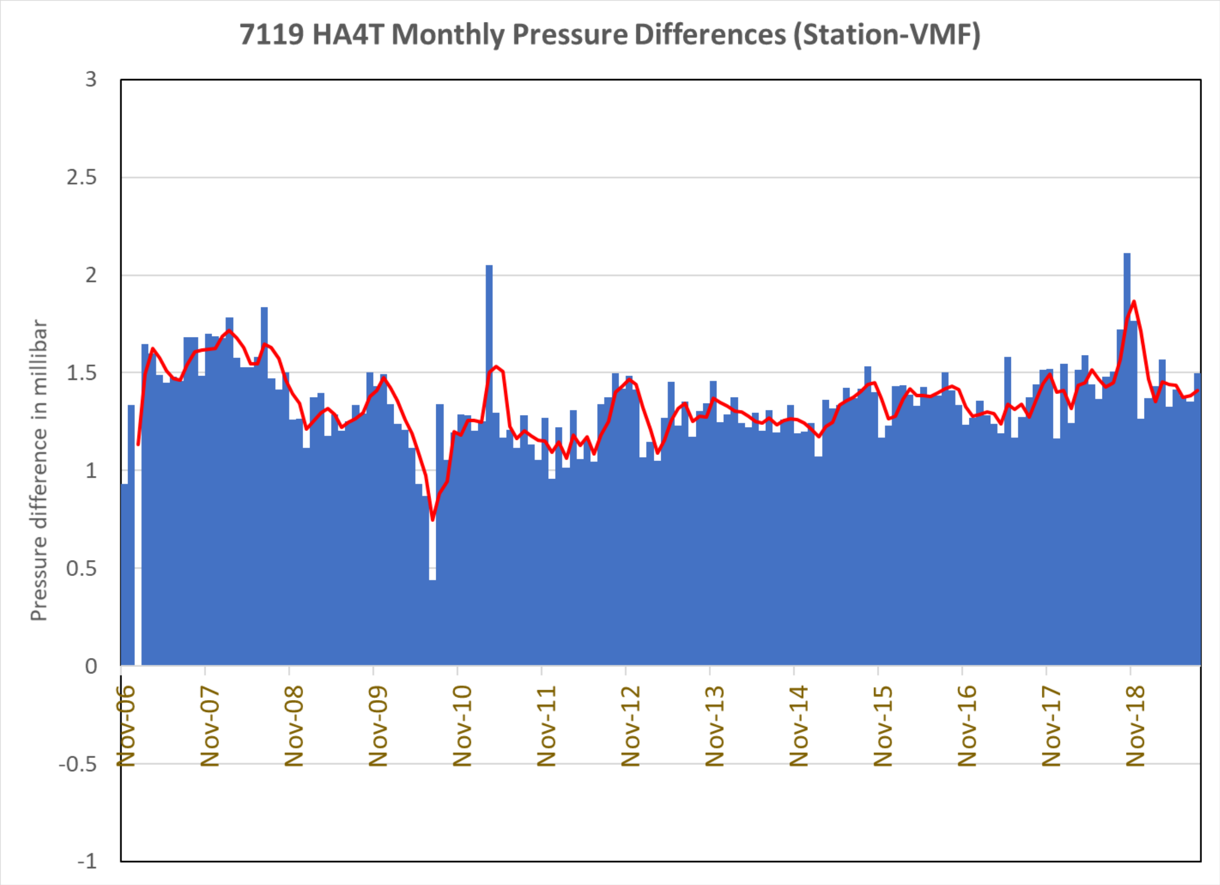




- ❑ The 7210 site log mentions there is ~2-meter height difference between the sensor and the system reference point. A 2-meter height difference equates to a 0.2 millibar pressure difference which was not modelled in the data processing.
- ❑ There is a difference in pressure before and after the data gap.

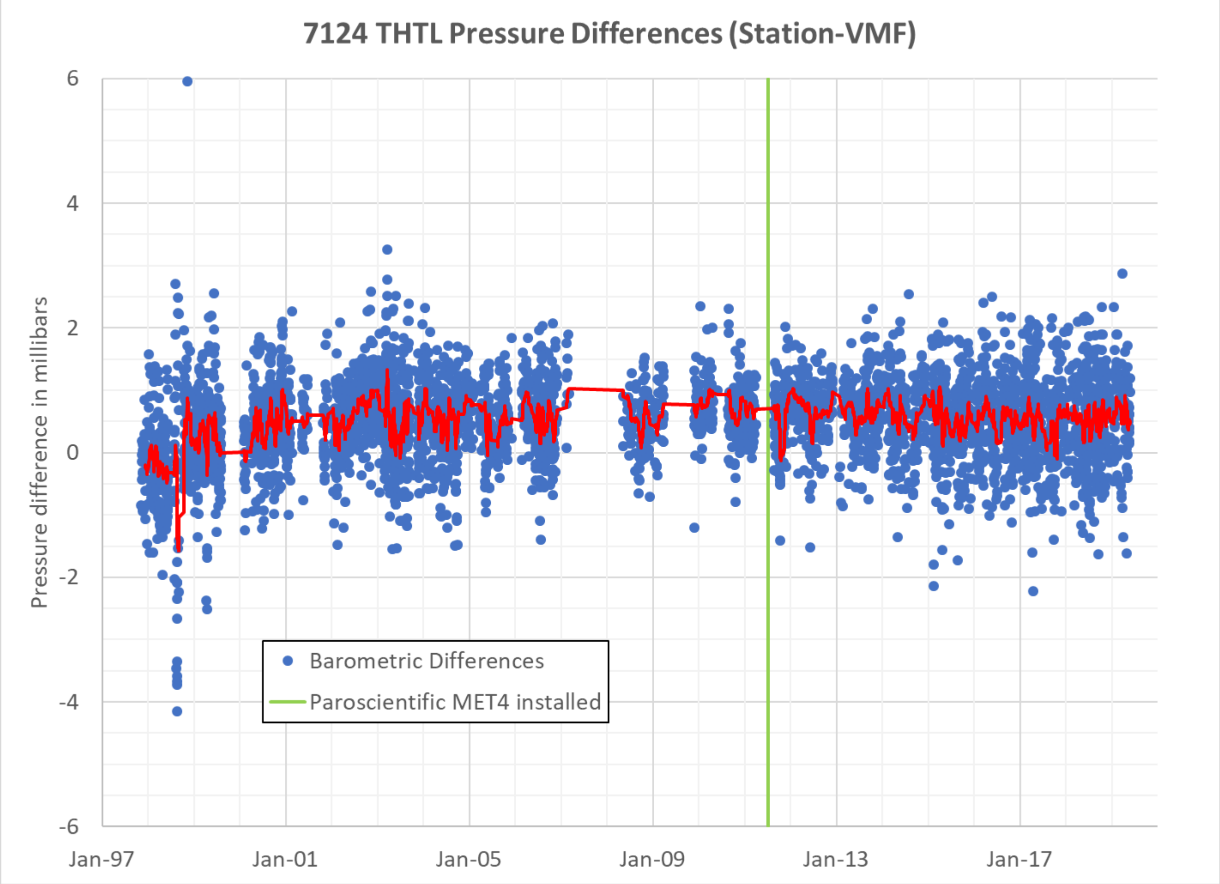
7119 HA4T Pressure Analysis

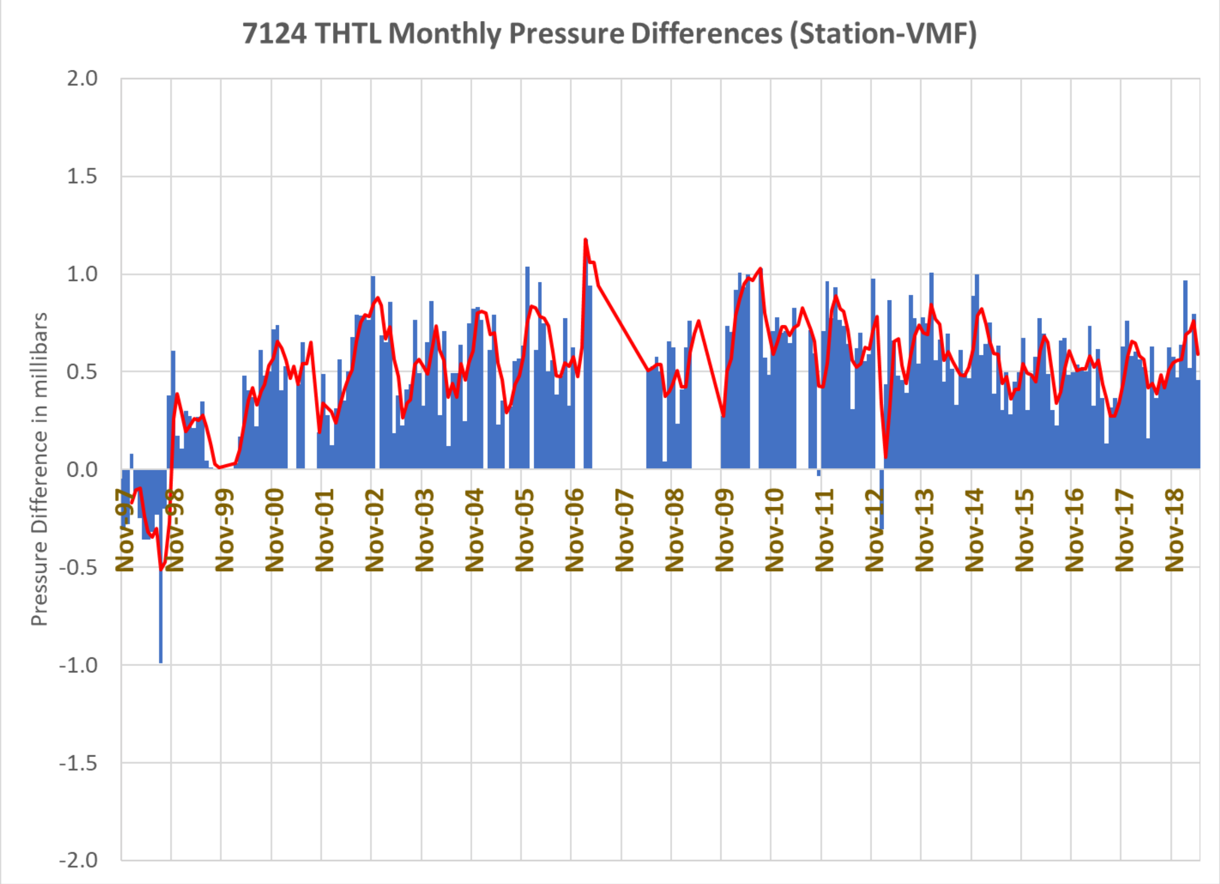




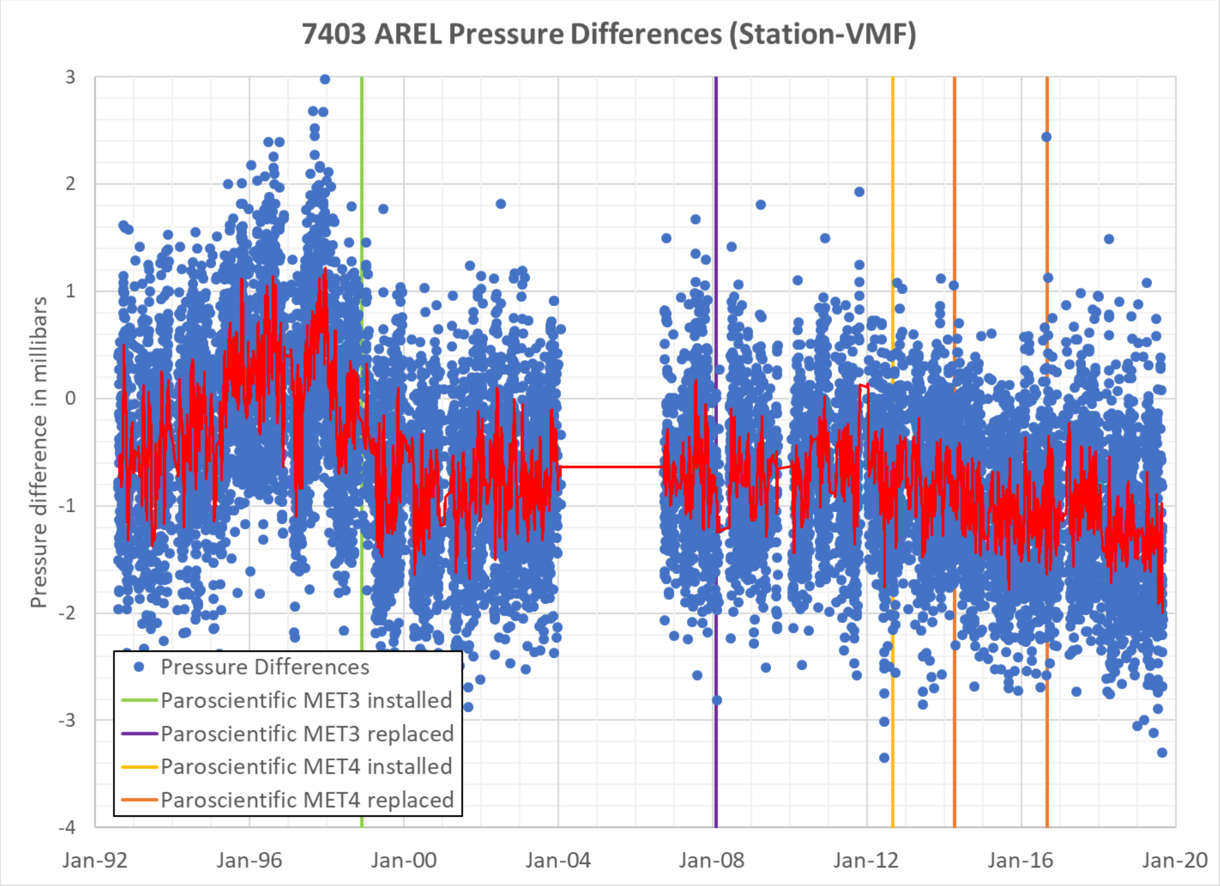
- **7210 HALL was closed in 2004 (see 7210 results on previous slide) and was replaced in 2006 with station 7119 HA4T (TLRS-4). Both stations have a positive barometric bias relative to VMF, but the apparent 7119 pressure bias is much larger. WHY?**

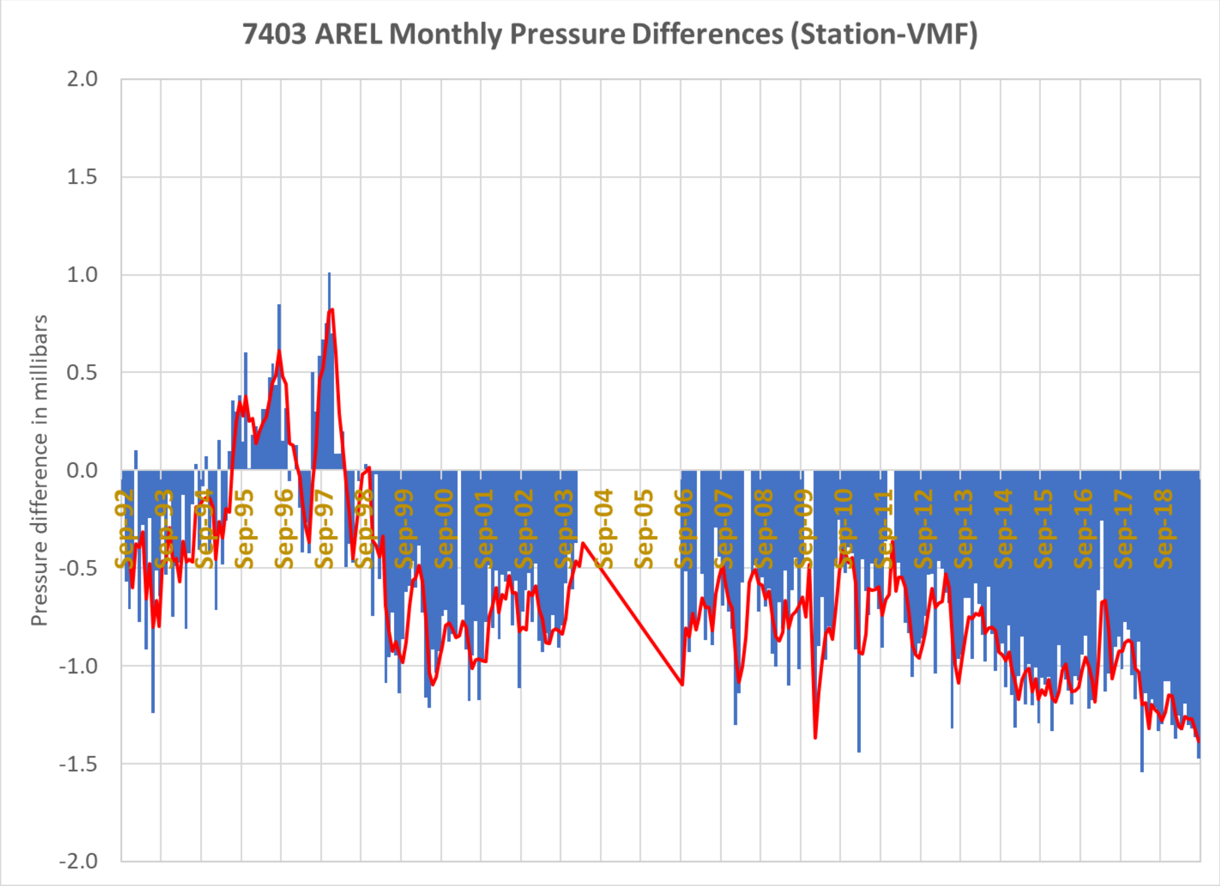
7124 THTL Pressure Analysis





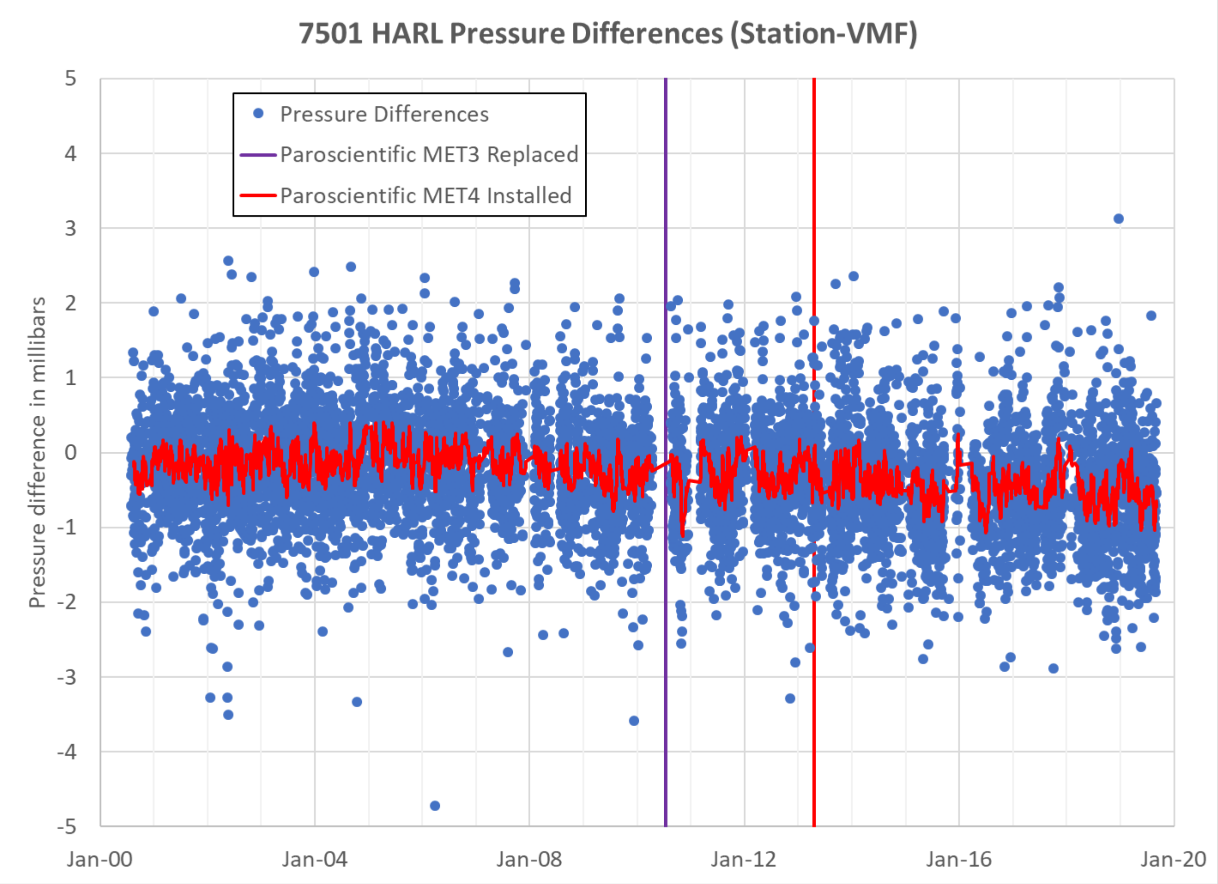
7403 AREL Pressure Analysis

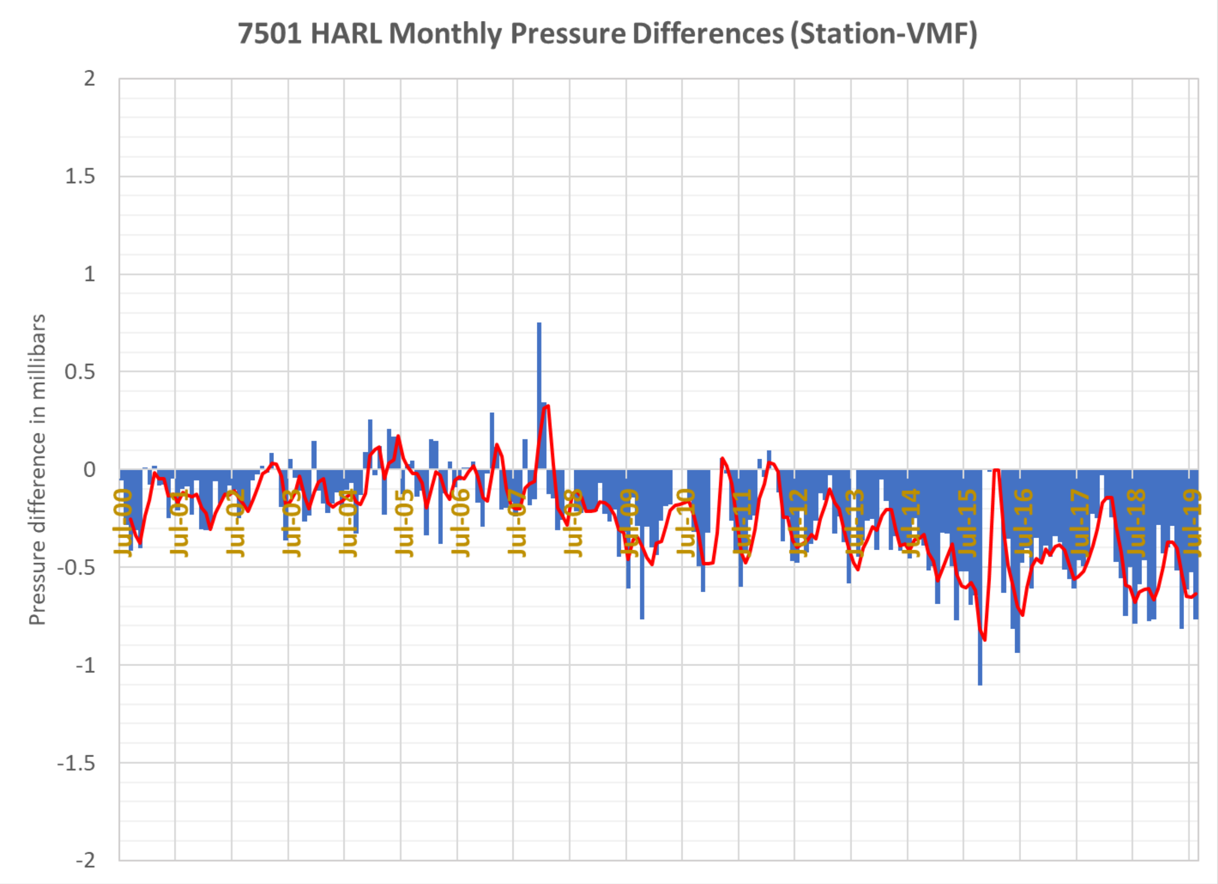




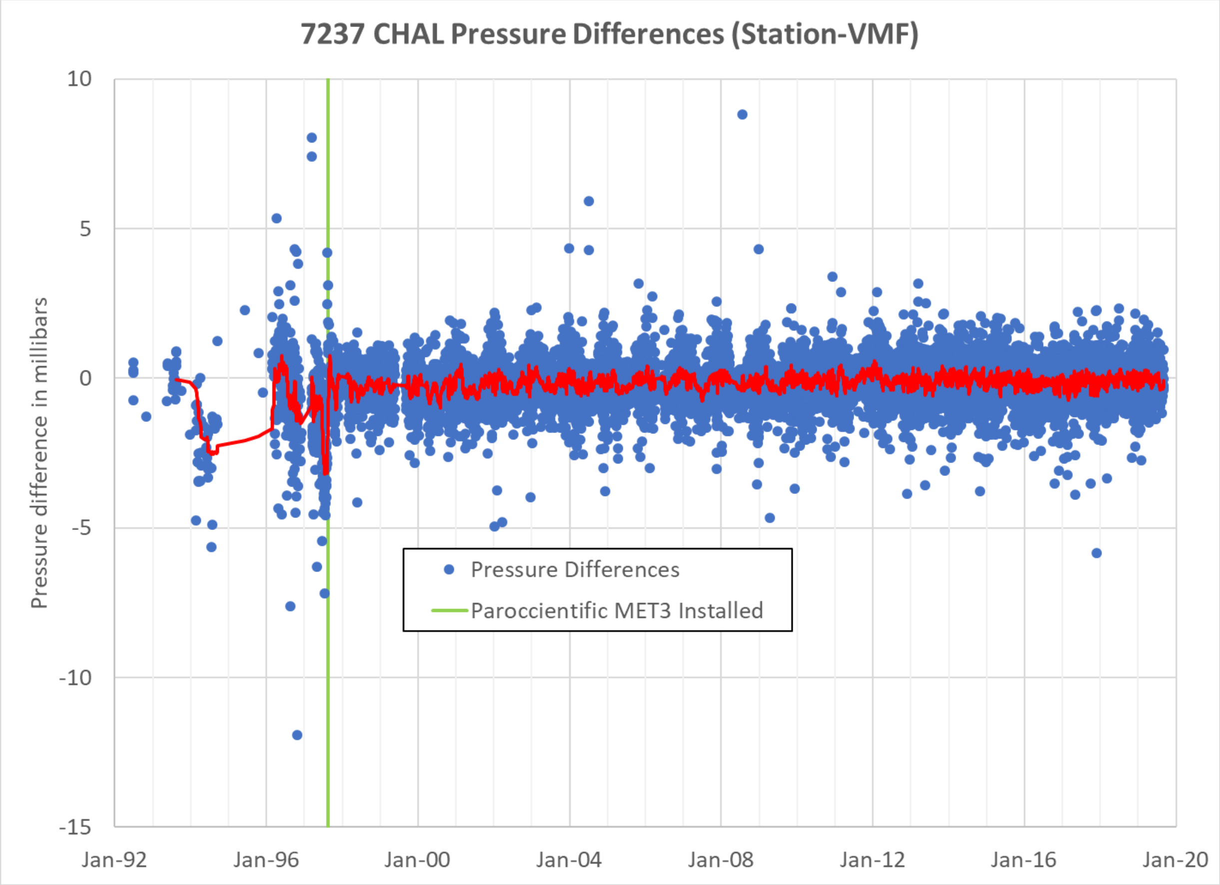
- **7403 Paroscientific MET sensors have been calibrated/replaced a few times, but there are large offsets vs VMF.**

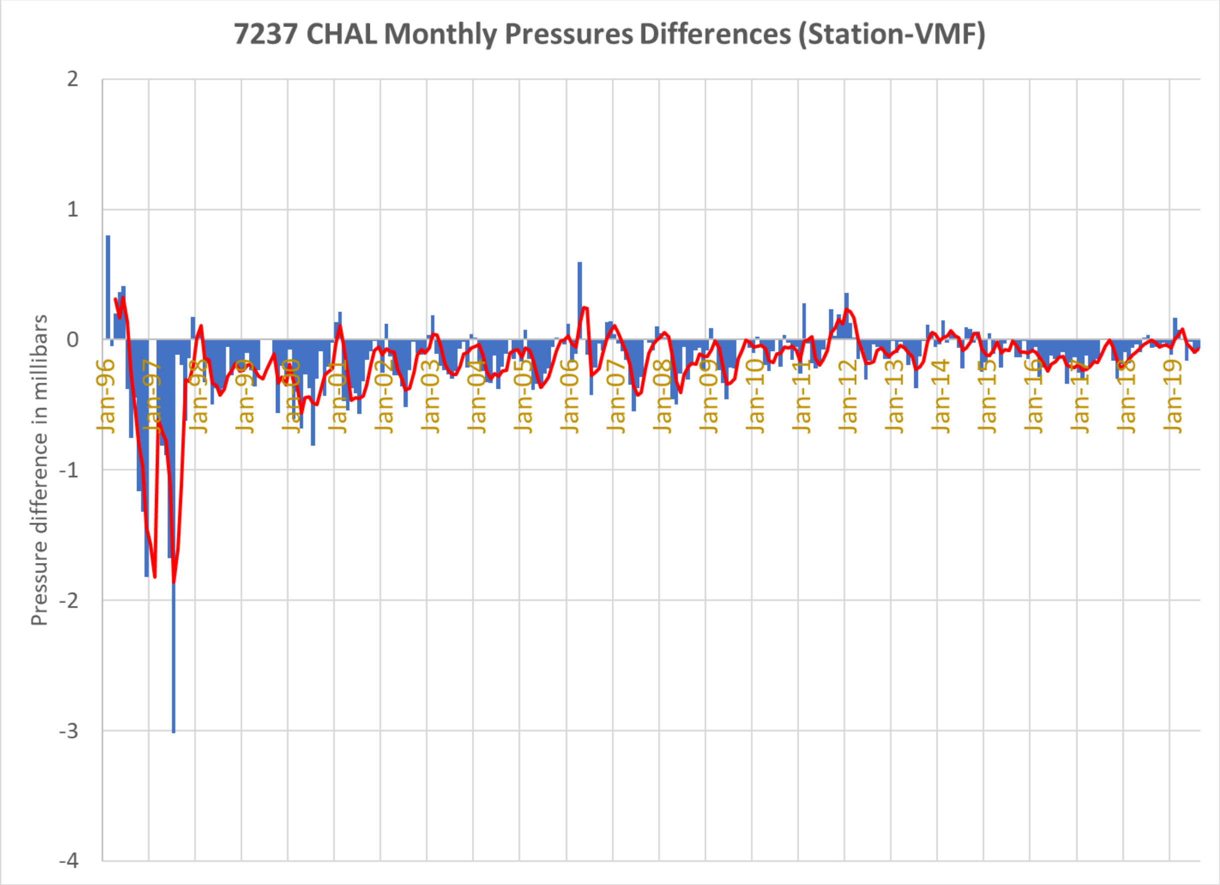
7501 HARL Pressure Differences



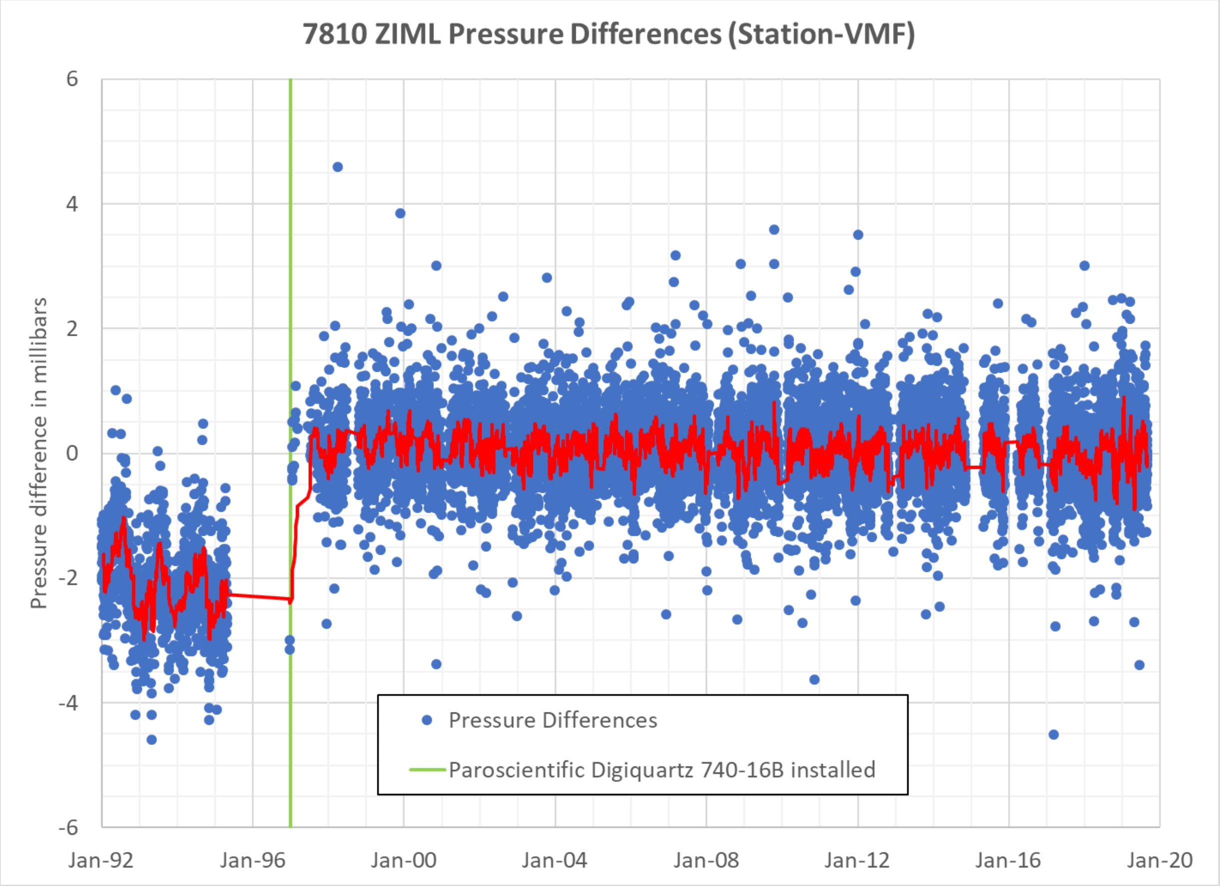


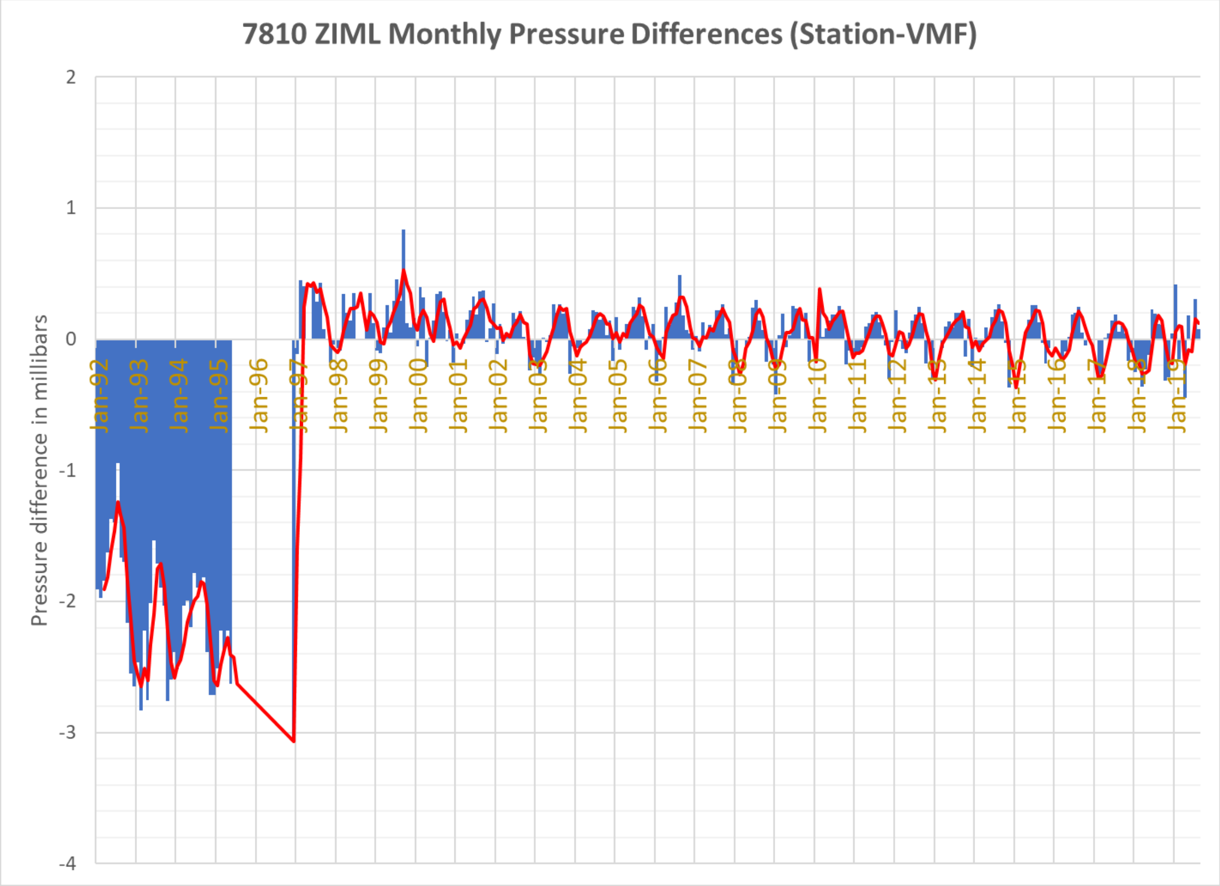
7237 CHAL Pressure Analysis



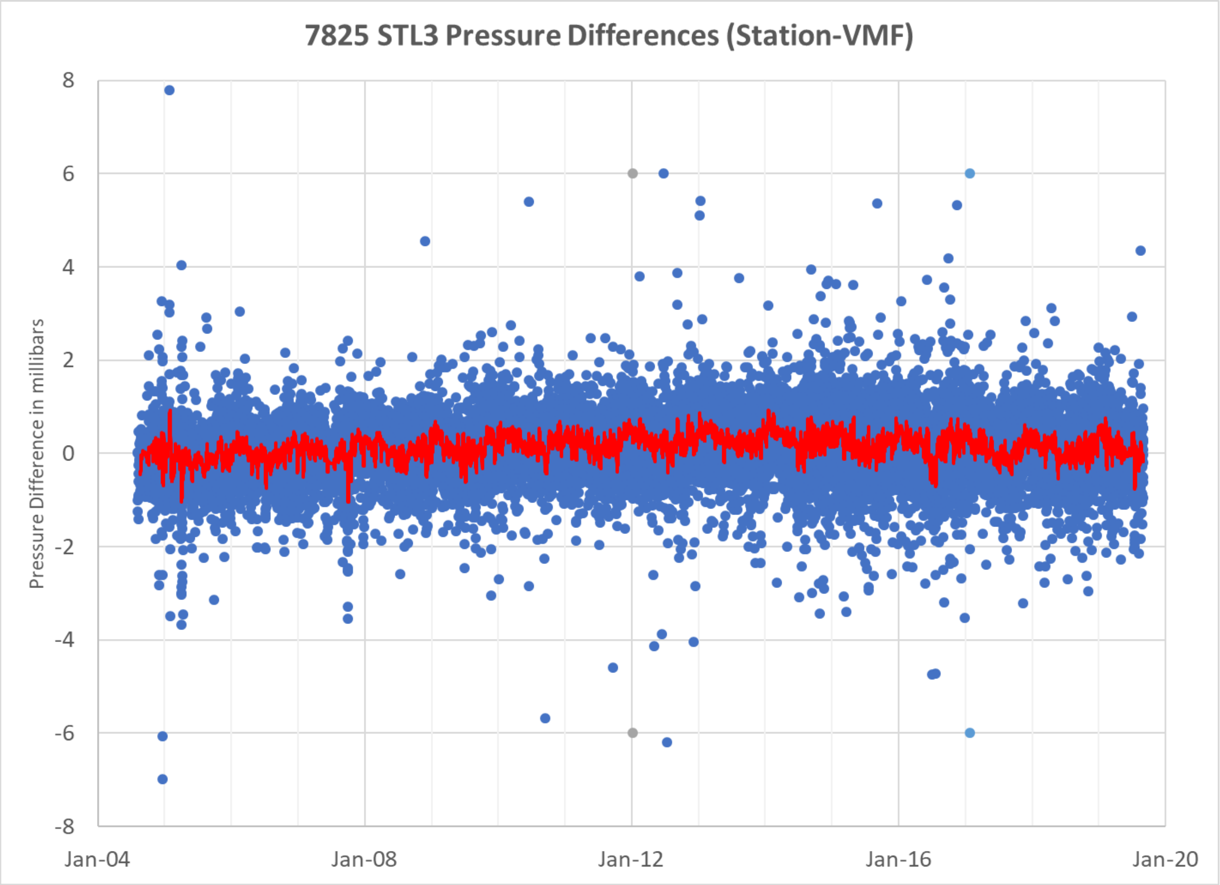


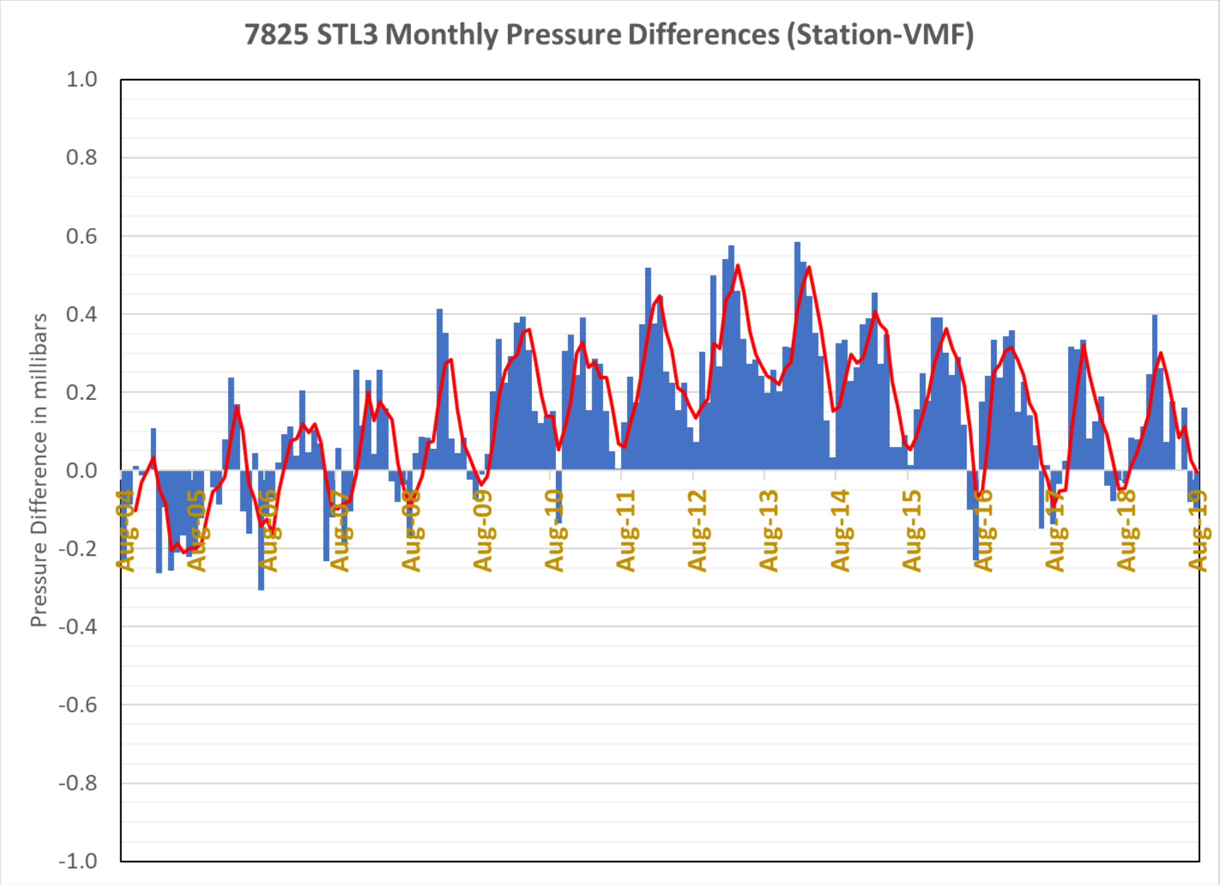
7810 ZIML Pressure Analysis



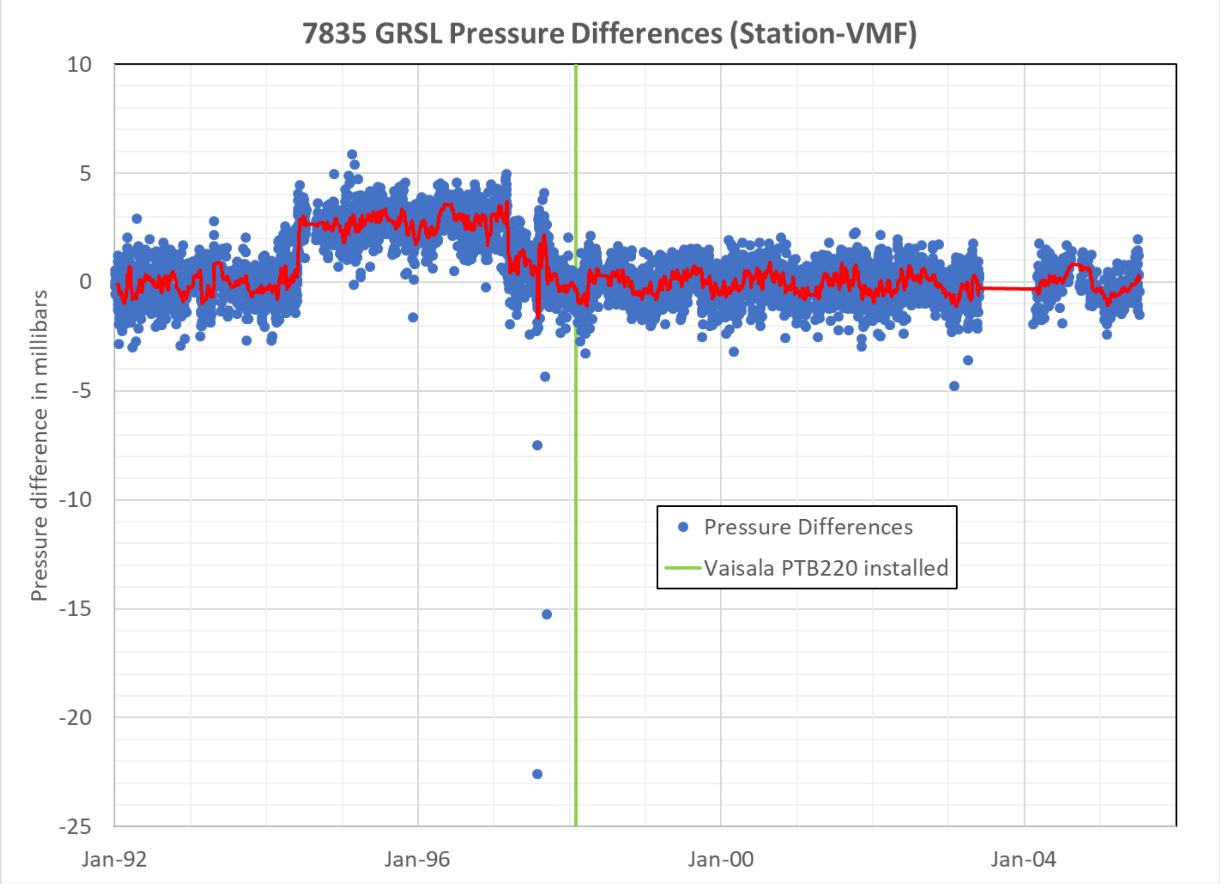


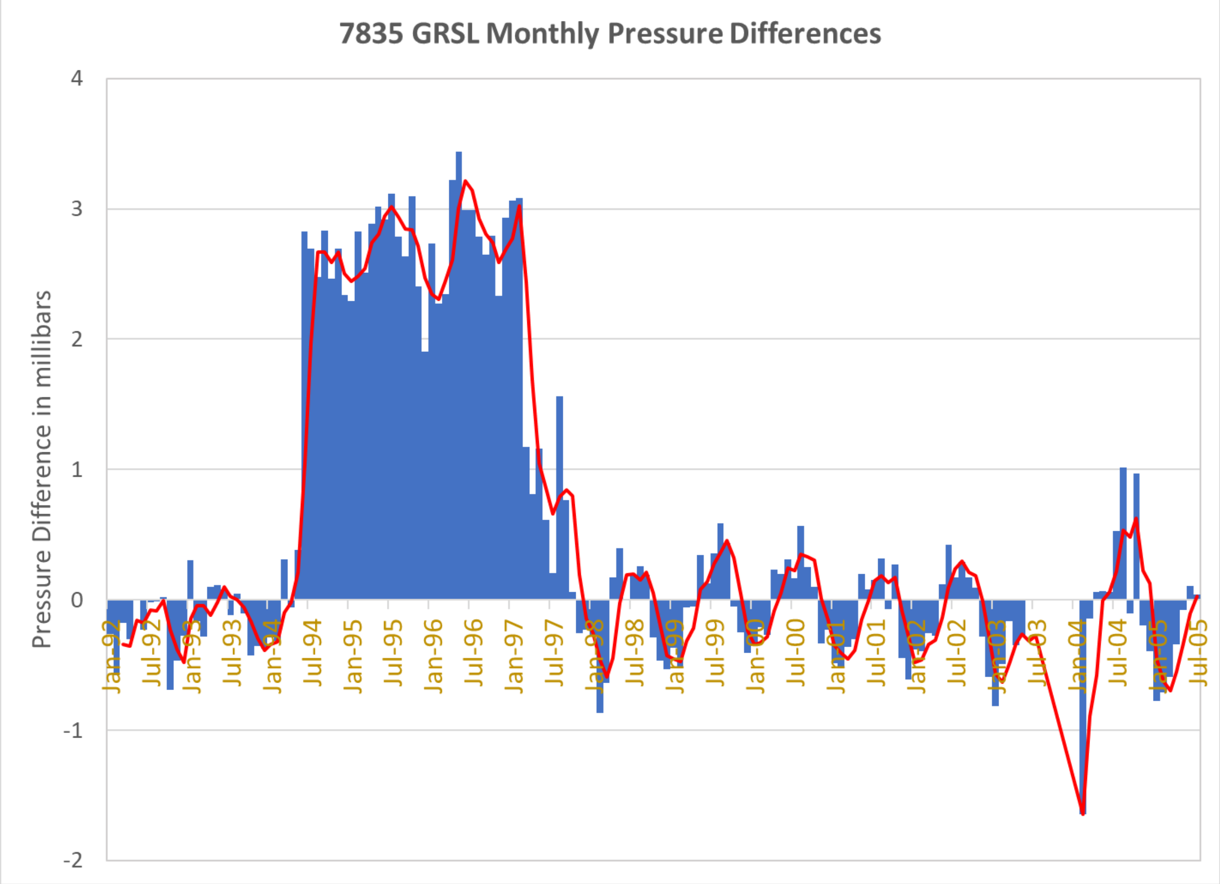
7825 STL3 Pressure Analysis





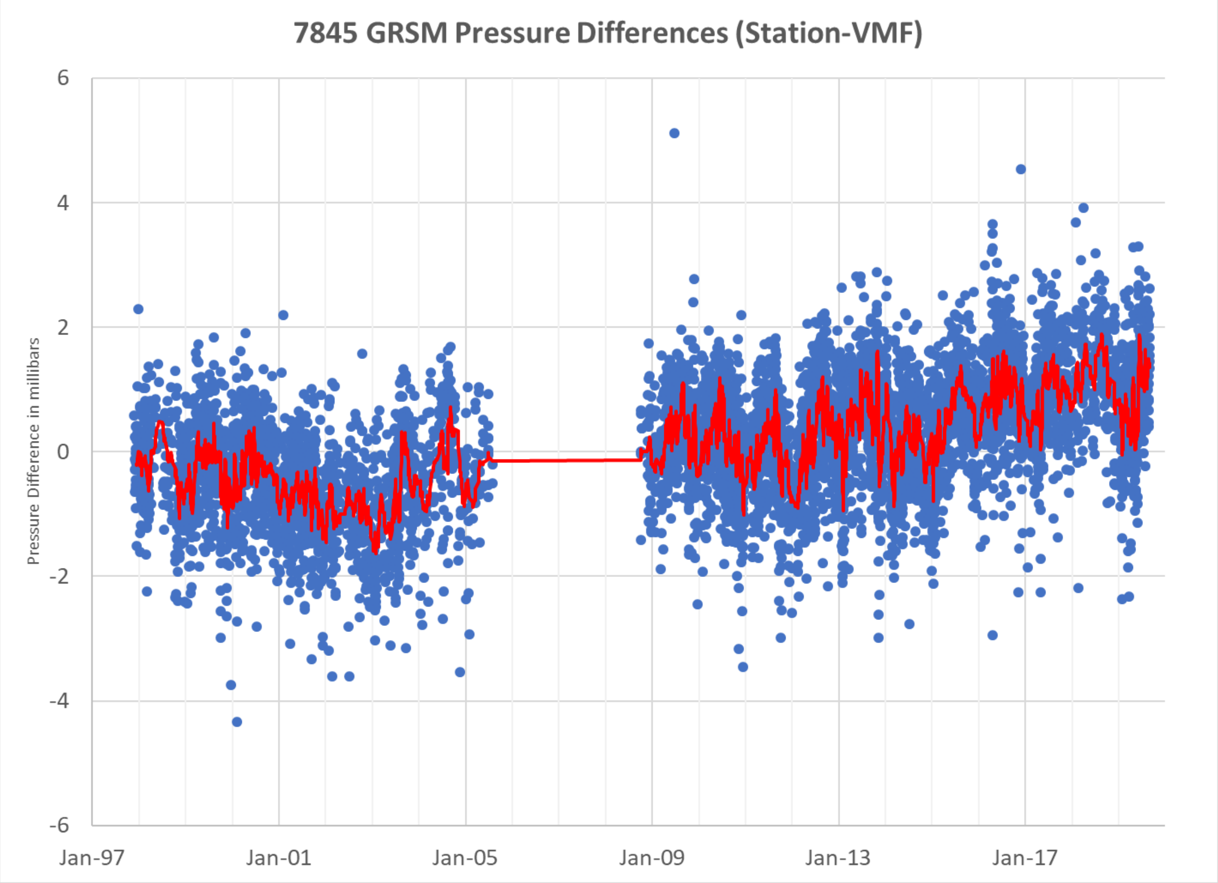
7835 GRSL Pressure Analysis

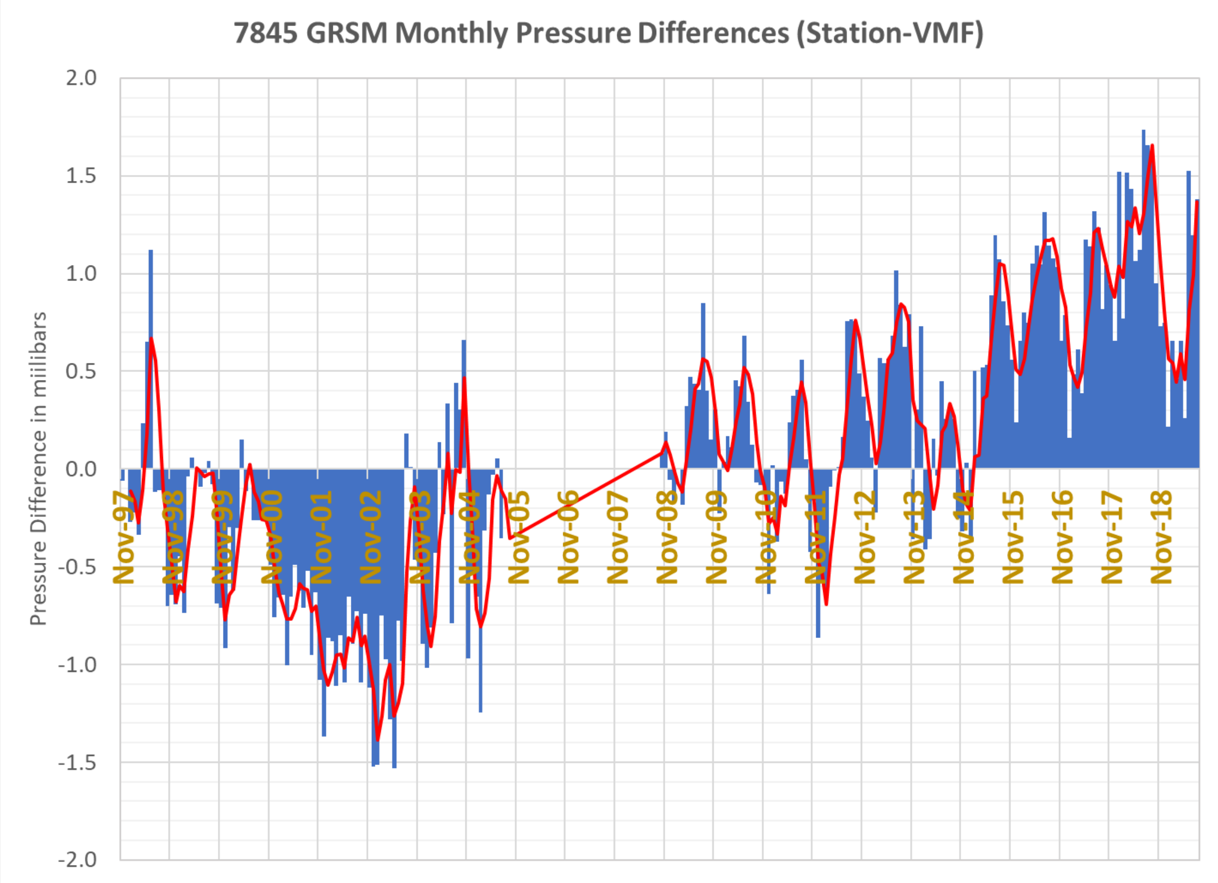




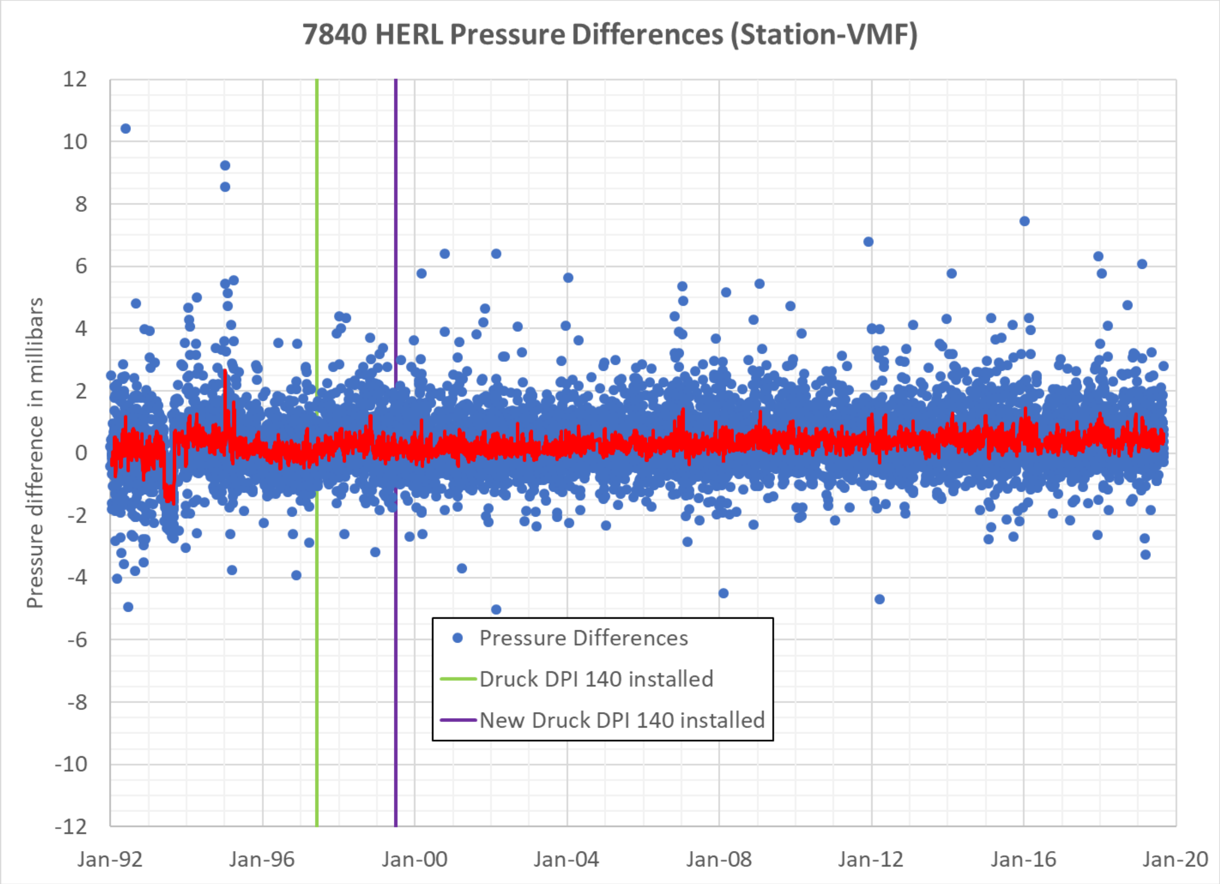
- Notice the seasonal oscillations in the differences after the Vaisala PTRB220 was installed.
- Based on the 7835 site log, there is 2.5 meter difference in height between the sensor and the system reference point. Was this height difference modelled in the data processing?

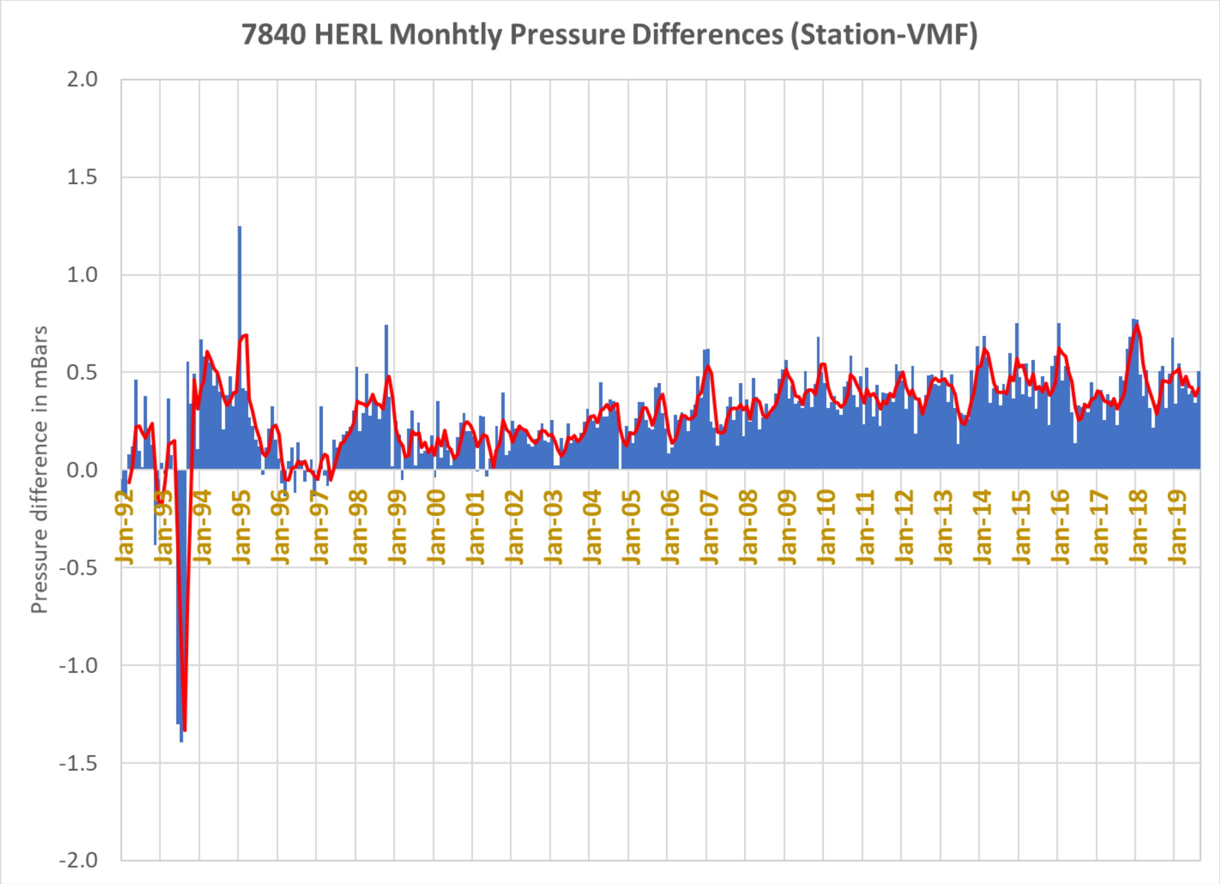
7845 GRSM Pressure Analysis



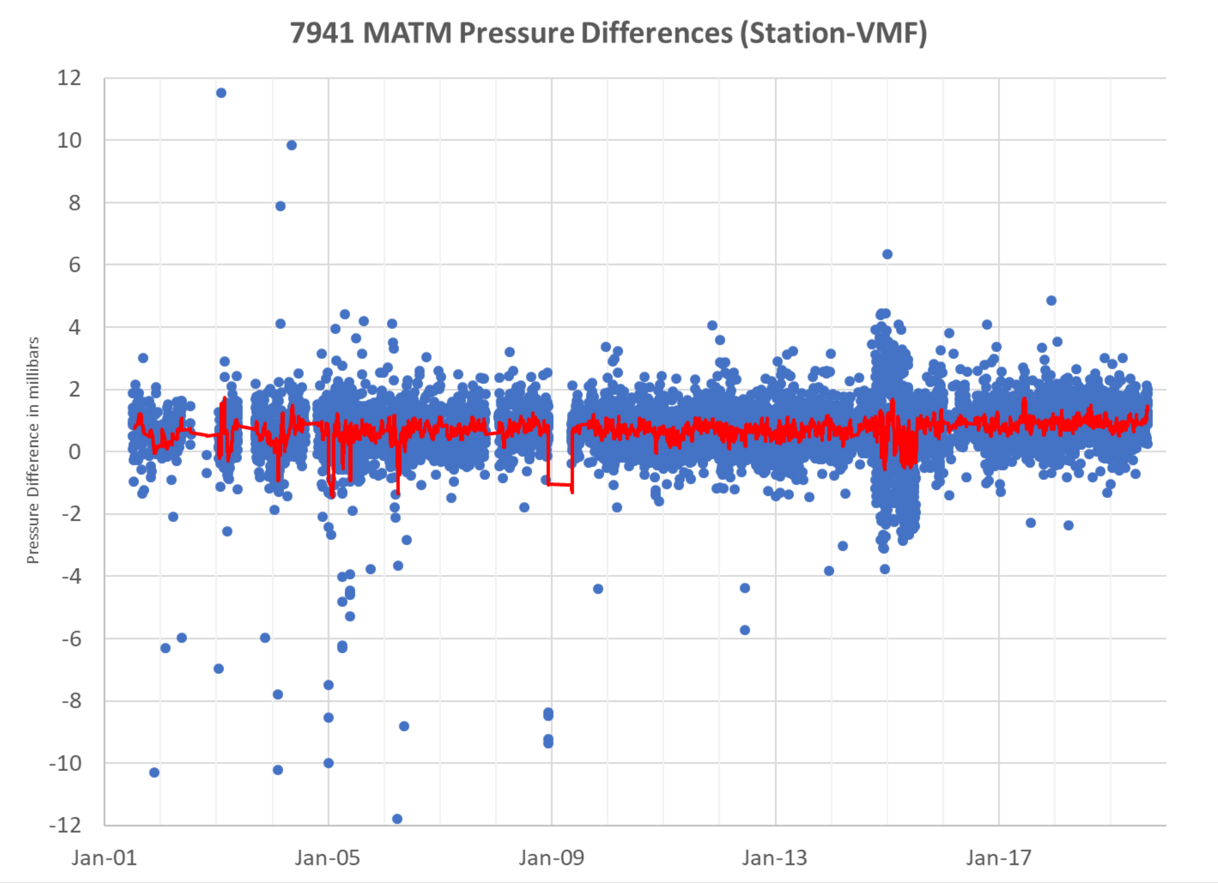


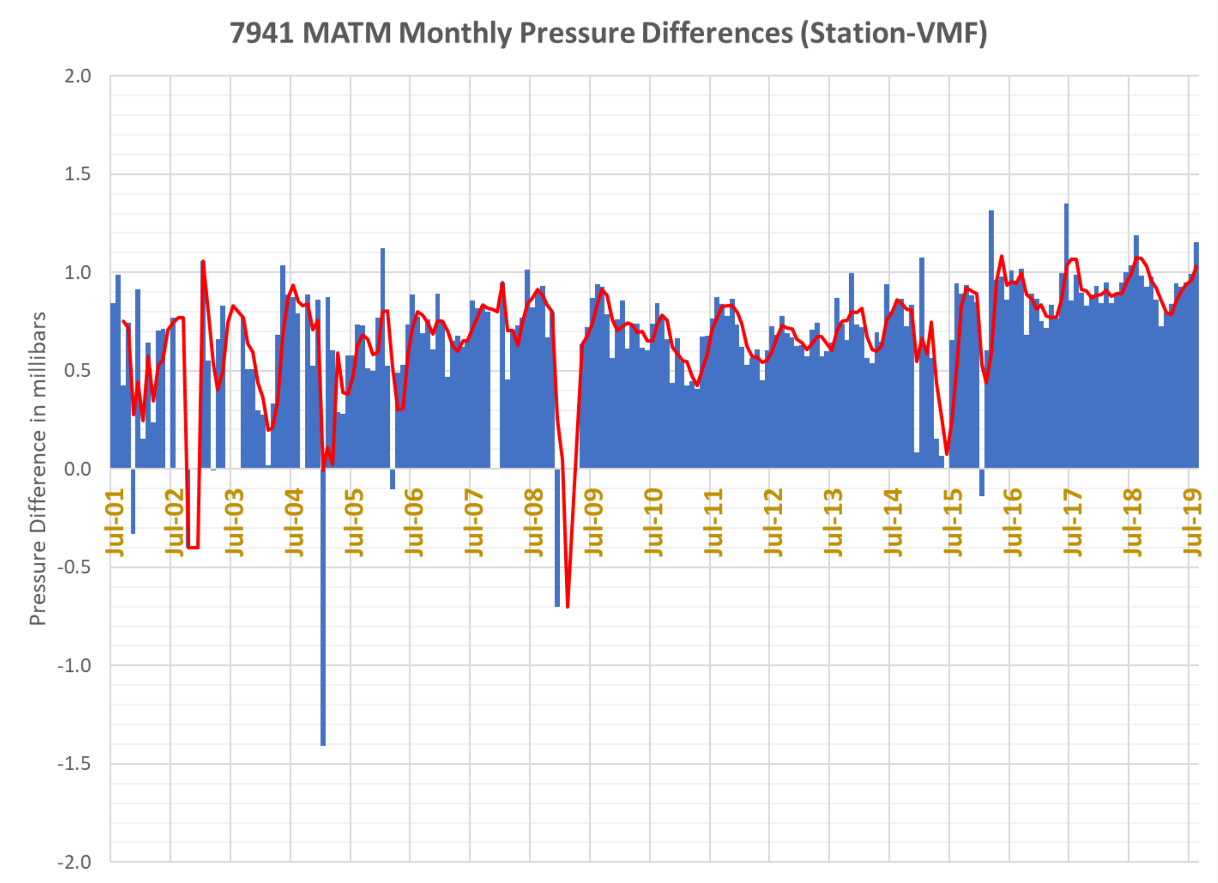
7840 HERL Pressure Analysis





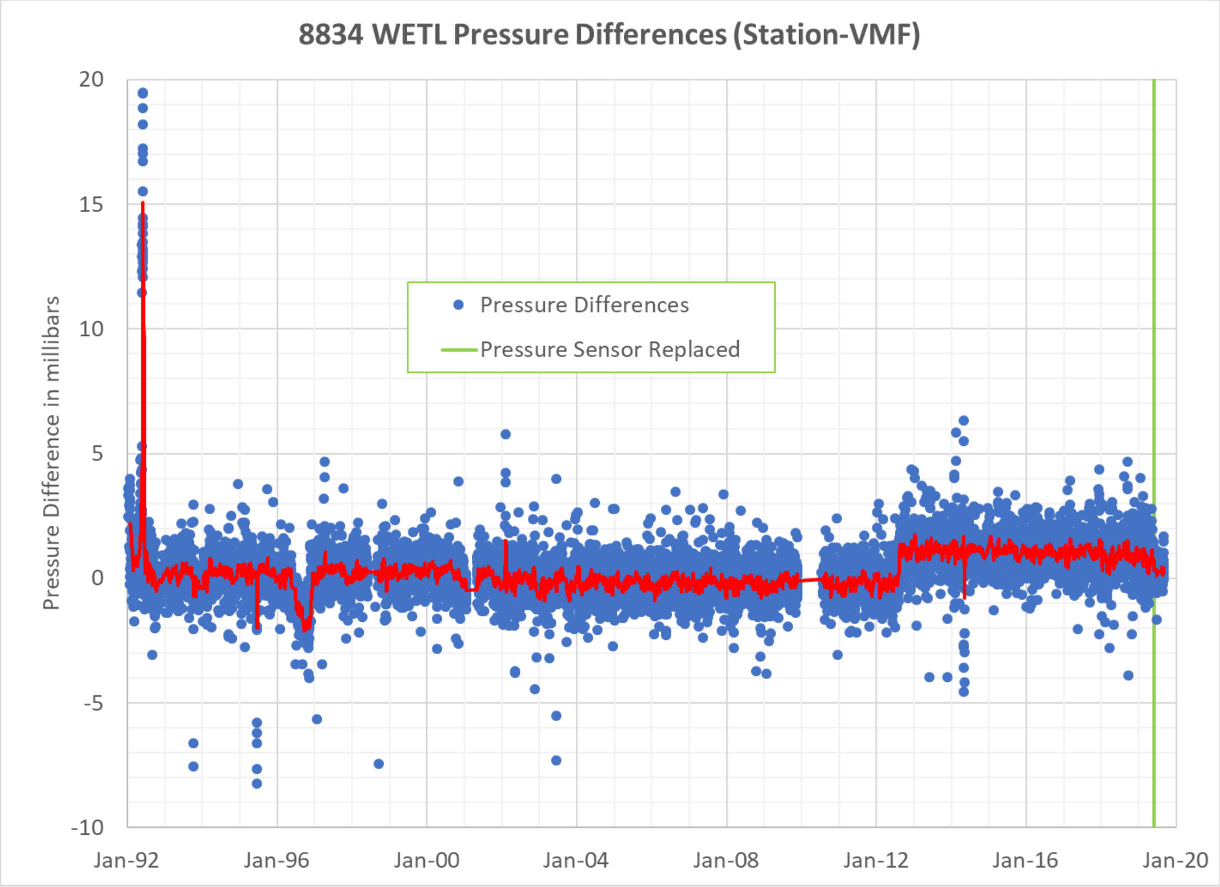
7941 MATM Pressure Analysis

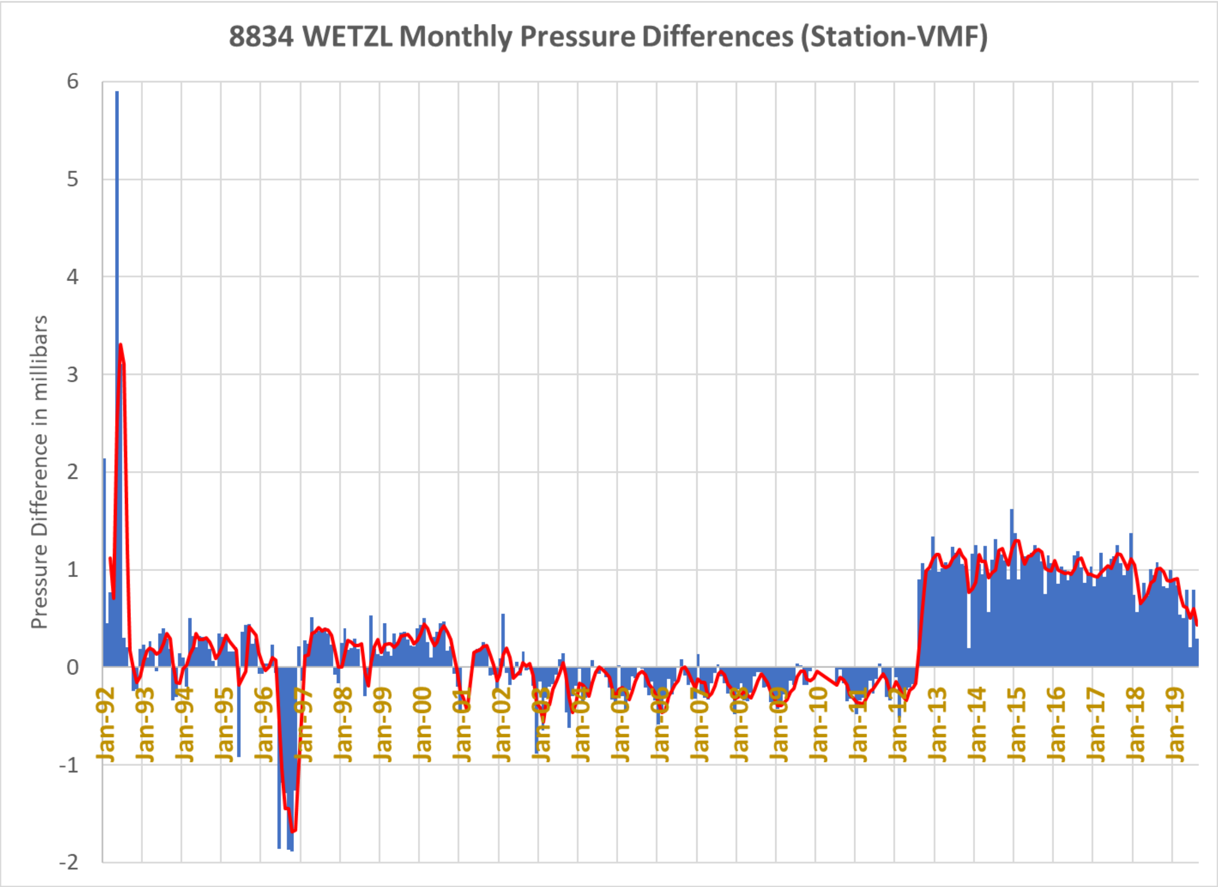




- **The 7941 site log mentions a ~2-meter height difference between the sensor and the SRP. Is this height difference modelled in the data processing?**

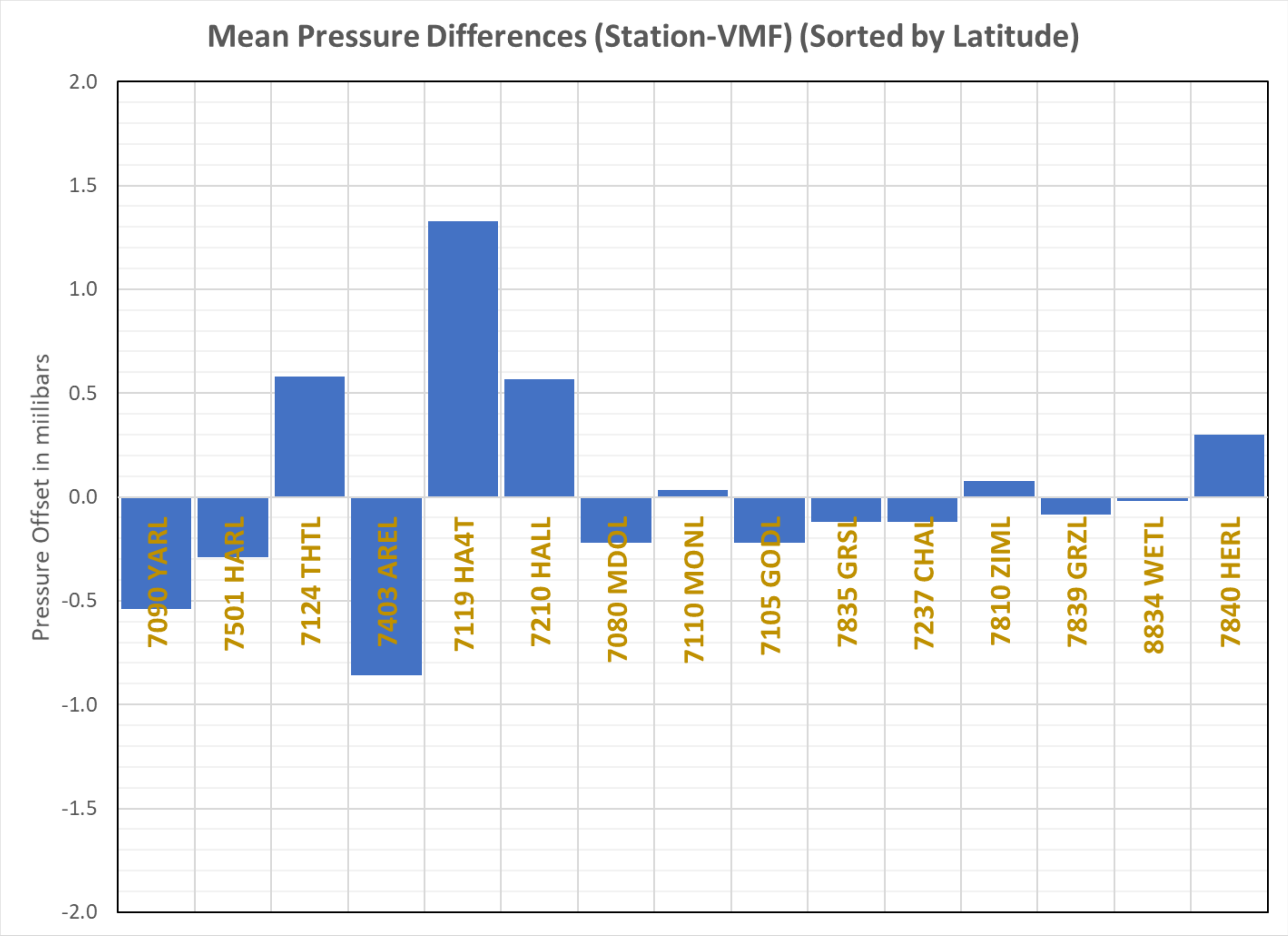
8834 WETL Pressure Analysis





- These results are based on release 0 of the 8834 data. Release 1 fixed a height correction (9.354 meter) between the pressure sensor and the system reference point. The pressure sensor was replaced on 29-May-2019 (ref: SLRMAIL #2580).

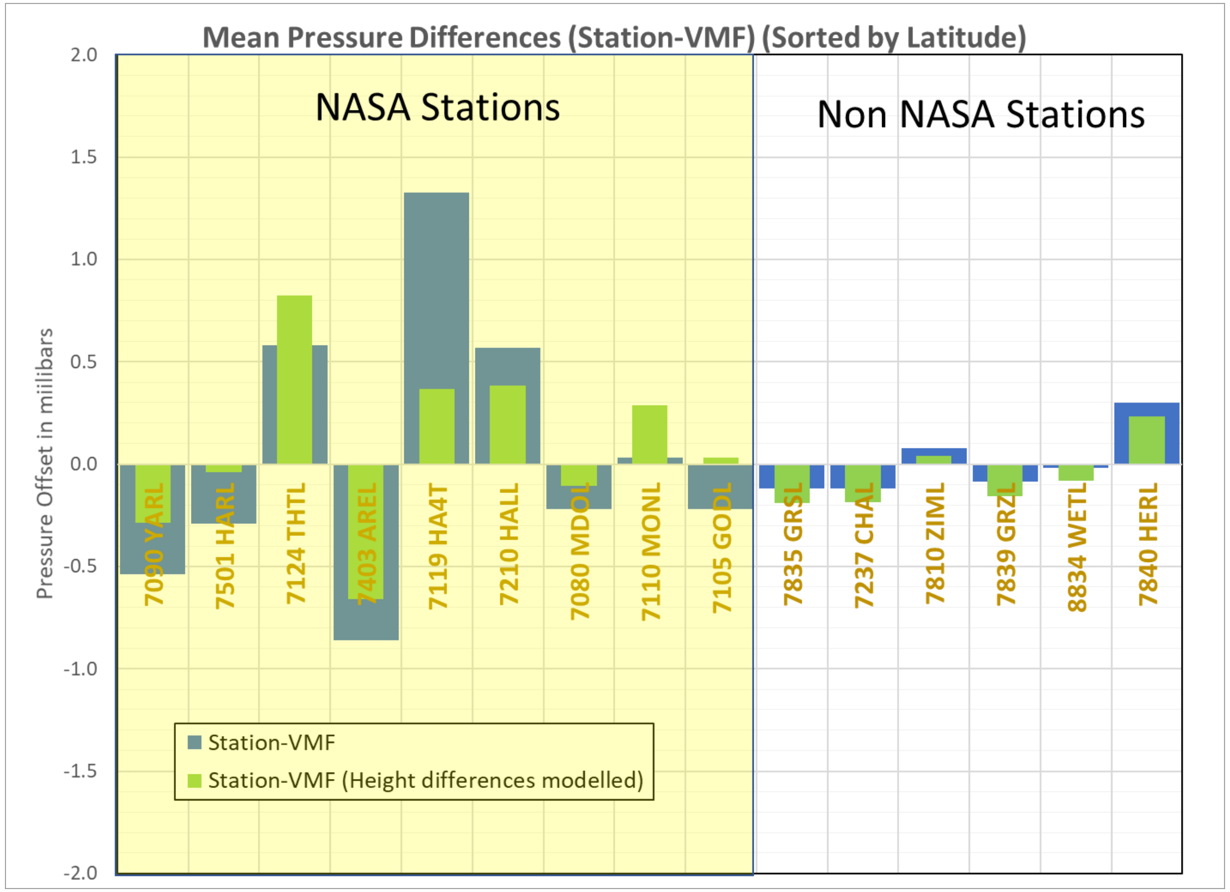
Mean Pressure Differences (Station-VMF) Summary



- **These are the mean pressure differences when the differences appear relatively stable between the site's measurements and the VMF.**
- **Potential errors sources are:**
  - The barometric sensor
  - Ray-Tracing
  - The station height used in the VMF
  - Unmodeled height errors between the barometric sensor and the system reference point
- **Reducing barometric systematic errors to the sub-mm level requires absolute pressure accuracies of 0.10 to 0.15 millibars**
- **Station heights in the VMF need to be accurate to better than 1 meter to keep the uncertainty in the barometric pressure to less than 0.1 millibars**

Mean Pressure Differences (Station-VMF) Summary

Station Type	Station	Latitude	VMF-Station SRP Height (m)
NASA	7090 YARL	-29.046	-2.516
NASA	7501 HARL	-25.890	-2.507
NASA	7124 THTL	-17.577	-2.429
NASA	7403 AREL	-16.466	-2.000
NASA	7119 HA4T	20.706	9.609
NASA	7210 HALL	20.707	-0.159
NASA	7080 MDOL	30.680	-1.140
NASA	7110 MONL	32.892	-2.517
NASA	7105 GODL	39.021	-2.521
Non-NASA	7835 GRSL	43.755	0.676
Non-NASA	7237 CHAL	43.791	0.669
Non-NASA	7810 ZIML	46.877	0.368
Non-NASA	7839 GRZL	47.068	0.714
Non-NASA	8834 WETL	49.144	0.621
Non-NASA	7840 HERL	50.867	0.700

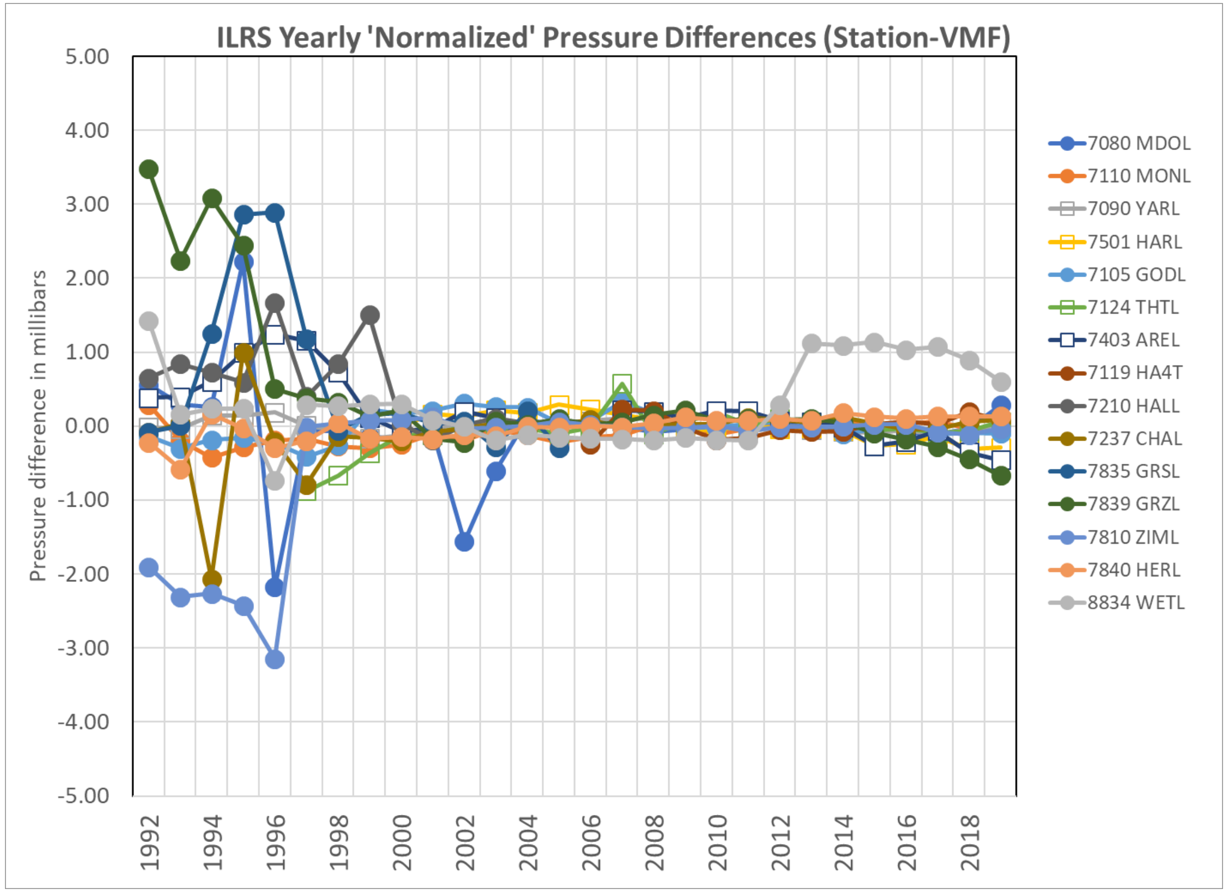


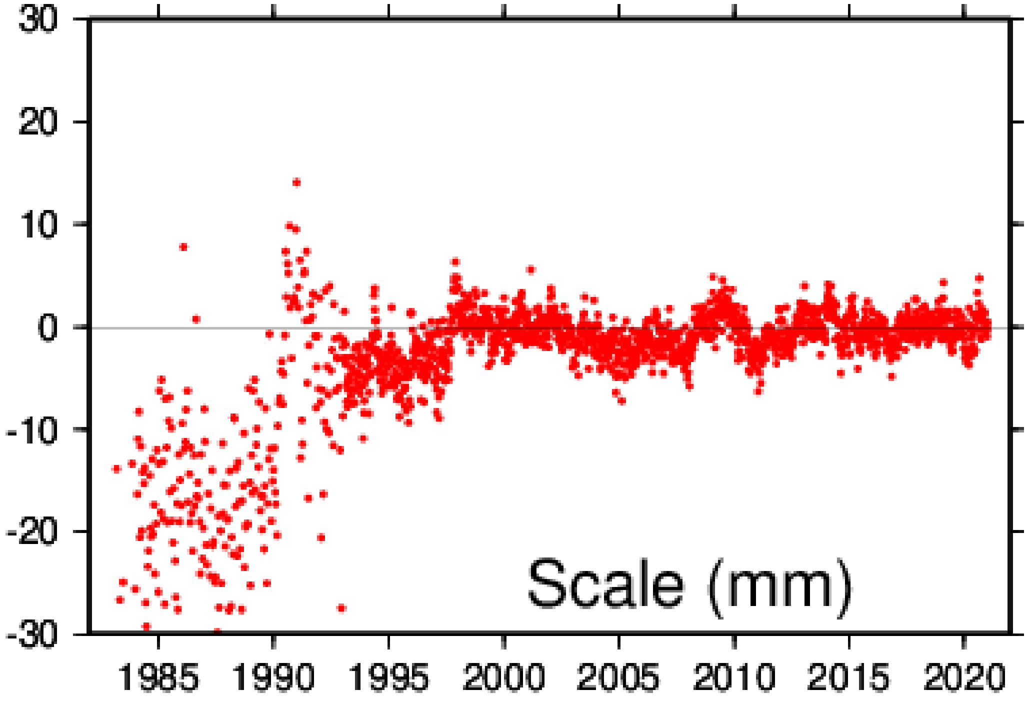
- The VMF station heights are based on approximate heights from the ILRS site eccentricity file.
- For the NASA systems, the VMF heights are based on the marker/monument and NOT the SRP
- NASA system pressure differences moved more toward the positive except for the Hawaii stations (7119, 7210) while the non-NASA pressure differences moved more toward the negative.

Notable Height Differences between the SRP and the Barometric Sensor

Mark	Location	Height Difference	Modelled
1824	Golosiiv, Russia	-2.5	?
1893	Katzively, Ukraine	-3.5	?
7210	Haleakala, HI, USA	2	?
7249	Bejing, China	-1.2	?
7810	Zimmerwald, Switzerland	2	?
7824	San Fernando, Spain	12	?
7821	Shanghai, China	2	?
7835	Grasse, France	2.5	?
7836	Potsdam, Germany	-2.28	?
7837	Shanghai, China	2	?
7838	Simosato, Japan	-3	Yes
7841	Potsdam, Germany	-5.2	?
7941	Matera, Italy	2	?
8834	Wettzell, Germany	9.354	Yes

ILRS Yearly Normalized Pressure Differences and ITRF SLR Scale





- As more accurate barometric sensors were installed at each site during the mid to late 1990's, the yearly barometric offsets stabilized at these sites.
- Did unmodeled barometric errors in the early 1990's, bias the SLR scale estimates prior to 1997?

Summary/Next Steps

- The absolute accuracy of the VMF3o is site dependent but can be modelled
- VMF3o System Characterization
  - There are systematic differences between VMF3oEI and VMF3oOP that are site-specific. When averaged over 12 years, these VMF differences for all sites are less +/- 0.4 hPa.
  - VMF3o uses approximates heights from the ILRS system eccentricity file. But any errors in the VMF SRP heights can be accurately modelled.
  - After modeling any VMF3o SRP height errors, there are still site-specific systematic differences between VMF3oEI and the SLR barometric pressures up to 0.8 hPa.
- The VMF3o data can be used to model historical errors in SLR barometric pressures which should improve SLR scale estimates
- The proliferation of more accurate SLR meteorological sensors in the mid to late 1990’s had a positive impact on our SLR data quality and SLR scale.
- **Next Steps:**
  - Continue this analysis for other SLR stations including legacy systems
  - Determine the best approach to model historical barometric errors

Wiener Filter for multiphoton systems

Summary

In a previous report the Wiener filter has been applied to normal point processing of single photon data mitigating the slope and dispersion in the normal point rms vs. normal point residual statistics.

In order to extend the application to multiphoton SLR systems using solely a unique transfer function as reference for center of mass corrections, the analogue signal processing chain of these kind of systems is modeled for the retrieval of a so called empricial system specific transfer function (ESSTF).

Monthly averages of these ESSTF's have been retrieved and are compared between the systems 7090,7105 and 7110 on the basis of statistical moments. It turns out that even systems with identical hardware show different ESSTF's. A reason for this could be how the hardware is set up at each individual SLR system.

In turn the monthly averaged ESSTF's are used to calculate normal points, which mitigates the dispersion in the normal point rms vs normal point residual statistics and confines the resulting normal points to rms values obtained in calibration measurements.