GuideTech

Precision Time & Frequency
Test & Measurement Instruments, ATE

GT668SLR Event-Timer

Multi-Channel, 2.7GHz, 0.9pS, 4M m/s

GT9000PSLR-USB3

GT9000SLR 10" touch–screen with GPS receiver

GT9000RSLR - 2 to 24 channels 19" Rack-Mount with GPS receiver

APPLICATIONS

- Event Timing, UTC Synchronized
- Laser Ranging Timing Subsystem
- Real Time, Time stamping
- Long Distance Time Transfer
- Radar & Ultrasonic timing
- 1 PPS Monitoring
- Fast Time Measurements & Analysis
- Variation in Pulse Timing
- Frequency Modulation
- Allan Variance
- Measure jitter and skew

SOFTWARE SUPPORT

- Software package & APIs for SLR
- SLR GUI
- Windows 32bit, 64 bit
- Linux 32bit, 64 bit
- NI LabVIEW
- Python
- Java
- Custom software Development/ Support

KEY FEATURES

- UTC synchronizable with 1 PPS
- Programmable gates controlling Source & receiver subsystems
- Easy cross-platform integration
- Very high throughput & accuracy
- Built-in NIST traceable time-base
- Expandable test systems 2 to 34 synchronized channels
- Available in PCI , PCIe, PXI, PXIe BUS & Test-System with SLR GUI

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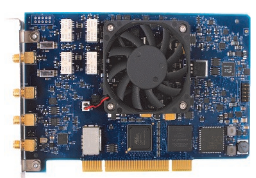
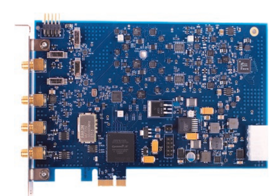
(408) 733-6555
(408) 988-9998
sales@guidetech.com
www.guidetech.com

With a 50% smaller foot-print and much more powerful performance than its previous generation **GT658** Event-Timers, **GuideTech's GT668SLR** computer-based **Event-Timer** was co-designed with the ILRS community to provide a one-box Multi-Channel system-solution for SLR.



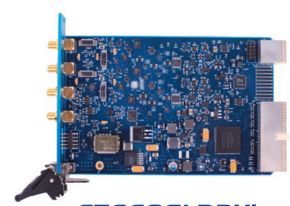
GT668SLRPCI

The **GT668SLR** Event-Timer has the following additional functions & software support:



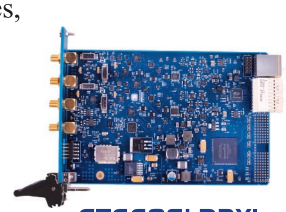
GT668SLRPCIe

- ♦ **1PPS input**
- ♦ **Integrated Two Programmable triggering outputs relative to beginning of measurement or to the Arming signal or at a user specified Real-Time to operate/control the Detector & other sub systems.**
- ♦ **Ability to synchronize with UTC time reference**
- ♦ **Software package, APIs for SLR & SLR GUI**
- ♦ **Integrated GPS receiver with OCXO, Rubidium or Cesium**



GT668SLRPXI

With easy expansion (up to 34 Channels) and modular capabilities, the **GT668SLR** is offered as follows:



GT668SLRPXIe

- * **GT9000SLR** Scalable system, 2 to 24 channels, Touch-Display
- * **GT9000RSLR** Rack-Mount scalable system, 2 to 24 channels
- * **GT9000PSLR-USB3** Portable 2 channel system
- * **GT8000SLR PXI/PXIe** scalable, 2 to 34 channels
- * **GT668SLR** 2 channels **PCI**, **PCIe**, **PXI & PXIe** plug-in boards

All of **GuideTech's** SLR systems & board products come with **NIST** traceable calibration, **SLR** APIs and customizable **SLR GUI.** The **GT9000SLR** & **GT9000RSLR** come with an optional integrated GPS receiver, providing a one-box, multi-channel solution for optimal test at lower cost.

7 Slot Hybrid
GT8000SLR - PXI /PXIe

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Precision Time & Frequency
Test & Measurement Instruments, ATE

GT668SLR Event-Timer

Multi-Channel, 2.7GHz, 0.9pS, 4M m/s

GT9000PSLR-USB3

SPECIFICATIONS

- Time Res. single-shot - 0.9ps
- Freq. Res. (Digits/S) - up to 12
- Max. Meas. rate - 4M m/s

GT8000SLR - PXI / PXIe
Scalable from 2 to 34 channels

MAIN INPUT CHANNELS:

- No. of channels: 2 per site, A & B
- Frequency range: DC - 2.7 GHz
- Sensitivity:
  - * 50 mV rms (DC - 2.7 GHz)
- Input impedance: 1KΩ / 10 pF, or 50Ω software programmable
- Coupling: DC or AC
- Threshold setting (each channel):
  - * Range: -5V to + 5V
  - * Resolution: 153µV
  - * Absolute accuracy: 0.1% of setting
  - * Automatic threshold setting option

TIMEBASE:

- Frequency 100MHz locked to:
  - * Internal 10MHz OCXO
  - * External clock: 5 or 10 MHz (±3KHz)
- Minimum pulse width: 6nS
- Oven Oscillator:
  - * Temp: 0 - 45ºC ± 25ppb
  - * Aging: ±1 ppm first year, ±3 ppm over 20 years

EXTERNAL CLOCK & ARM INPUTS:

- Sensitivity: 50mV rms
- Input impedance: 1KΩ
- Threshold setting
  - * Range: - 5V to + 5V
  - * Resolution: 153µV
  - * Absolute accuracy: 0.1% of setting
- Automatic threshold setting available

EXTERNAL CONNECTIONS

- Main channels: 2, SMA per site
- External clock: 1, SMA
- External arm: 1, SMA
- Digital input: 1 SMA (for 1PPS UTC synch)
- Digital output: 2, SMA (software programmable, to control user subsystems)

GT668SLR MODELS

PCI

- GT668SLRPCI-1
- GT668SLRPCI-2
- GT668SLRPCI-15
- GT668SLRPCI-40

PCIe

- GT668SLRPCIe-1
- GT668SLRPCIe-2
- GT668SLRPCIe-15
- GT668SLRPCIe-40

PXI

- GT668SLRPXI-1
- GT668SLRPXI-2
- GT668SLRPXI-15
- GT668SLRPXI-40

PXIe

- GT668SLRPXIe-1
- GT668SLRPXIe-2
- GT668SLRPXIe-15
- GT668SLRPXIe-40

* -1 = 0.9pS resolution
* -2 = 1.8pS resolution
* -15 = 15pS resolution
* -40 = 40pS resolution

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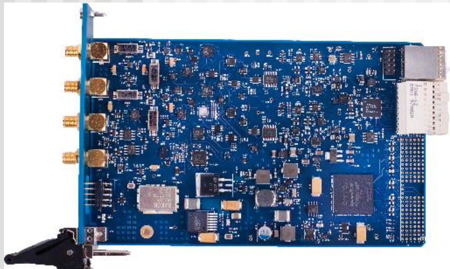

GT668PXIe

GT668PXI

GT668PCIe

GT668PCI

GT9000R PXIe
19” Rack-Mount, 2 to 24 channels

GT9000 **with** 10” touch–screen

GT9000R 2 to 24 Channels

GT9000P-USB3 Portable

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Some Basics

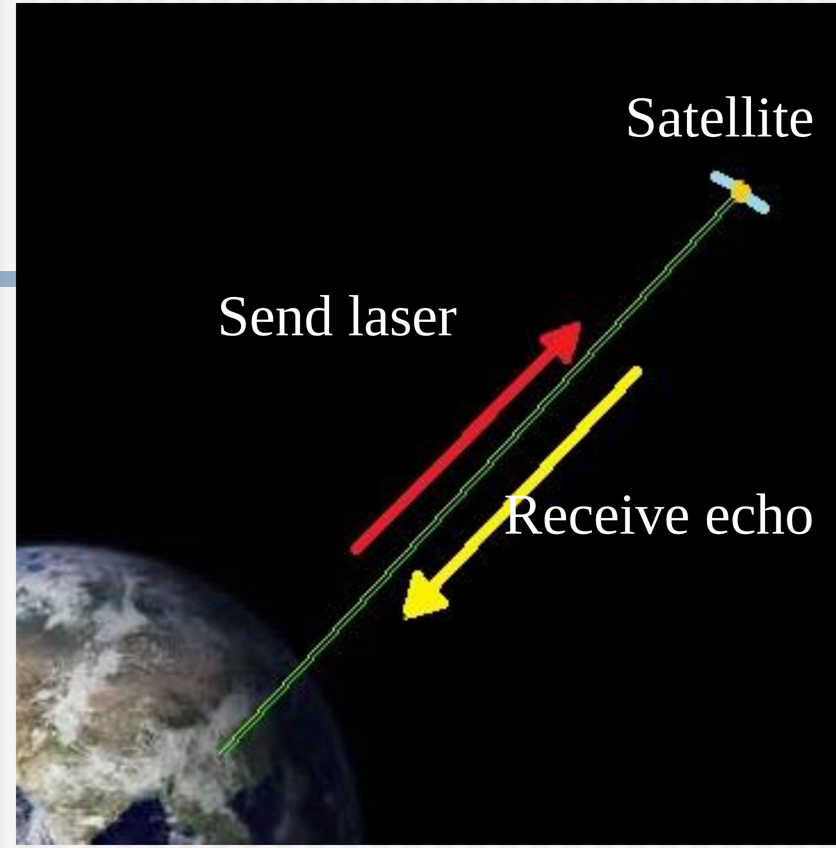
- Principle of Laser Ranging

- Send laser pulse toward the Satellite and record the transmitting time point

- Receive the echo and record the returning time point

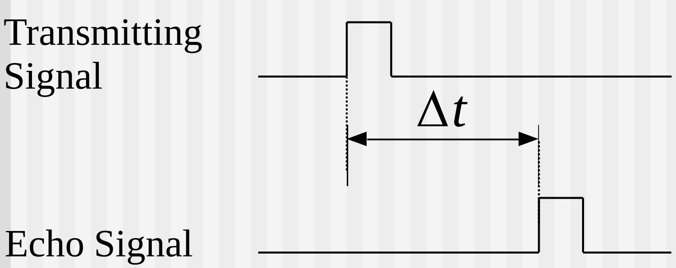
- Calculate the distance (Ideal):

$$DISTANCE = (t|_{receive} - t|_{transmit})*C$$



- Event Timer: Epoch Measurement

Time tag listed by Event Timer



Time data view of An Event Timer

Events	Time/second
t0	1234.0012345678
t1	1234.0022345678
...	...

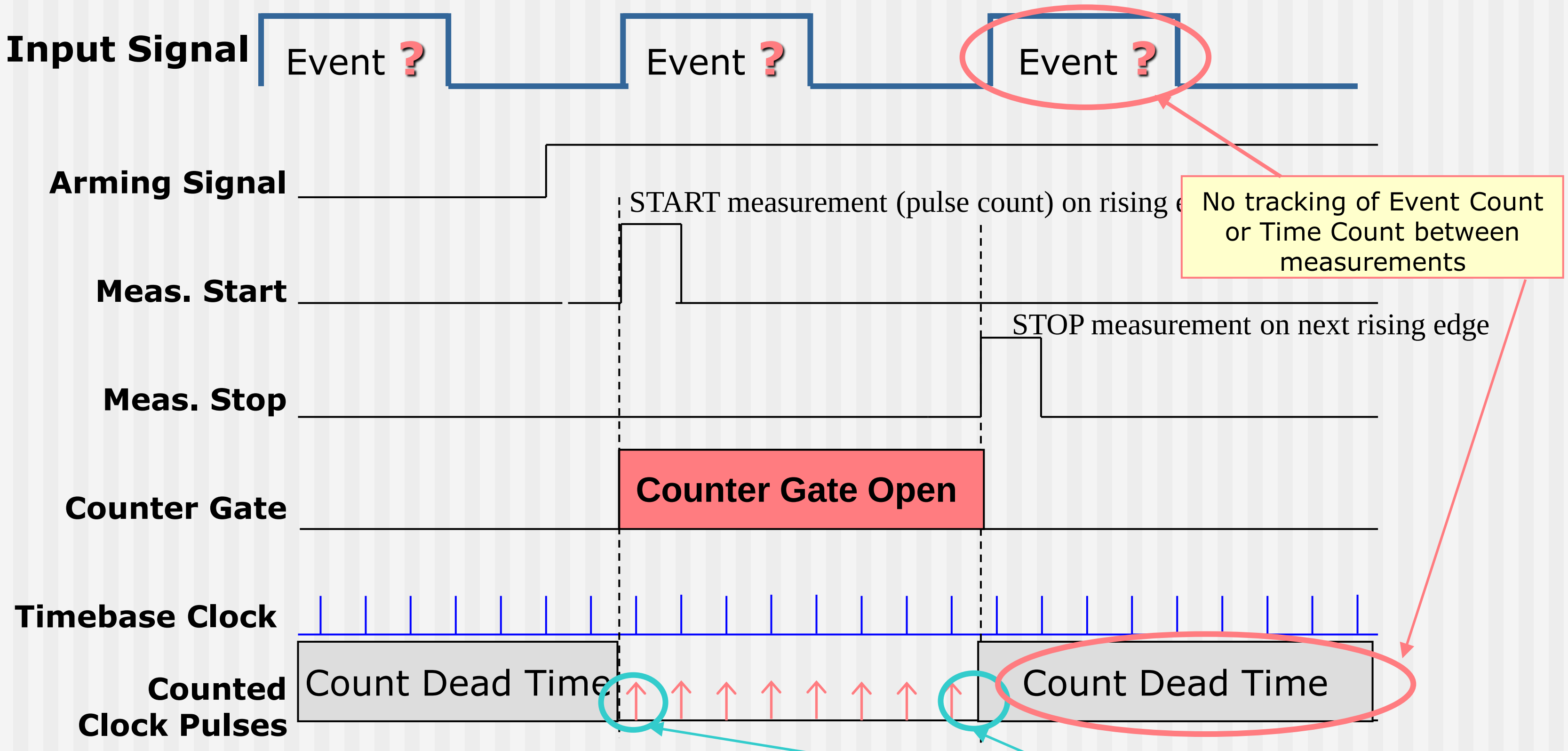
Overview
Time Interval Measurement Options

Time Counter (TC)	Measures the ***delta time interval*** between two electrical events.
Time Interval Analyzer (TIA)	Measures and records a "***time stamp***" (**Time Tag**) for multiple events ***measured continuously*** (no dead-time) on one or more electrical signals ***with correlation to a common time reference***, T0.
Digital Sampling Oscilloscope (DSO)	Samples and reconstructs electrical waveforms (repetitive only) and *interpolates between measurement points to determine the* ***delta time interval*** between two electrical events.
High-Speed Digitizer	Digitizes electrical waveforms in one-shot and *interpolates between measurement points to determine the* ***delta time interval*** between two electrical events.
Digital Edge Search	***Calculates intervals of time*** between rising and falling edges of electrical signals (repetitive signals only) by *sweeping a digital pattern capture strobe* through a signal to search for the zero/one crossover points then multiplying by digital capture strobe period.

Overview

Time Interval Measurement Theory

Time Counter (TC) Method

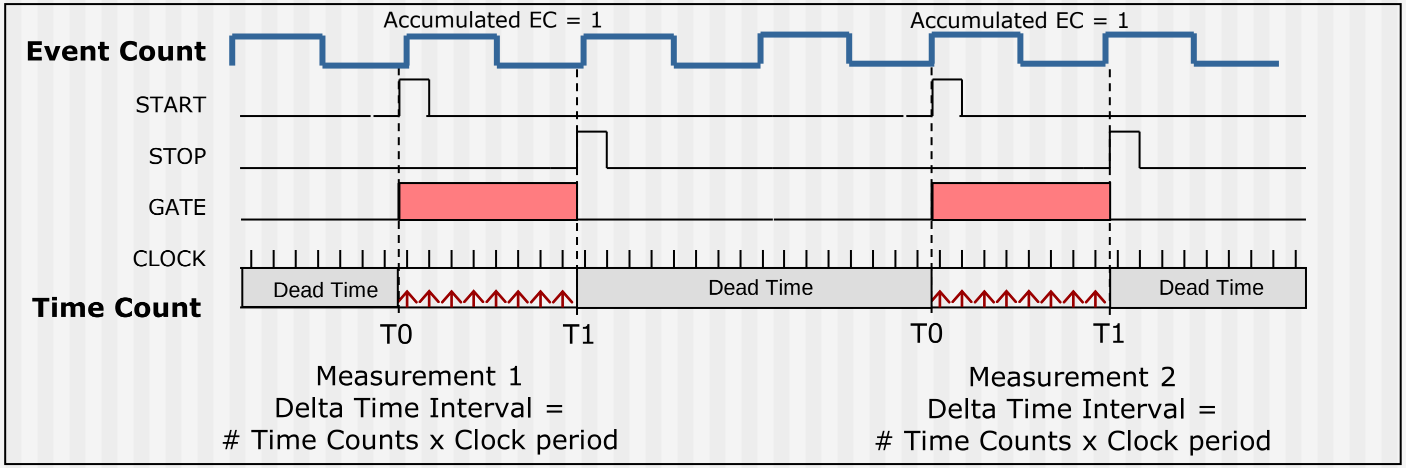


Time Interval = (*# Pulses counted* x *Timebase period*) + *Interpolation values (optional)*

Overview

Time Interval Measurement Theory

Time Counter (TC) Method



TC architecture obtains:

Delta # of Time Counts

- Number of Timebase Clock Pulses between two events

Delta # of Event Counts

- Number of Events between two events

To provide user with:

Delta Time Interval (non-continuous and non-correlated with other measurements)

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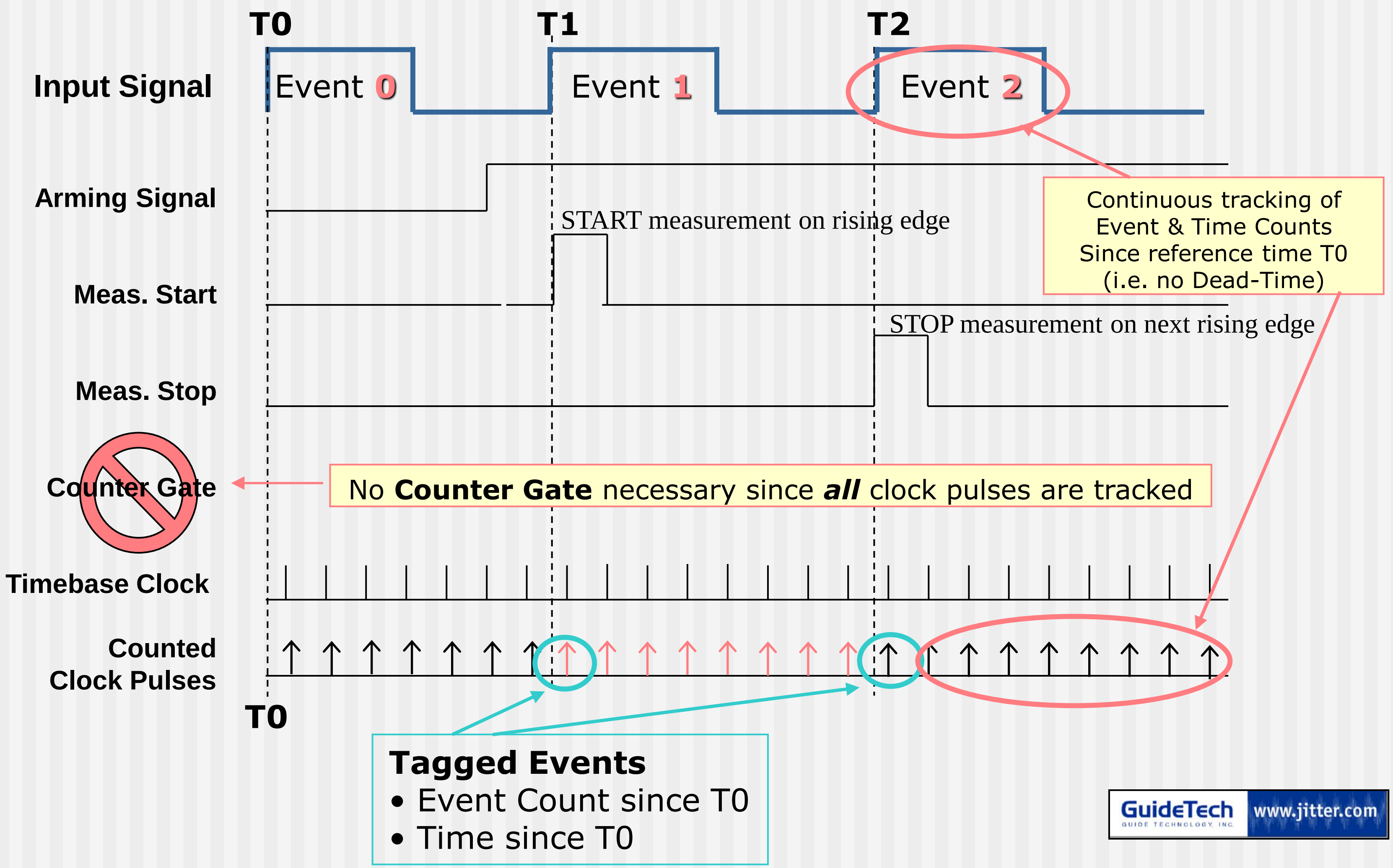
Overview

Time Interval Measurement Theory

Time Interval Analyzer (TIA) Method



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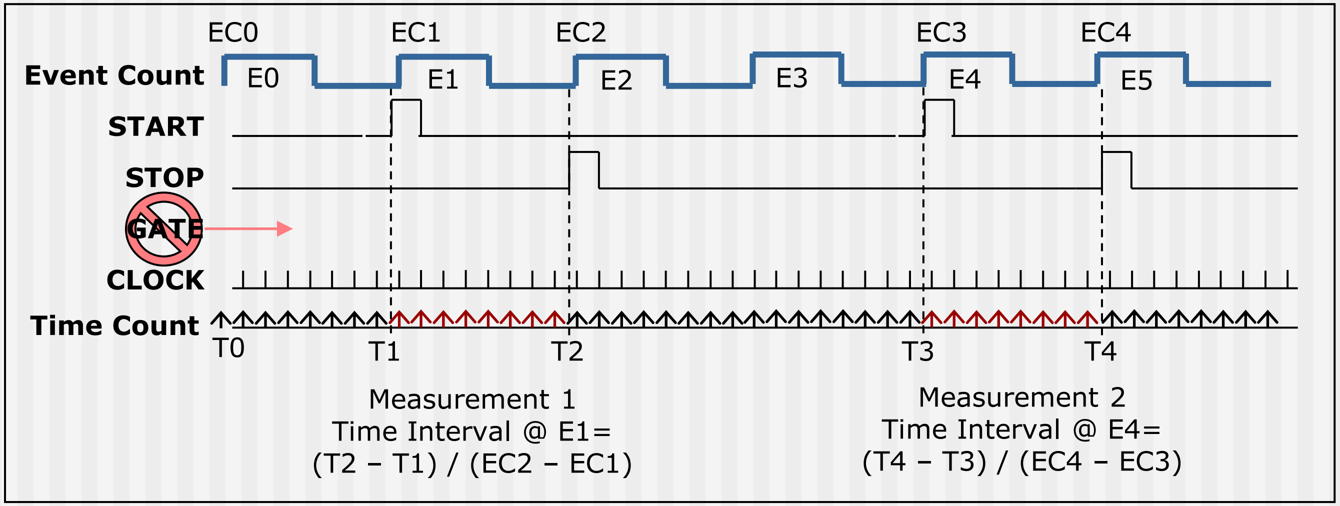
Overview
Time Interval Measurement Theory
Time Interval Analyzer (TIA) Method



TIA architecture obtains:

Continuous, Correlated Event Count (Tag)

- Number of Events since "time zero", T0, for each measurement

Continuous, Correlated Time Count (Tag)

- Number of Clock Pulses since "time zero", T0, for each measurement

To provide user with:

Correlated Time Interval (all measurements referenced to same T0)

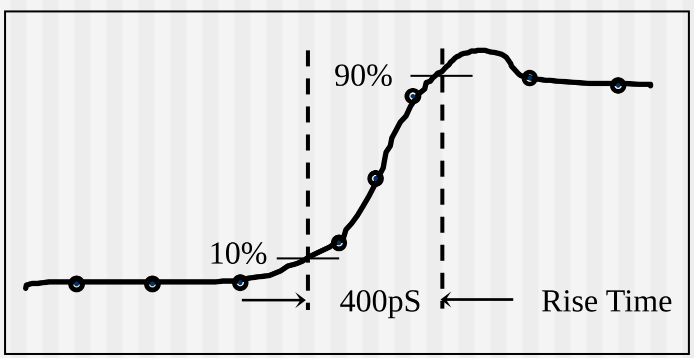
Overview

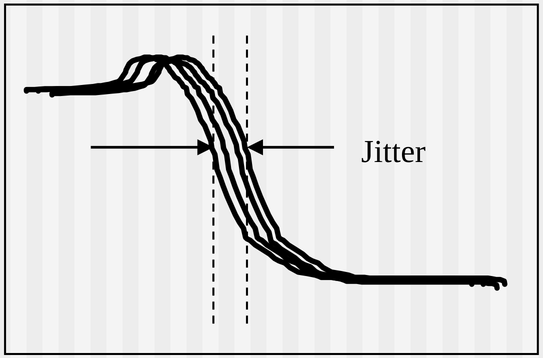
Time Interval Measurement Theory

Digital Sampling Oscilloscope (DSO) Method

Step 1: Under-sample at a coherent time interval **T = Nt + delta t**

where T is the time between measurement samples; N = integer;
t = Input signal period; delta t = effective sampling period





Step 2: Reconstruct the waveform & interpolate between sample points
Step 3: Calculate time interval between two measured (or interpolated) points

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Overview
Time Interval Measurement Techniques
Comparison Summary

	Time Interval Analyzer	Time Counter	Digital Sampling Oscilloscope	High-Freq Digitizer	Digital Edge Search
Frequency & Time Interval Measurement	**Y**	**Y**	**Y**	**Y**	**Y**
Time-Correlation between measurement points	**Y**	**N**	**Y**	**Y**	**?**
Speed of Time Measurements	**VERY FAST**	**SLOW**	**SLOW**	**VERY SLOW**	**SLOW**
PLL Loop BW Analysis	**Y**	**N**	**Y**	**Y**	**N**
Jitter Measurement < 100ps	**Y**	**Y**	**N**	**N**	**N**
Jitter Modulation Analysis	**Y**	**N**	**N**	**N**	**?**
> 2 channels measured simultaneously	**Y**	**N**	**N**	**N**	**Y**

l'Observatoire de Paris | SYRTE
Systèmes de Référence Temps-Espace

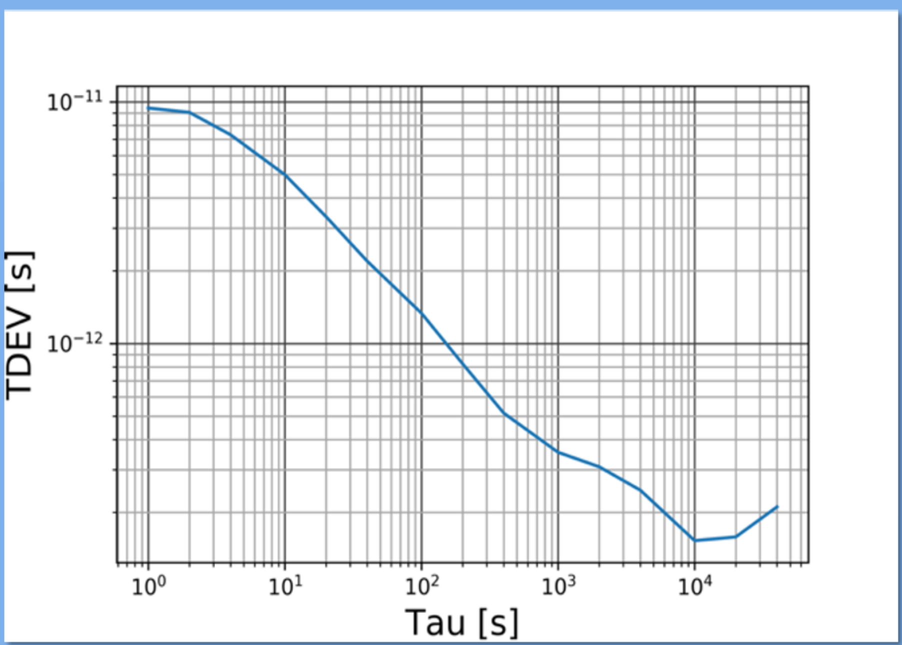
GT 9000 at Paris Observatory

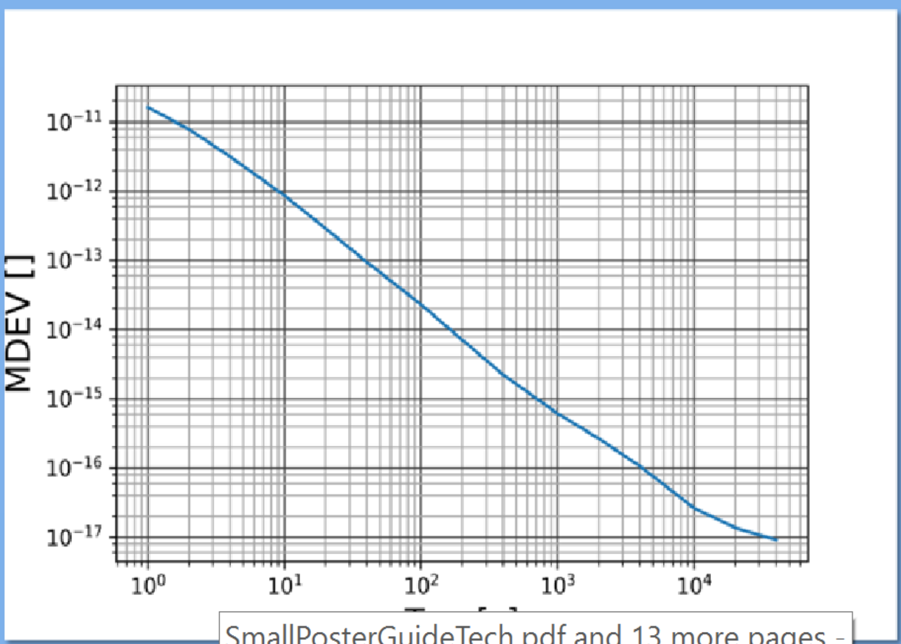
F. FRANK, P.-E. POTTIE

GT 9000 is in use at Paris Observatory for :
- measuring phase noise at high rate,
- frequency and time interval counter

For remote operation and integration into a LAN, GuideTech released for us an **integrated solution with Ubuntu as OS**.
We are presenting here the measurement of time interval between two PPS signals. The PPS are from TimeTech PPS distribution unit. The average delay between the two PPS is 2 ns. The clock signals are derived from an ultra-stable 1 GHz microwave signal generated and distributed over fiber link at SYRTE.

The data set is 200kpts long, acquired in one shot, at 1 Hz rate. The short term deviation is limited by the rising time of the PPS signal. The deviation averages out as sqrt(tau) as expected and reach the very low 1^{e}-13 s level. Regarded as Modified Allan deviation, the resolution of the measurement reaches 1^{E}-17 within one day of measurement.





SmallPosterGuideTech.pdf and 13 more pages -

GT668SLR Solutions

- **1PPS input**
- **Integrated Two Programmable triggering outputs relative to beginning of measurement or to the Arming signal or at a user specified Real-Time to operate/control the Detector & other sub systems.**
- **Ability to synchronize with UTC time reference**
- **Software package, APIs for SLR & SLR GUI**
- **Integrated GPS receiver with OCXO, Rubidium or Cesium**

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GT668SLR Solutions

With easy expansion (up to 34 Channels) and modular capabilities, the GT668SLR is offered as follows:

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- GT8000SLR PXI/PXIe scalable, 2 to 34 channels
- GT668SLR 2 channels PCI, PCIe, PXI & PXIe plug-in boards

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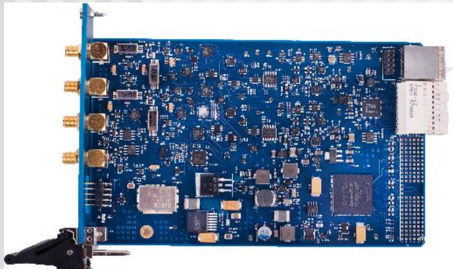
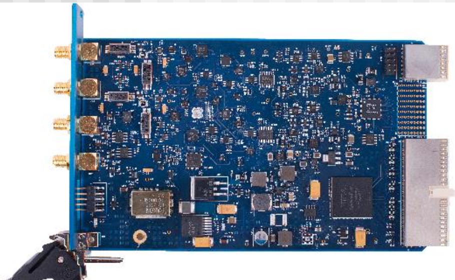
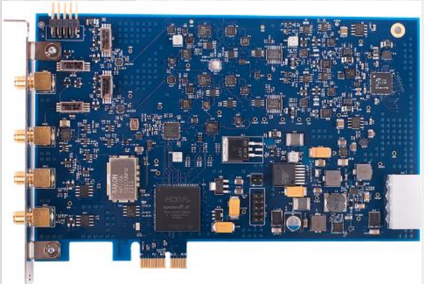


GT668PXIe

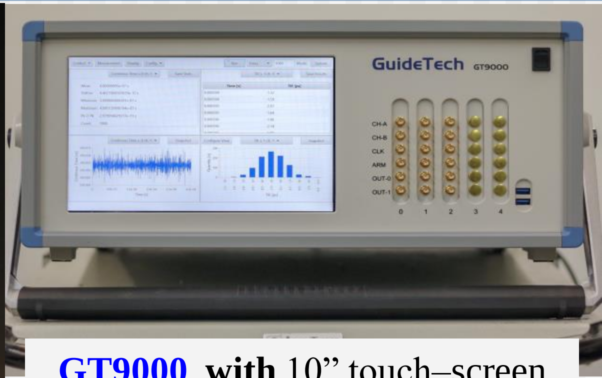


GT668PXI



GT668PCIe

GT668PCI



GT9000 with 10” touch–screen

GT9000R 2 to 24 Channels

GT9000P-USB3 Portable

GT9000R PXIe

19” Rack-Mount, 2 to 24 channels

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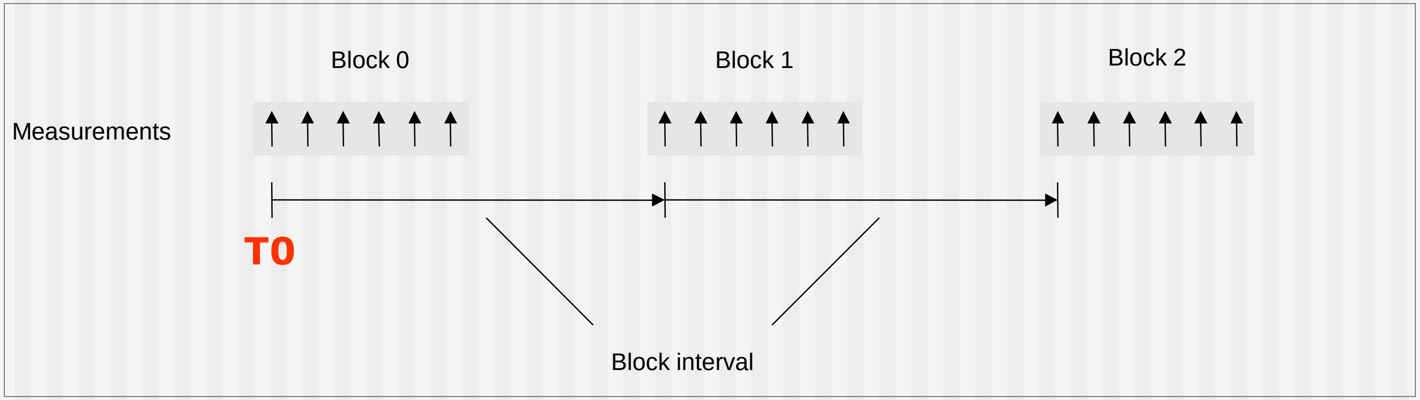
Measurement Terminology

Measurement Blocks



The Femto 2000 supports collection of multiple sets, or ***blocks***, of measurements. For measurements requiring multiple sets of blocks, all measurements in each block maintains its time reference to **T0** for the entire measurement period.

The user can specify:

- Number of measurements per block
- Number of blocks
- Block arming

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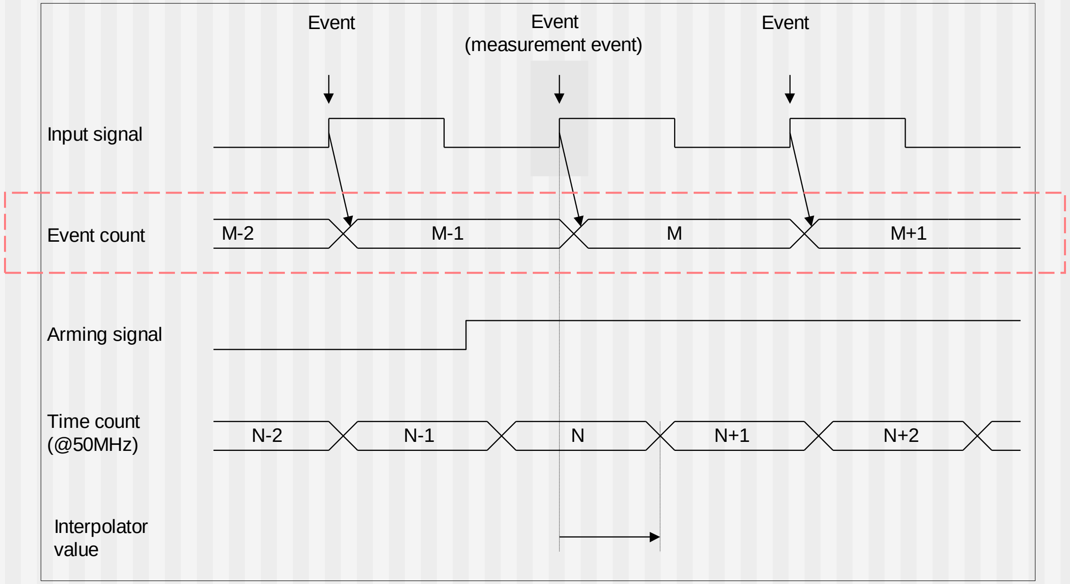
Measurement Terminology
Event Counter



Every measurement channel has an **Event Counter** that is incremented on every input event (input pulse) from beginning of each set of measurement blocks

Tracking all event counts enables the ability to "tag" each measurement on every channel with its corresponding Event ID# with respect to T0 for each set of measurement blocks.

Example:

Period	Event Count
1us	0
1.1us	100
0.9us	200

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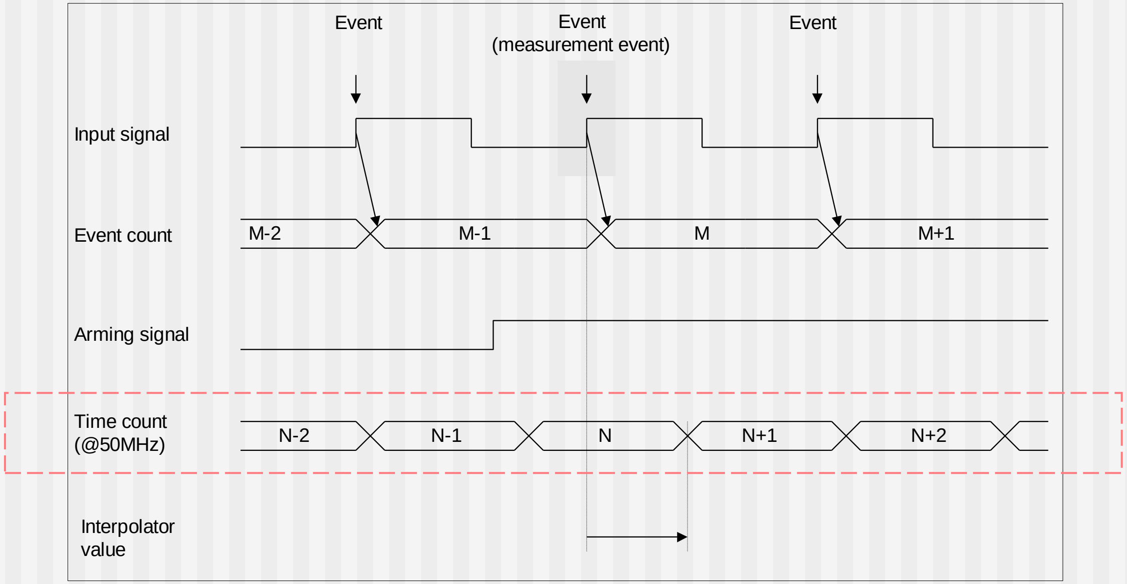
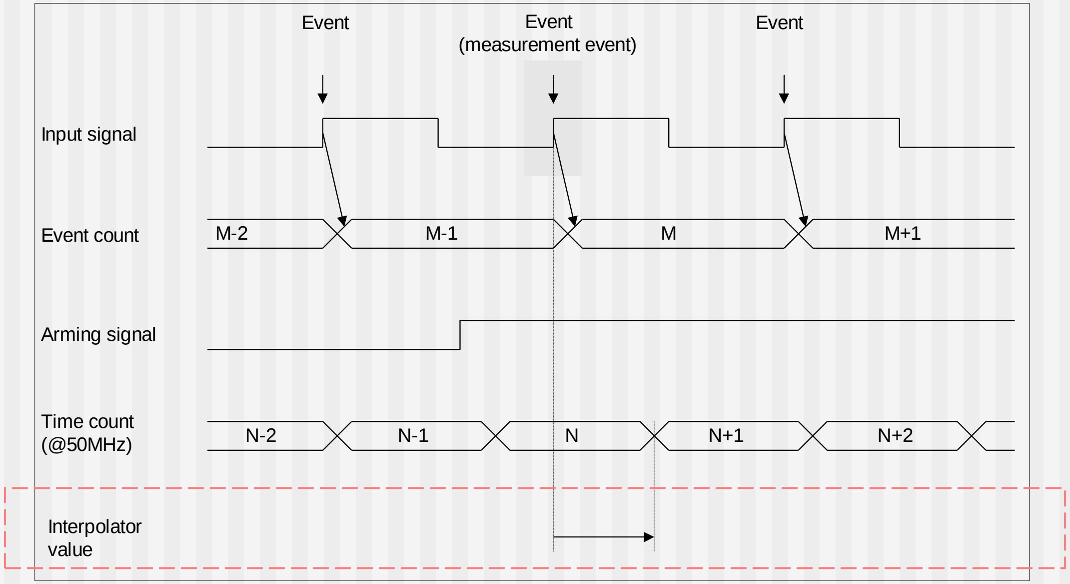
Measurement Terminology
Time Counter



Every measurement channel has a **Time Counter** that is <u>incremented after every reference timebase pulse from time T0 (system power up).</u>

Measurement Terminology

Edge



Every measurement channel has an **Edge** that measures the time interval between a triggered measurement (timetag) event and the next rising edge of the timebase clock.

The edge measures this interval by starting a precision voltage ramp at the triggered measurement event, then stopping the ramp at the next rising edge of the timebase clock.

Measurement Terminology
Arming Signals

Arming Modes

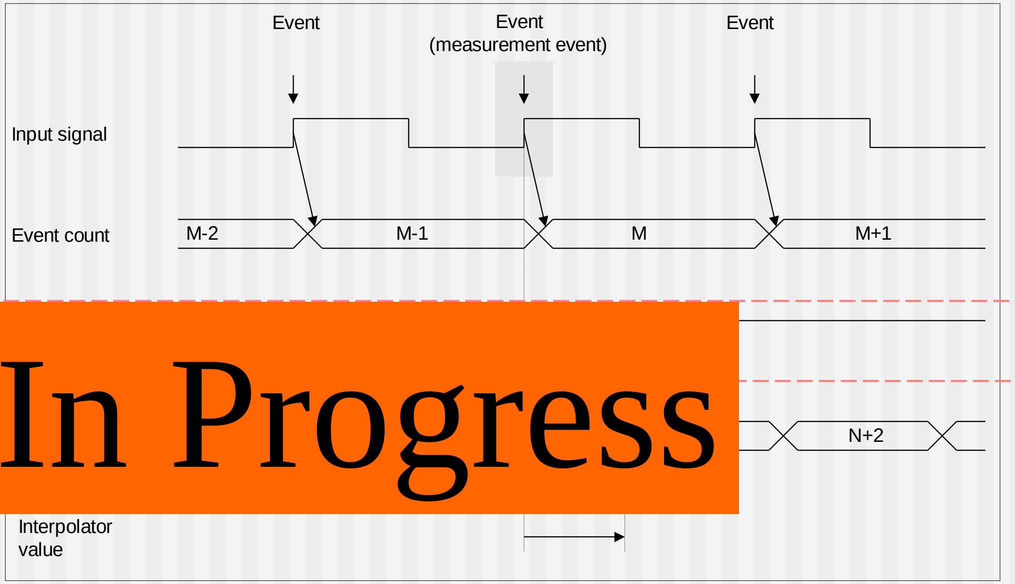
•

External Block Arm Signals

•

Time Tag Ar

•



February 2000

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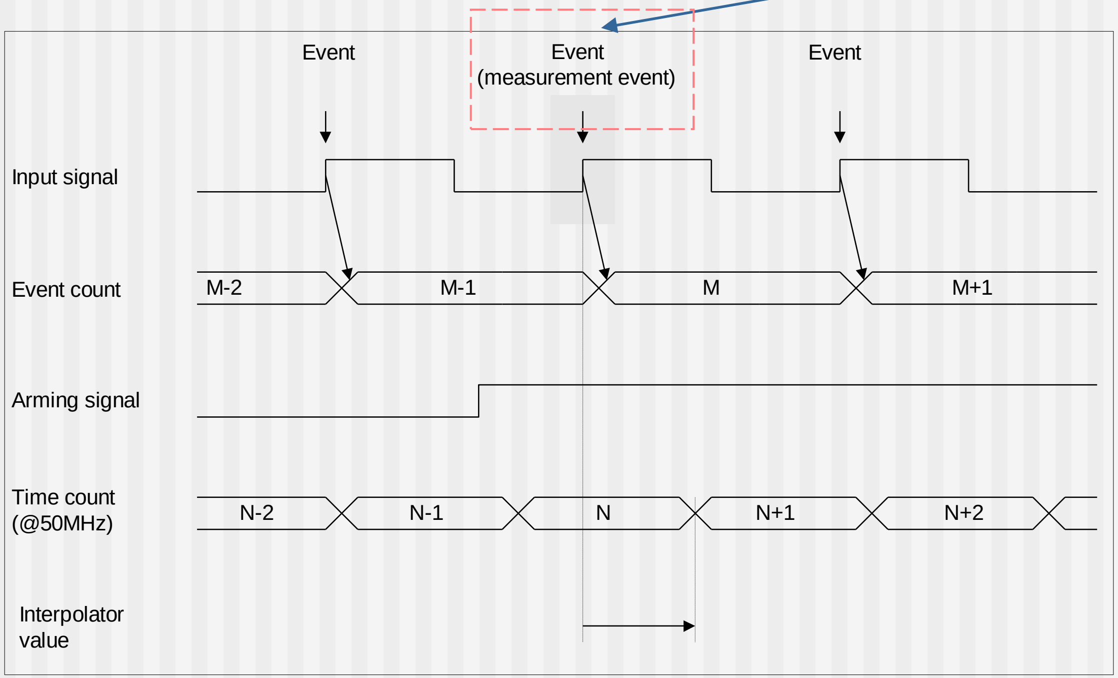
Measurement Terminology
Timetags



Timetag =
- Event Count
- Time value

The Time Interval Analyzer uses timetags to calculate time intervals between measured events. Since the Event Location is preserved in each timetag, the measurement results from a TIA can include the Event Count at which each measurement was taken as shown below:

Period	Event Count
1us	0
1.1us	100
0.9us	200

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Measurement Terminology
Timing Diagram Notations

Femto-2000 measurements can be categorized by the number of Edges needed to generate the Time Tags for each measurement.

In each of the following measurement descriptions:

- **ECn** represents the *Event Count* for measurement event n
- **Tn** represents the *time at which measurement event n occurs*
- **A0, A1, B0** and **B1** represent the *edges* used to generate the Time Tags for each measurement

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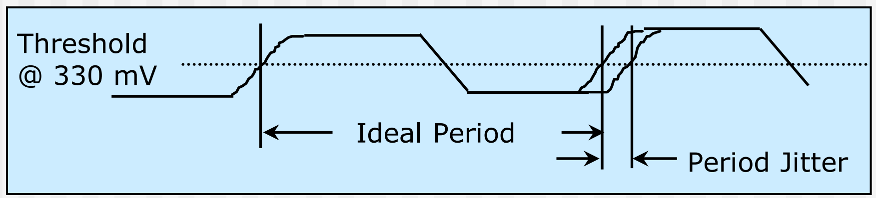
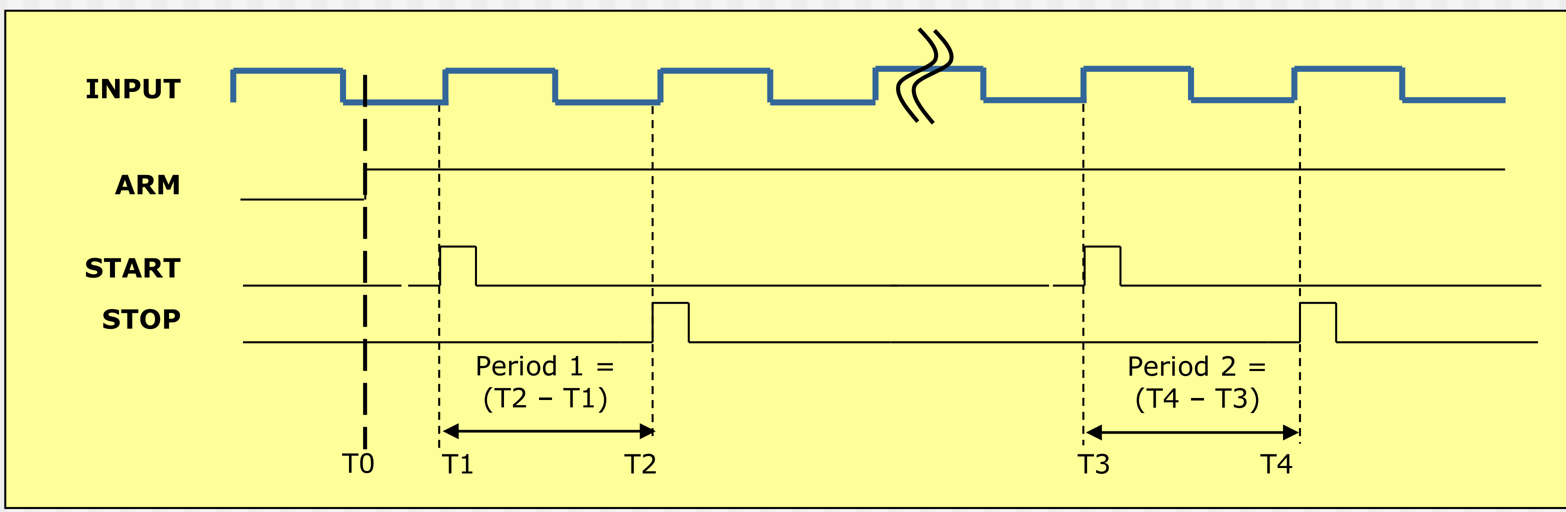
Jitter Test

Using Single Period Measurement Mode

Jitter = change in period over time





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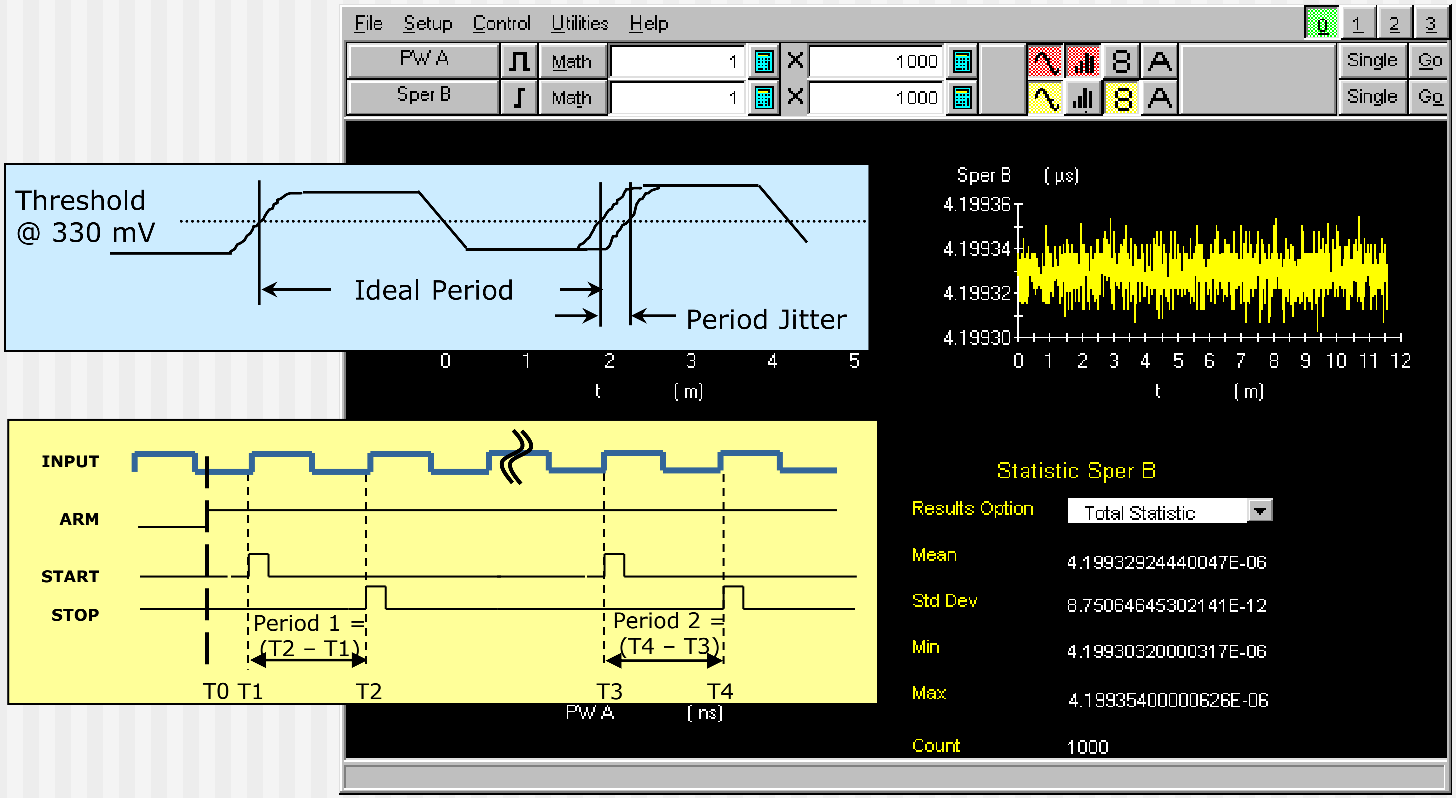
Jitter Test

Using Single Period Measurement Mode

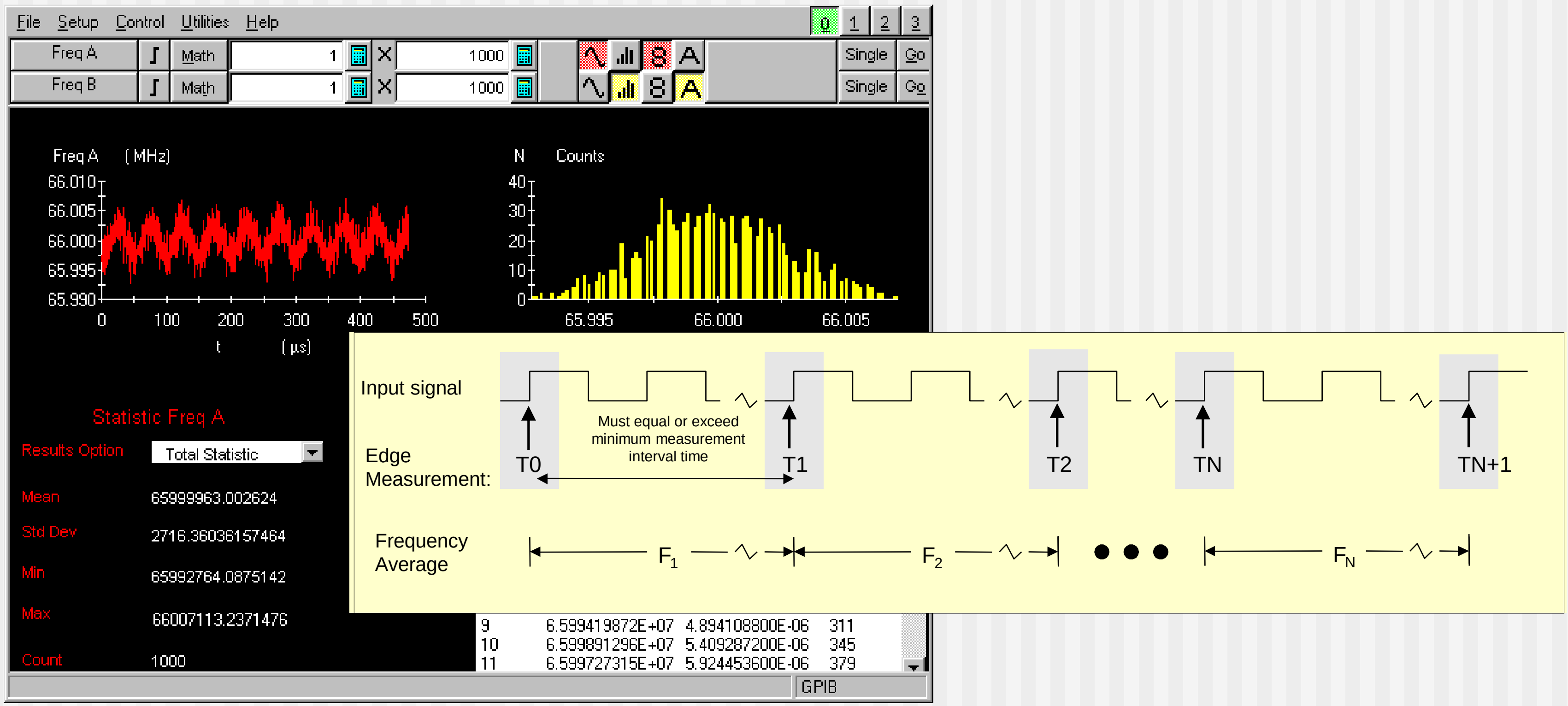


Jitter = STANDARD DEVIATION of Single Period Measurement

February 2000

Frequency Test

Using Frequency Average Measurement Mode



Frequency = MEAN of the Frequency Average Measurement

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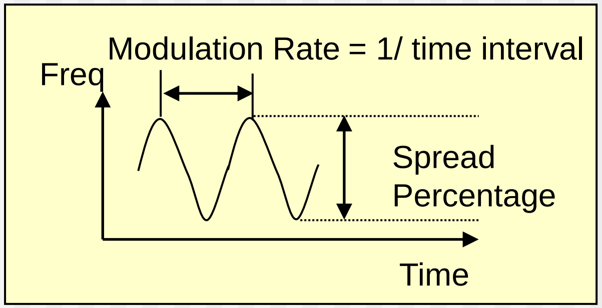
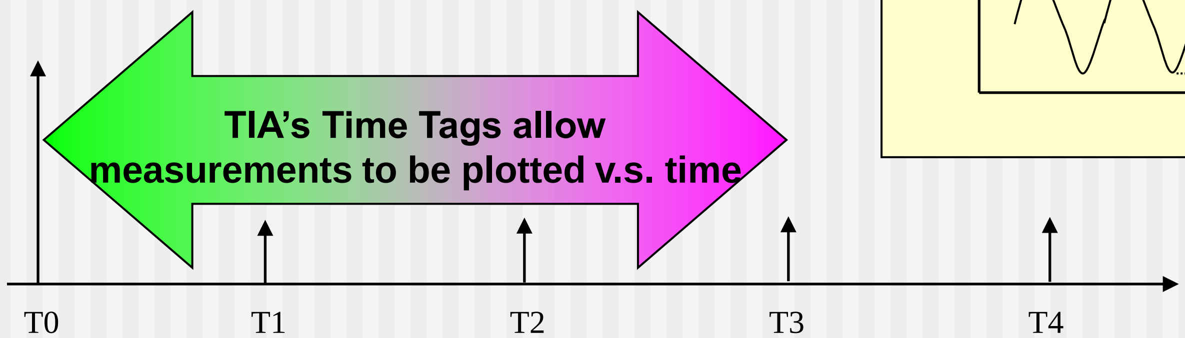
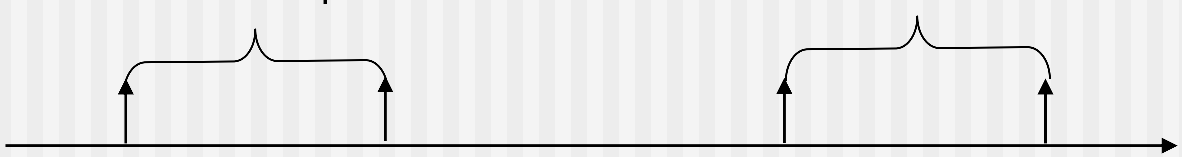
TIA Measurement Theory

Frequency Modulation Measurement Example





Time Counters provide Time Interval values with no reference to time

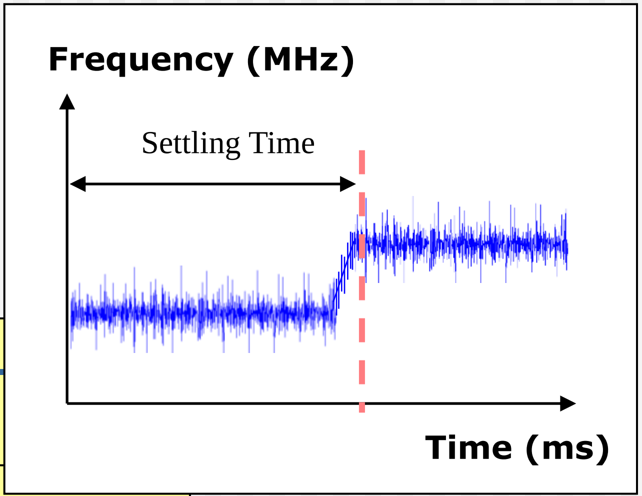


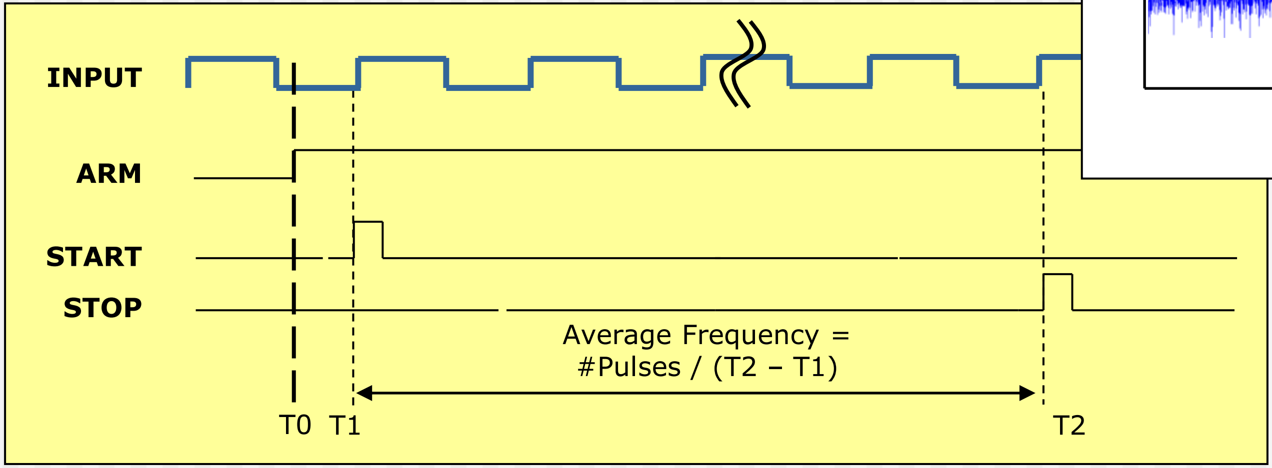
Frequency Settling Time Test

Using Frequency Measurement Mode, Ext ARM

Set an EXTERNAL ARM to trigger a Frequency measurement at the time of a change in the PLL input frequency.

Frequency Settling Time is calculated by searching the measurement result data array for the time when the MEAN values of the Frequency measurement result array corresponds with the final frequency expected.





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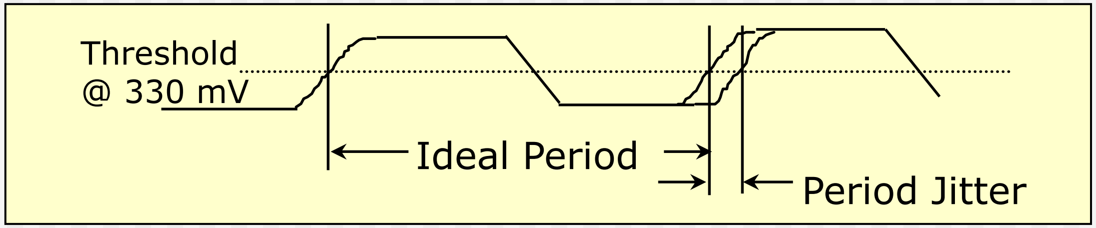
Short-Term Jitter Test
Using Single Period Measurement Mode

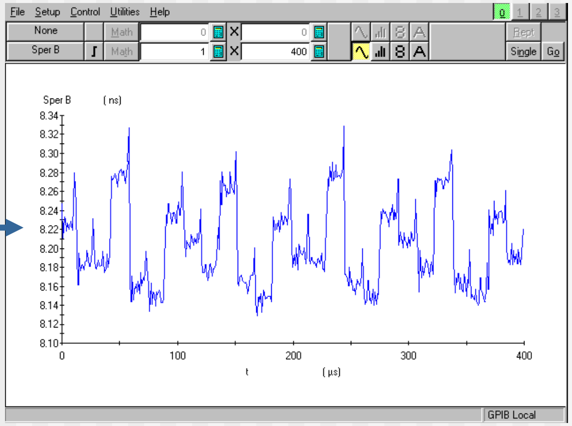
Objective: Verify the amount of deviation of clock output edges from the ideal position (i.e. the amount of *deviation* from the *ideal period*) on the PLL output

TIA Measurement Mode: Single Period

Period Jitter = Standard Deviation of Single Period measurement



8.22nS



Cycle Time: 8.22ns (+ jitter)

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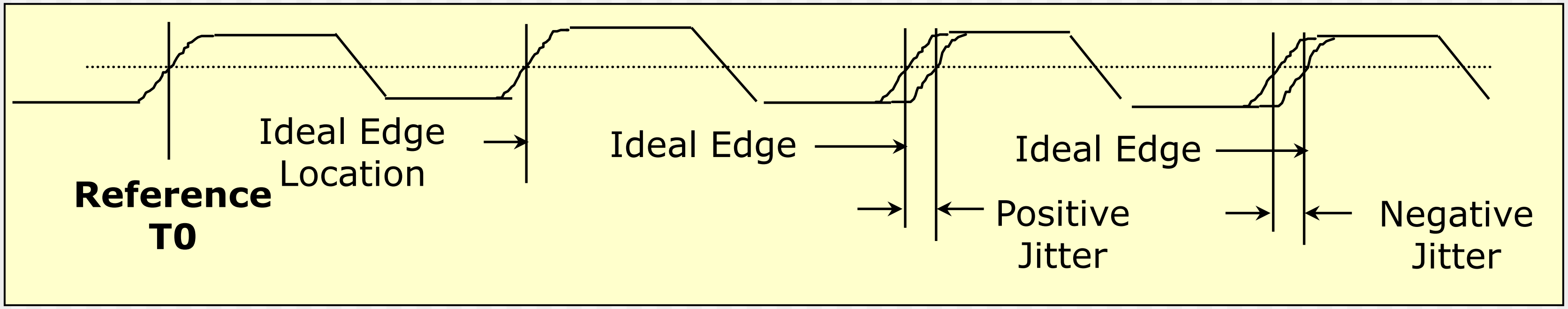
Long-Term Jitter Test

Using Time Interval Error Measurement Mode

Objective: Verify the amount of deviation of clock output edges over many cycles from the ideal position at reference time T0 (i.e. the amount of *deviation* from the *ideal edge location over a long period of time*) on the PLL output

TIA Measurement Mode: Time Interval Error (TIE)

Long-Term Jitter = Standard Deviation of TIE measurement



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Single-Edge Measurement Modes
Introduction

Single-edge measurements:

- Require only a single input signal (e.g. Channel A or Channel B)
- Use only one edge (e.g. A0 or B0)

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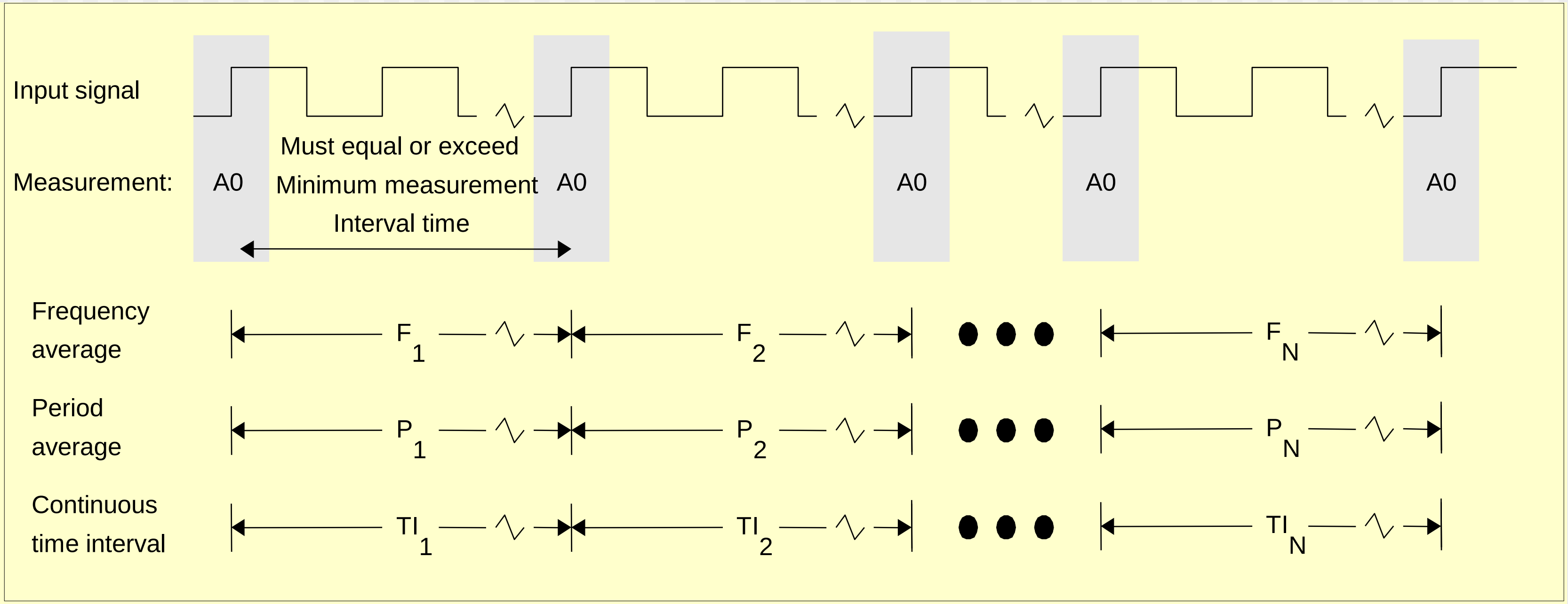
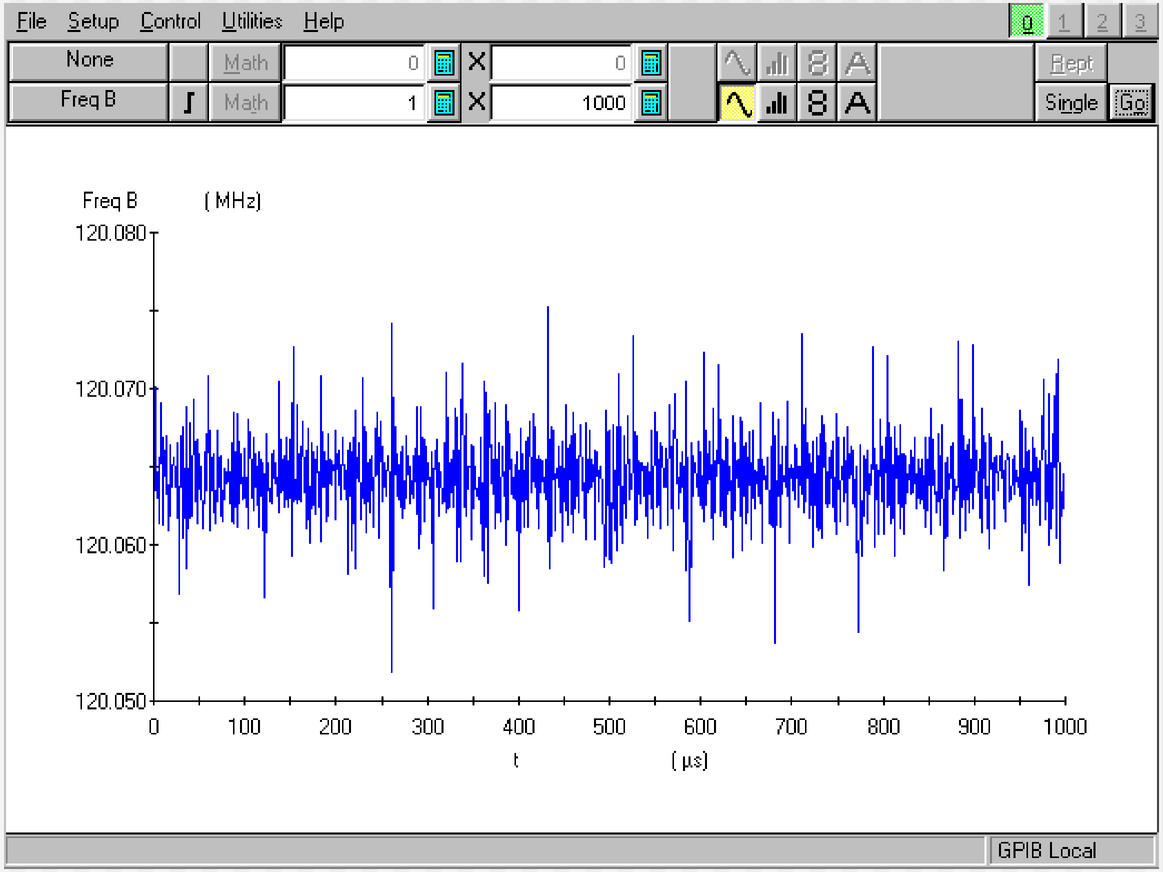
Single-Edge Measurement Modes
Frequency Averaging



Single-Edge Measurement Modes
Frequency Averaging



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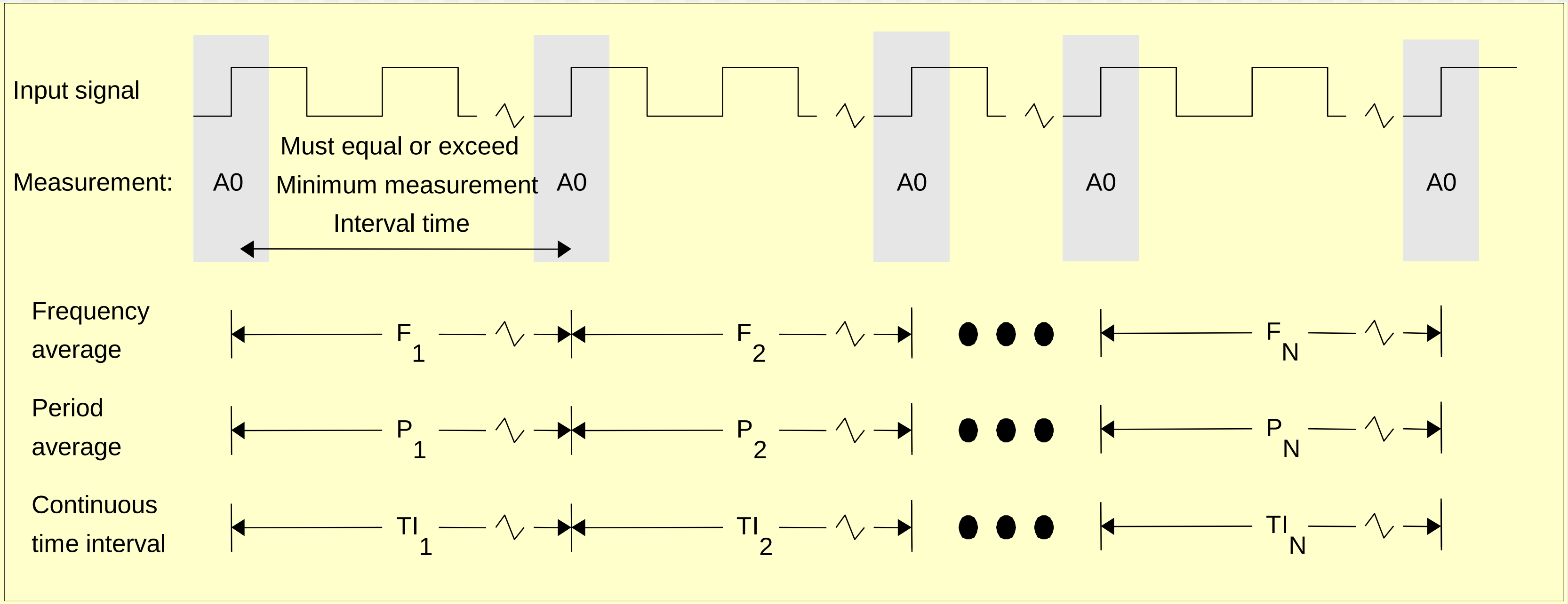
Single-Edge Measurement Modes
Period Averaging



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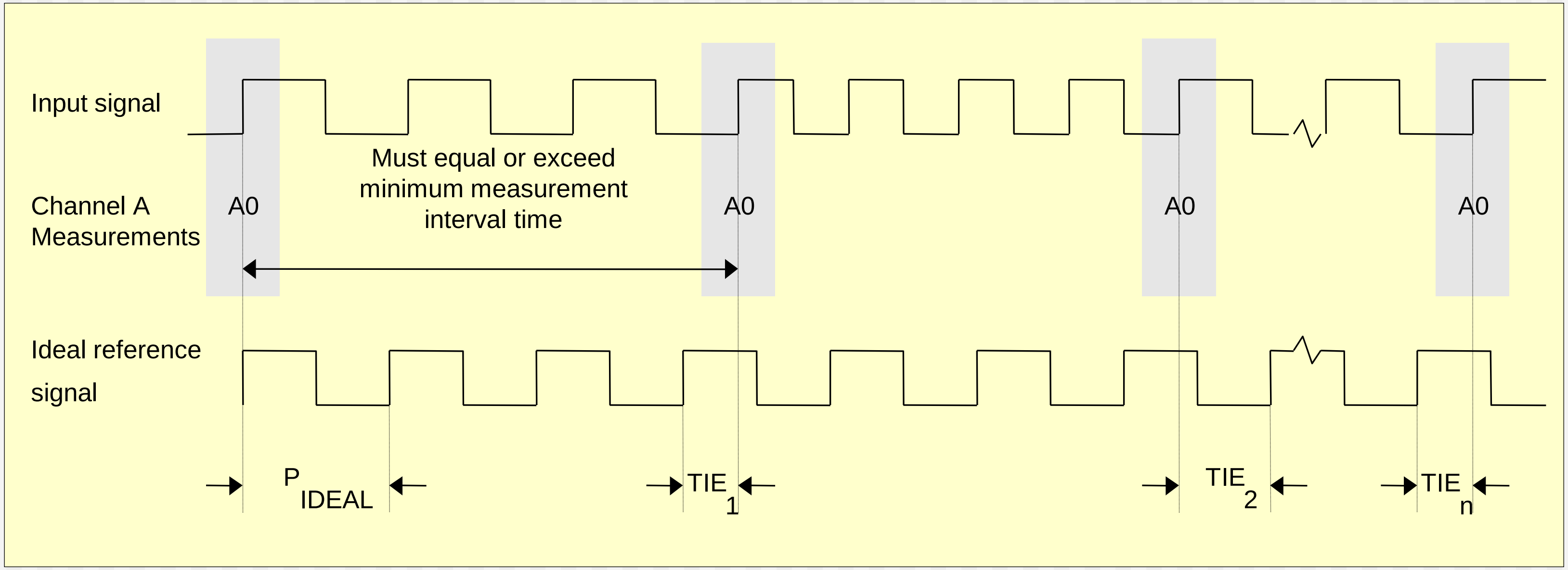
Single-Edge Measurement Modes
Time Interval Error (TIE)



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Two-Edge Measurement Modes
Introduction

Single-edge measurements have a fundamental limitation:

The minimum time between successive single-edge measurements is limited by the edge measurement circuit recovery time.

By using two edge measurement circuits, the time measurement between close successive edges can be dramatically reduced.

Two-edge measurements can measure very small intervals:

- Require two edge measurements (e.g. A0 & A1, A0 & B0 or B0 & B1)
- Two edges can be measured on a single channel (e.g. A0 & A1)
- Two edges can be measured between two different channels (e.g. A0 & B0)

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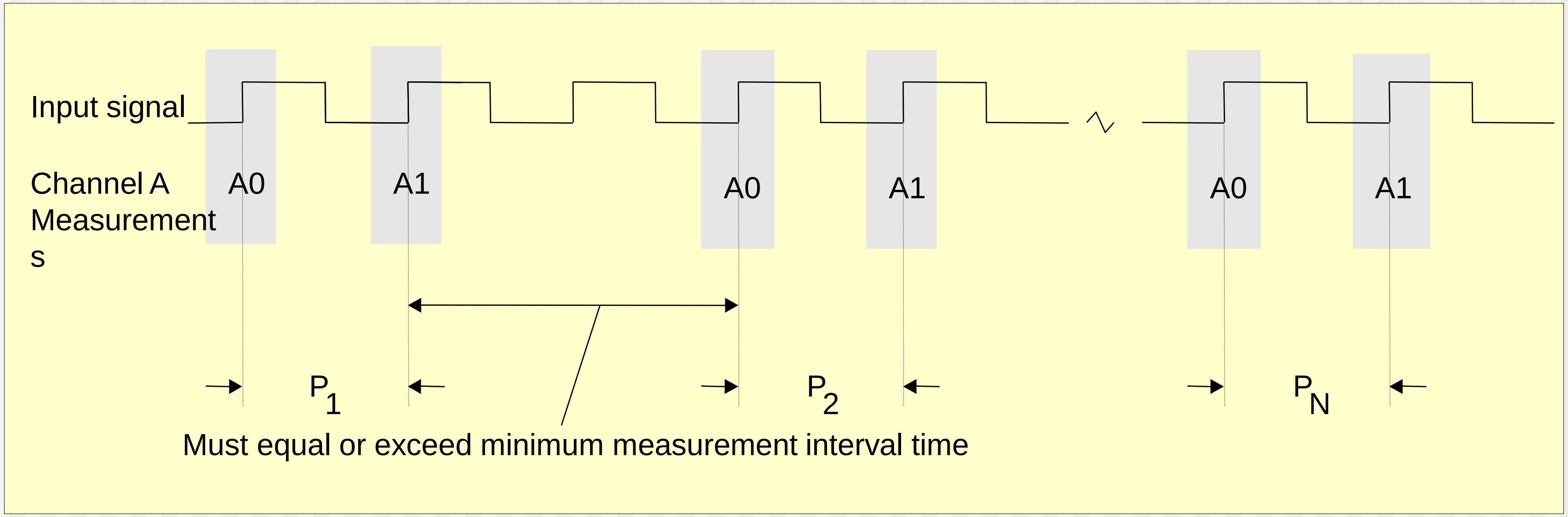
Two-Edge Measurement Modes
Single Period



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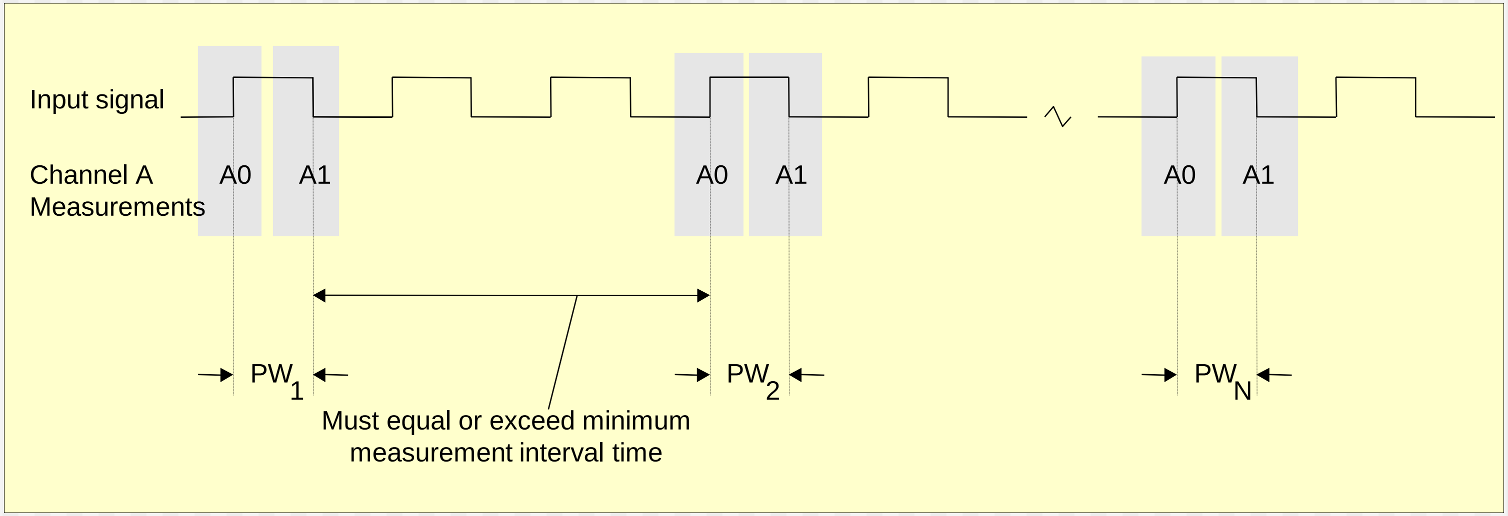
Two-Edge Measurement Modes
Pulse Width (PW)



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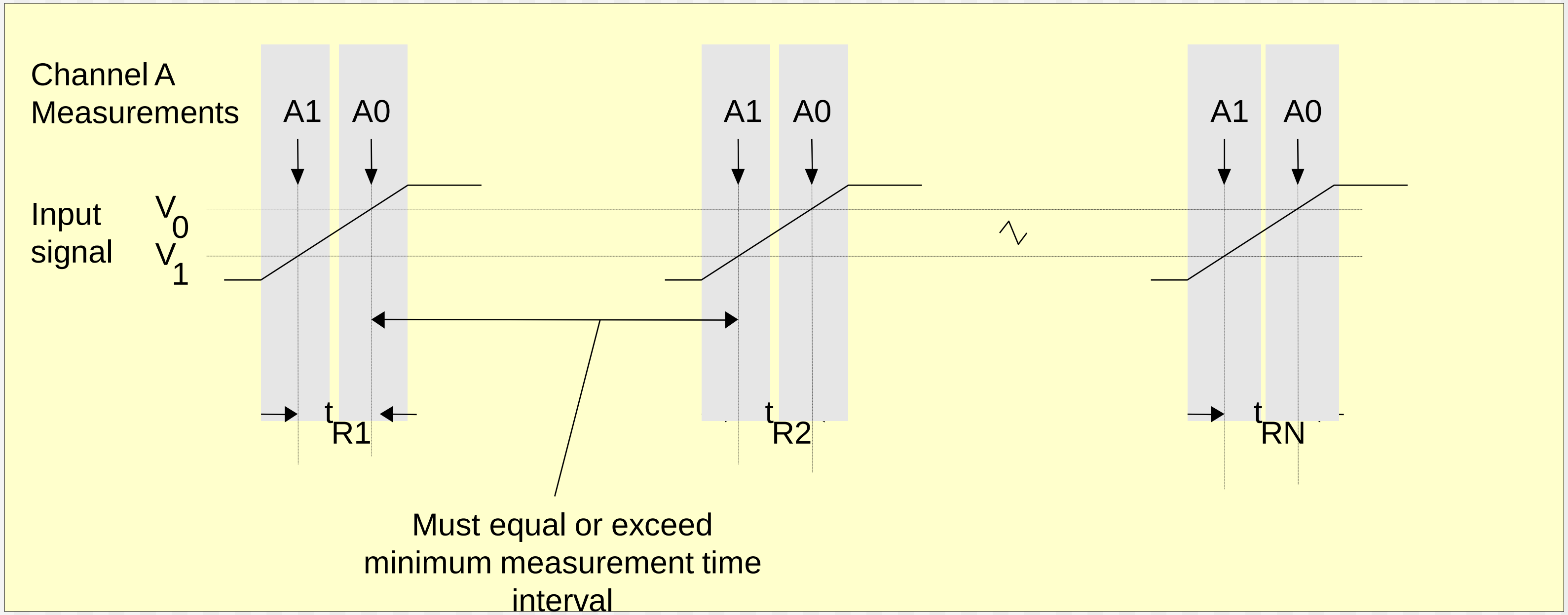
Two-Edge Measurement Modes

Risetime / Falltime



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Two-Edge Measurement Modes
Time Interval (Single-Channel)

Time Interval (Single-channel) – This two-edge measurement mode is a more general form of the single-period, single-pulse-width, and Rise Time/Fall Time measurement modes above. In this mode, the time intervals between pairs of events on an input channel are reported, but with flexible arming of several types:

- Each measurement event can be armed by an external arming signal
- The second measurement event of each pair can be armed with the divide-by-N counter, so that the instrument measures the time between N events. If, for example, the measured events are rising edges, the instrument could measure the distance between a rising edge and the N^{th} subsequent rising edge
- Arming of the types used in the single-period, single-pulse-width, or Risetime/Falltime measurements

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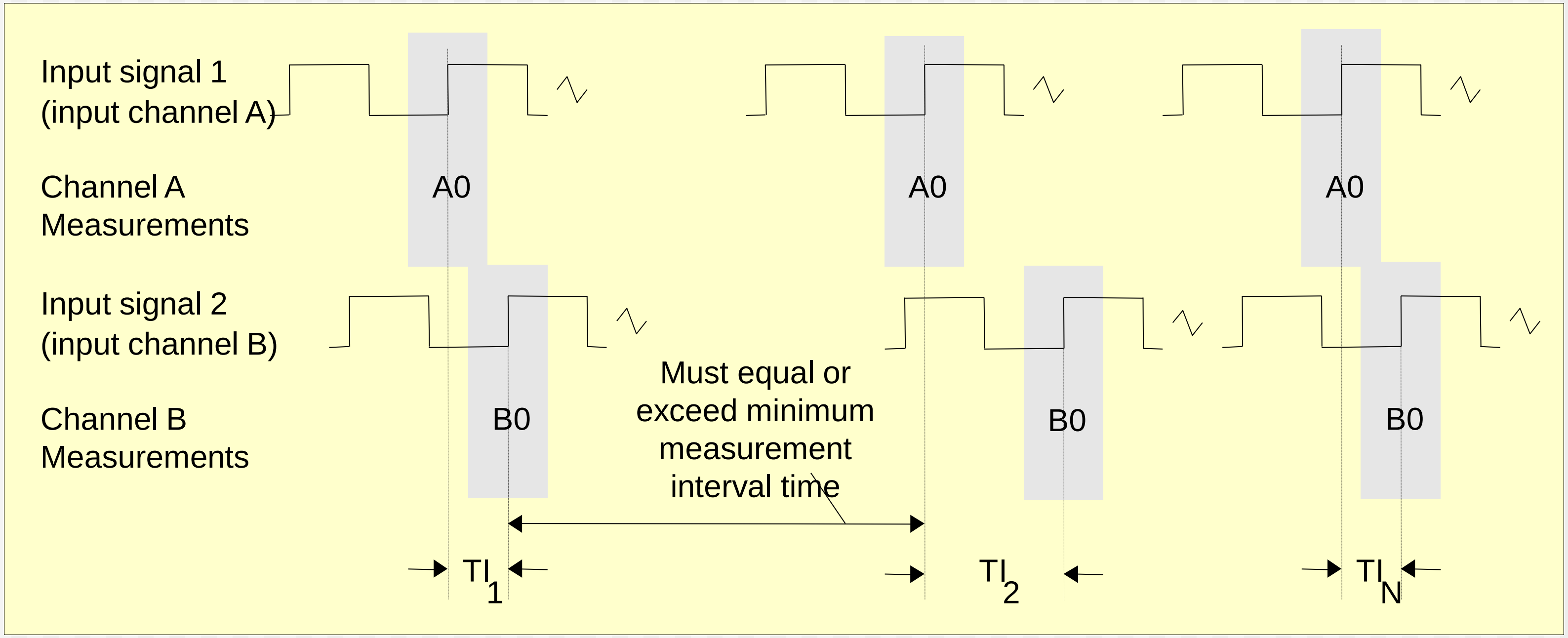
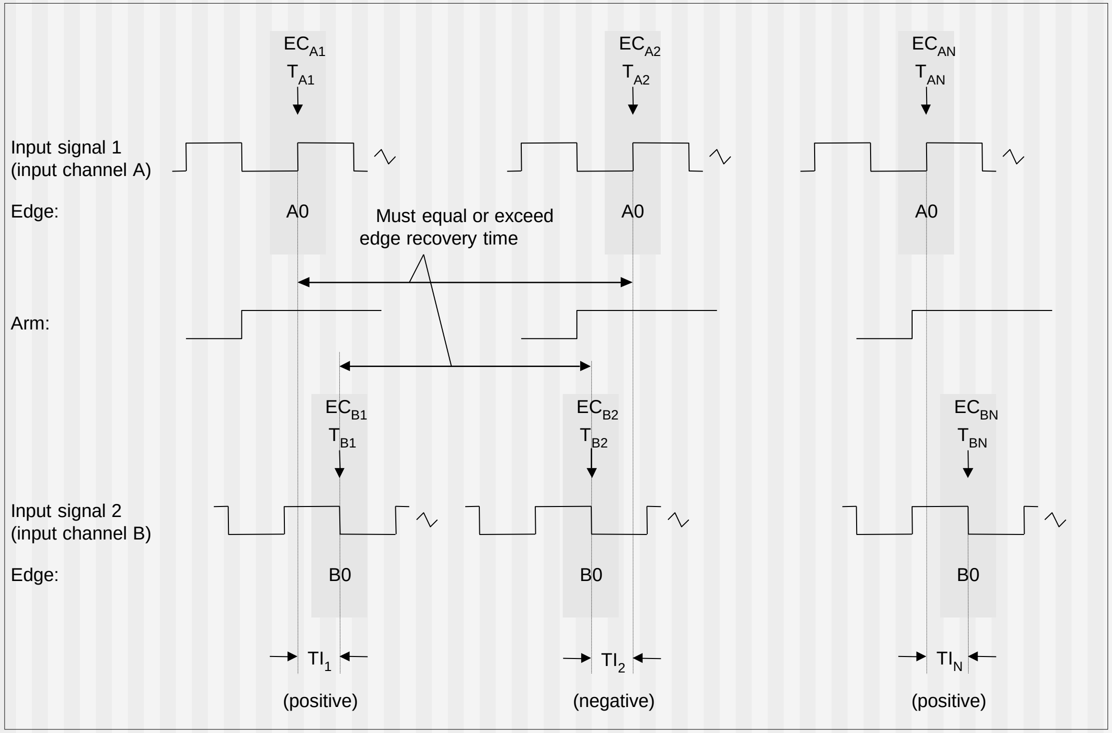
Two-Edge Measurement Modes
Time Interval (Two-Channel)



Two-Edge Measurement Modes

+/- Time Interval

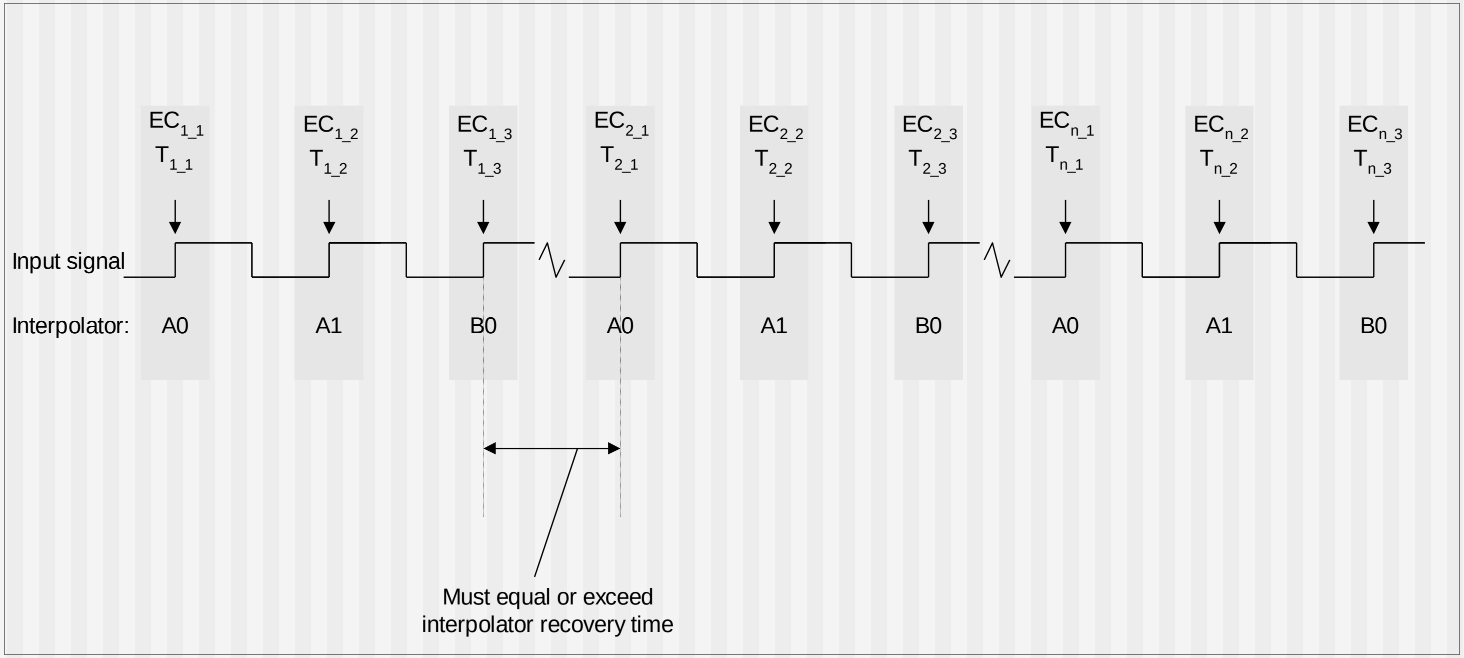


$$TI_n = T_{Bn} - T_{An}\ , \quad n=1..N \qquad \text{(for TI Ch\_A to Ch\_B)}$$

where T_{An} are the time measurements for the input signal on input channel A and T_{Bn} are the time measurements for the input signal on input channel B

Three-Edge Measurement Mode

Cycle-to-Cycle (ΔP)

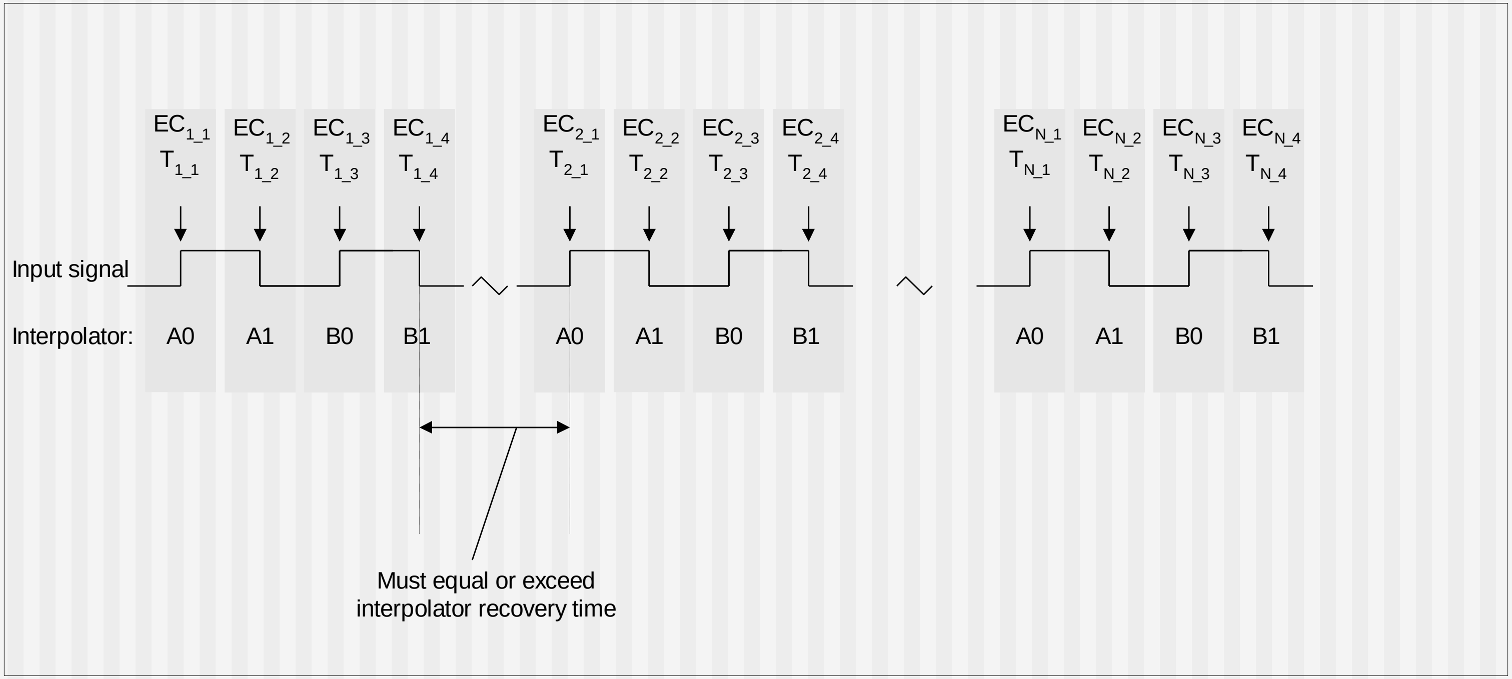


$$\Delta P_n = (T_{n\_3} - T_{n\_2}) - (T_{n\_2} - T_{n\_1}), \quad n = 1..N$$
$$= T_{n\_3} - 2T_{n\_2} + T_{n\_1}$$

where T_{n_1}, T_{n_2}, and T_{n_3} are the times of the first, second, and third edge measurements.

Four-Edge Measurement Mode

Pulse-Width-to-Pulse-Width (ΔPW)



$$\Delta PW_n = (T_{n\_4} - T_{n\_3}) - (T_{n\_2} - T_{n\_1}), \quad n = 1..N$$

where T_{n_1}, T_{n_2}, T_{n_3}, and T_{n_4} are the times of the first, second, third, and fourth edge measurements.

The University of Texas at Austin
Oden Institute for Computational Engineering and Sciences

Geosynchronous LRA performance analysis with NP data

Daniel Kucharski[1], David A. Arnold[2]

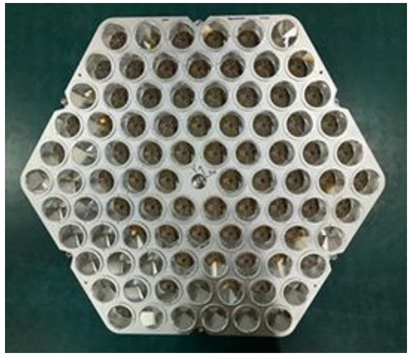
[1]The University of Texas at Austin, TX
[2]Smithsonian Astrophysical Observatory, Cambridge, MA (retired)

NESC, July 7, 2022

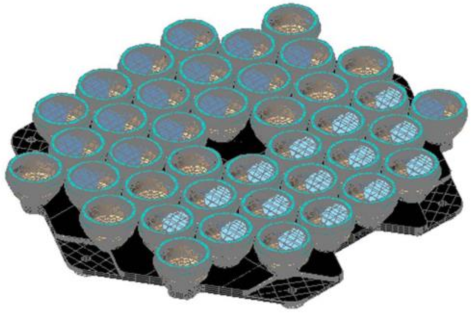
GEO SLR: satellites

Mission	Satellites (18)	Orbit altitude [km]	Orbit inclination	Data	LRA
ETS-8	1	36,000	0°	Legacy NP data (pre-CRD)	Planar, 36 CCRs, 1.6" (41 mm)
COMPASS	5: G1, I3, I5, I6B, IS1	35,680-35,790	55.5°	NP CRD	Hexagonal, 90 CCRs, 1.5" (38 mm)
IRNSS	7: 1A, 1B, 1C, 1D, 1E, 1F, 1I	35,790-42,290	5°, 29.5°, 30°	NP CRD	Hexagonal, 40 CCRs, 1.5" (38 mm)
QZSS	5: 1, 2, 3, 4, 1R	32,000-40,000, 36,000	0°, 45°	NP CRD	Planar, 56 CCRs, 1.6" (41 mm)

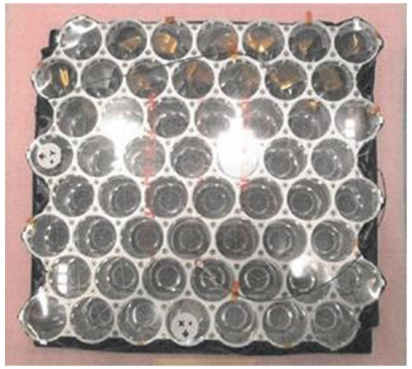
ETS-8 (JAXA)



COMPASS
(Chinese Academy of Sciences)

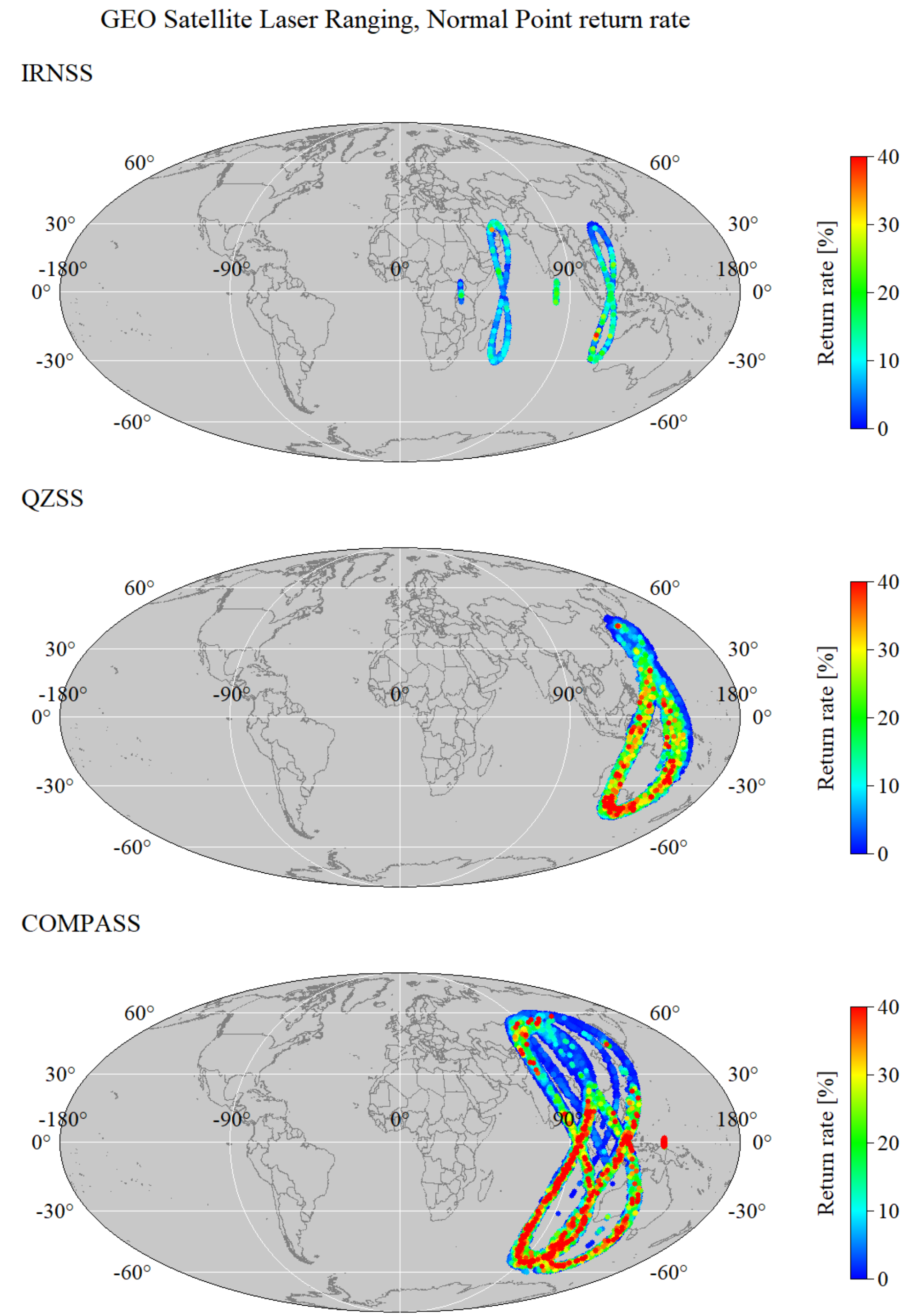


IRNSS (ISRO)



QZSS (JAXA)

GEO SLR: NP data



Earth-fixed (ECEF) distribution of NP CRD, color coded by return rate.

The NP data of GEO-synchronous satellites can be analyzed in Sun-Earth-satellite frame with respect to the argument of satellite latitude Δu and the elongation angle ε.

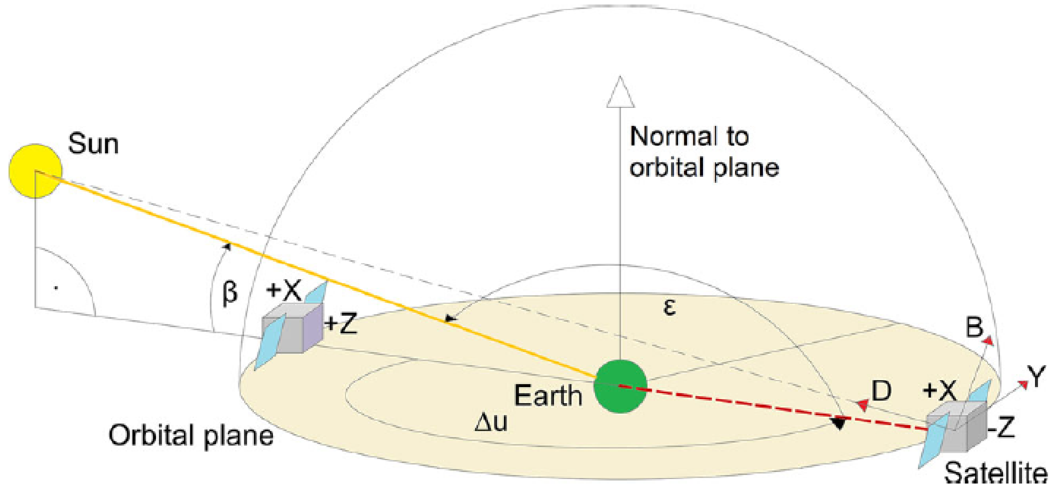
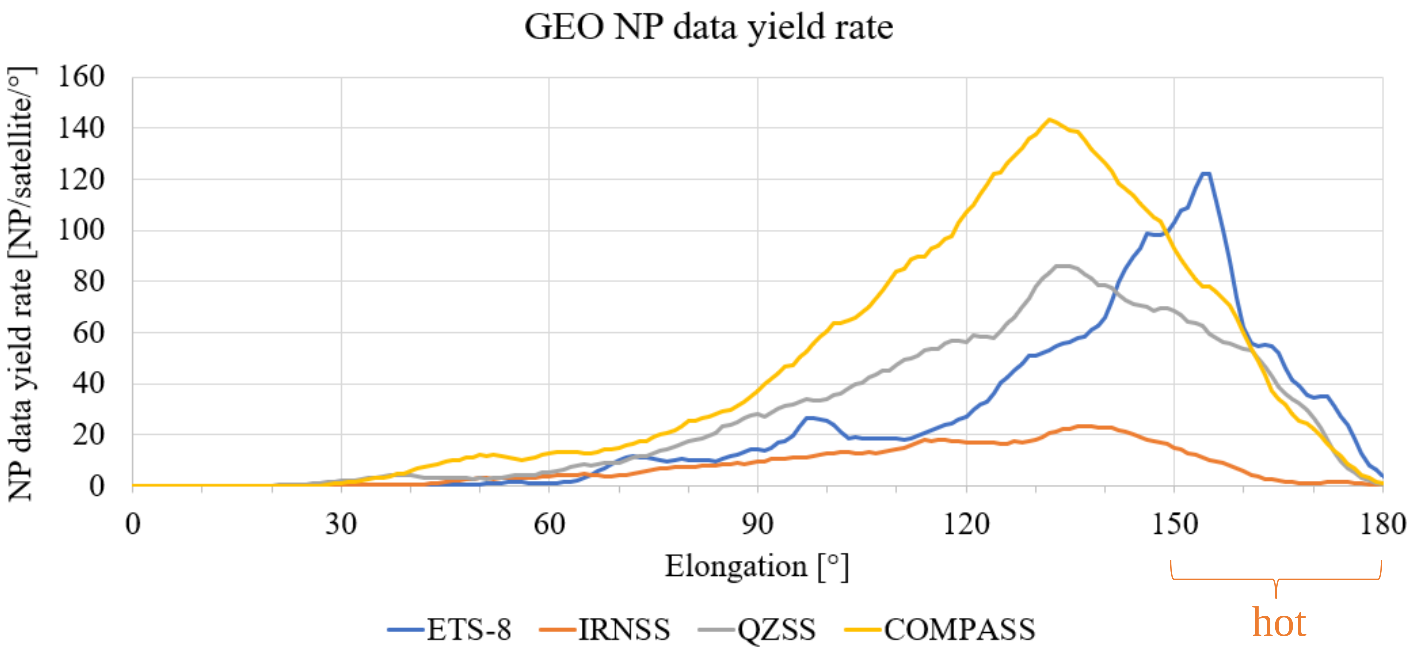


Fig. 2 Sun–Earth–satellite reference frame showing the elevation angle of the Sun over orbital plane β, argument of satellite latitude with respect to the Sun Δu and the elongation angle ε

Ref: Validation of Galileo orbits using SLR with a focus on satellites launched into incorrect orbital planes, Sosnica et al., 2017.

GEO SLR: NP data yield rate comparison



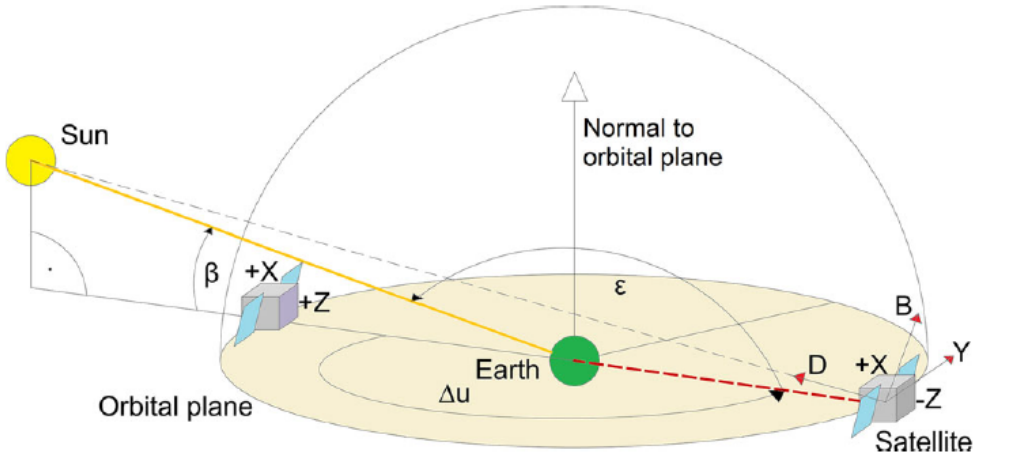


Fig. 2 Sun–Earth–satellite reference frame showing the elevation angle of the Sun over orbital plane β, argument of satellite latitude with respect to the Sun Δu and the elongation angle ε

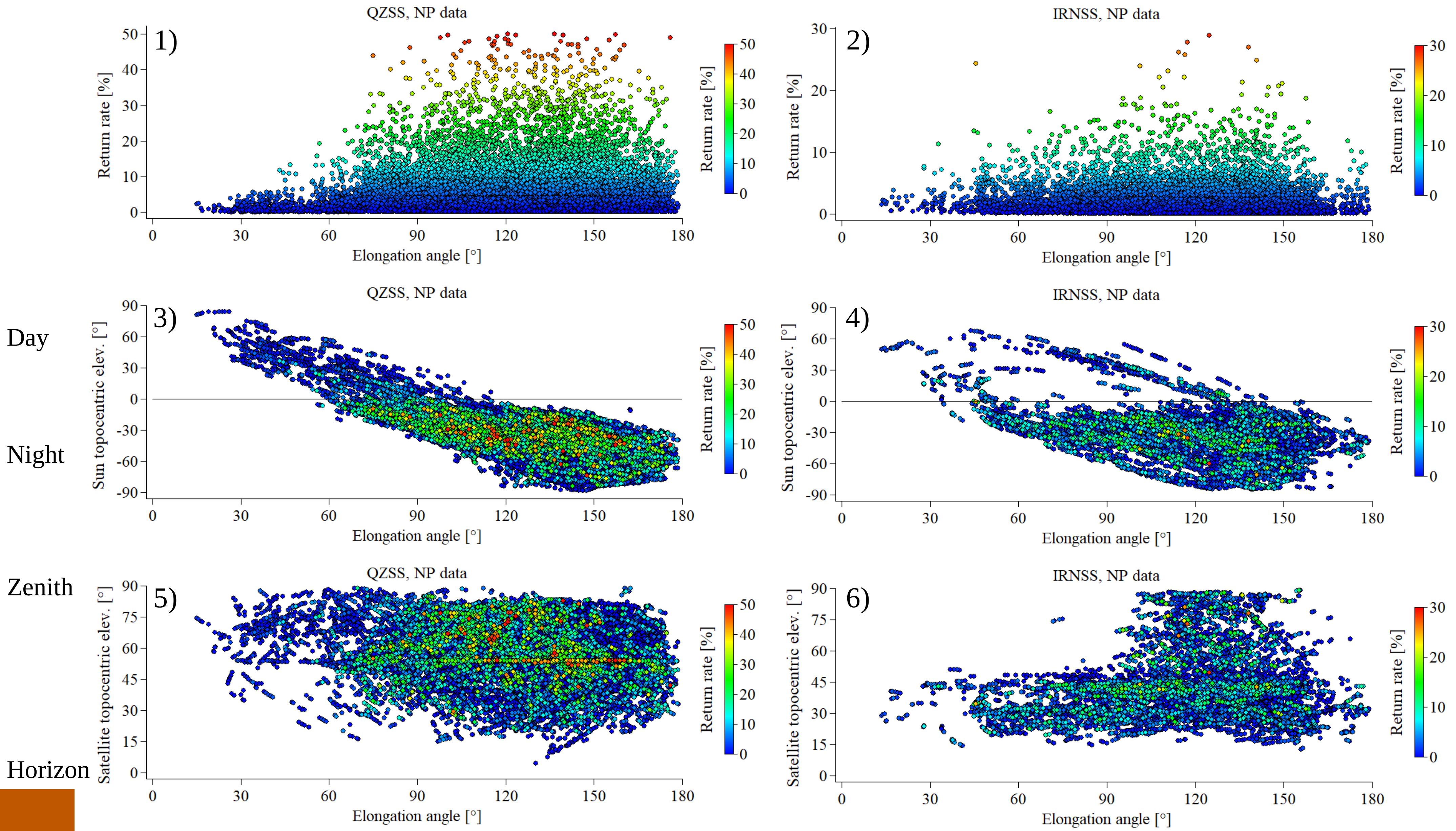
Ref: Validation of Galileo orbits using SLR with a focus on satellites launched into incorrect orbital planes, Sosnica et al., 2017.

Moving average trends represent number of NPs collected at different elongation angles.

The orbits are slightly different, but the IRNSS trend significantly deviates from the group – especially at high elongation angles where the retroreflectors are facing the Sun.

GEO SLR, NP distribution – a closer look

How does the elongation angle ε relate to day/night time tracking?



Orbital inclinations:
QZSS: 0°, 45 °
IRNSS: 5°, 29.5°, 30°

IRNSS satellites spend 3%-5% of their yearly orbital time at the elongation angles >160°.

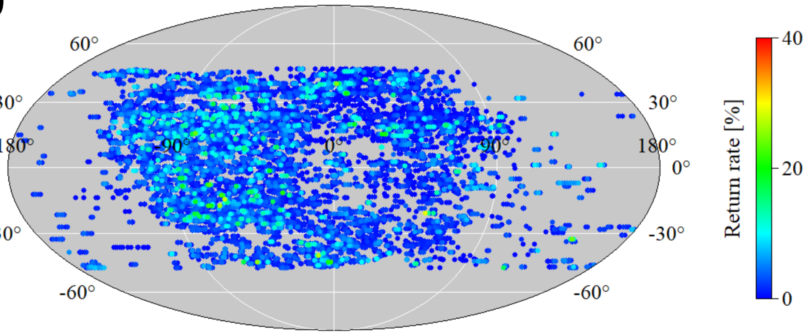
GEO SLR: NP v Sun vector

NP Return Rate

Solar power at CCR front face

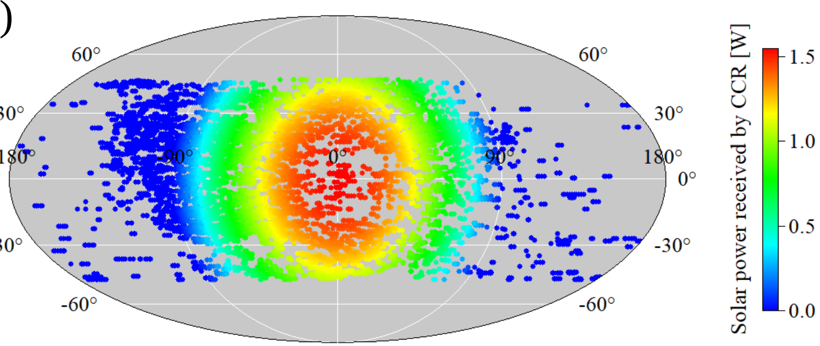
IRNSS, (Δu+180°, β)

1)



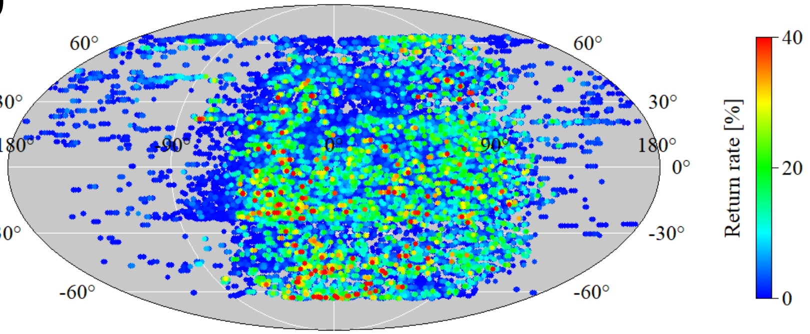
IRNSS, (Δu+180°, β)

2)



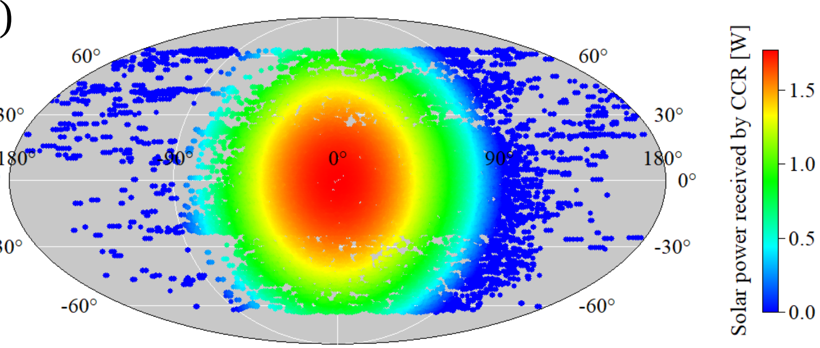
QZSS, (Δu+180°, β)

3)



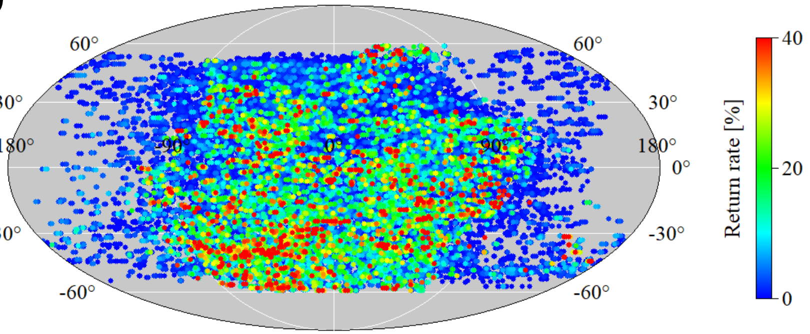
QZSS, (Δu+180°, β)

4)



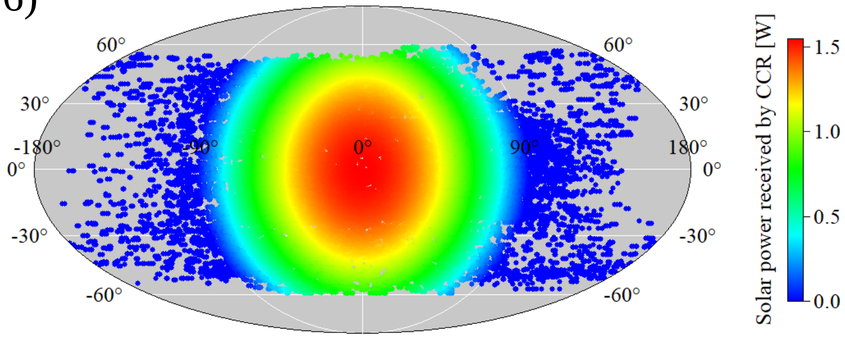
COMPASS, (Δu+180°, β)

5)



COMPASS, (Δu+180°, β)

6)



NPs are plotted at Sun vector coordinates of Δu+180°, β.

The origin (0°,0°) corresponds to the situation when the Sun is in normal direction of the LRA panel ("noon").

Solar power at CCR aperture is calculated as $P = S_0 A cos(\varphi)$, where S_0 is the solar constant, A is a CCR's front face area and φ is an incident angle between satellite-Sun direction vector and LRA normal ($0° \leq \varphi \leq 90°$).

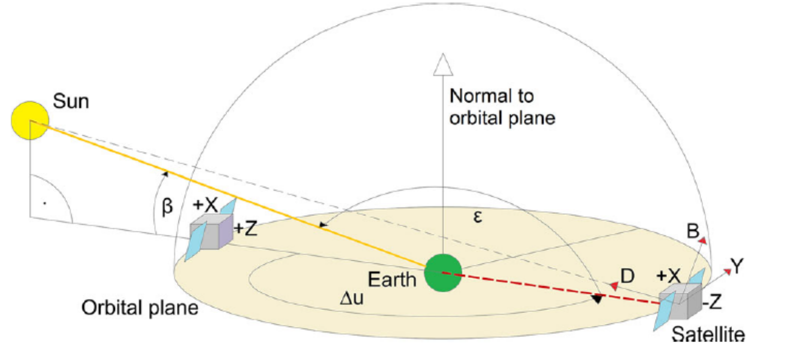


Fig. 2 Sun–Earth–satellite reference frame showing the elevation angle of the Sun over orbital plane β, argument of satellite latitude with respect to the Sun Δu and the elongation angle ε

Ref: Validation of Galileo orbits using SLR with a focus on satellites launched into incorrect orbital plane Sosnica et al., 2017.

IRNSS LRA: pre-launch thermo-optical tests at Frascati

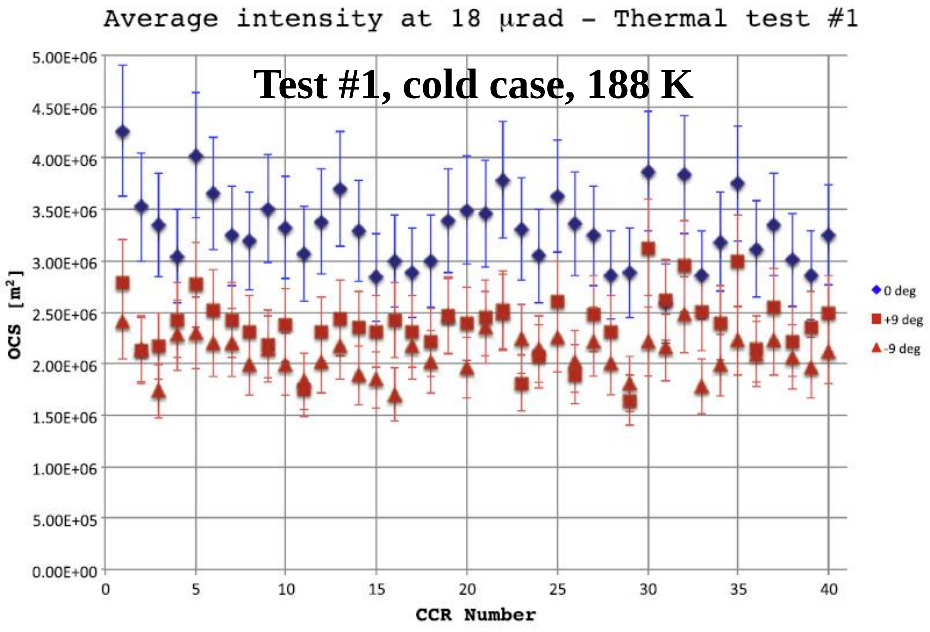


Fig. 5. Average intensities at 18 µrad for each IRNSS CCR for the *Thermal test #1*.

ELSEVIER
Advances in Space Research
Volume 60, Issue 5, 1 September 2017, Pages 1054-1061

Thermo-optical vacuum testing of IRNSS laser retroreflector array qualification model

L. Porcelli [a], A. Boni [a], E. Ciocci [a], S. Contessa [a], S. Dell'Agnello [a], G. Delle Monache [a], N. Intaglietta [a], M. Martini [a], C. Mondaini [a], G. Patrizi [a], L. Salvatori [a], M. Tibuzzi [a], C. Lops [a], C. Cantone [a], P. Tuscano [a], M. Maiello [a], R. Venkateswaran [b], P. Chakraborty [b], C.V. Ramana Reddy [b], K.V. Sriram [b]

[a] Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali di Frascati (INFN-LNF), Via E. Fermi 40, 00044 Frascati, Rome, Italy

[b] Indian Space Research Organisation – Laboratory for Electro-Optics Systems (ISRO-LEOS), First Cross, First Phase, Peenya Industrial Estate, Bangalore 560 058, India

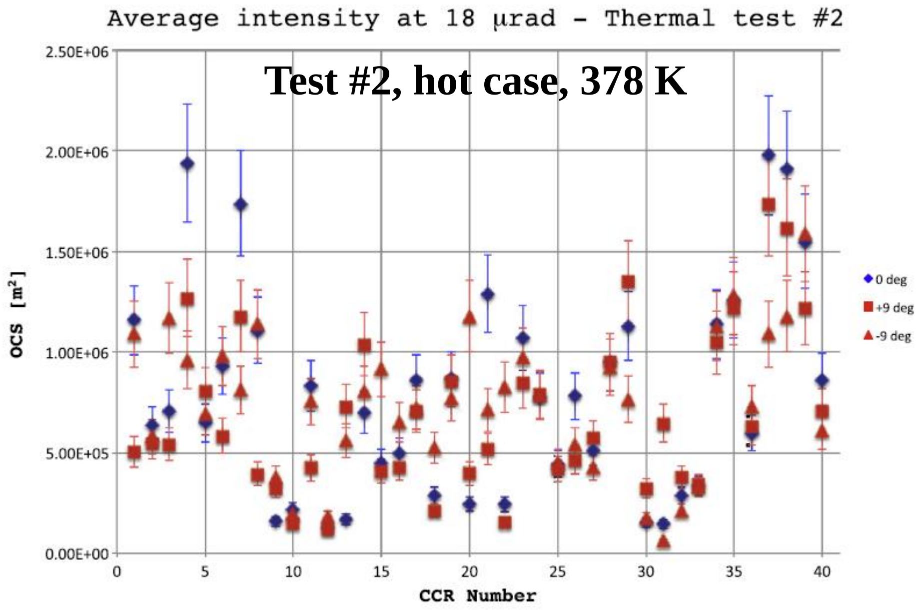


Fig. 6. Average intensities at 18 µrad for each IRNSS CCR for the *Thermal test #2*.

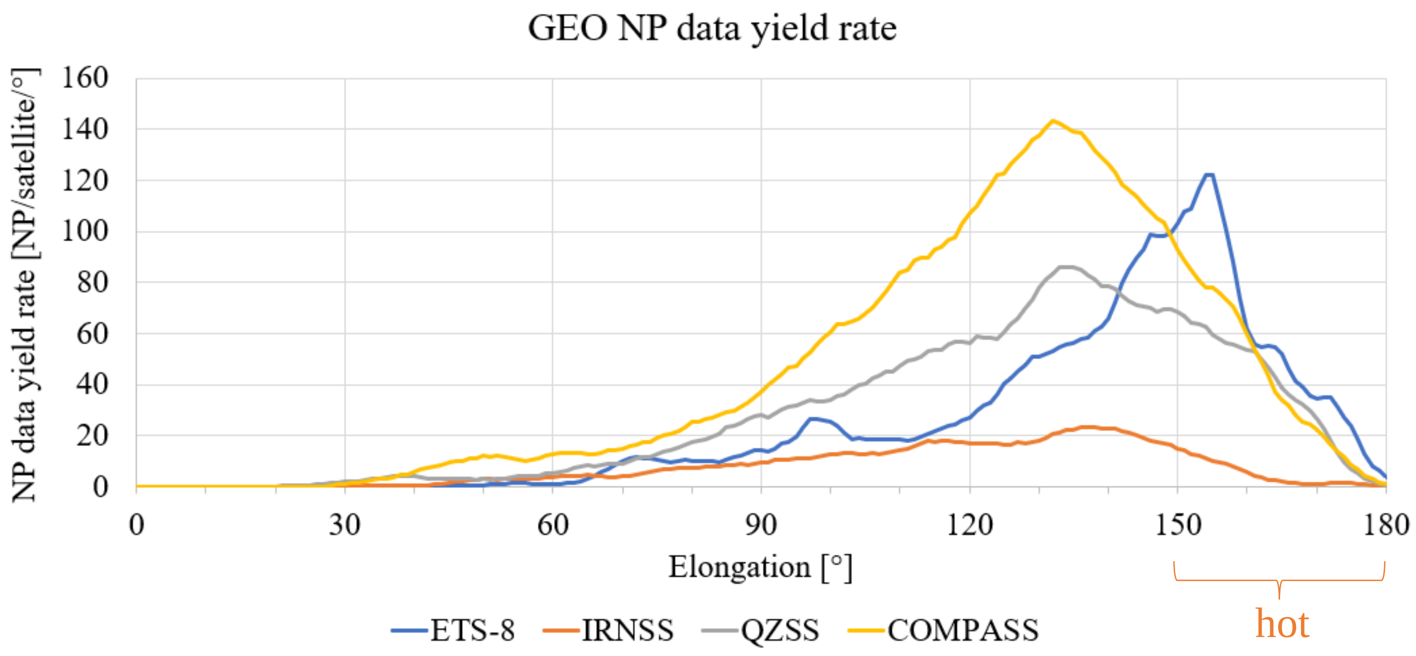
Test #1: "cold case" in vacuum at 188 K (-85 C, -121 F), w/o solar simulator illumination. Thermal gradients inside the solid CCRs are contained and retroreflection is highly efficient.

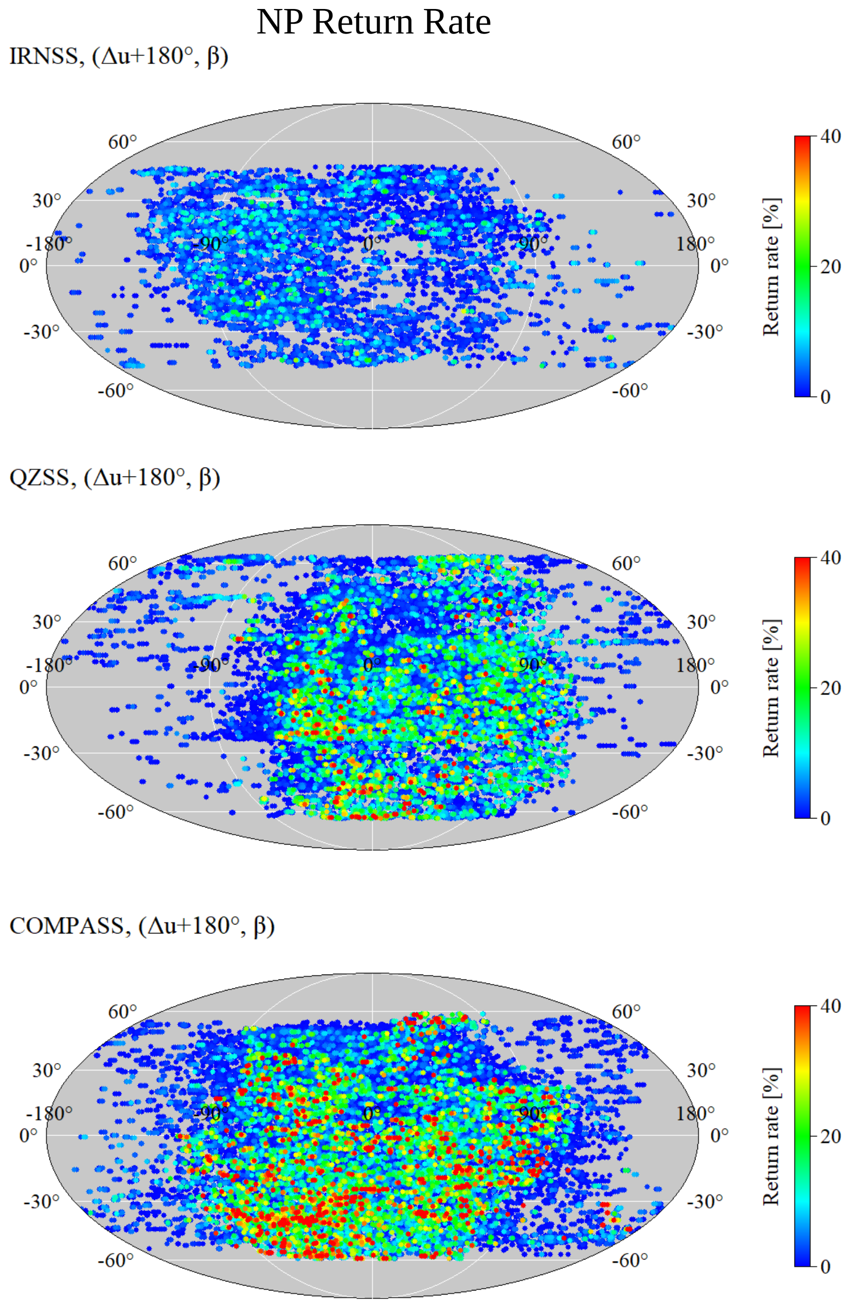
Test #2: "hot case" in vacuum at 378 K (105 C, 221 F), w/o solar simulator illumination. OCS decreases significantly when the CCRs are hot. FFDPs are highly deformed. This "hot case" is the worst-case scenario for IRNSS LRA operations.

Another paper reports on "thermal breakthrough" effect that can occur at specific orientations of the CCRs with respect to the direction of incoming solar flux. In such cases the total internal reflection is broken as rays of sunlight pass through the glassy cubes and heat up the internal surfaces of the housing.
For uncoated CCRs this effect can occur at the Sun incident angles above 17° with respect to the cube's optical axis.

Conclusions/remarks

- High temperature causes thermal gradients within the solid retroreflectors. The thermal gradients cause the distortion of the FFDP that weakens Optical Cross Section of an LRA. Additionally, loss of total internal reflection causes thermal breakthrough at specific incidence angles of the incoming solar flux.
- The thermo-optical LRA design of ETS-8 (by David Arnold) leads in the hot-zone of high elongation angles.
- The NP data indicates relatively low performance of IRNSS LRAs, especially under the hot conditions when the retroreflectors are facing the Sun.





Station Barometric Comparisons using the Vienna Mapping Function (1993 to 2019: VMF3o_El)

Van S. Husson

vhusson@peraton.com

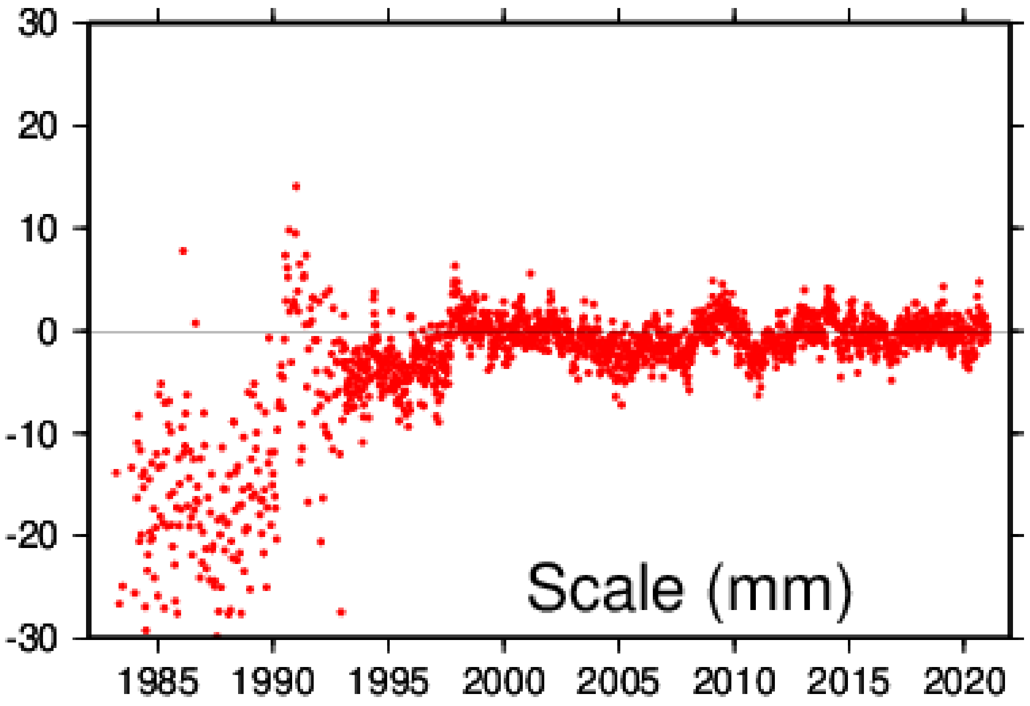
ILRS Network and Engineering Standing Committee Meeting

07-Jul-2022

Vienna Mapping Function (VMF)

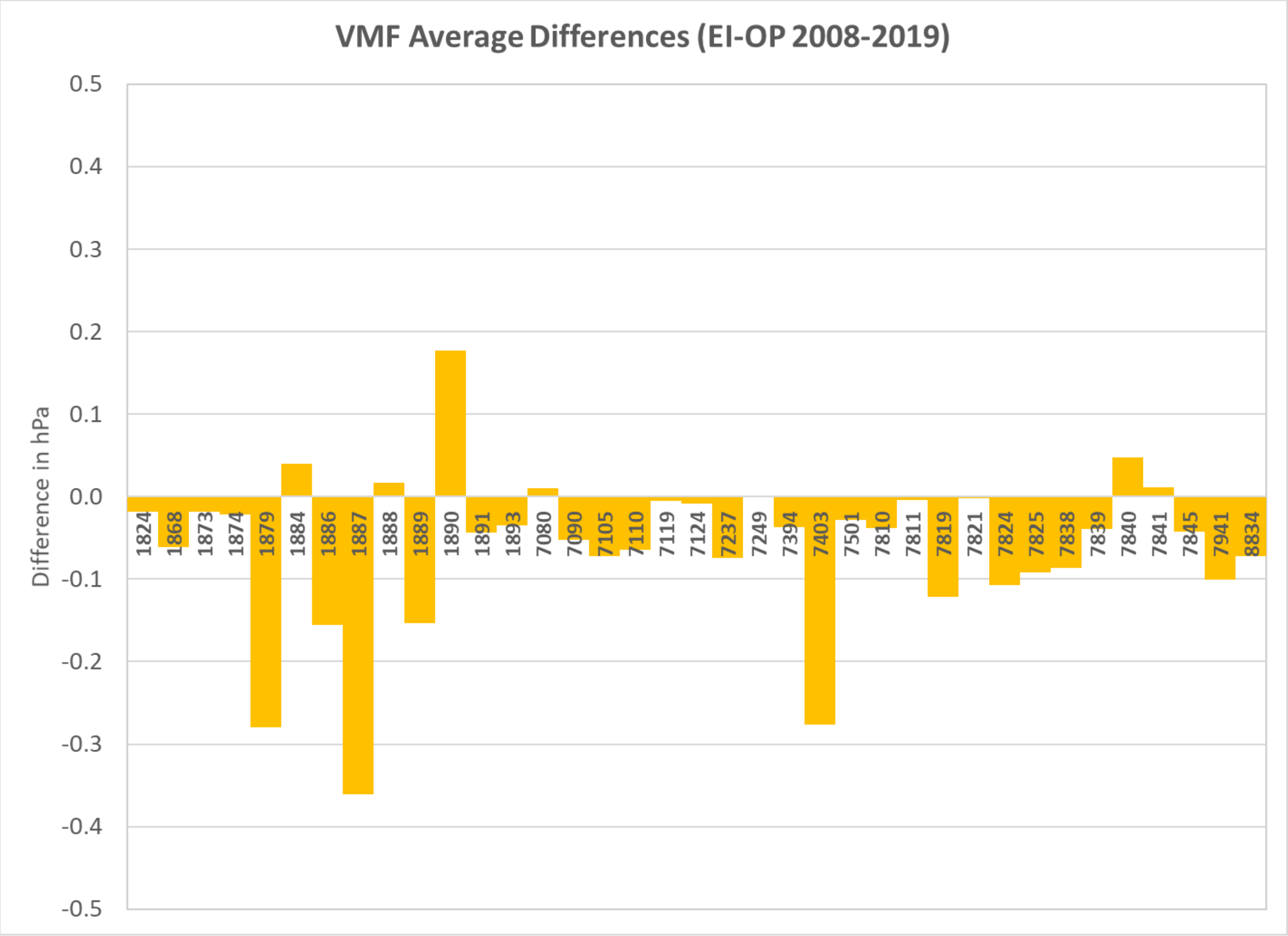
- **VMF Reference: re3data.org: VMF Data Server; editing status 2020-12-14; re3data.org - Registry of Research Data Repositories. http://doi.org/10.17616/R3RD2H**
- **VMF data is available on the VMF Data Server at https://vmf.geo.tuwien.ac.at/trop_products/SLR/VMF3o/VMF3o_EI/ and VMF Data Server (tuwien.ac.at)**
  - 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.
- **Note: Erricos mentioned caution using the operational data (VMF3o_OP) because it is not as accurate as the climate reanalysis (VMF3o_EI). He also cautioned that for sites near large bodies of water, the ray tracing technique is not as accurate.**

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 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 requirement can be derived:**
  - ➢ Absolute barometric accuracies better than 0.10 to 0.15 millibars dependent upon the site's minimum tracking elevation angle

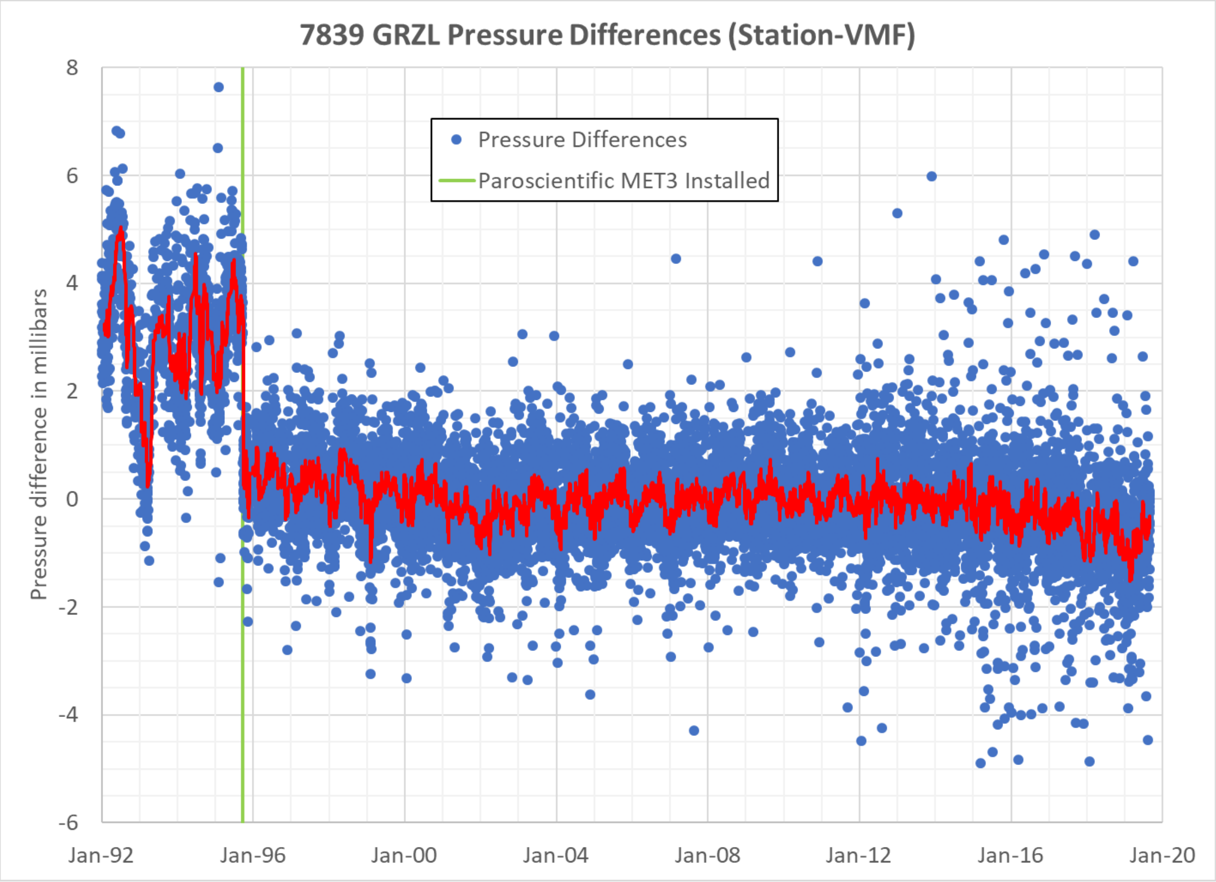
VMF System Characterization (EI versus OP)

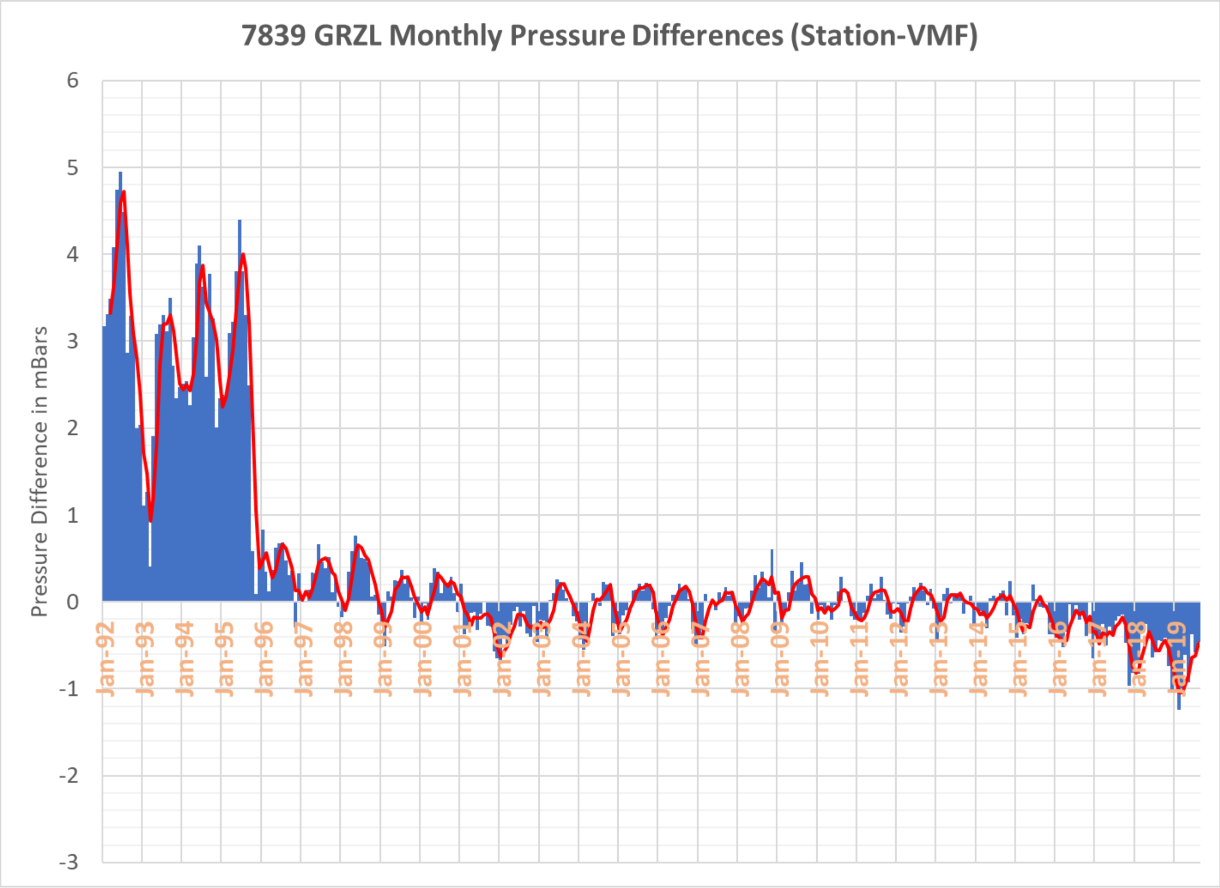


Mark	Location
1824	Golosiiv, Russia
1868	Komsomolsk-na-Amure, Russia
1873	Simeiz, Ukraine
1874	Mendeleevo, Russia
1879	Altay, Russia
1884	Riga, Latvia
1886	Arkhyz, Russia
1887	Baikonur, Kazakhstan
1888	Svetloe, Russia
1889	Zelenchukskya, Russia
1890	Badary, Russia
1891	Irkutsk, Russia
1893	Katzively, 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 VMF3o_EI and VMF3o_OP 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.**

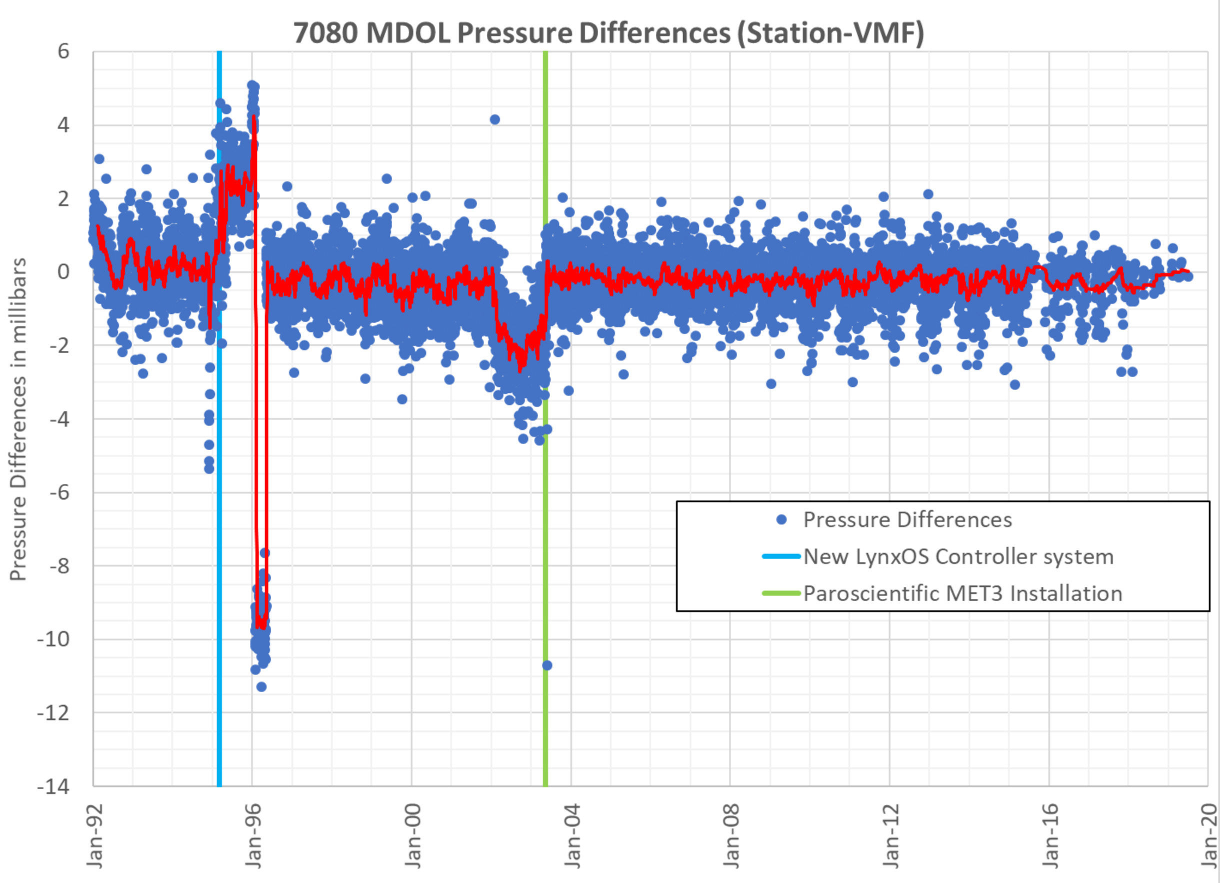
7839 GRZL Pressure Analysis

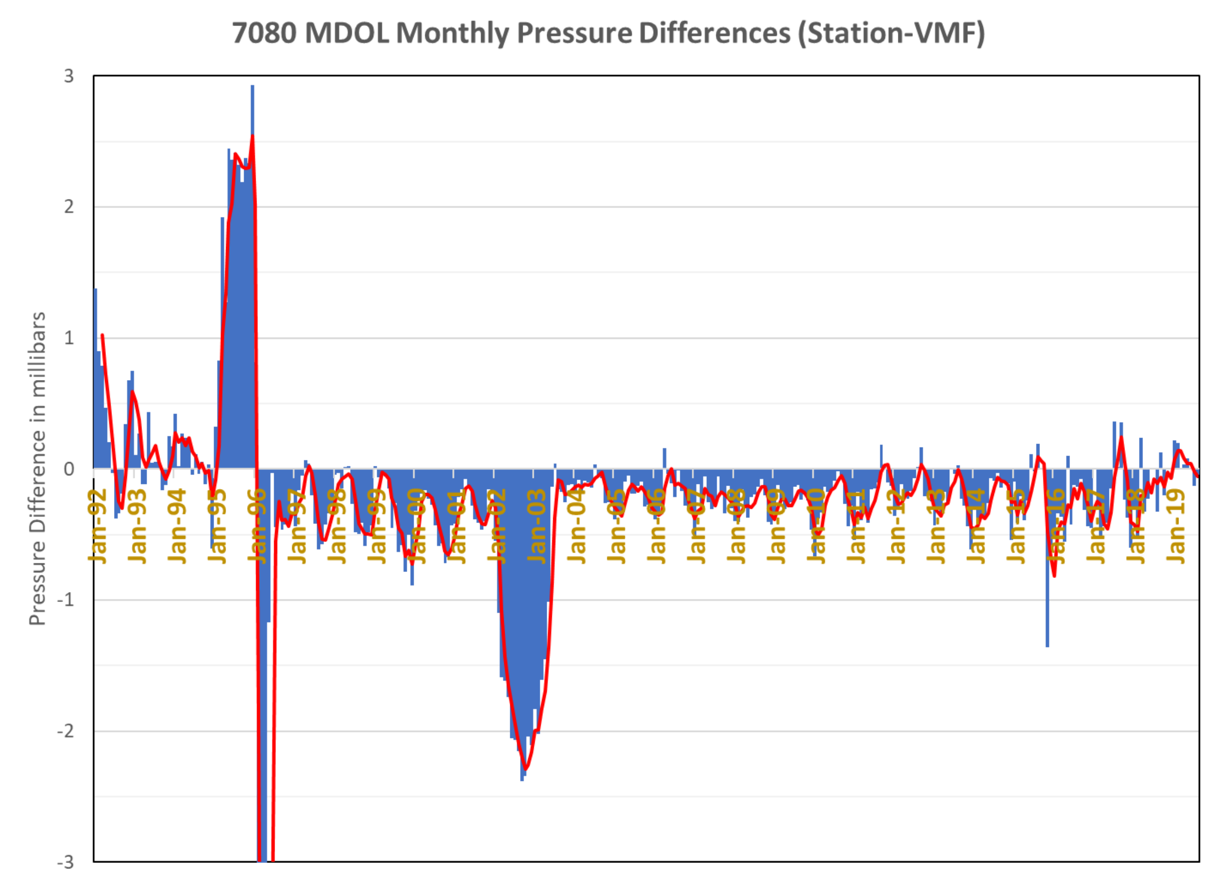




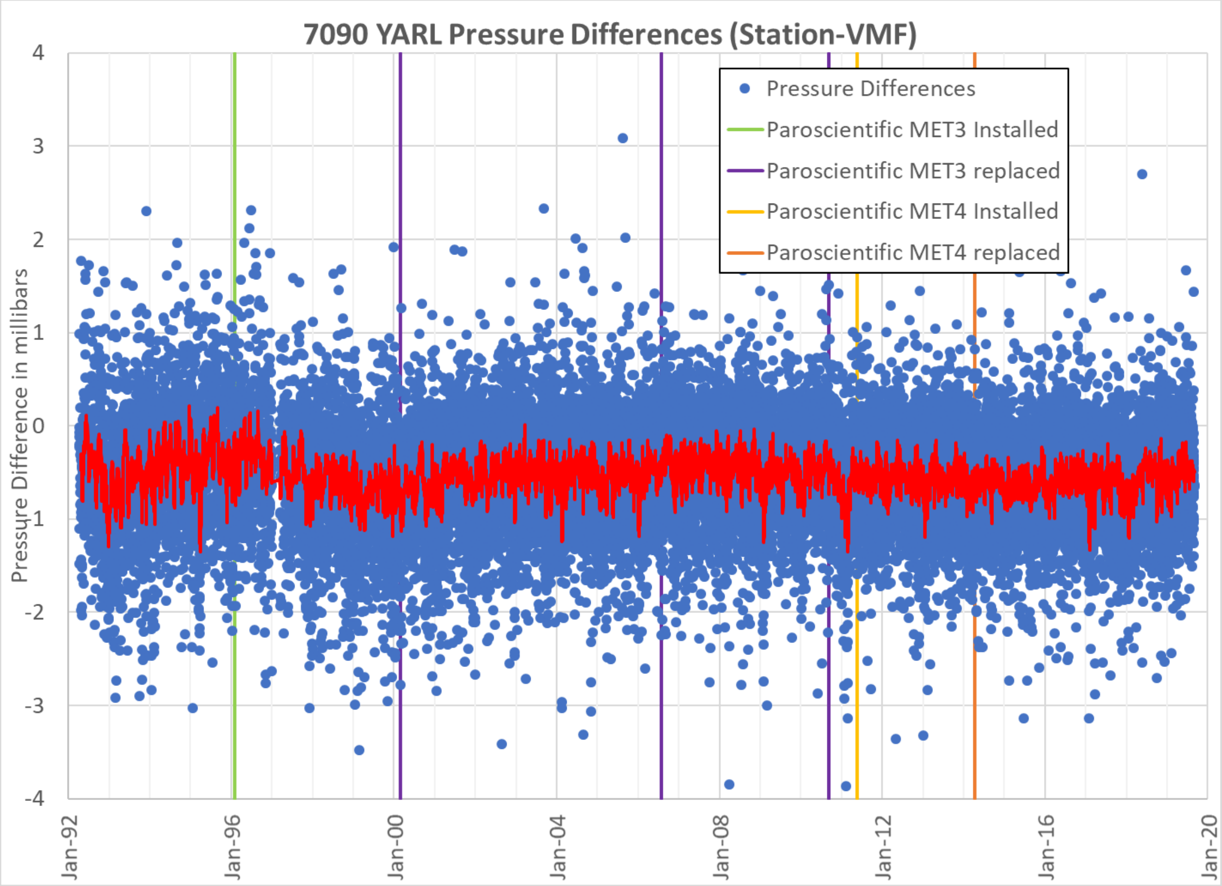
- ❑ Left & right charts are pressure differences (Station-VMF3oEI) aggregated every 6 hours and monthly; respectively.
- ❑ Red lines on the left & right chart are a 20-point running average and a 3-month running average; respectively.
- ❑ On the left chart, there is sudden discontinuity when the Paroscientific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

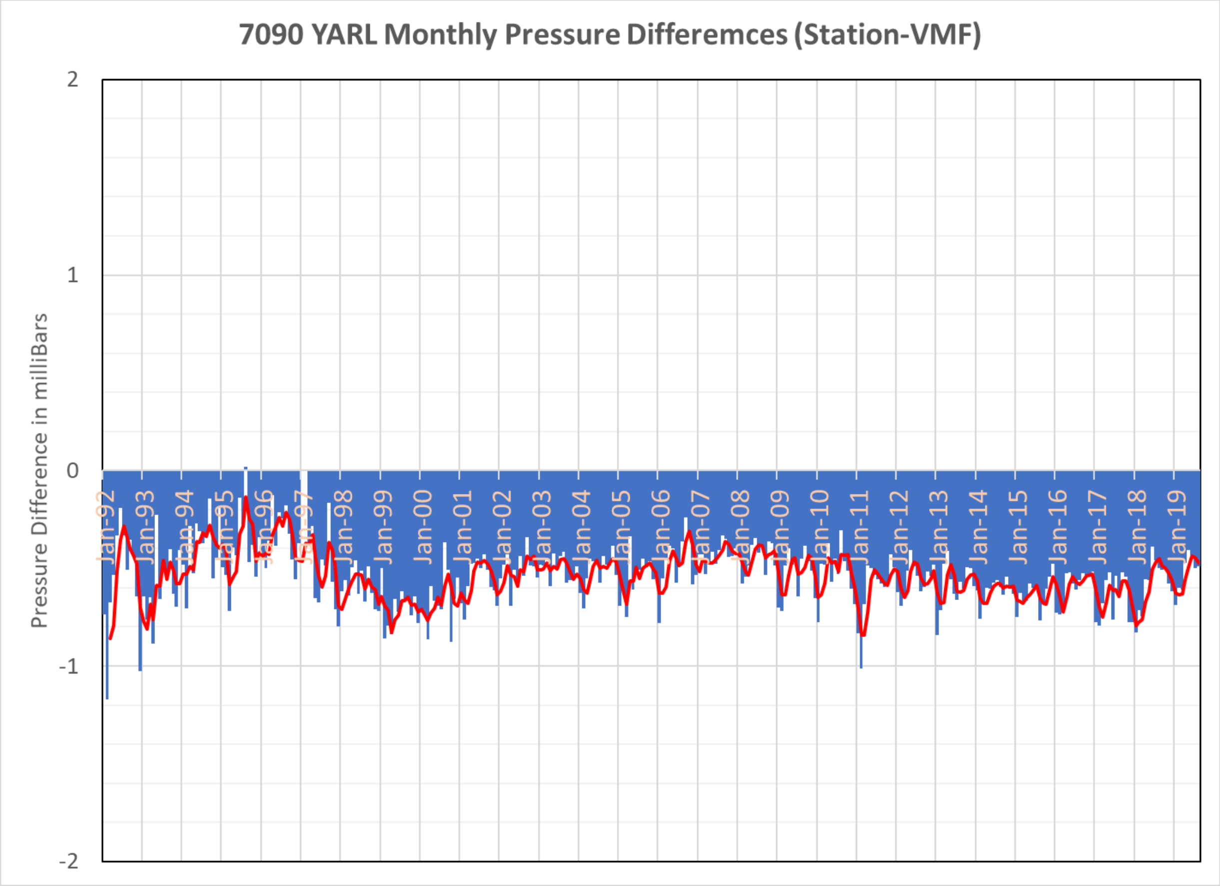
7080 MDOL Pressure Analysis





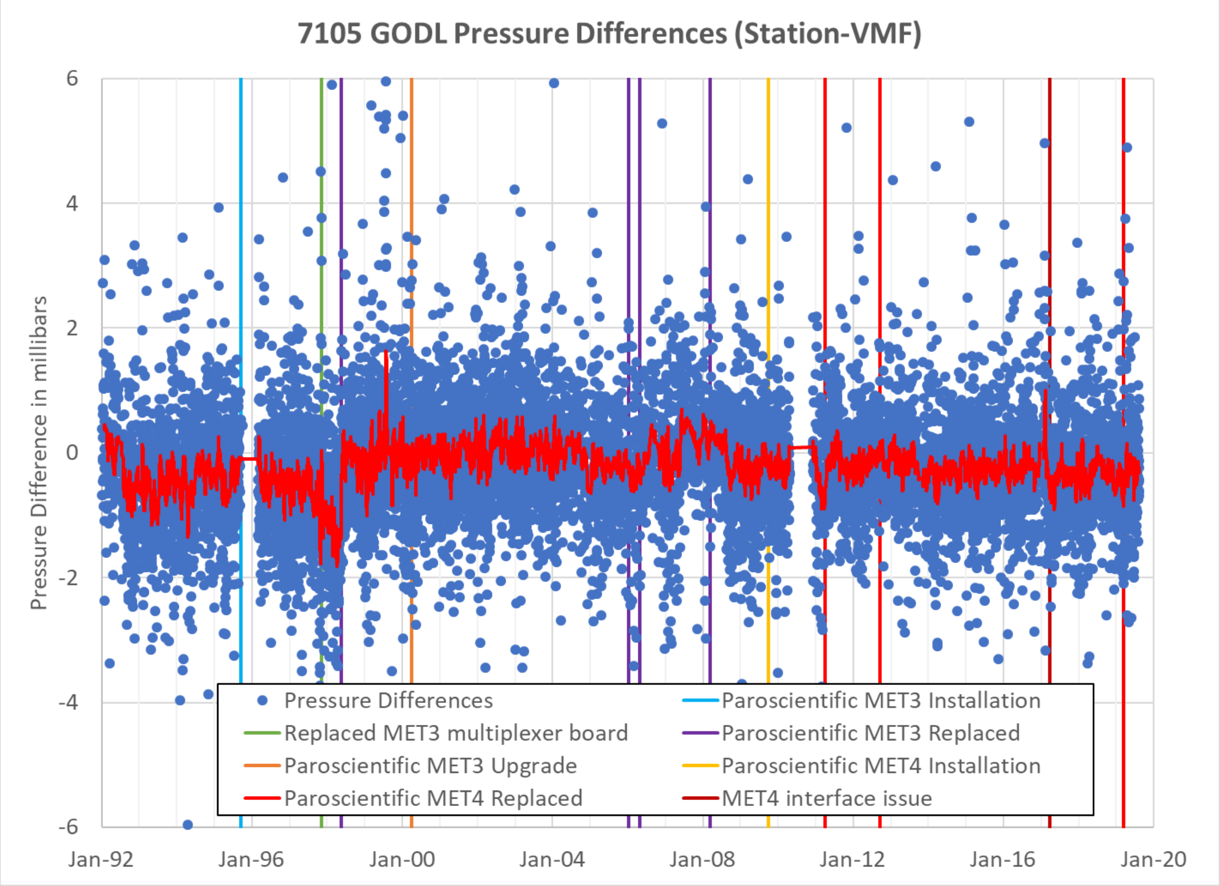
7090 YARL Pressure Analysis

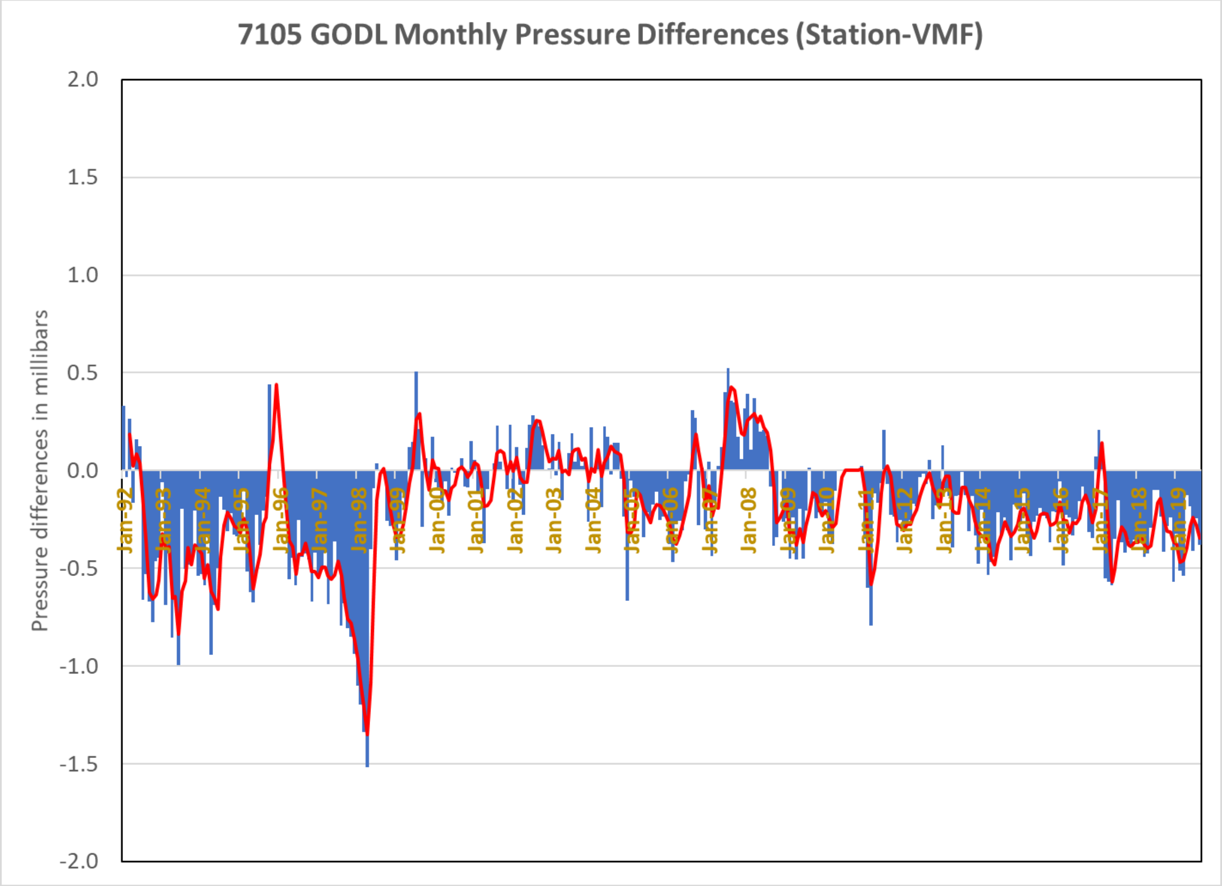




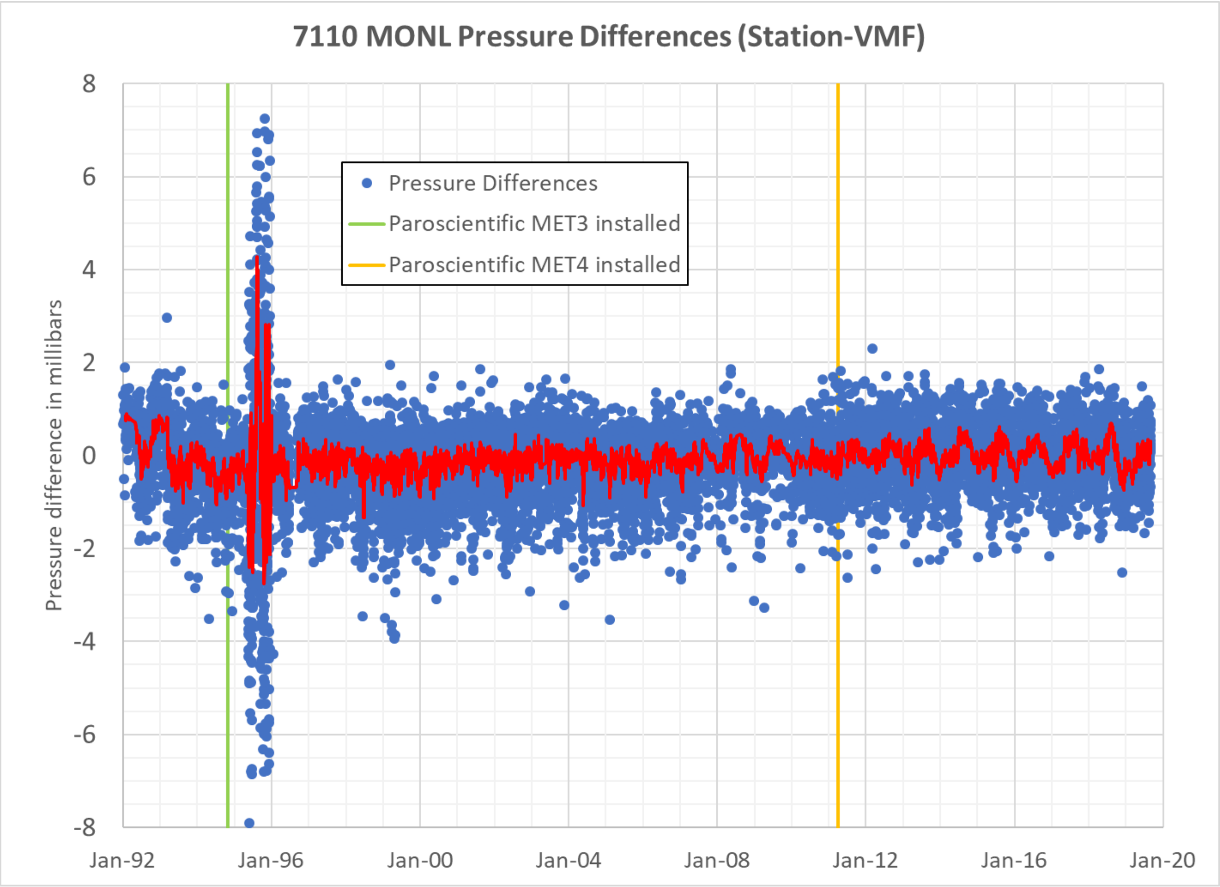
- There is -0.54 millibar offset between the Station and the VMF. Based on the left chart the 7090 meteorological sensors were calibrated/replaced every few years. This begs the question, which data is more accurate?

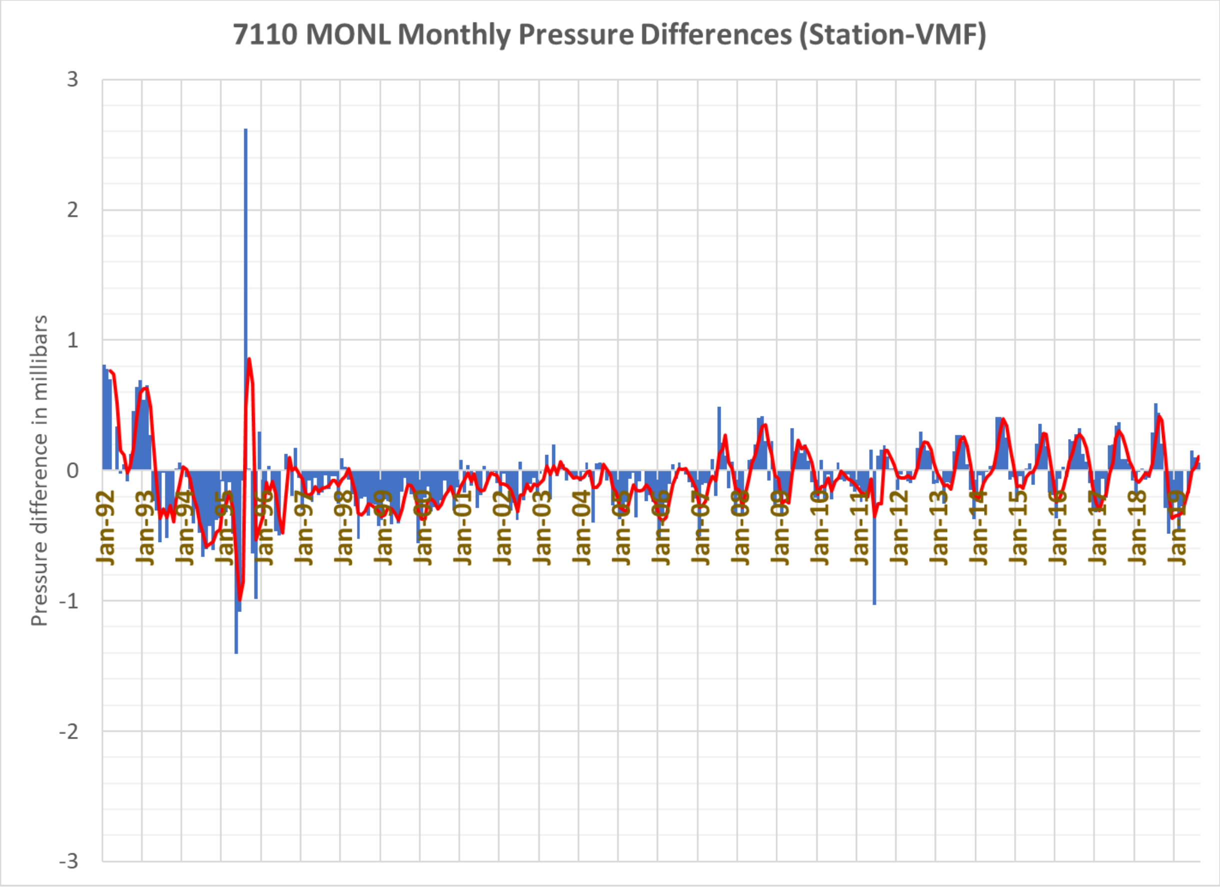
7105 GODL Pressure Analysis





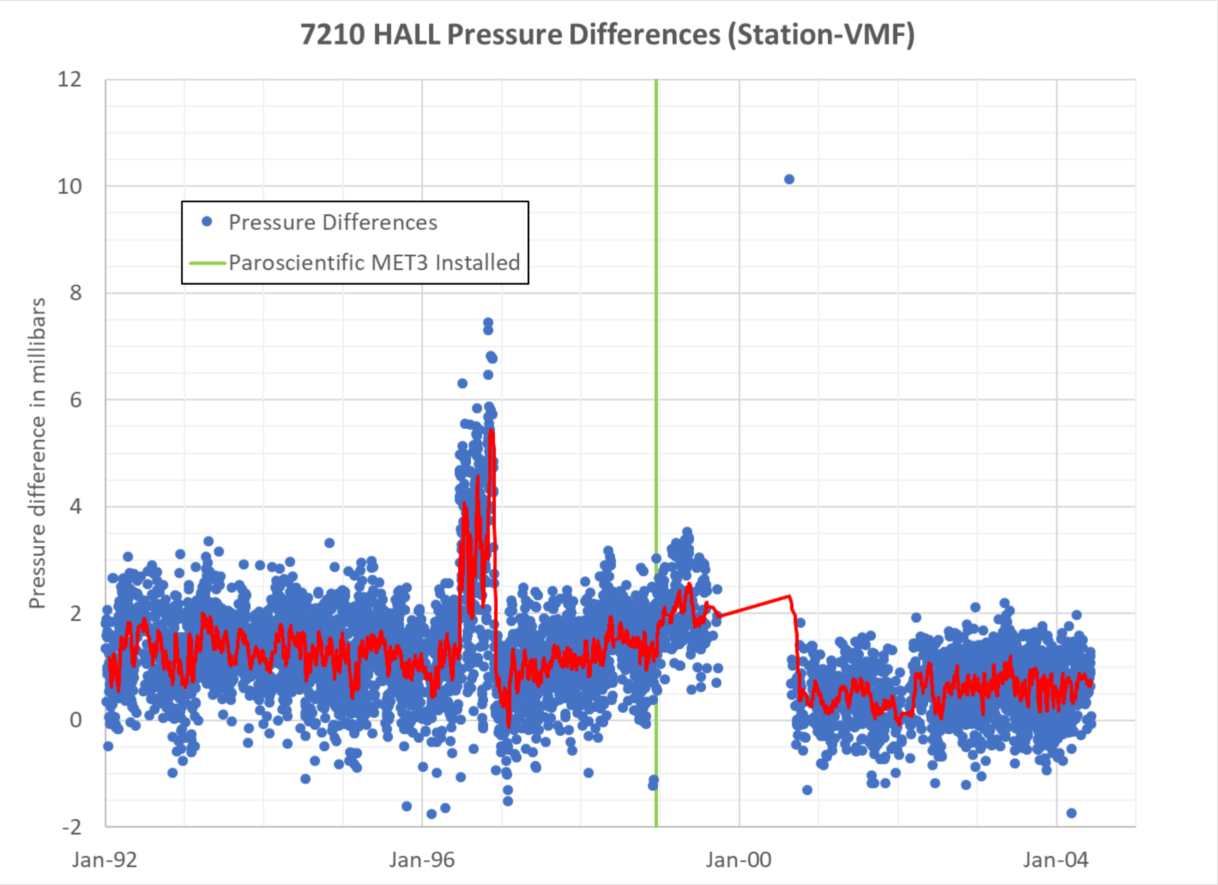
7110 MONL Pressure Analysis

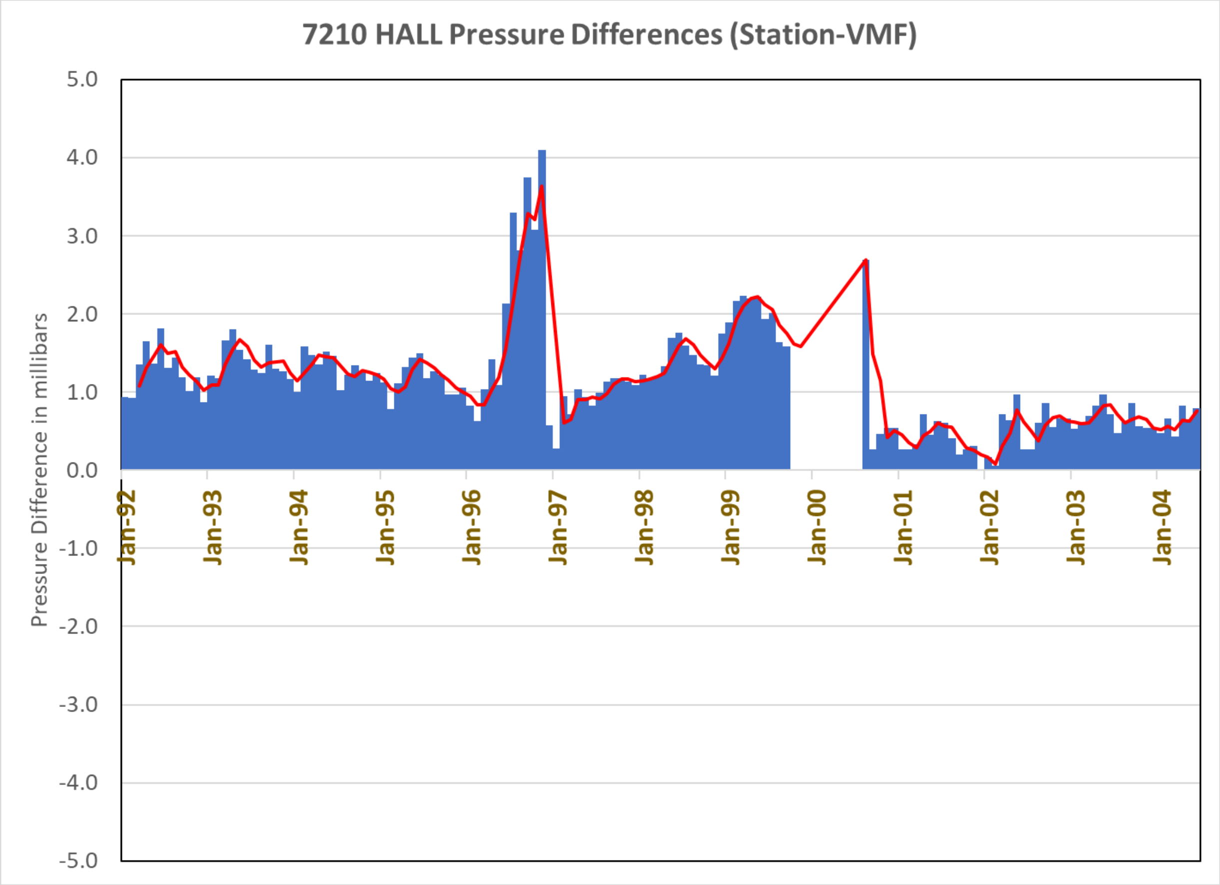




- There was an issue with the 7110 barometer in 1995 causing an increase in the scatter and a possible bias.

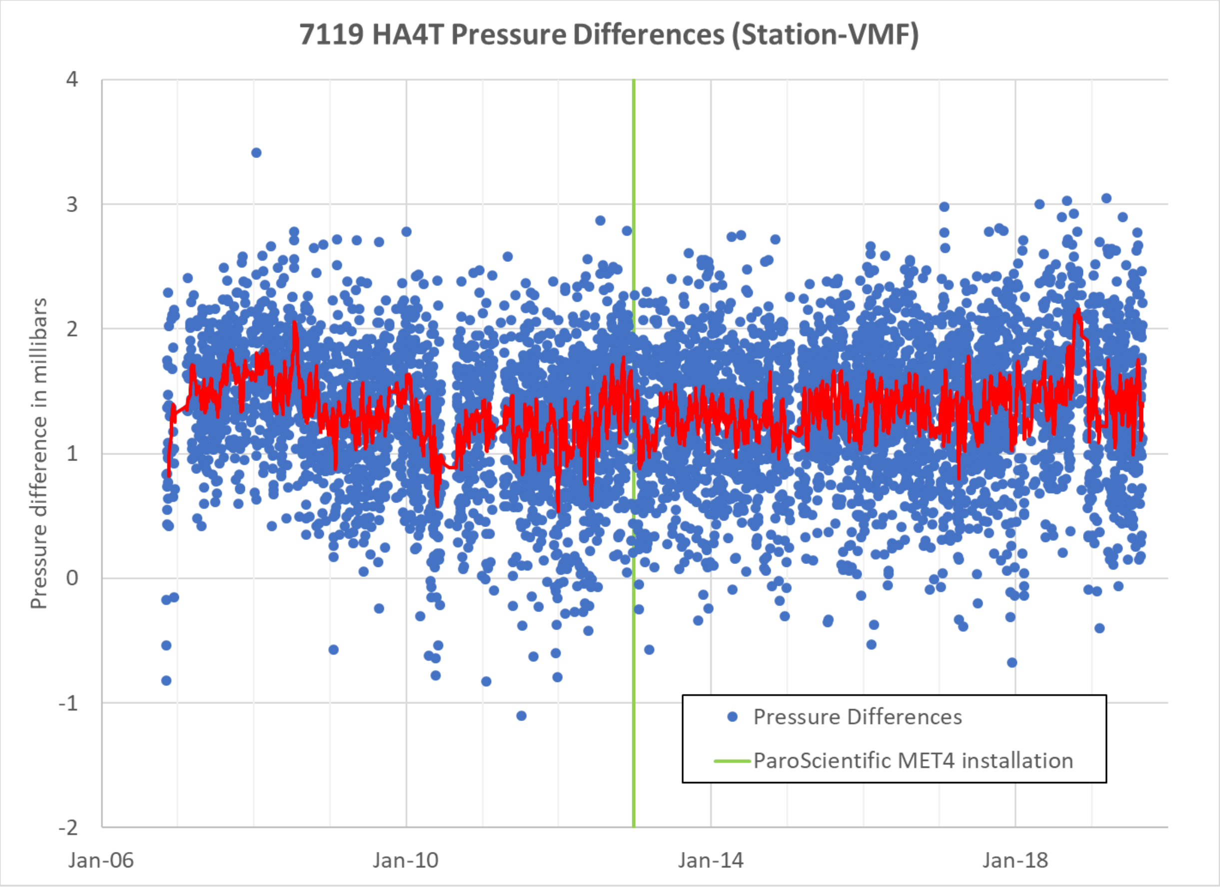
7210 HALL Pressure Analysis

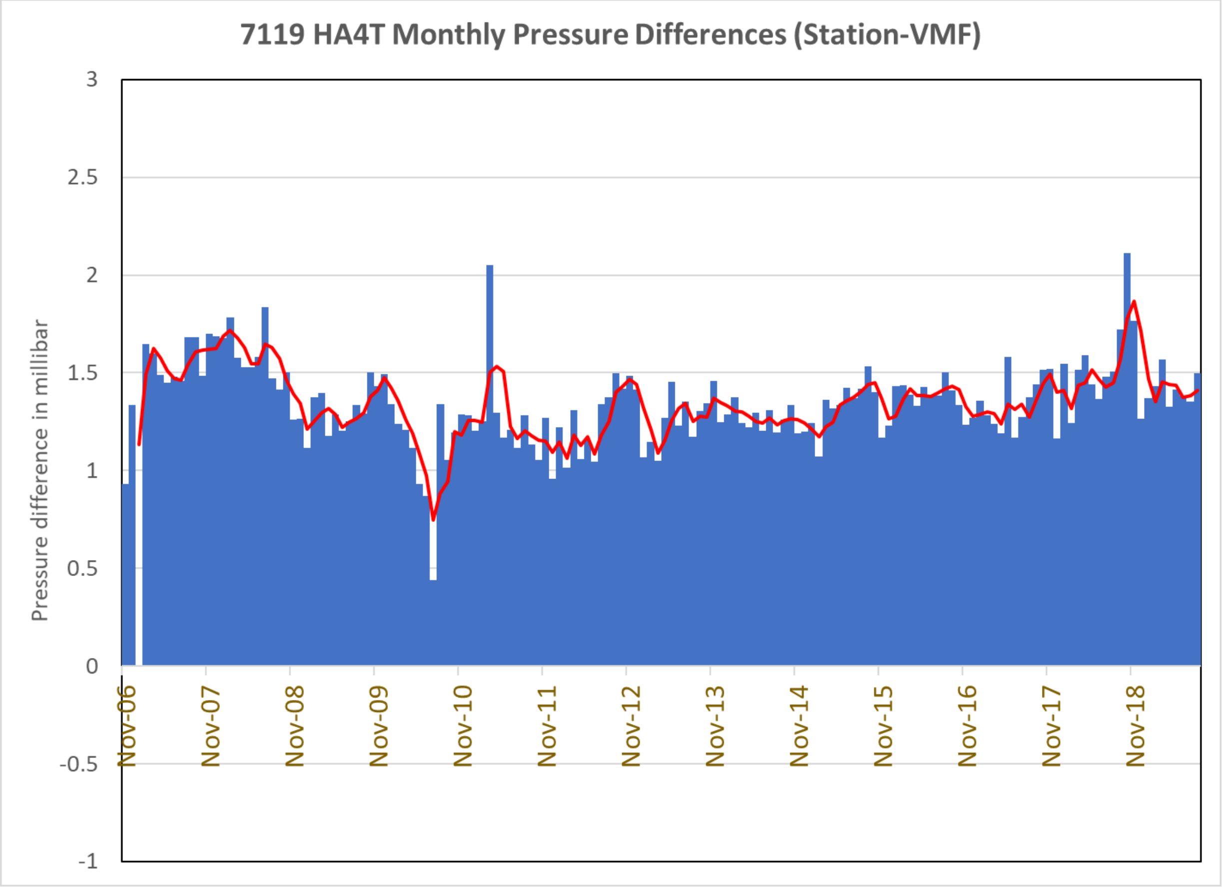




- **The 7210 site log mentions there is ~2-meter height difference between the sensor and the system reference point. A 2-meter height difference equates to a 0.2 millibar pressure difference which was not modelled in the data processing.**
- **There is a difference in pressure before and after the data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

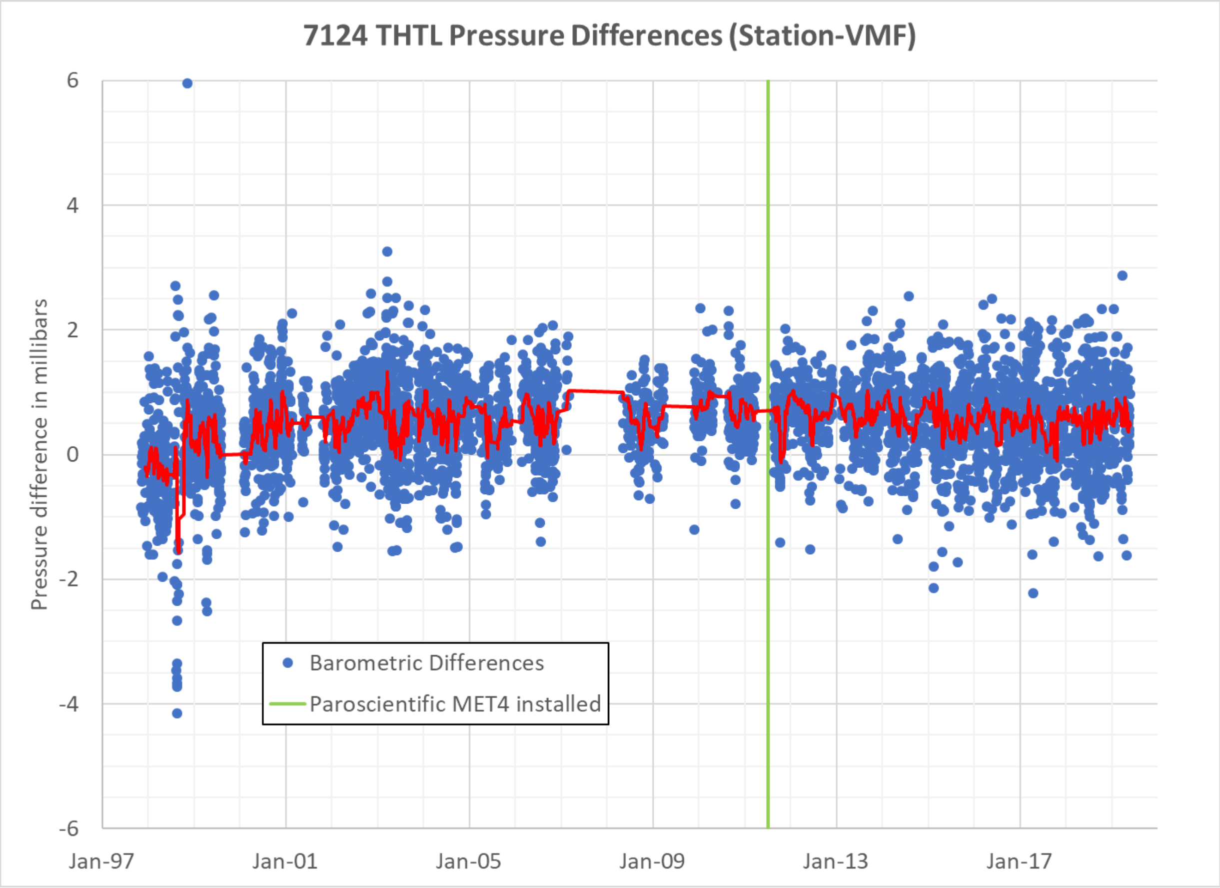
7119 HA4T Pressure Analysis

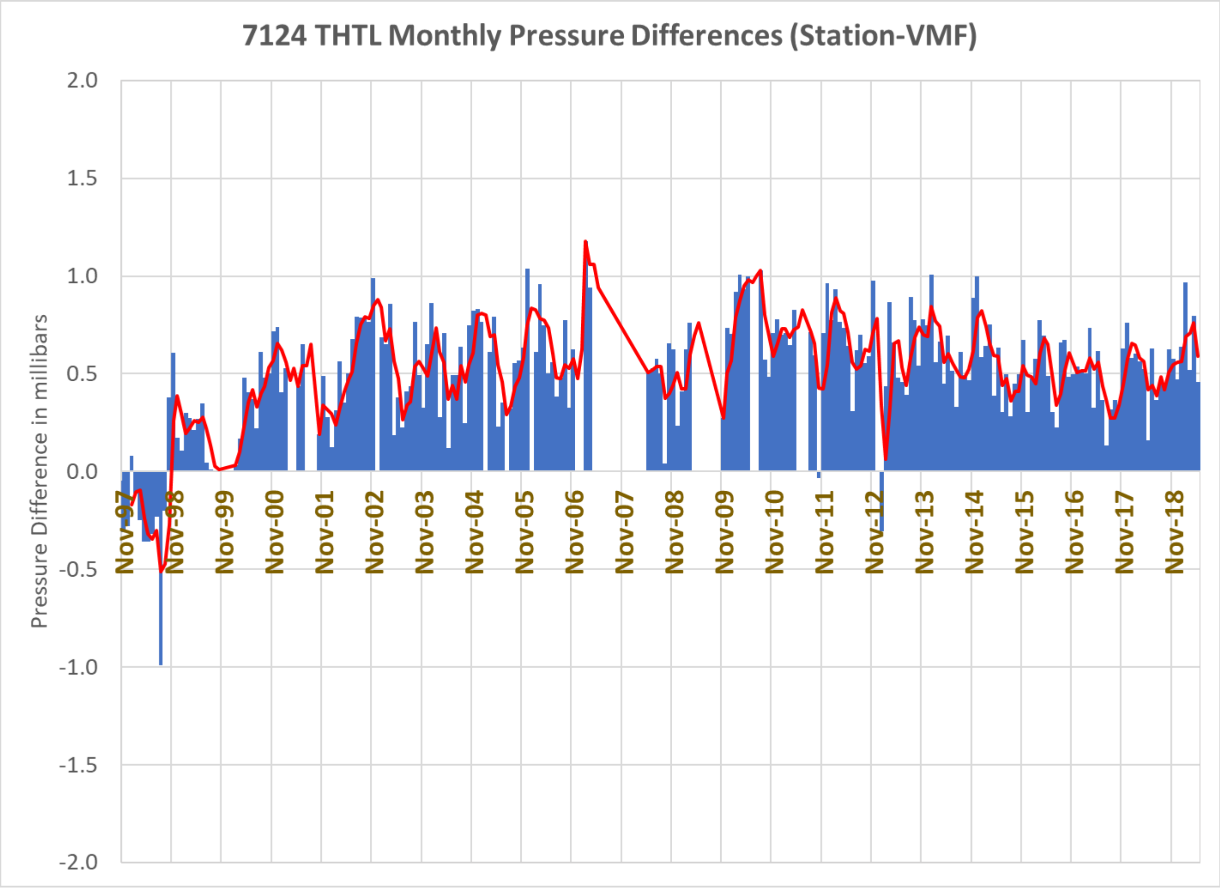




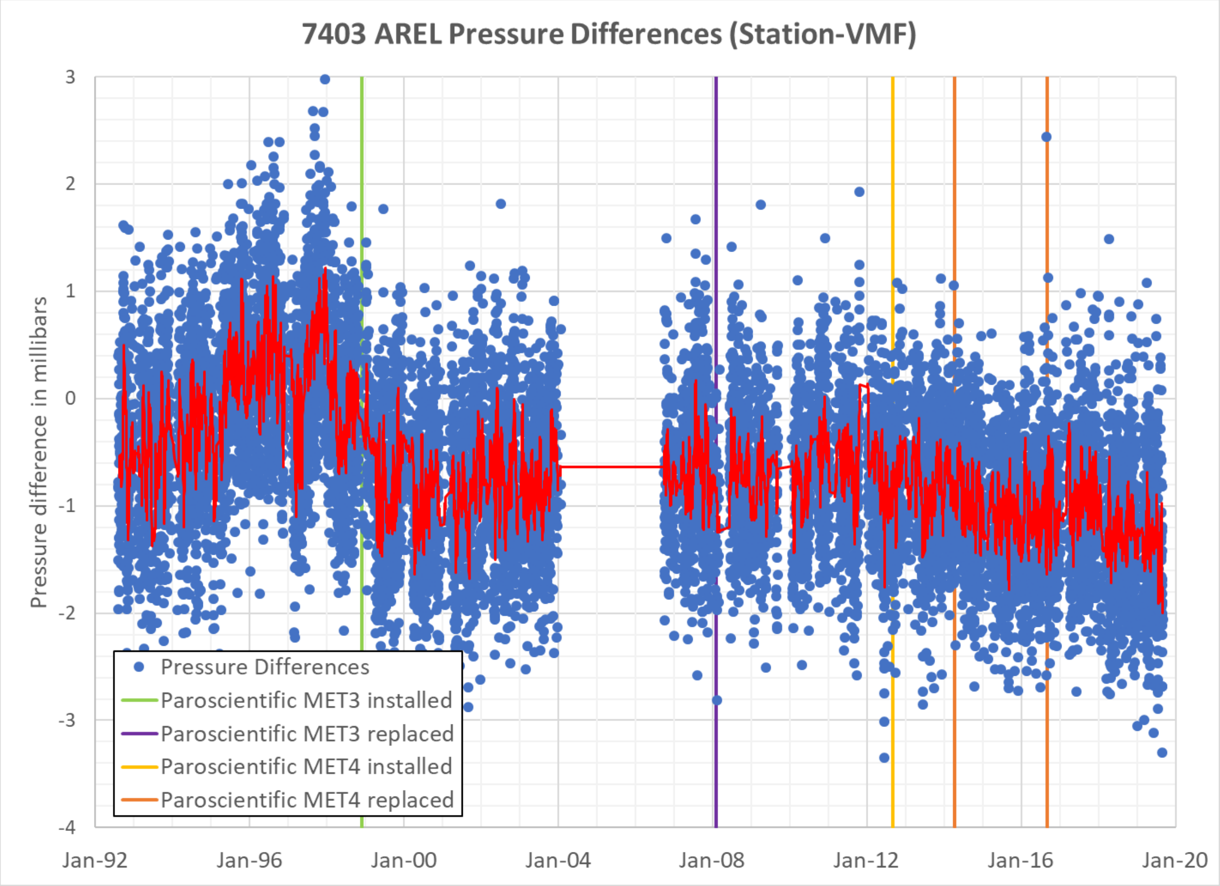
- **7210 HALL was closed in 2004 (see 7210 results on previous slide) and was replaced in 2006 with station 7119 HA4T (TLRS-4). Both stations have a positive barometric bias relative to VMF, but the apparent 7119 pressure bias is much larger. WHY?**

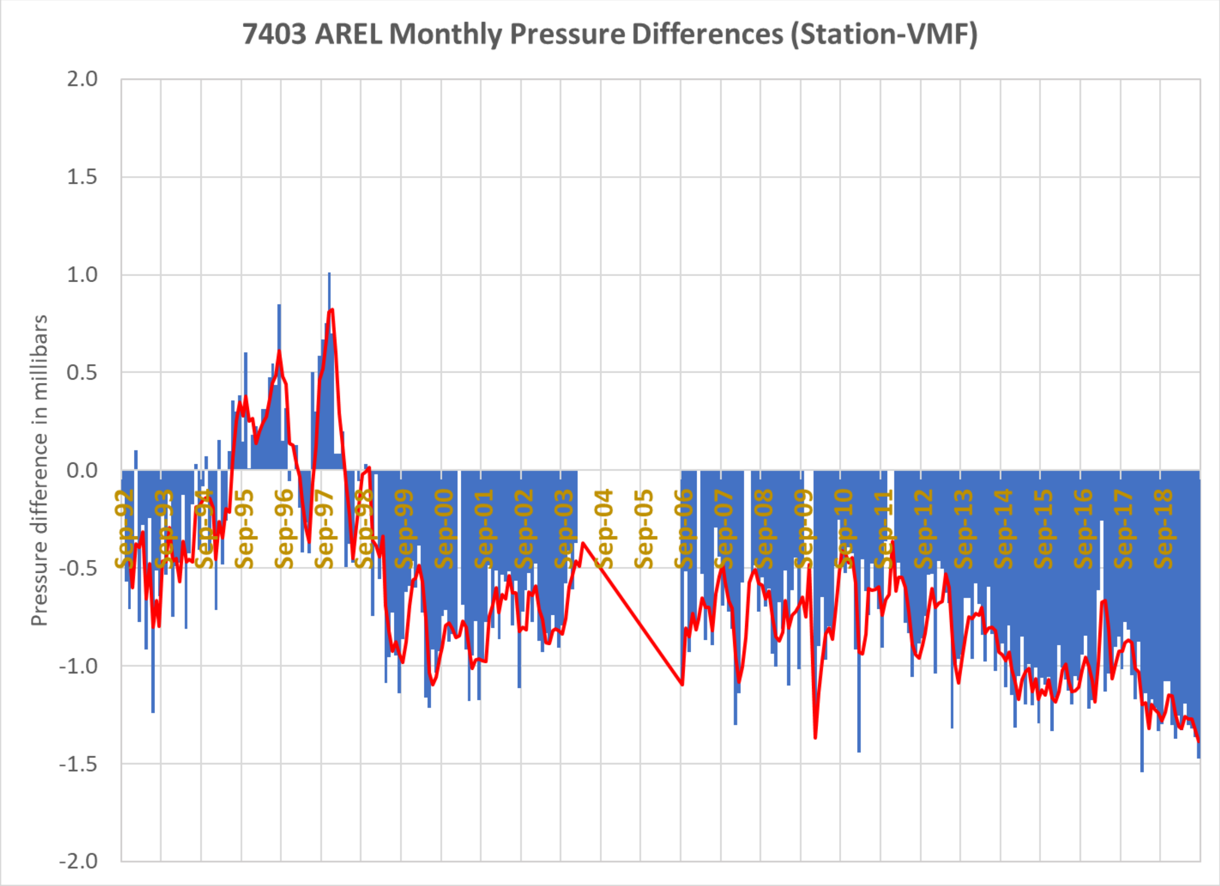
7124 THTL Pressure Analysis





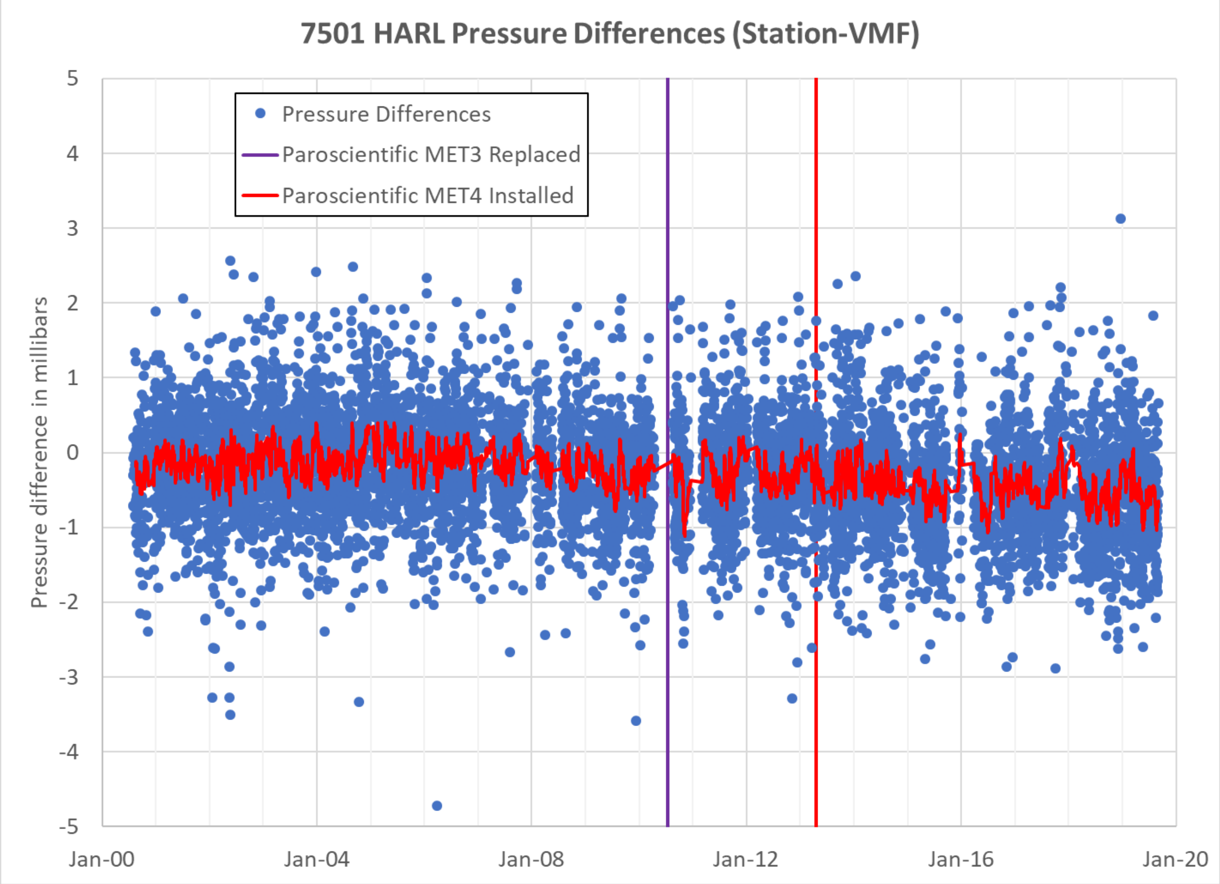
7403 AREL Pressure Analysis

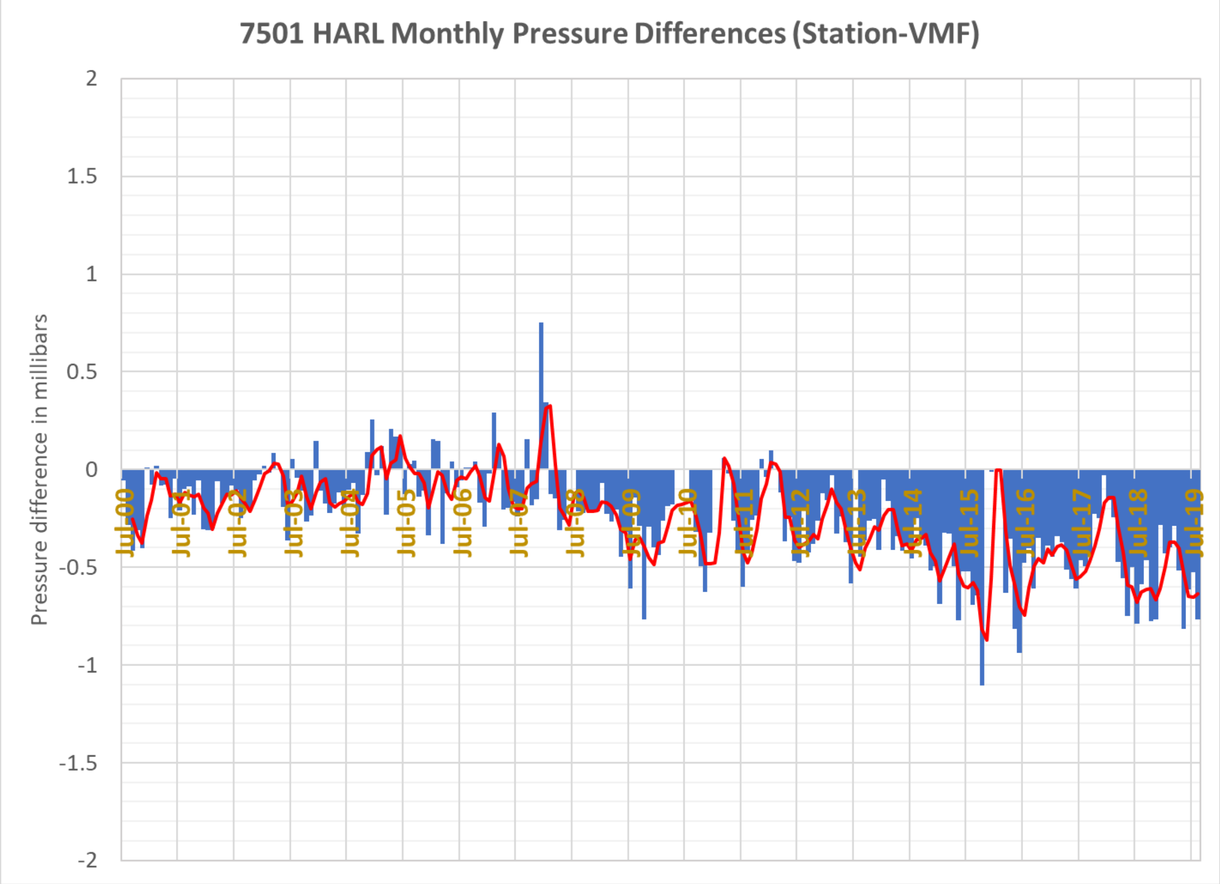




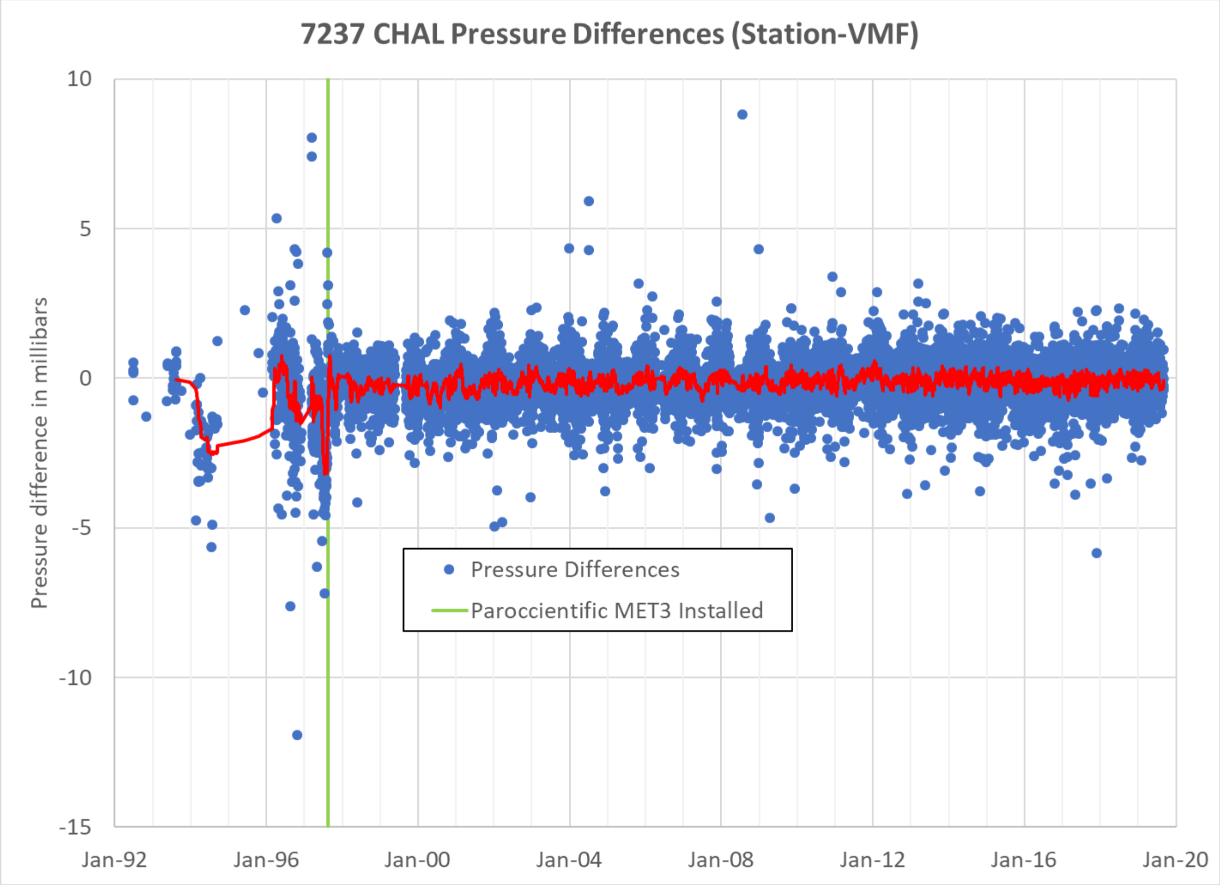
- **7403 Paroscientific MET sensors have been calibrated/replaced a few times, but there are large offsets vs VMF.**

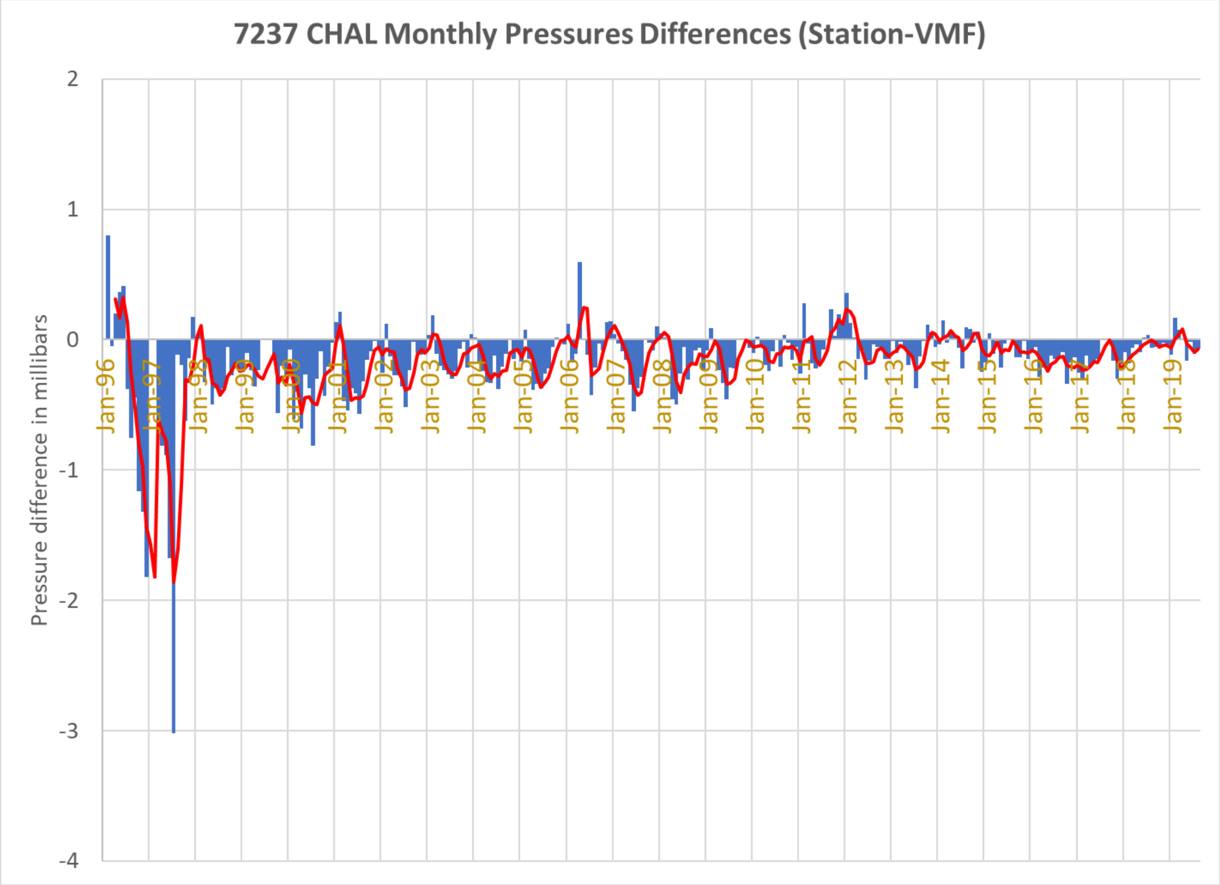
7501 HARL Pressure Differences



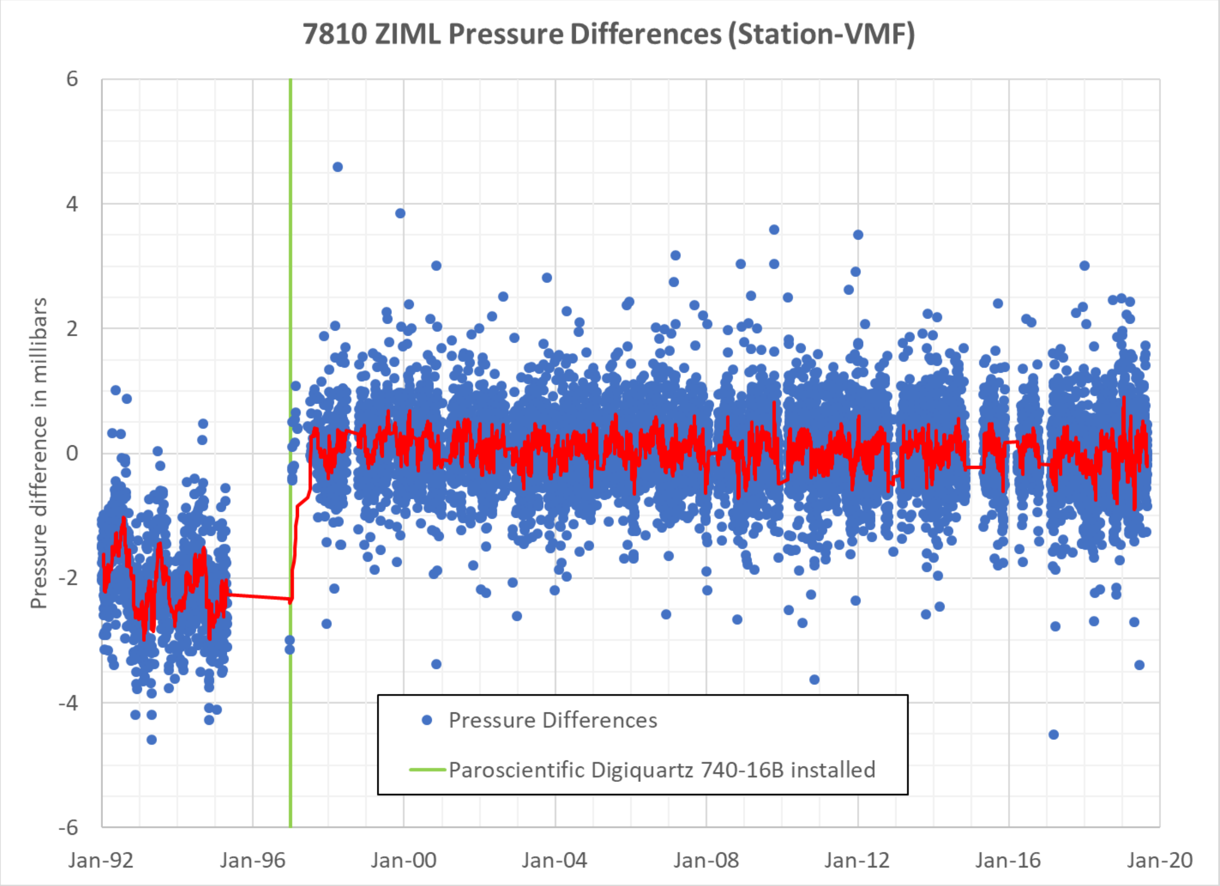


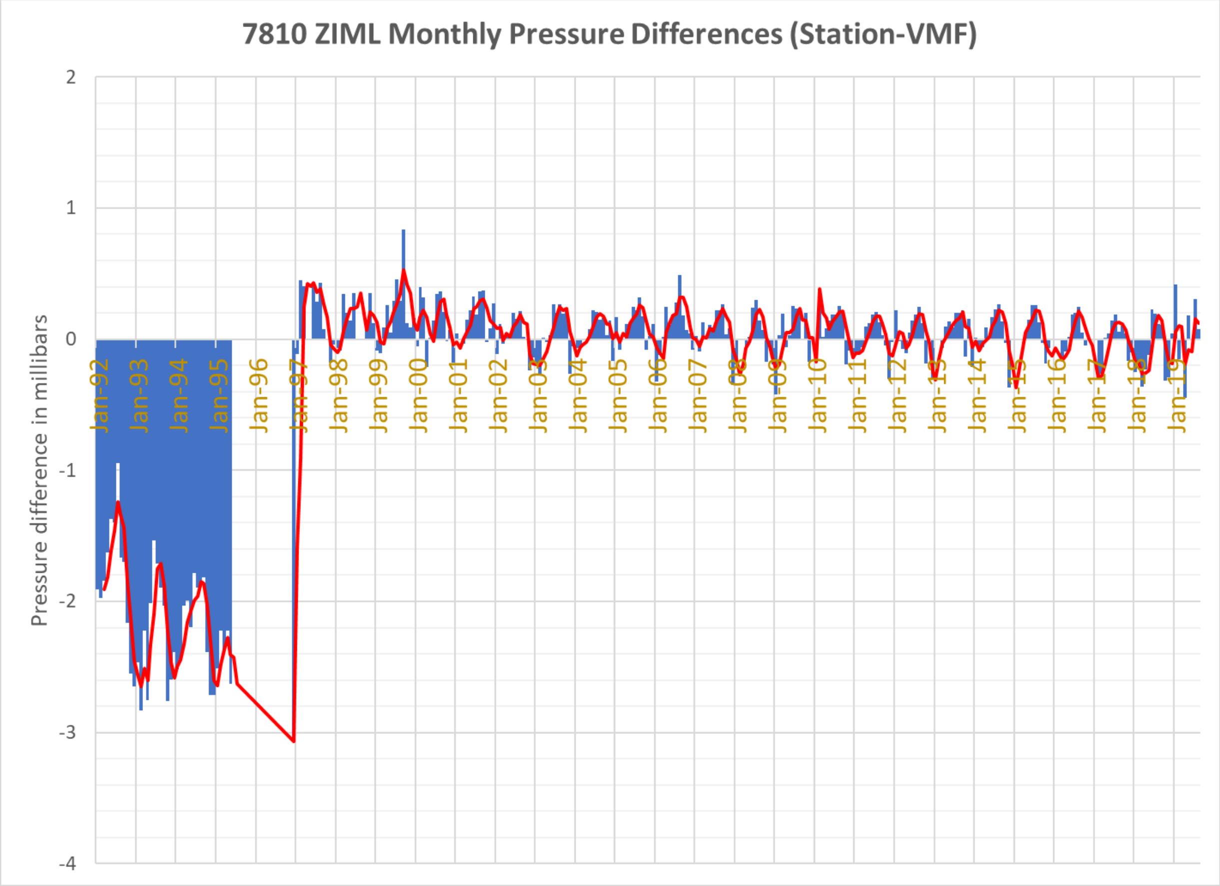
7237 CHAL Pressure Analysis



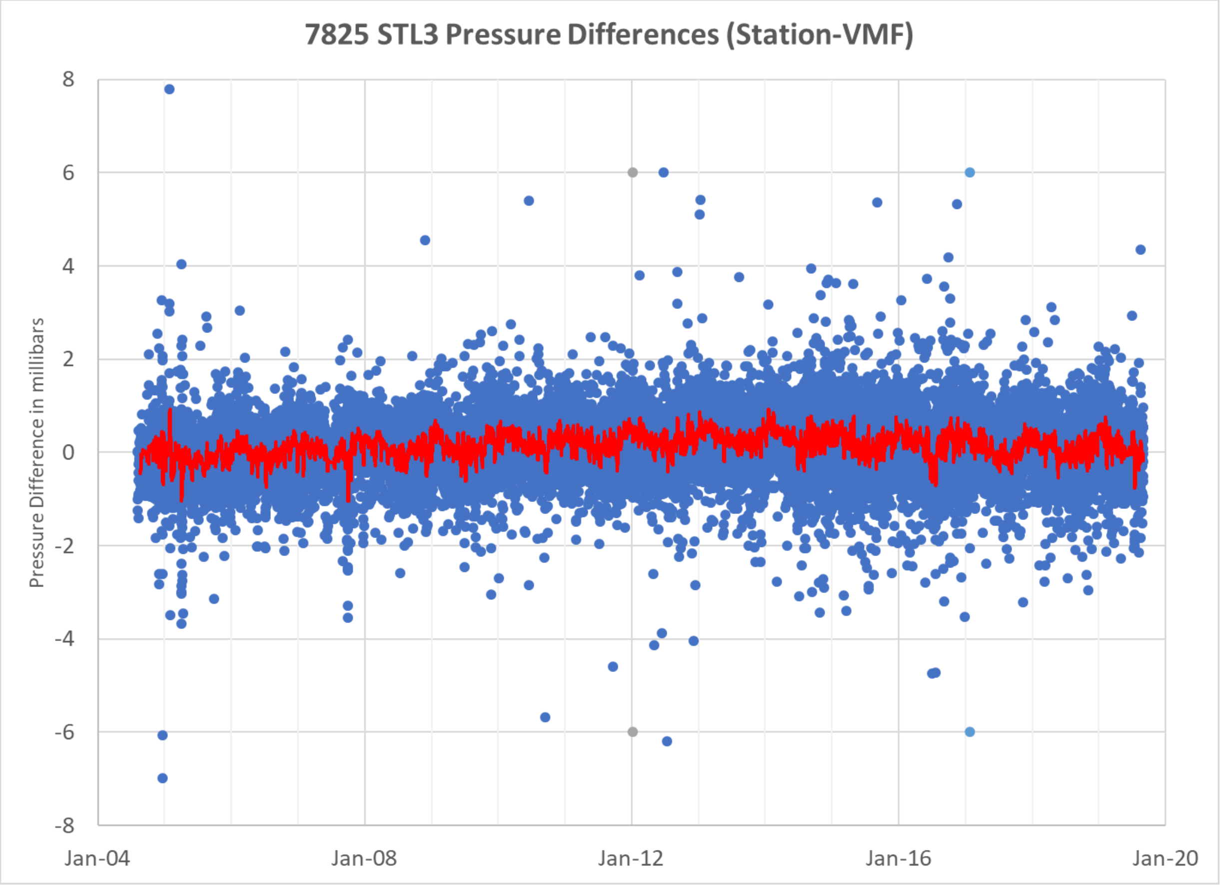


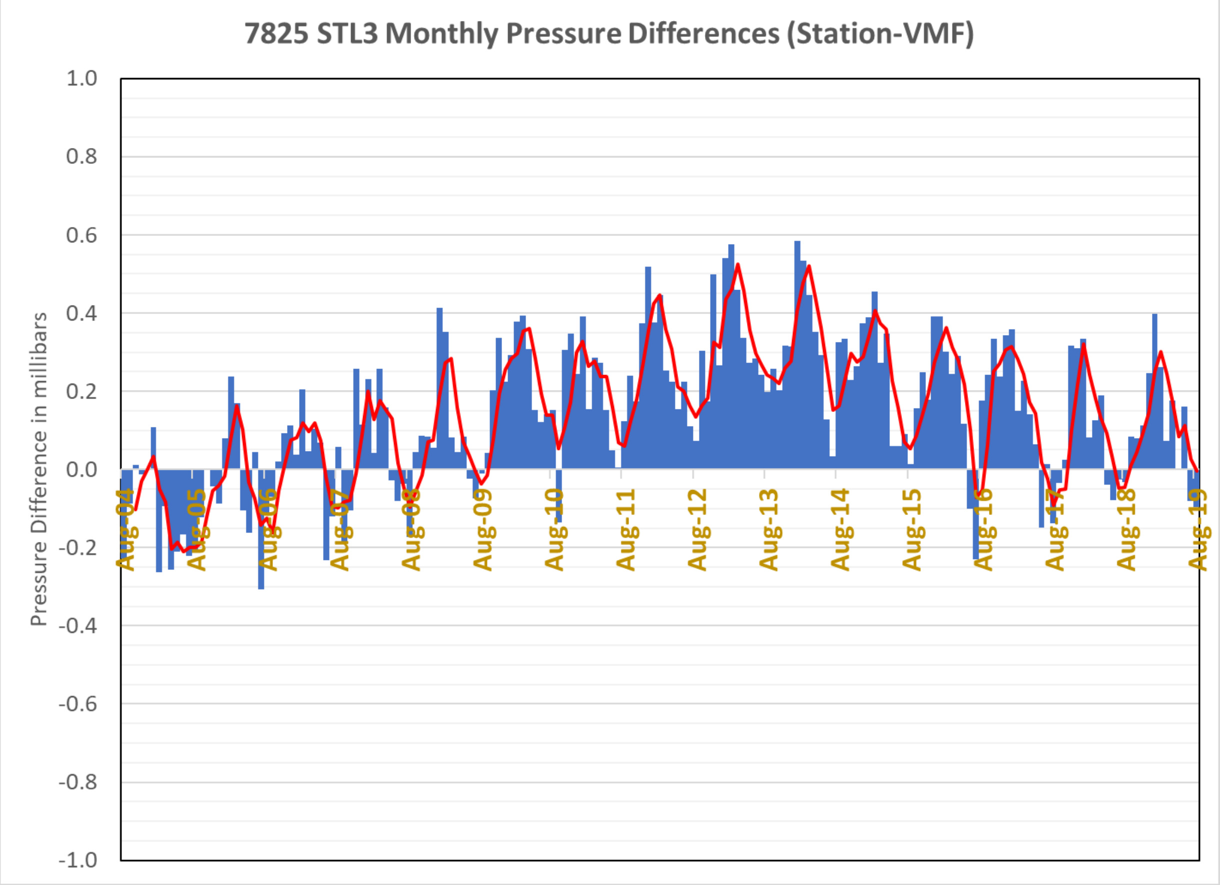
7810 ZIML Pressure Analysis



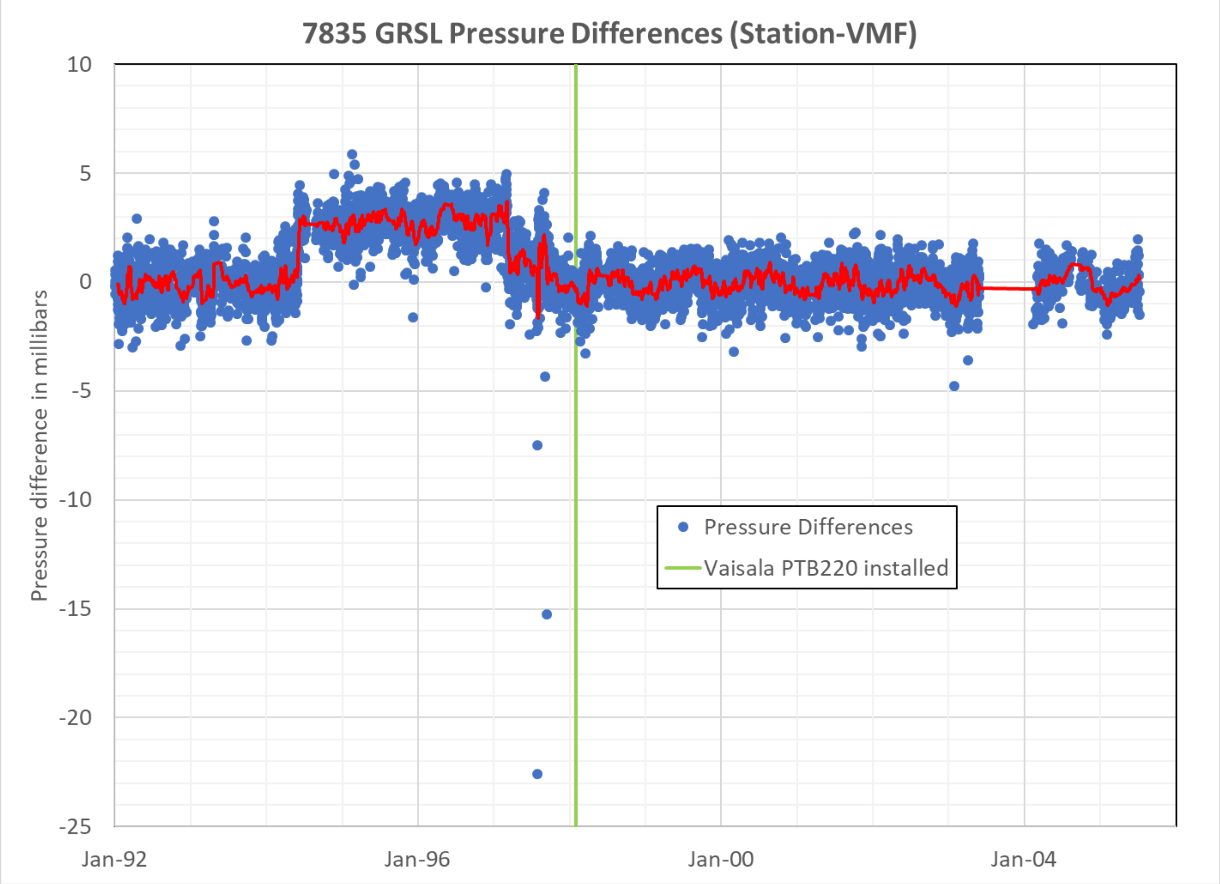


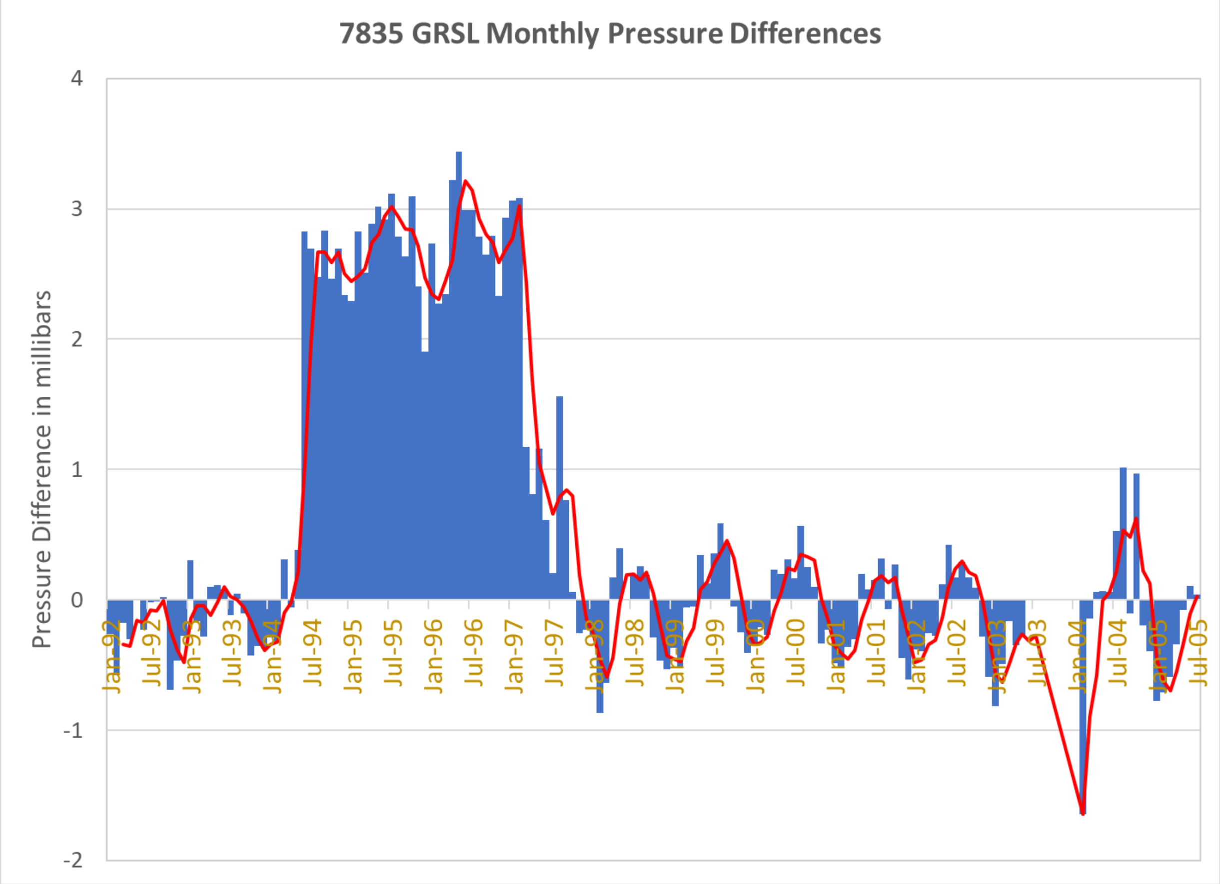
7825 STL3 Pressure Analysis





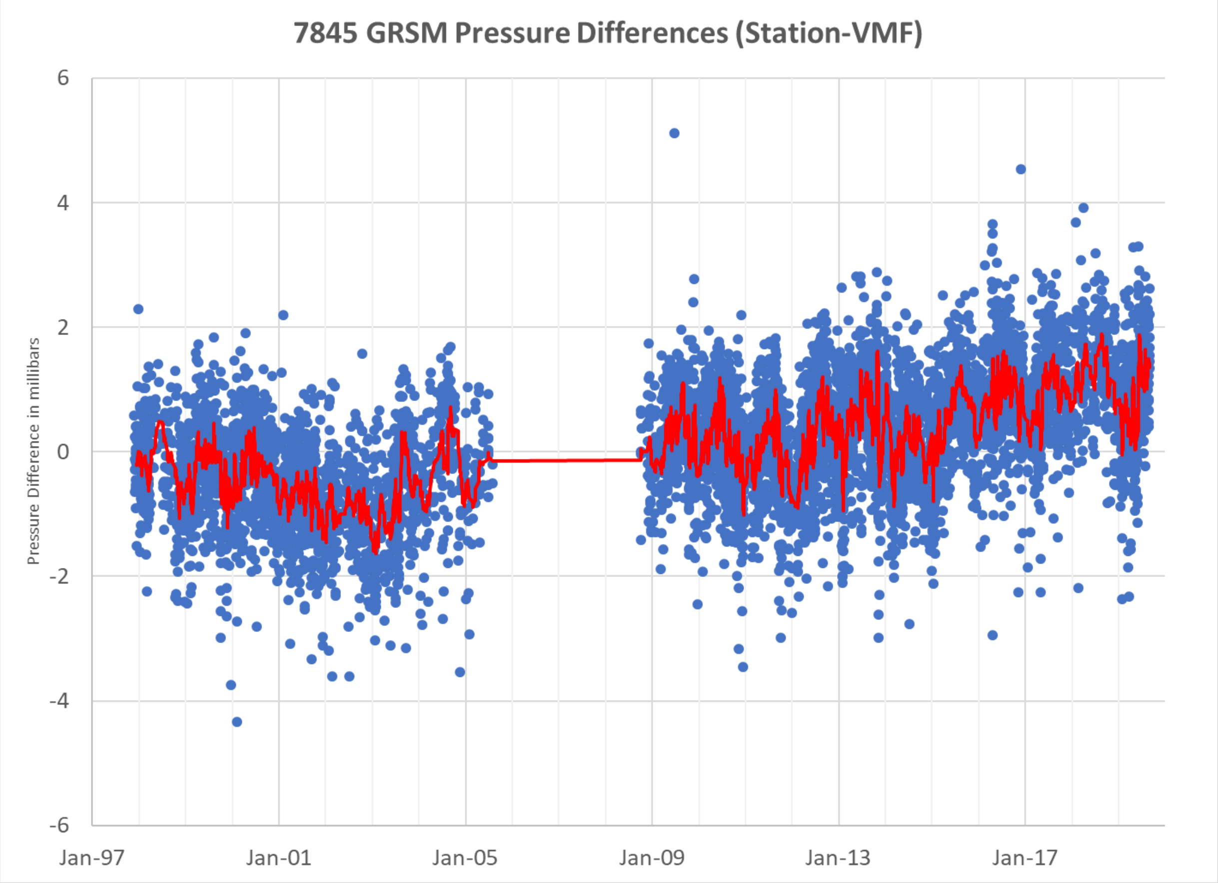
7835 GRSL Pressure Analysis

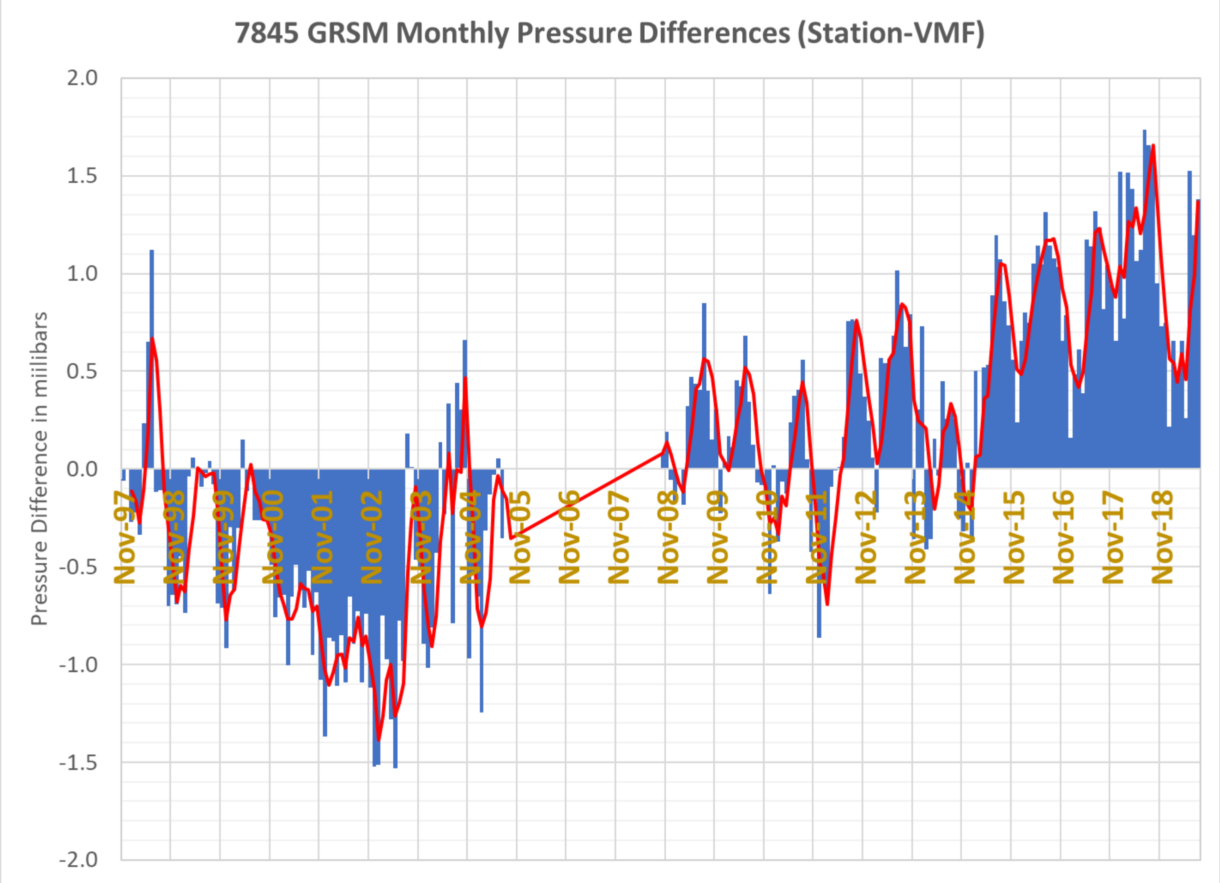




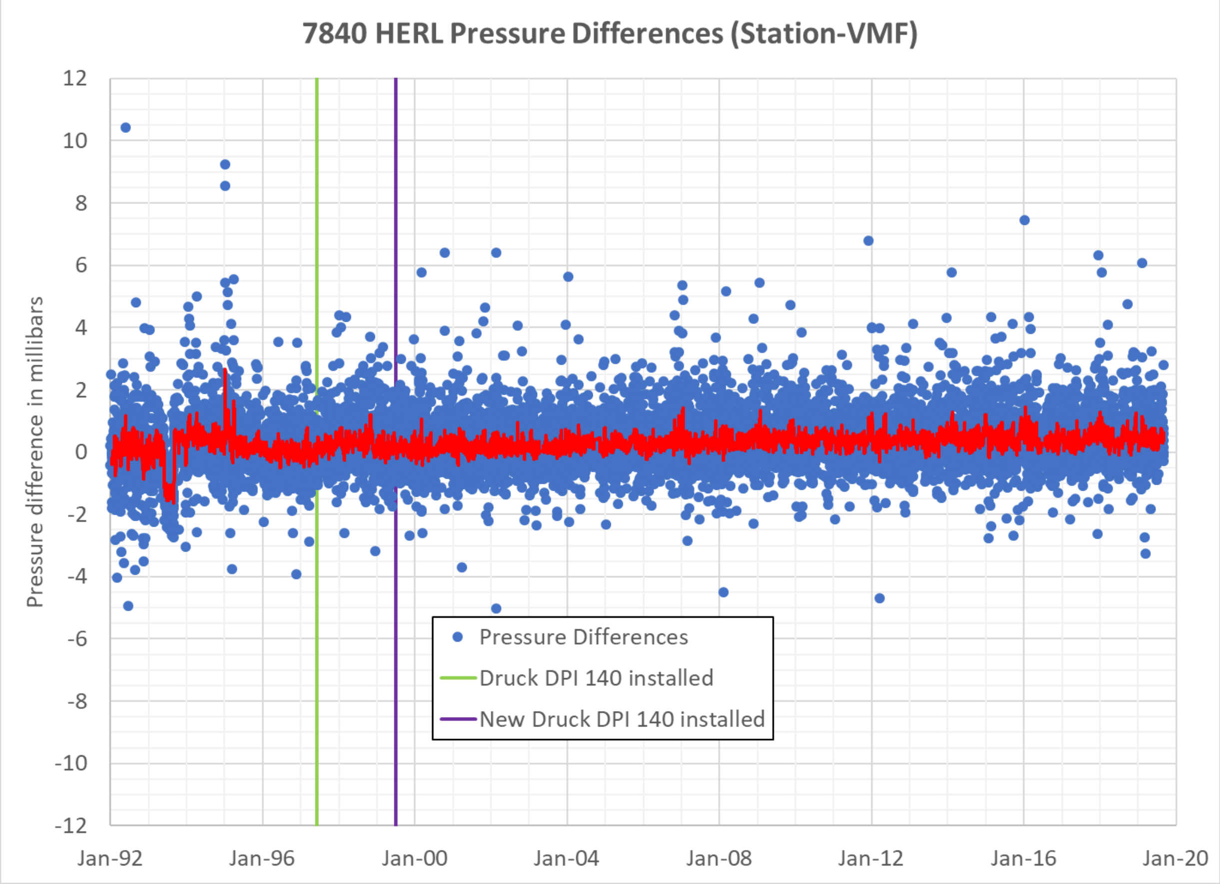
- Notice the seasonal oscillations in the differences after the Vaisala PTRB220 was installed.
- Based on the 7835 site log, there is 2.5 meter difference in height between the sensor and the system reference point. Was this height difference modelled in the data processing?

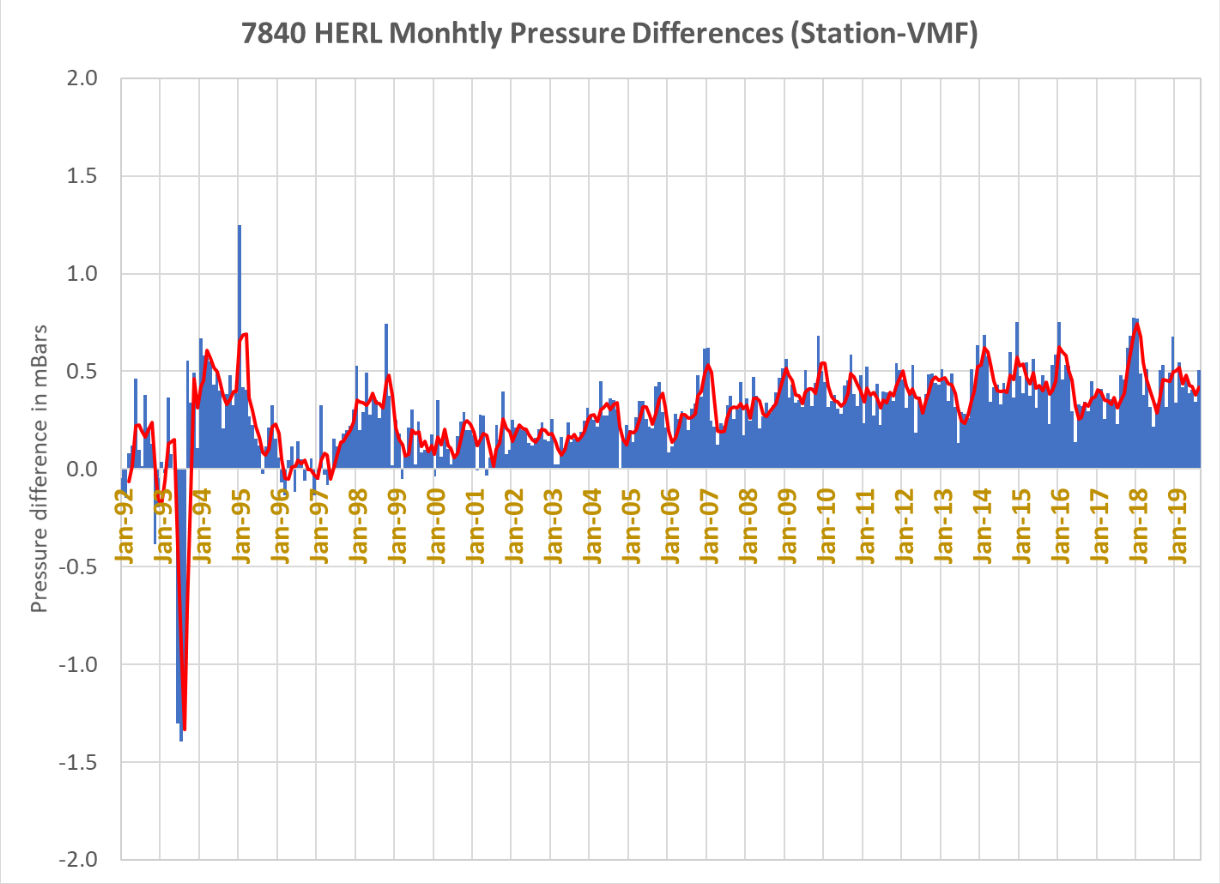
7845 GRSM Pressure Analysis



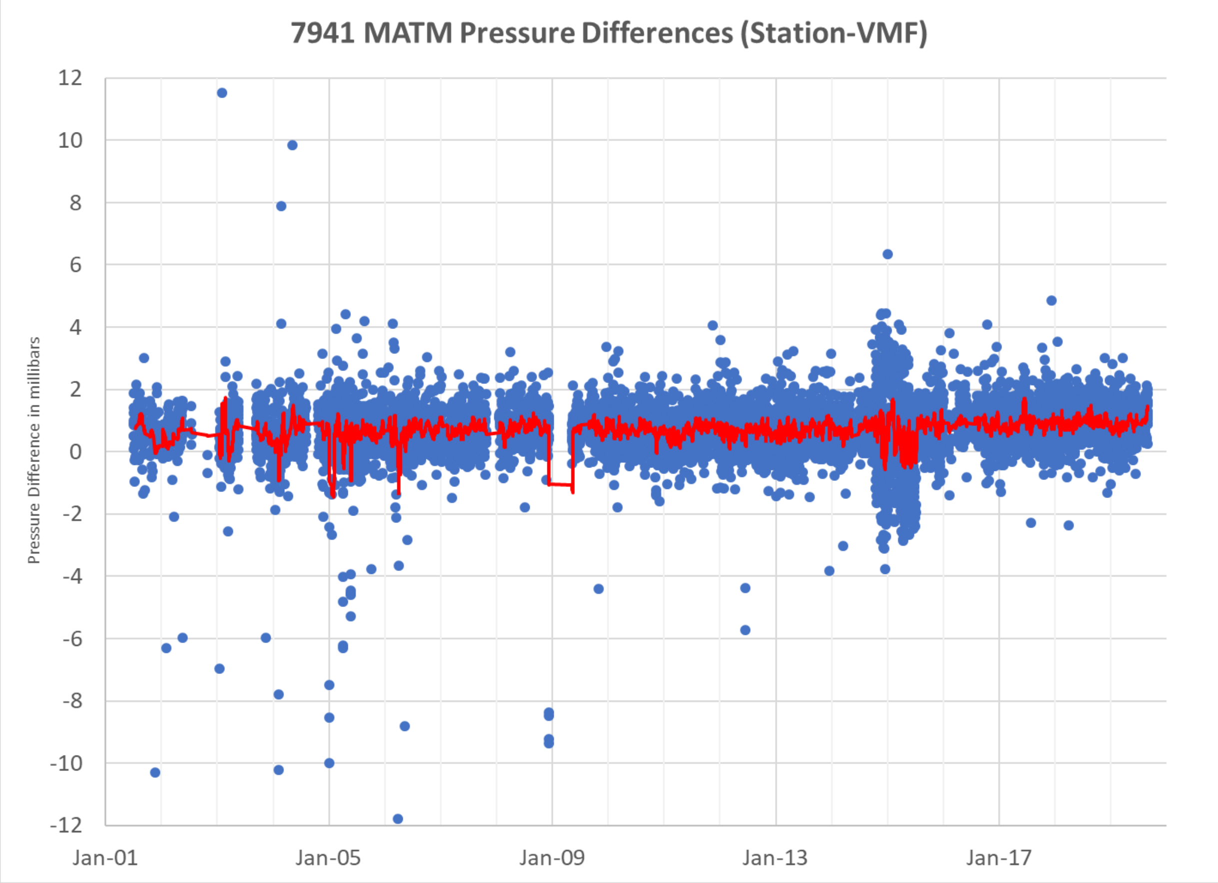


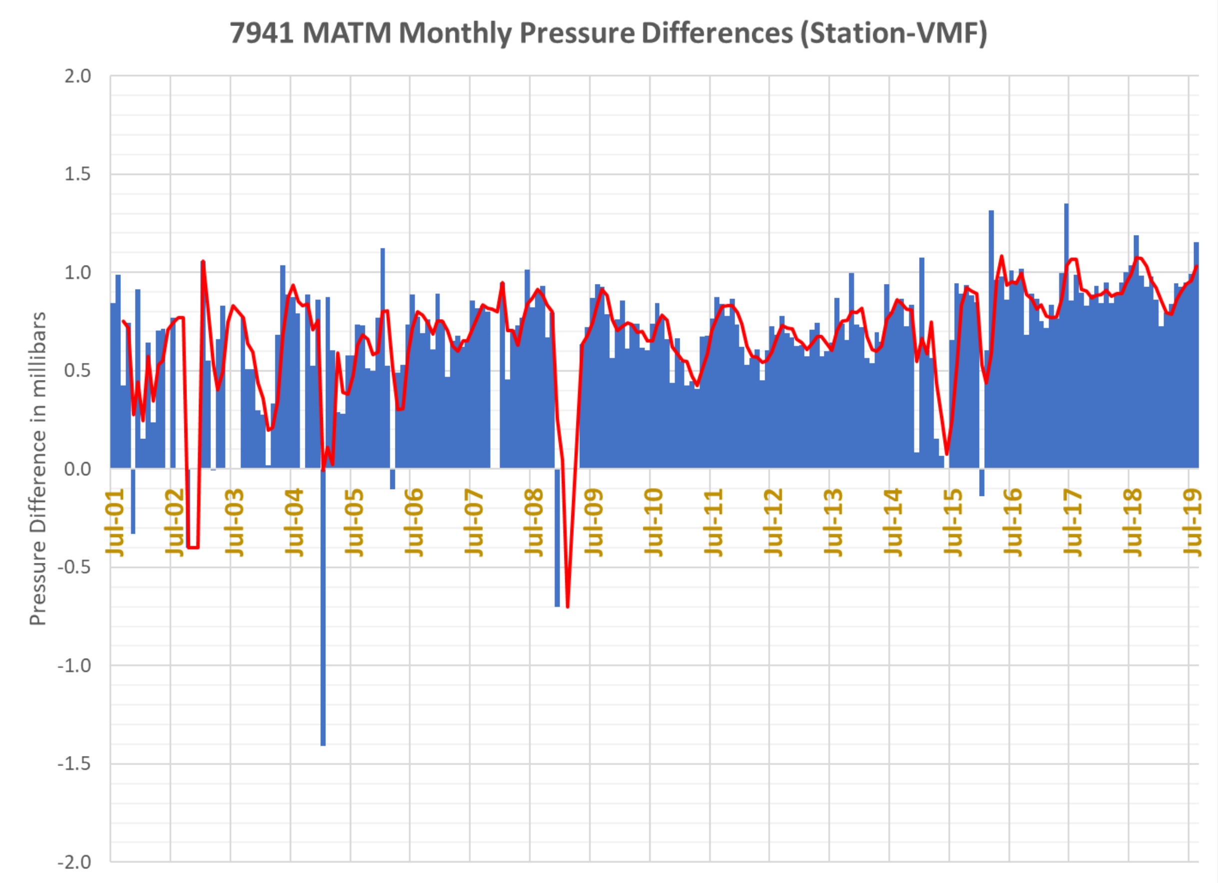
7840 HERL Pressure Analysis



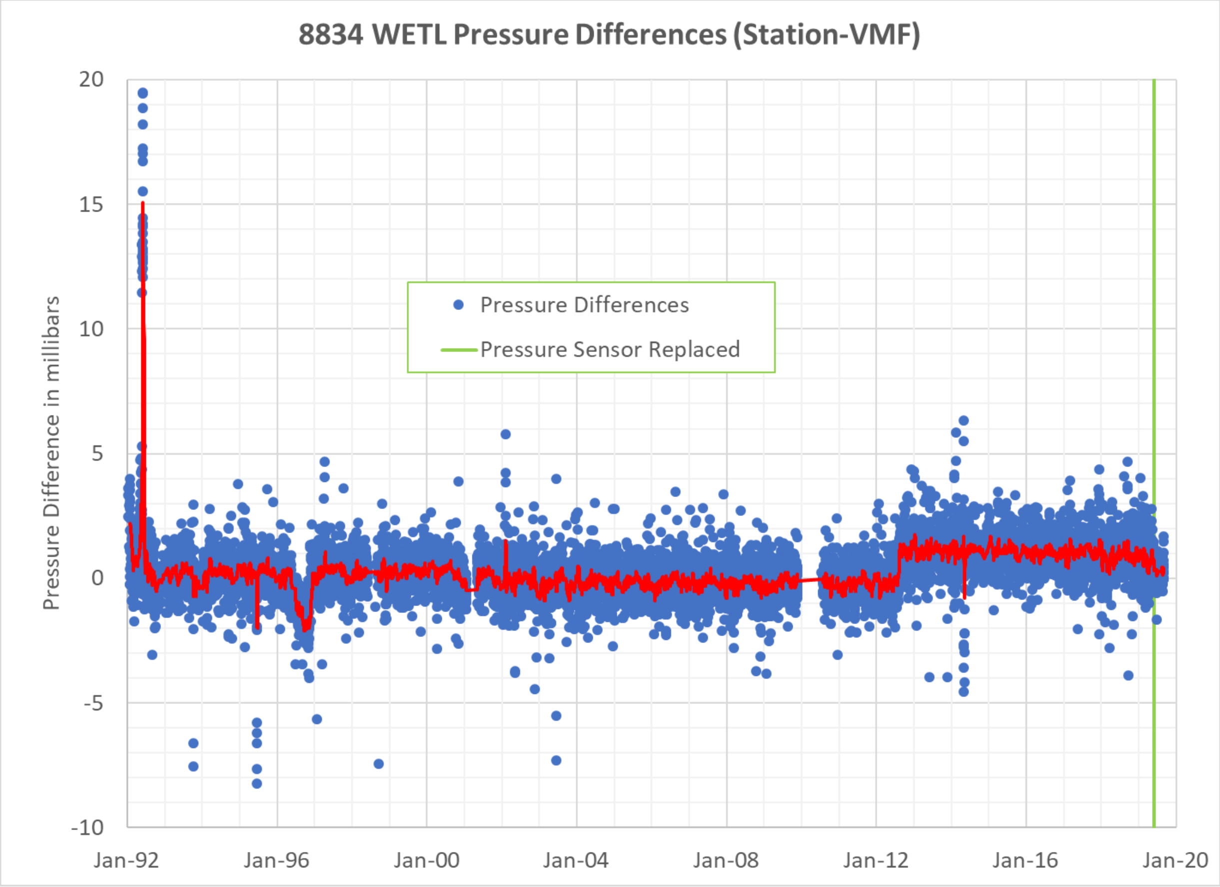


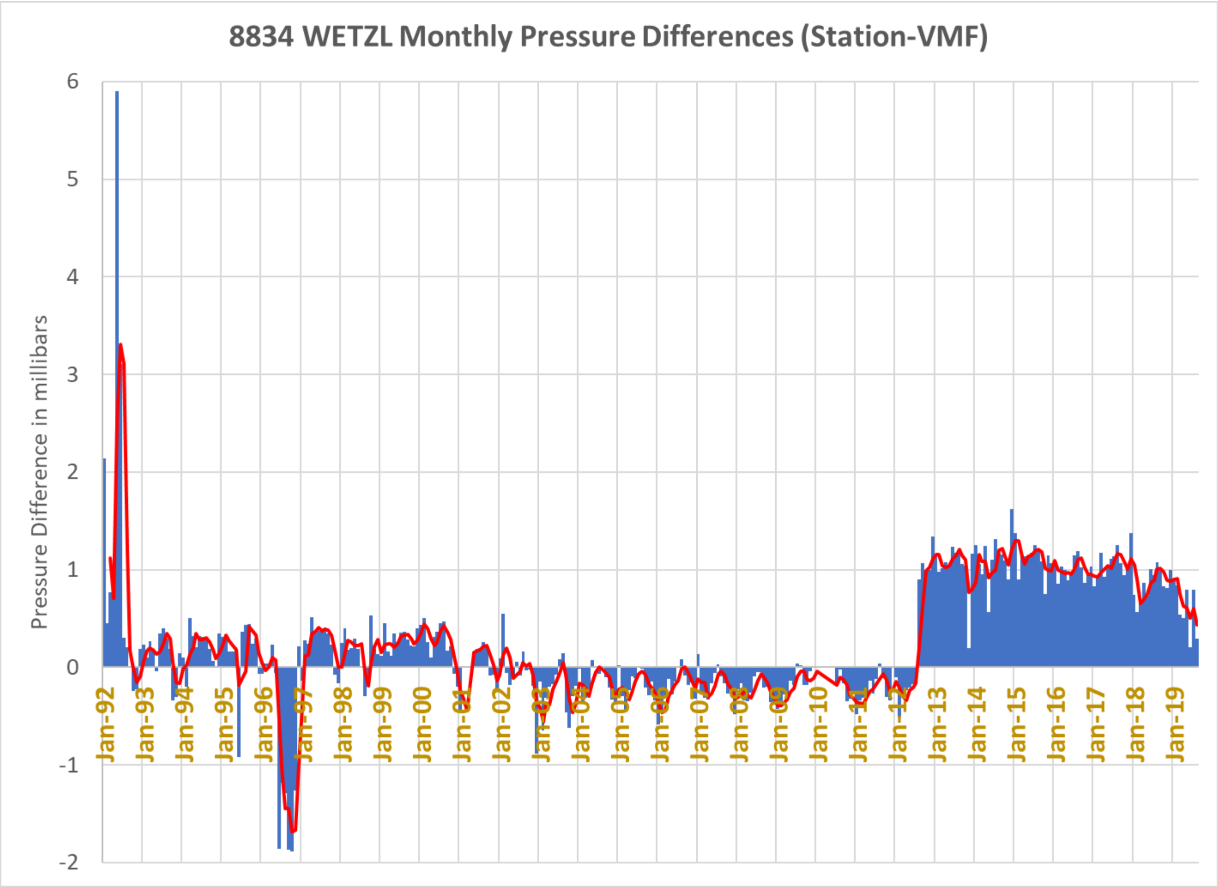
7941 MATM Pressure Analysis





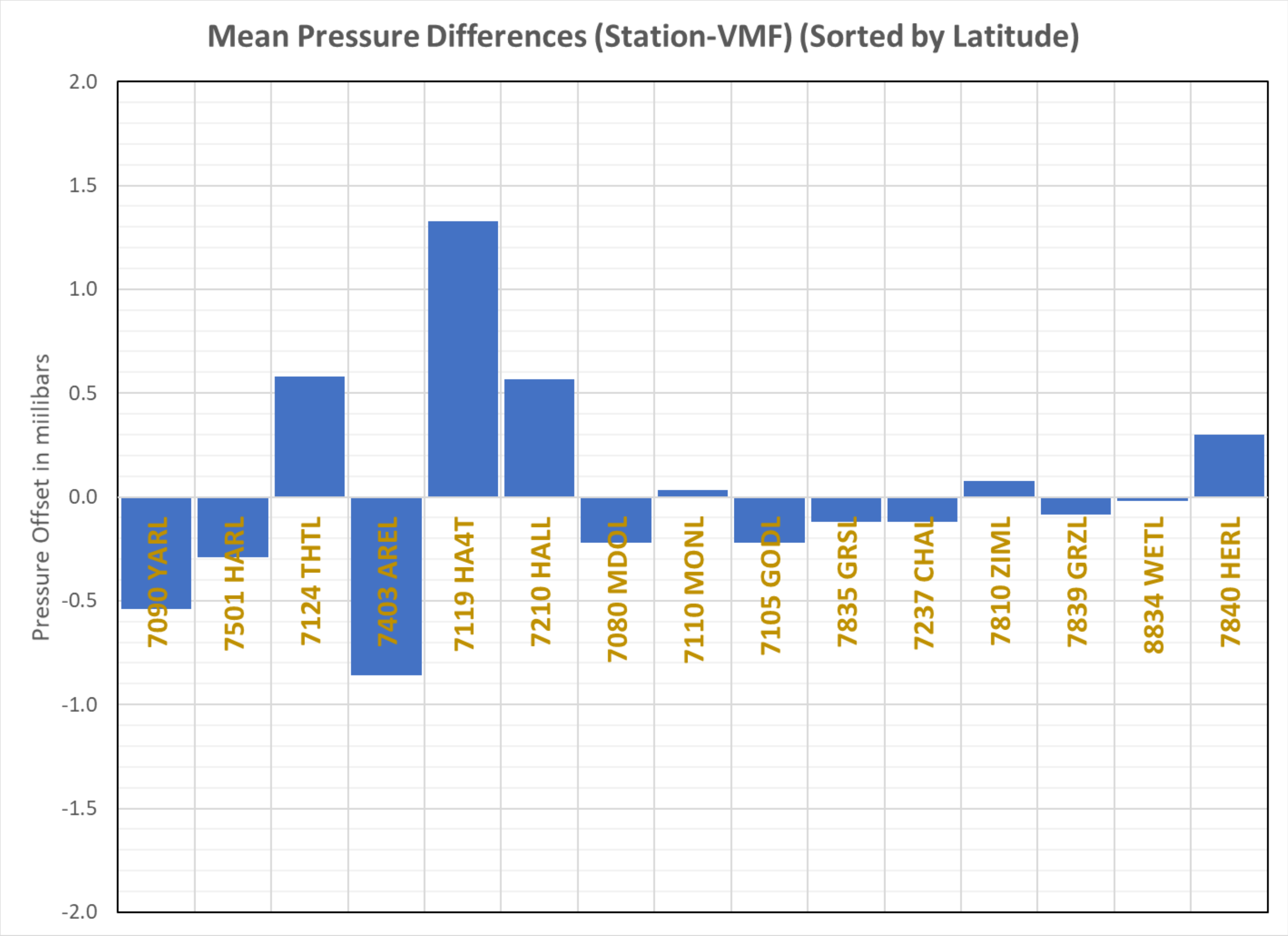
8834 WETL Pressure Analysis





- **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).**

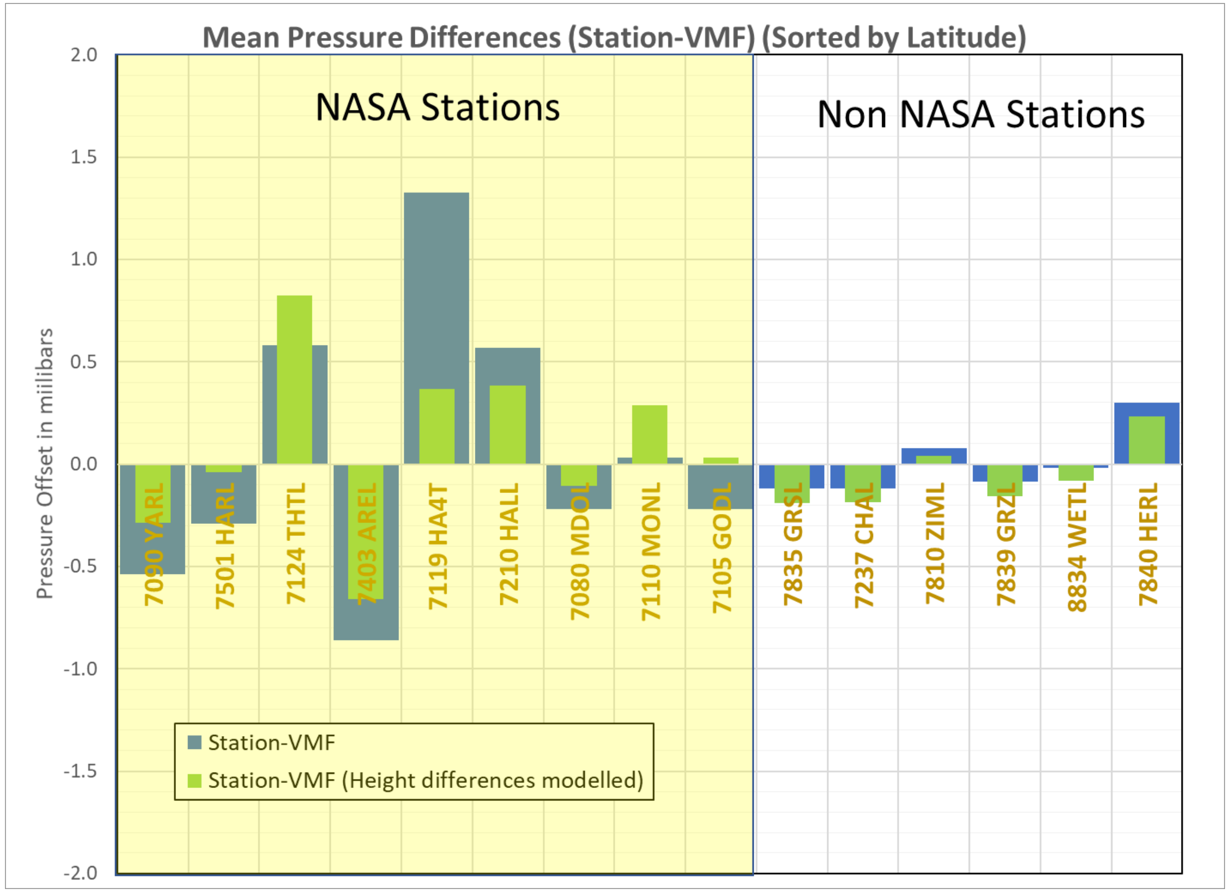
Mean Pressure Differences (Station-VMF) Summary



- **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

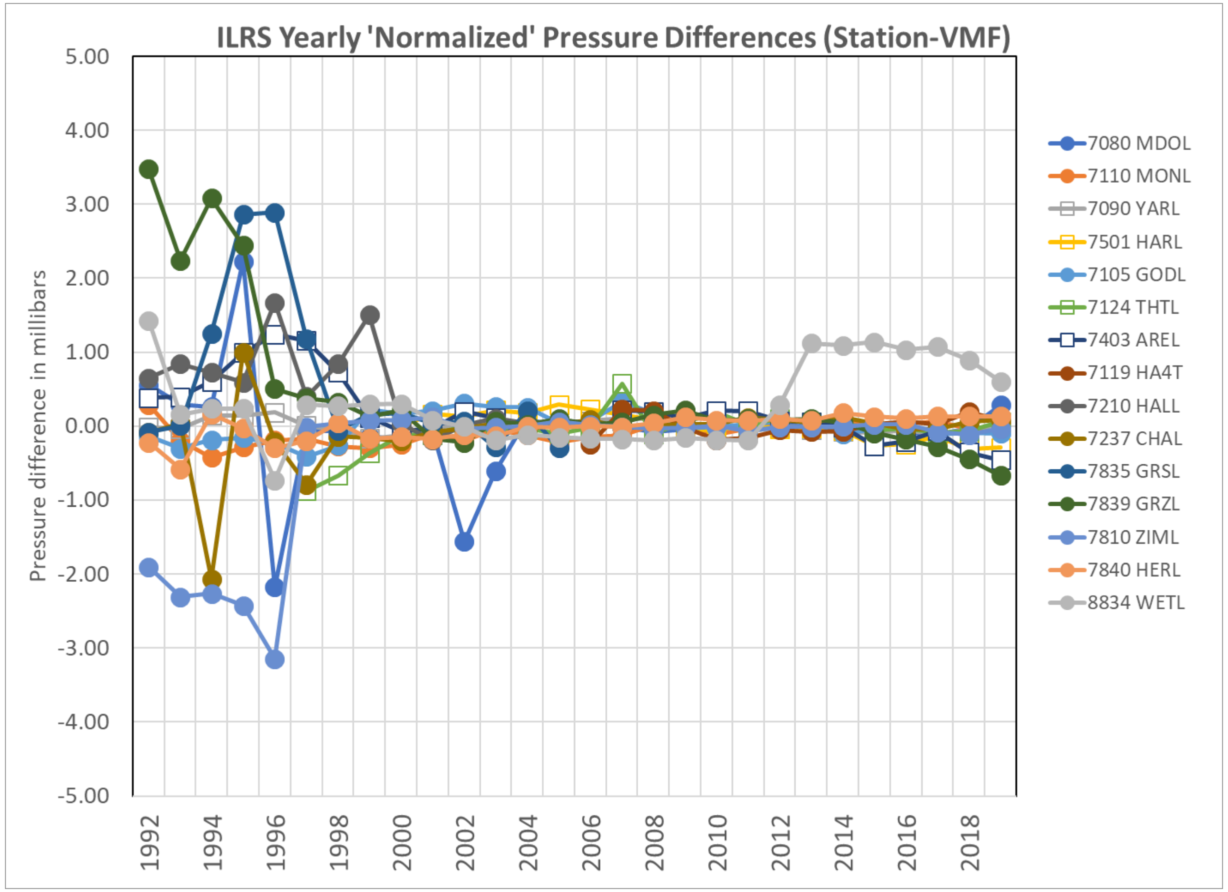


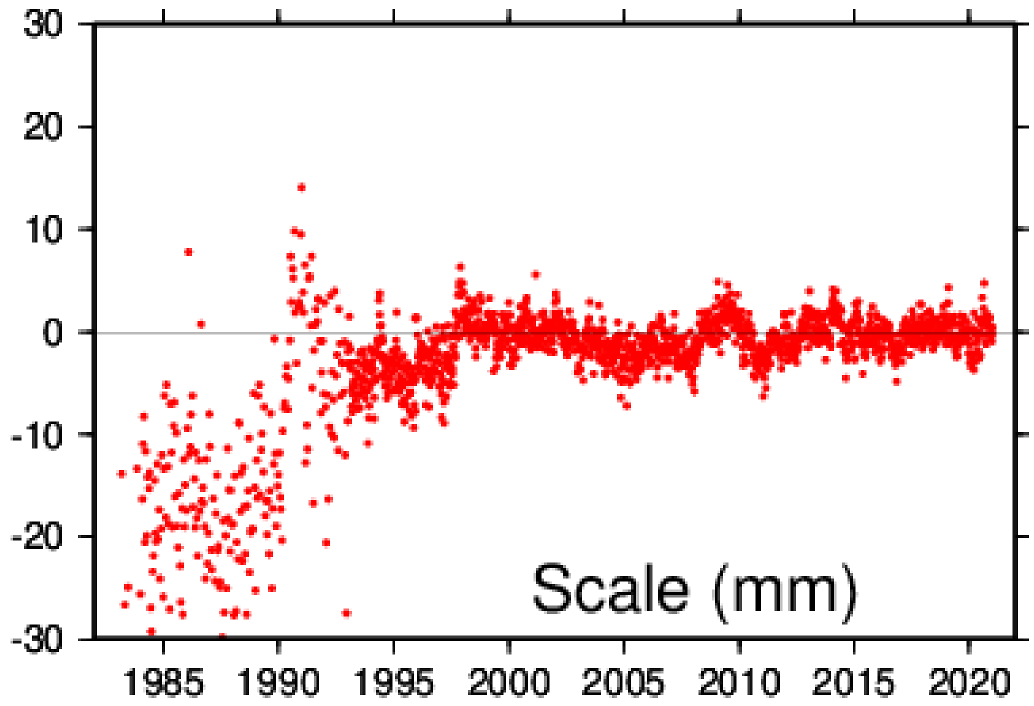
- The VMF station heights are based on approximate heights from the ILRS site eccentricity file.
- For the NASA systems, the VMF heights are based on the marker/monument and NOT the SRP
- NASA system pressure differences moved more toward the positive except for the Hawaii stations (7119, 7210) while 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	2.4	Yes
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/Recommendations

- **Summary:**
  - The absolute accuracy of the VMF3o is site dependent but can be modelled
  - 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
- **Recommendations:**
  - For stations that have their barometer located more than 1 meter above or below their SRP, please update the additional information in Section 12.01 of your site log, to let users know what barometric offset if any is applied to your barometric measurements!