SGSLR Development and Deployment Progress

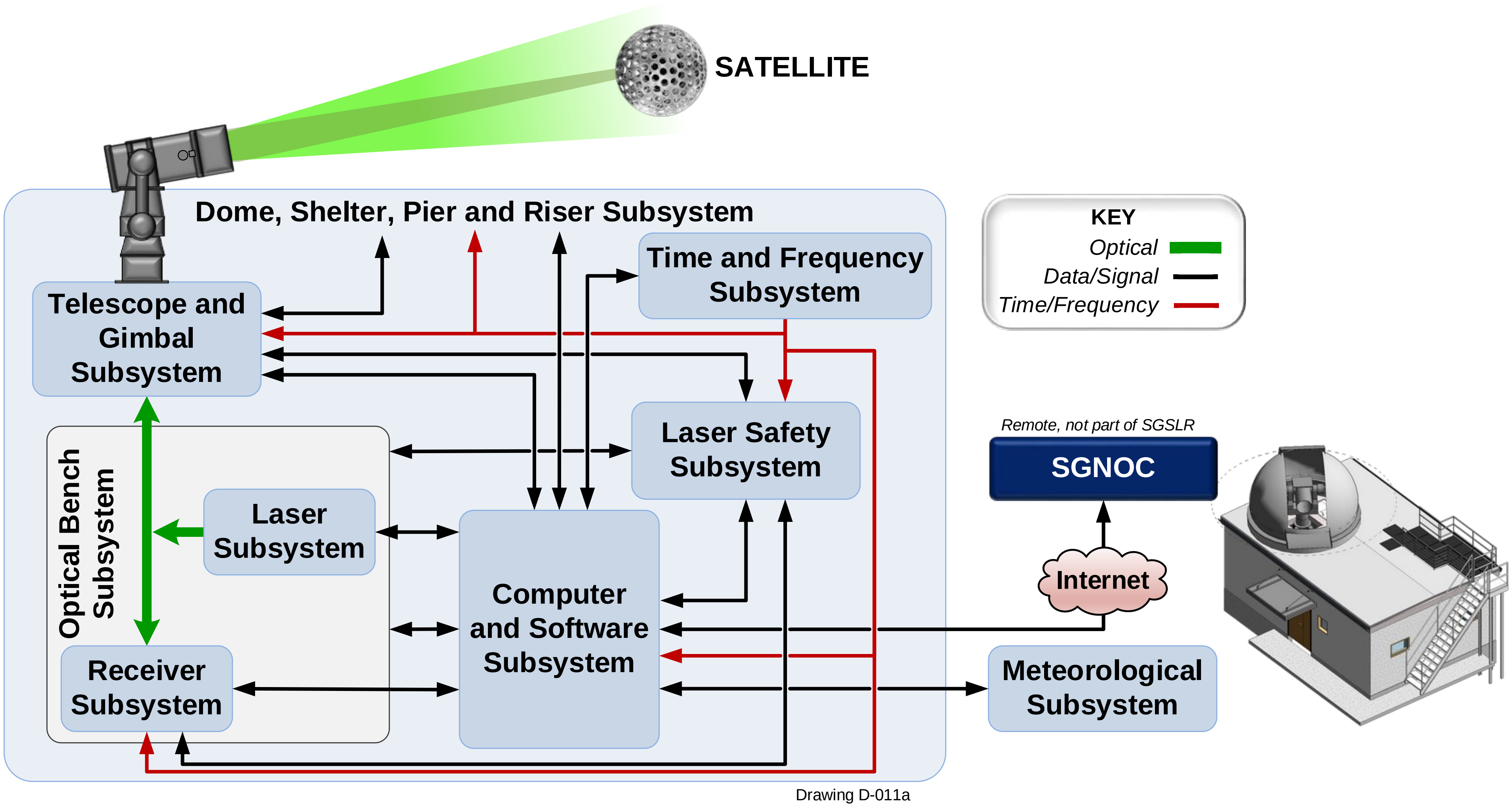
Evan Hoffman

NASA Goddard Space Flight Center

NASA's Space Geodesy Satellite Laser Ranging (SGSLR) System

- Millimeter-level range precision
- Rapid satellite acquisition and data collection to support increasing number of satellites (>100) requiring tracking
- Phased roll-out of automation capabilities:
  1. Local operator: Human present at station
  2. Nearby-remote: Human operating from a nearby location with direct network connections
  3. Remote: Human operating/monitoring over the internet from anywhere in the world

SGSLR Overview



SGSLR's Nine Major Subsystems

- **Timing & Frequency (T&F)**
  - GPS tie to USNO – heartbeat of system
  - Monitoring of timing using 2nd GPS
  - Monitoring info supplied to software
- **Meteorological (MET)**
  - Pressure, Temperature, Humidity for data quality
  - Horizontal Visibility, Precipitation, Wind, Sky Clarity for automation
- **Telescope and Gimbal**
  - Gimbal & Telescope Assembly **(GTA)** – pointing and tracking
  - Camera on GTA is Visual Tracking Aid for operator
- **Optical Bench (OB)**
  - Transmit path, Receive path, Star Camera, Optical Device Control
  - Software will be able to automatically configure for all modes
- **Laser**
  - Expected eventually to provides health & diagnostic information to software
  - Repetition rate controlled by software via RCE
- **Laser Safety (LSS)**
  - NASA/ANSI compliant, Failsafe, Redundant, Highly responsive
  - Provides information to Software on actions it takes and reasons why
  - GGAO version incorporates a radar and ADSB.
  - Will respond to request for block by Software as well as by operator
- **Receiver**
  - Sigma Space Range Receiver **(SSRx)** – Precise signal timing coupled with angular offset info to optimize pointing
  - Range Control Electronics **(RCE)** – sets range window and laser fire rate based on information from software
- **Dome, Shelter, Pier, Riser (DSPR)**
  - Provides clean stable environment and protection from weather
  - Software will eventually control power through UPS units and will be able to shut everything down
- **Computer and Software (C&S)**
  - Ties all subsystems together for manned, remote, and automated operations

Gimbal and Telescope Assembly (GTA)

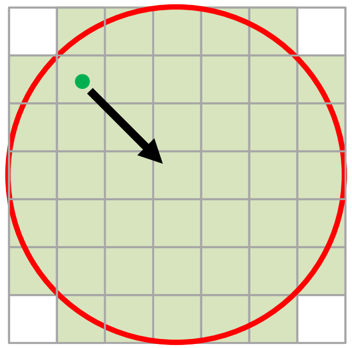
Better than 0.0008° pointing accuracy and 1 mm invariant point knowledge

Acceptance tests at Ny-Ålesund included sunlit satellite tracking

Ny-Ålesund GTA demonstrated excellent stability over several months (order of arcseconds).

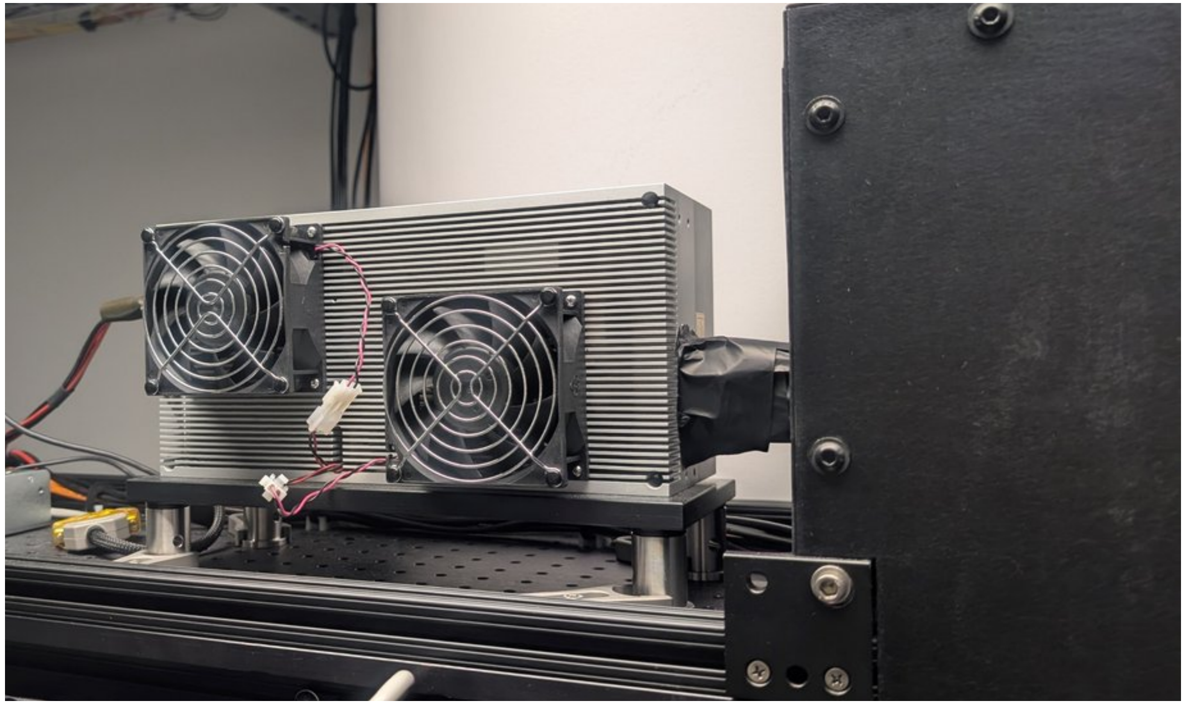
Receiver Subsystem

- Design from ICESat-2/ATLAS detector.
- Multi-pixelated SiPM detector (7x7)
- Provides precise, stable ranging measurement
- Provides automation of GTA pointing correction

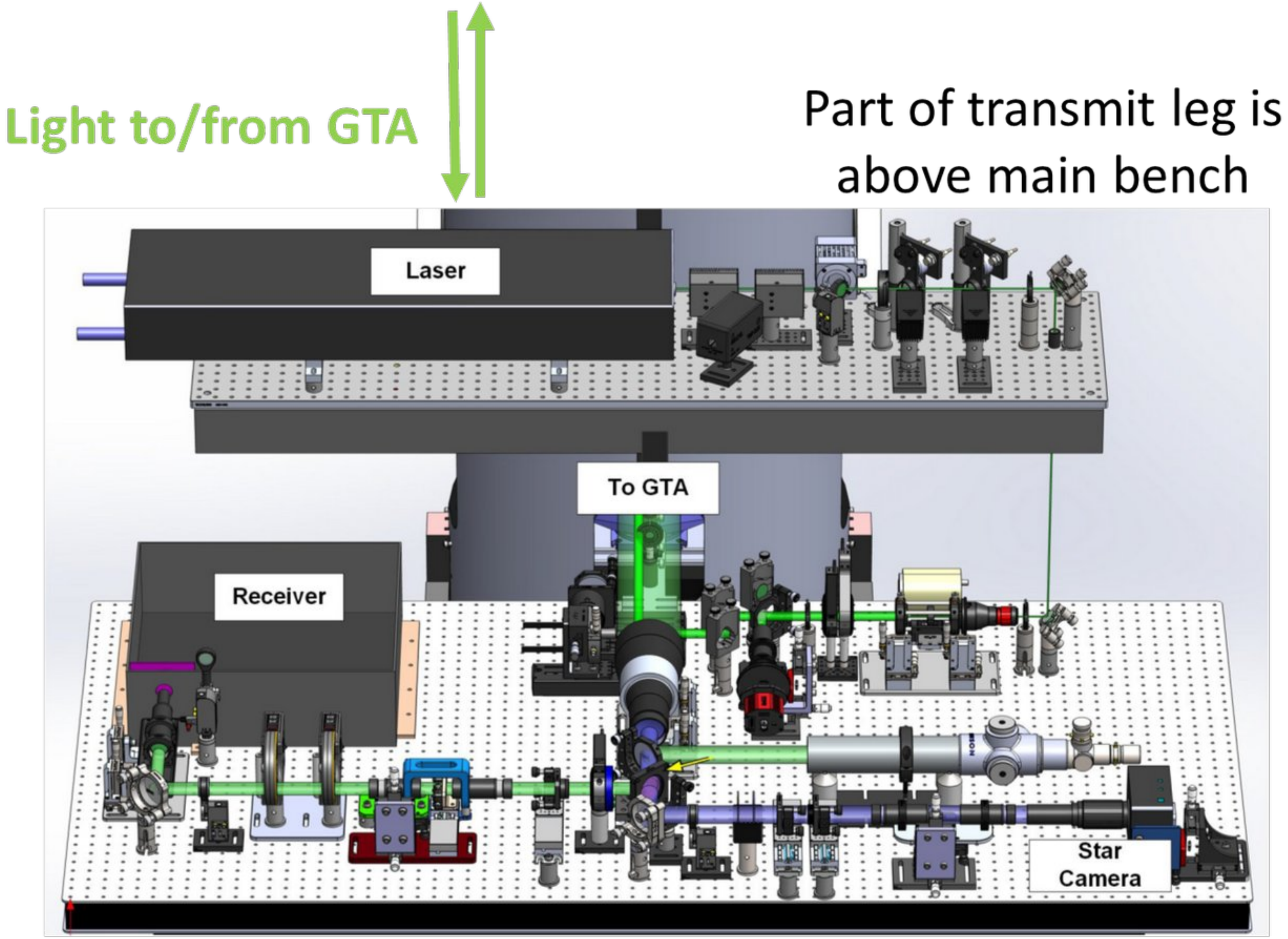


Laser Subsystem

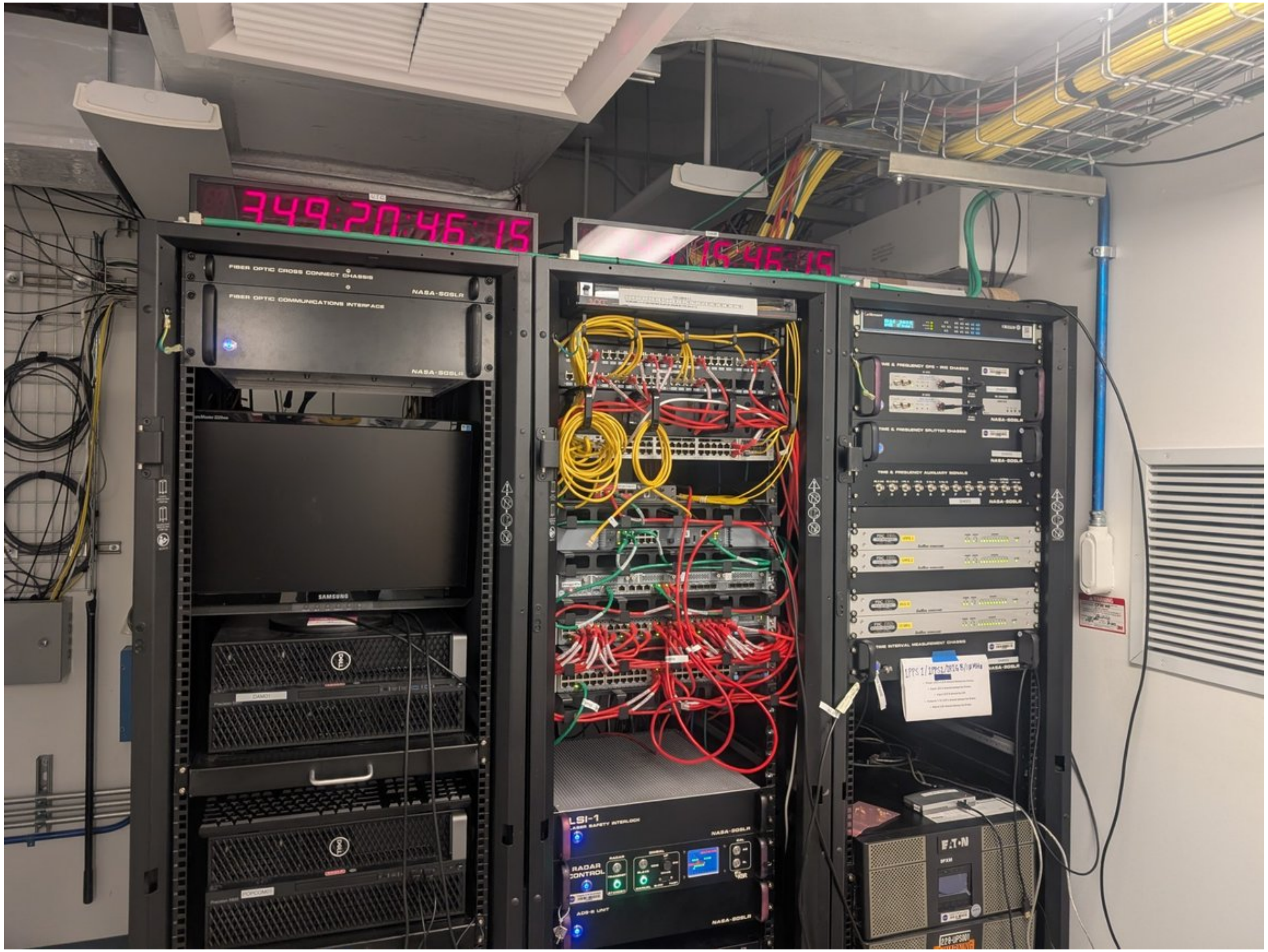
- Original laser selected for SGSLR had multiple failures leading to a change to a different manufacturer (Bright Solutions).
- Current COTS laser has 300 uJ pulse energy and 300 ps pulse width.
- Laser will be replaced with 3 mJ / 50 ps laser not long after commissioning.



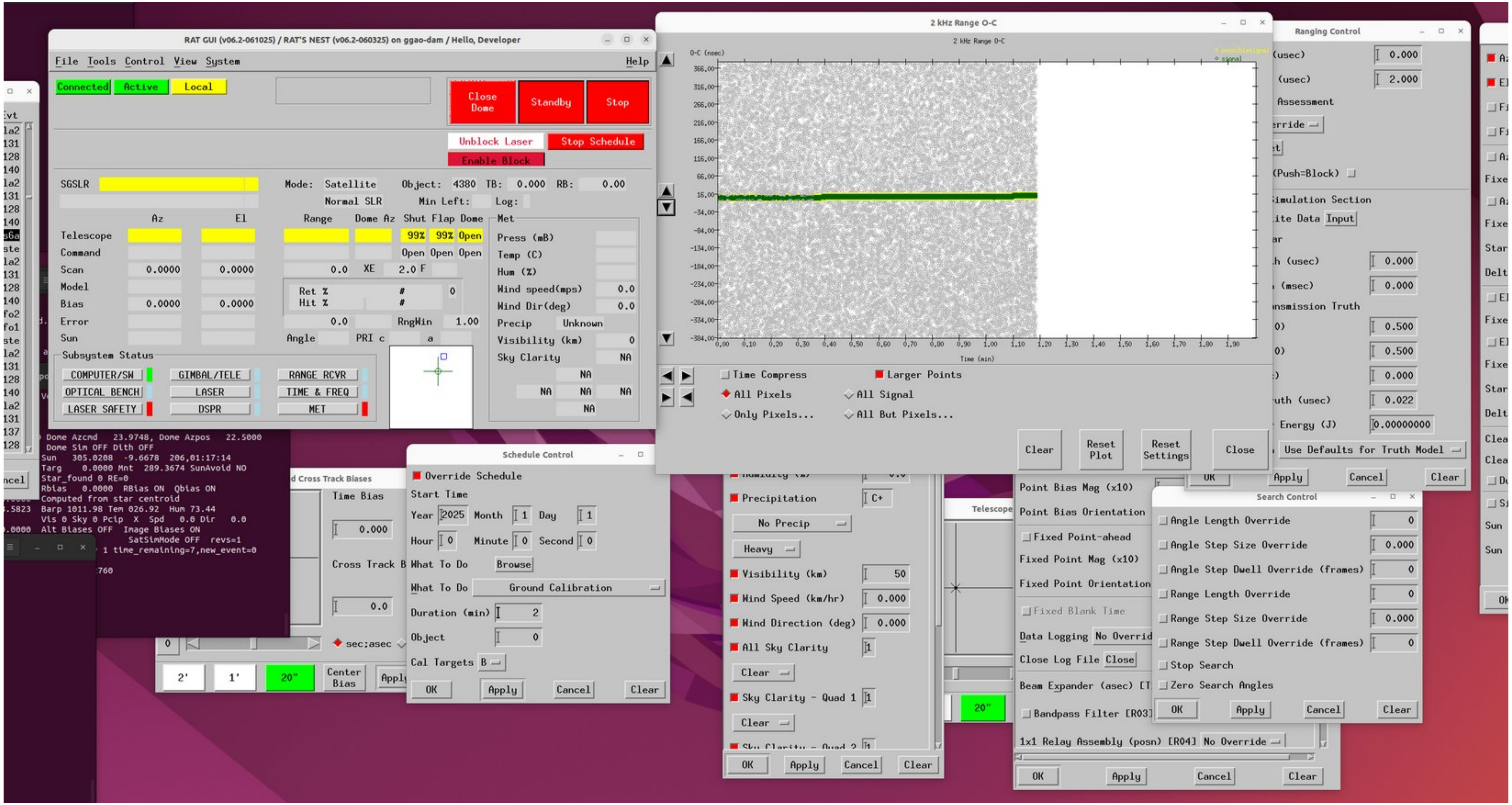
Optical Bench Subsystem



Computer/Software and Timing



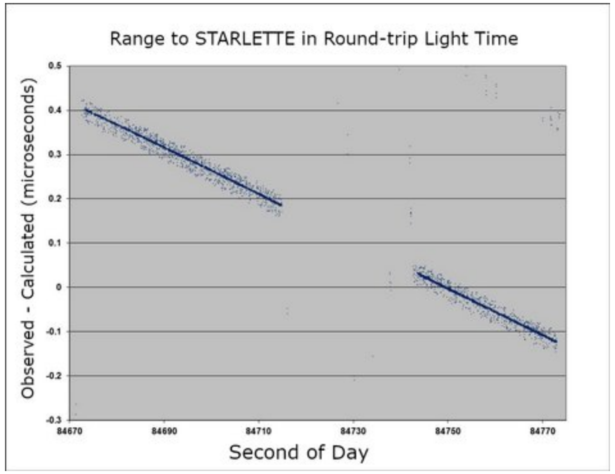
Tracking Display



Ny-Ålesund system built and operating at GGAO

- System acquired and tracked its first satellite (STARLETTE) at Goddard at 6:17 PM EST November 26th , 2024.
  - First acquisition and tracking of a satellite is one of the most difficult points in SLR system development.
- This major milestone was followed by extensive system-level testing.

STARLETTE



Strong detections of the return photons are shown.

SGSLR in action. Photo courtesy of Chris Pirner

What is Collocation?

- SLR Collocation is a test to verify a system’s performance by inter-comparison (i.e. comparing ranging data to that of a known standard).
- The test is performed by freezing each system’s configuration for a period of time and comparing simultaneously tracked data.
- The known SLR network standard is MOBLAS-7 at GGAO, which has been operational for over ~40 years and has been involved in many collocation tests.
- The range data is transformed from the origin of one station to the other and a direct range difference is calculated.
- The close proximity of the stations eliminates any range differences due to refraction, ground water motion, and seasonal effects. The purely geometric technique removes any discrepancies introduced by orbits.

- This analysis is an excellent engineering tool available for rapid identification of systematic error sources in a new SLR system at the few millimeter level. It has helped NASA SLR achieve uniformity and consistency of performance across its current global SLR network

Collocation Status

- Dozens of low-earth orbit and geodetic satellite passes have been taken and analyzed, in daylight and during the night.
- Collocation concluded successfully at the end of December 2025. Report is currently being generated.
- Analysis shows excellent stability on the order of millimeters for geodetic and LEO targets.

Personnel from NMA trained on the SGSLR system to learn operations, maintenance, and witnessed collocation activities.

Deployment – Installation/Testing

- Gimble and Telescope were installed in February 2024
- Site stabilization was necessary due to melting permafrost. This work was completed in 2025 by Kartverket.
- NASA will travel to Ny-Ålesund beginning in May. A rotating NASA and NMA cast, depending on the activity, are expected to be in Ny-Ålesund until ORR.
- Installation of all systems will complete by mid-July.
- Verification testing begins after installation. All subsystems, ground calibration, satellite tracking and system performance will be tested.
- Testing is scheduled to conclude one month after installation is completed (mid-August).

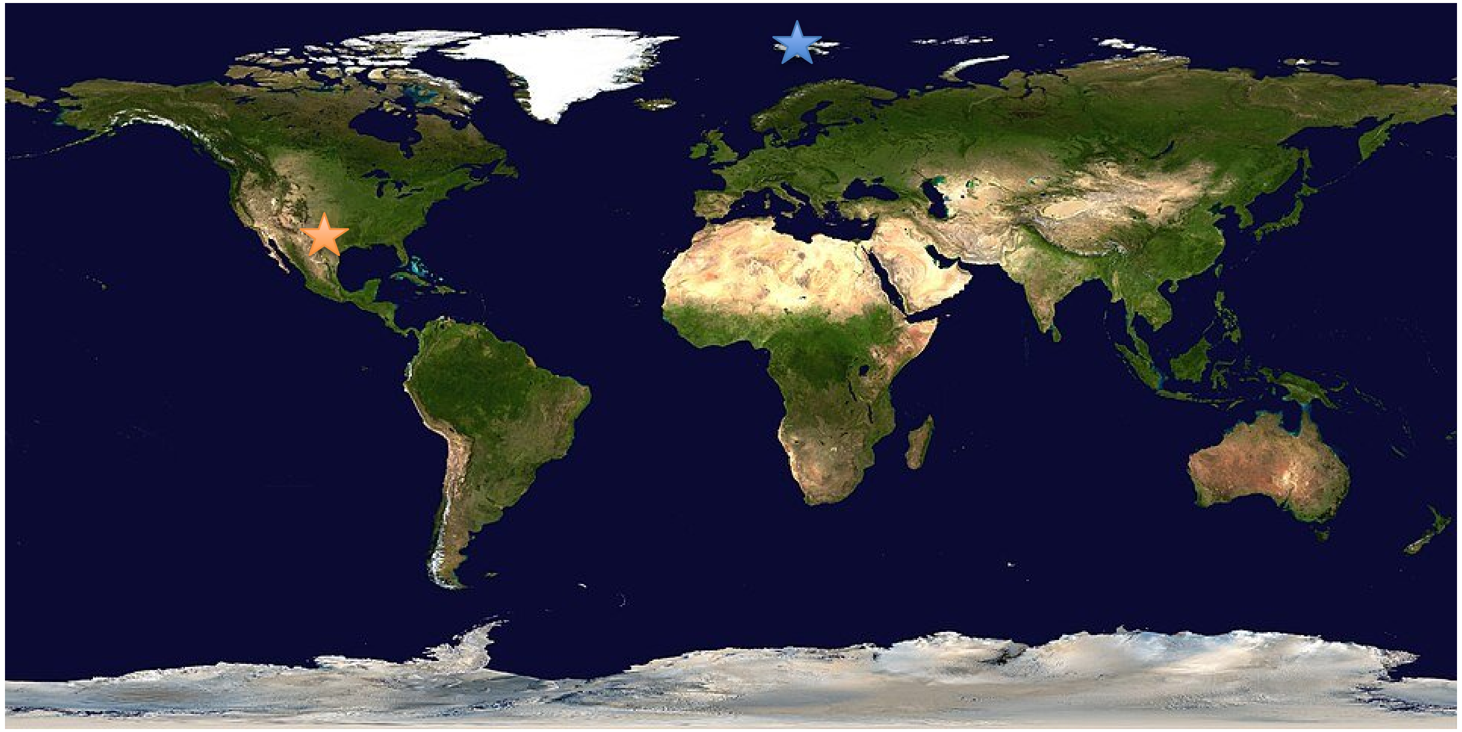
Deployment – Commissioning

- Begins after successful verification testing.
- The system is now **Ranging Ready!** This means it will be collecting actual satellite data that can be shared with ILRS analysts. After an initial inspection and discussion, the data can be delivered to the community in a quarantined state. This will happen in **August 2026**
- After a number of ranging passes with geodetic satellites with no anomalies, the data can be released from quarantine.
- NASA will be training operators on local and nearby remote operations, while collecting data.

Activities to Follow Operational Readiness Review

- Installation of Operational Laser (shorter pulse width, more energy per pulse)
- Installation of Upgraded Receiver (SSRx) and associated electronics
- Planned Optical Bench improvements
- Software updates

SGSLR Deployment



Ny-Ålesund Observatory
Summer/Fall 2026

McDonald Observatory
2028

Pending
2029

Latest Developments in Barometric Quality Control

Van S. Husson, Mary Fenno, Sean Mayer

vhusson@peraton.com, mary.fenno@peraton.com, smayer@peraton.com

ILRS Networks and Engineering Standing Committee

16-Apr-2026

Peraton

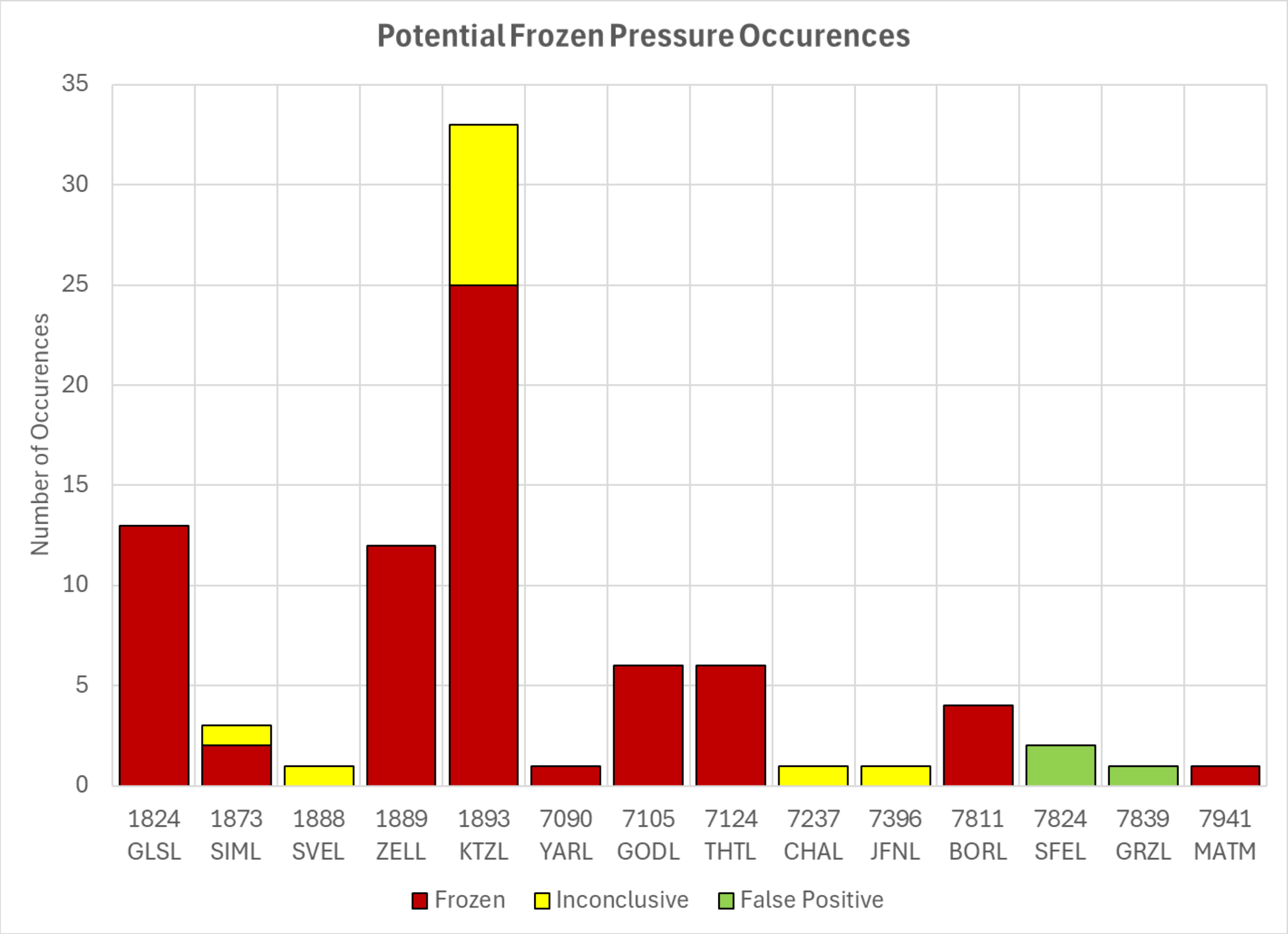
Issues with SLR Barometric Measurements

- The meteorological measurements fail to update
- Inexplicable jumps in the barometric measurements
- Barometric sensors can drift over time
- Changing barometric sensors and/or recalibration may induce a discontinuity
- A height difference between the barometric sensor and the System Reference Point (SRP) are not modelled in the data pre-processing

Latest Developments

- In March 2025, the NASA SLR Data Operations Center (DOC) developed an algorithm to identify frozen pressures
- In April 2025, the NASA SLR DOC began to store every CRD Normal Point 20 Meteorological record to a relational database. Using this new database, the NASA SLR DOC implemented an algorithm to identify any CRDs where the peak-to-peak pressure variation exceeded a configurable value (e.g. 2 mBars/2 hPa)
- In February 2026, the NASA SLR DOC automated these two algorithms to run weekly

Potential Frozen Pressures (1-Jan-2024 to 31-Jan-2026)



- ❑ When the pressures were frozen, most of the time the temperatures were also frozen
- ❑ Incorrect temperatures can influence the system delay calculations which are dependent on the range to the calibration target
- ❑ Note: The resolution of the 1893 KTZL barometric measurements was 1 mBar making it difficult to tell if the pressures were changing
- ❑ Very few false positives and inconclusives

Frozen Meteorological Data Example from 1889 ZELL

pad	sat	start date & time	pressure (mbar)	temp (K)	hum (%)
1889	STRL	1/24/2023 11:37	896.2	281.4	28
1889	LAG1	1/24/2023 12:51	896.3	280.6	35
1889	STRL	1/24/2023 13:25	896.3	280.6	35
1889	LARS	1/24/2023 15:05	896.3	280.6	35
1889	STRL	1/24/2023 15:13	896.3	280.6	35
1889	LAG2	1/24/2023 15:21	896.3	280.6	35
1889	AJI1	1/24/2023 15:56	896.3	280.6	35
1889	LAG1	1/24/2023 16:11	896.3	280.6	35
1889	STEL	1/24/2023 16:38	896.3	280.6	35
1889	LARS	1/24/2023 17:02	896.3	280.6	35
1889	LAG2	1/24/2023 19:39	896.3	280.6	35
1889	LAG1	1/24/2023 19:57	896.3	280.6	35
1889	STRL	1/24/2023 20:42	896.3	280.6	35
1889	AJI1	1/24/2023 22:03	895.3	271.9	47
1889	AJI1	1/25/2023 23:13	892.9	271.1	41
1889	STEL	1/26/2023 4:24	893.1	270.4	36
1889	LAG1	1/26/2023 10:25	892.3	279.4	22
1889	LAG2	1/26/2023 11:25	892.3	279.4	22
1889	STRL	1/26/2023 12:11	892.3	279.4	22
1889	LAG1	1/26/2023 13:39	892.3	279.4	22
1889	STRL	1/26/2023 14:06	892.3	279.4	22
1889	AJI1	1/26/2023 14:11	892.3	279.4	22
1889	LARS	1/26/2023 14:56	892.3	279.4	22
1889	LAG2	1/26/2023 15:11	892.3	279.4	22
1889	STRL	1/26/2023 15:50	892.3	279.4	22
1889	AJI1	1/26/2023 16:11	892.3	279.4	22
1889	LARS	1/26/2023 16:51	892.3	279.4	22
1889	LAG1	1/26/2023 17:05	892.3	279.4	22
1889	STRL	1/26/2023 17:41	892.3	279.4	22
1889	AJI1	1/26/2023 18:15	892.3	279.4	22
1889	LAG2	1/26/2023 19:13	891.4	270.8	50

8 hours

8 hours

- ❑ **Did an operational shift change resolve the issue?**

Pressure Variation Algorithm Results

Pad	Satellite	Date and start time YYYY-MM-DD HH:MM:SS	Wave	Pres Var	Elapsed Minutes	# Met
7249	COMPI3	2026-02-05 12:45:00	532.0	3.49	328.43	109
7825	GALILEO220	2025-07-13 09:14:00	532.1	3.35	383.50	3
7825	GALILEO203	2025-08-18 06:34:00	532.1	3.10	273.17	3
7827	BEIDOU3M17	2025-10-30 12:01:00	849.8	3.12	324.22	3
7839	GALILEO208	2025-05-19 14:44:00	532.0	3.24	280.52	2
7839	GALILEO227	2025-10-24 03:47:00	532.0	3.74	216.05	2
7839	GALILEO221	2025-11-23 17:04:00	532.0	3.06	284.72	2
7840	GALILEO213	2025-04-11 23:11:00	532.0	3.70	318.10	61
7840	GALILEO208	2025-09-04 17:39:00	532.0	3.22	216.00	41
7840	GALILEO201	2025-09-04 22:07:00	532.0	3.08	227.95	43
7840	GALILEO224	2025-10-29 21:52:00	532.0	3.63	246.08	46
7840	GALILEO227	2025-11-17 07:53:00	532.0	3.31	264.08	49
7840	GALILEO204	2026-02-16 17:34:00	532.0	3.93	238.03	47
7840	GALILEO102	2026-03-02 15:26:00	532.0	3.02	338.98	66
7840	GALILEO102	2026-03-02 15:26:00	532.0	3.02	338.98	66
1893	STARLETTE	2025-08-22 19:55:00	532.0	5.00	9.07	2
7838	GRACE-FO2	2025-08-17 21:01:00	532.0	9.60	1.28	13
7941	HY-2D	2025-05-07 10:55:00	532.0	4.80	2.05	4

- **Here are the results for 2025, where the pressure variation tolerance was set at 3 mBars**
- **Barometric pressures can change by more 3 mBars during GNSS passes which can up to 8 hours**
- **The last three highlighted passes are from LEO CRDs which have inexplicable barometric changes**

Inexplicable Jumps in Barometric Pressure

station	satellite	YYYY-MM-DD	Seconds of Day	Pressure (mBar)	Hum (%)	Temp (K)
7838	GRACE-FO1	2025-08-17	75580	1009.5000	78	300.4
7838	GRACE-FO1	2025-08-17	75583	1009.5000	78	300.4
7838	GRACE-FO1	2025-08-17	75585	1009.5000	78	300.4
7838	GRACE-FO1	2025-08-17	75594	1009.5000	78	300.4
7838	GRACE-FO1	2025-08-17	75608	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75617	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75623	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75626	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75632	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75639	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75649	1009.5000	77	300.4
7838	GRACE-FO1	2025-08-17	75653	1009.5000	77	300.4
7838	GRACE-FO2	2025-08-17	75695	1019.5000	78	300.4
7838	GRACE-FO2	2025-08-17	75697	1019.5000	78	300.4
7838	GRACE-FO2	2025-08-17	75713	1019.5000	78	300.4
7838	GRACE-FO2	2025-08-17	75717	1019.5000	78	300.4
7838	GRACE-FO2	2025-08-17	75723	1009.9000	78	300.4
7838	GRACE-FO2	2025-08-17	75727	1009.9000	78	300.4
7838	GRACE-FO2	2025-08-17	75735	1009.9000	78	300.4
7838	GRACE-FO2	2025-08-17	75738	1009.9000	78	300.4
7838	GRACE-FO2	2025-08-17	75741	1009.9000	78	300.4

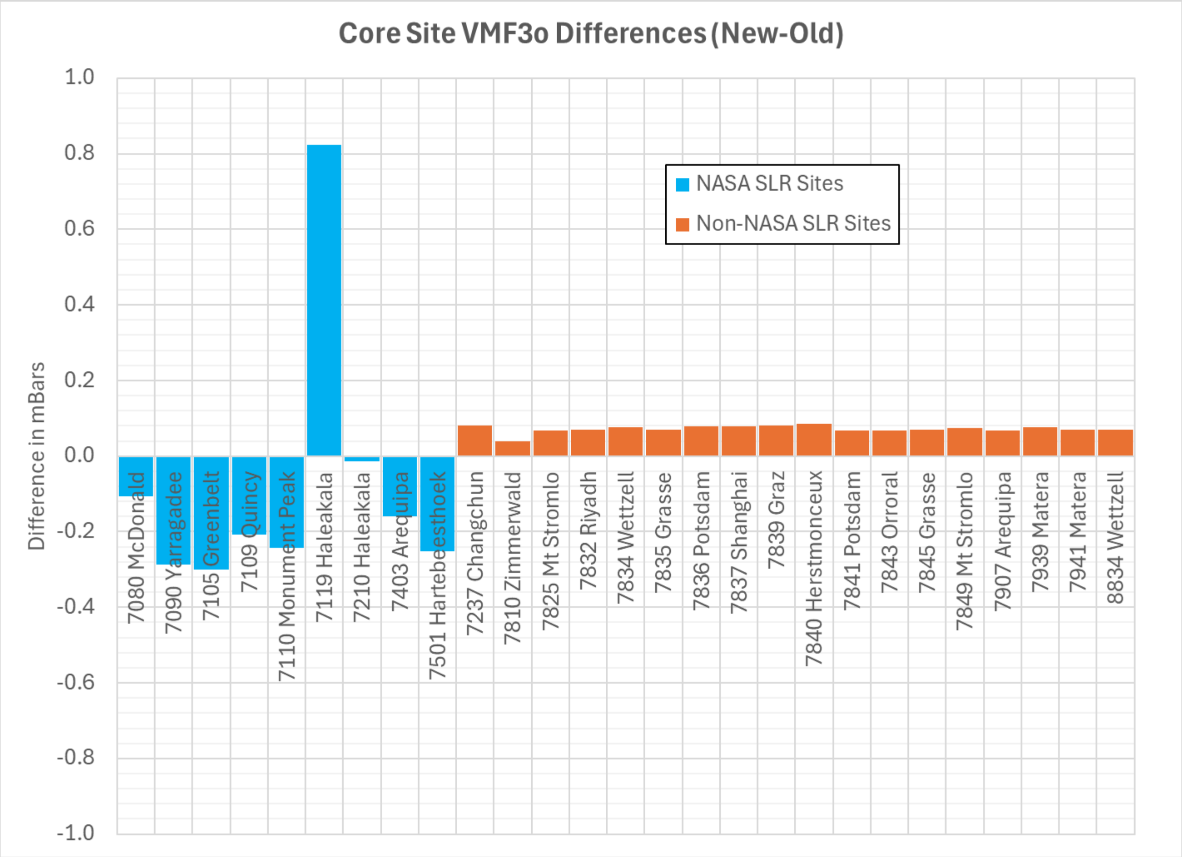
- **Simosato (7838) was tracking both Grace follow-on satellites and the barometric pressures jumped twice by 10 mBars in 42 seconds and 6 seconds; respectively**
- **It would be nice to know the root cause of this issue**

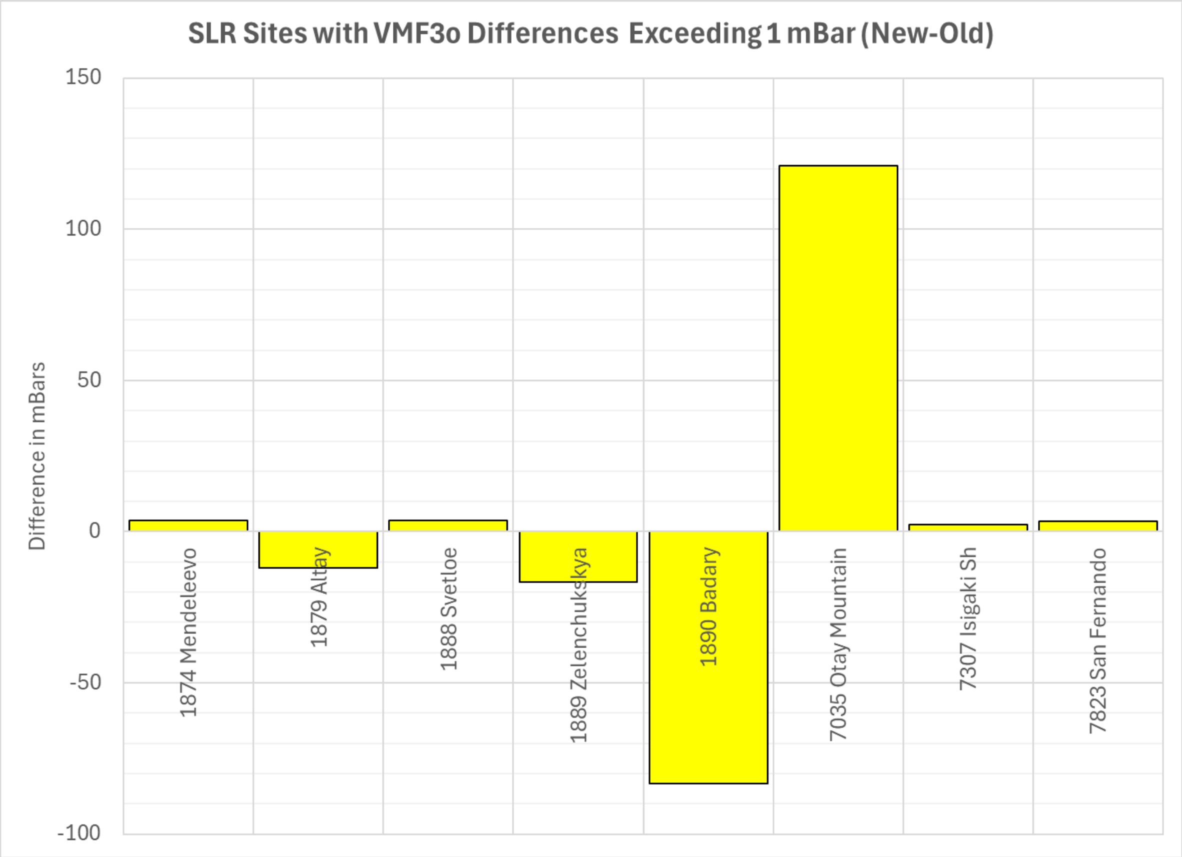
Incorporation of VMF3o data in Barometric Quality Control

Vienna Mapping Function for Optical Frequencies (VMF3o)

- **In 2017, the Vienna Mapping Function for optical wavelengths (VMF3o) was developed (ref: DOI:10.1007/s00190-020-01385-5), but was not part of any automated quality control. There are 3 categories of VMF3o data**
  - VMF3o_EI: European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim Numerical Weather Models (NWM) data
    - Time Span: January 1, 1990, to August 31, 2019 (the most accurate VMF3o data)
  - VMF3o_FC: ECMWF forecasted NWM
    - Time span: January 1, 2019, to present
  - VMF3o_OP: ECMWF operational NWM. Data is available next day
    - Time Span: January 1, 2008, to present
- **VMF3o data has a temporal resolution of 6 hours and exists for every ILRS site**
- **The original VMF3o time series was based on ‘approximate’ site heights**
- **All three VMF3o time series were updated in August 2025 based on more accurate SLR station heights and the addition of newer SLR sites**

Comparisons of the Old and New versions of VMF3o data by SLR station



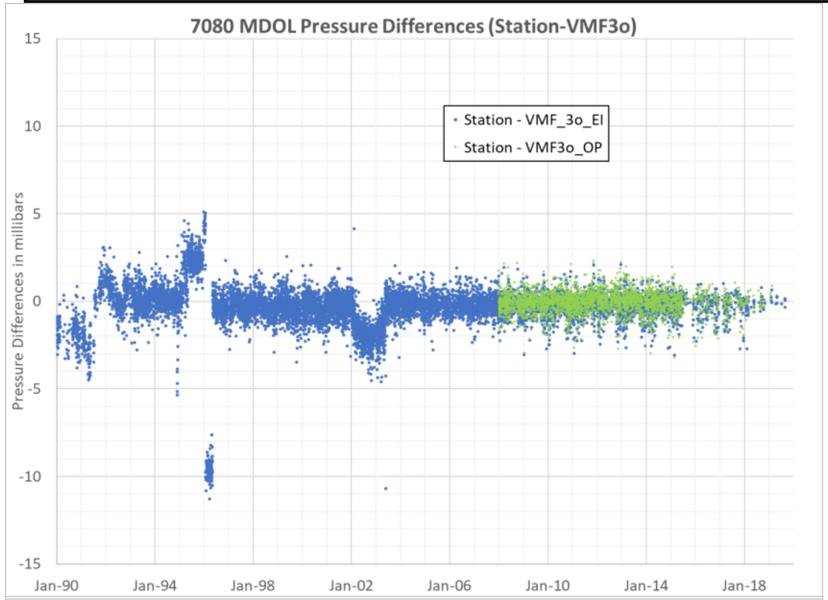


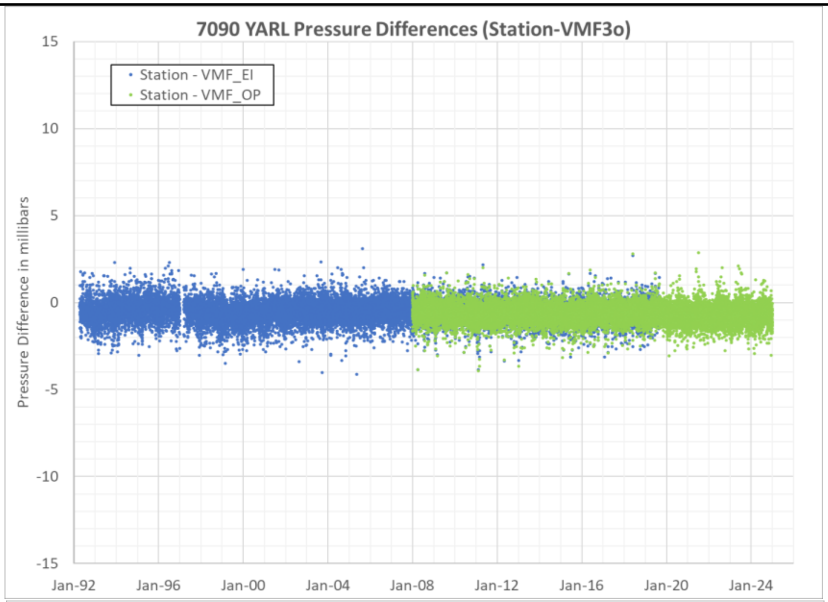
- The old VMF3o data was based on the approximate station heights from the ILRS station eccentricity file
- The new VMF3o data is based on ITRF2020 heights. ITRF monument heights were adjusted based on the Up eccentricities (i.e. the system refence point for NASA SLR systems and other legacy transportable systems)
- The differences between the old and new VMF3o data are systematic. For Core ILRS sites the differences are sub 1 mBar. The original 7119 station height used was off by ~10m

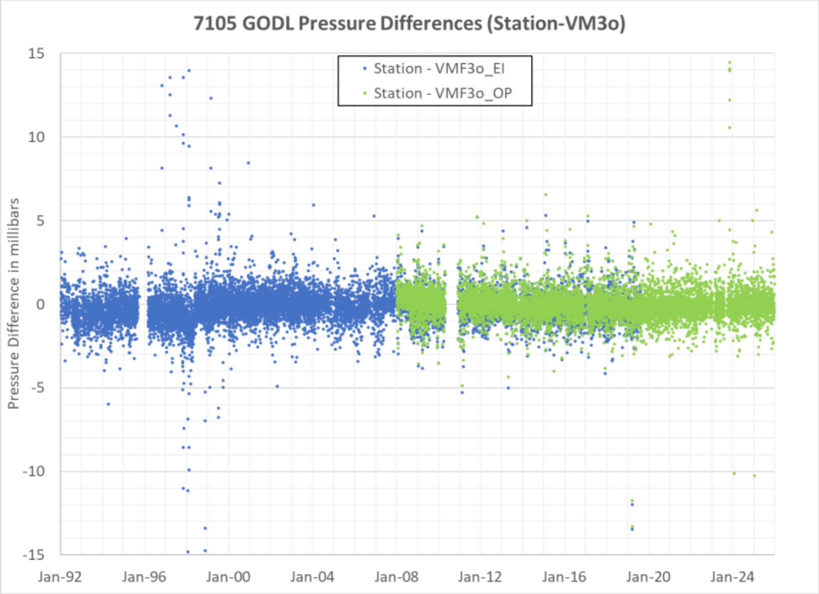
Latest Developments

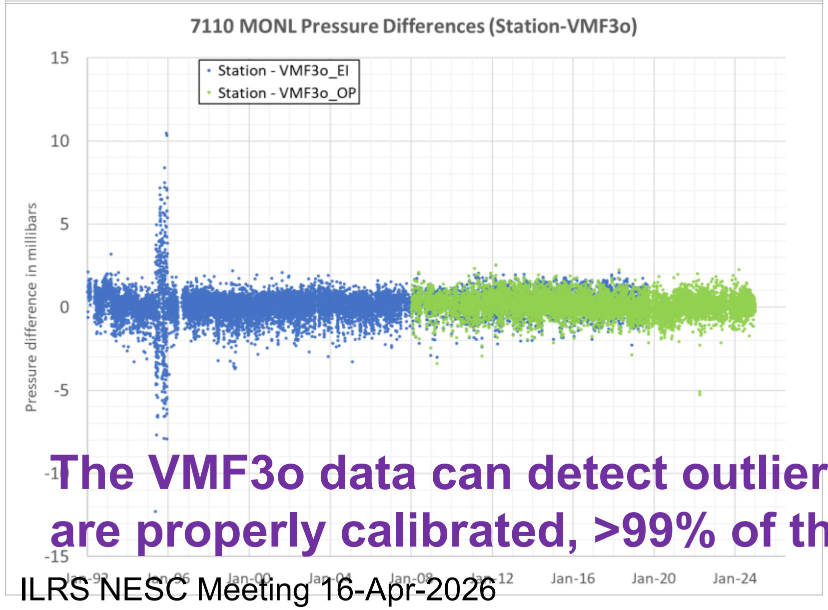
- In July/August 2025, the NASA SLR DOC migrated from an Oracle relational DataBase (DB) to MariaDB, an open-source relational database
- Post August 2025, the NASA SLR DOC began automatic loading of the daily VMF3o Operational (VMF3o_OP) time series into a relational DB along with averaging station pressures every 6-hour to enable comparisons with the VMF3o

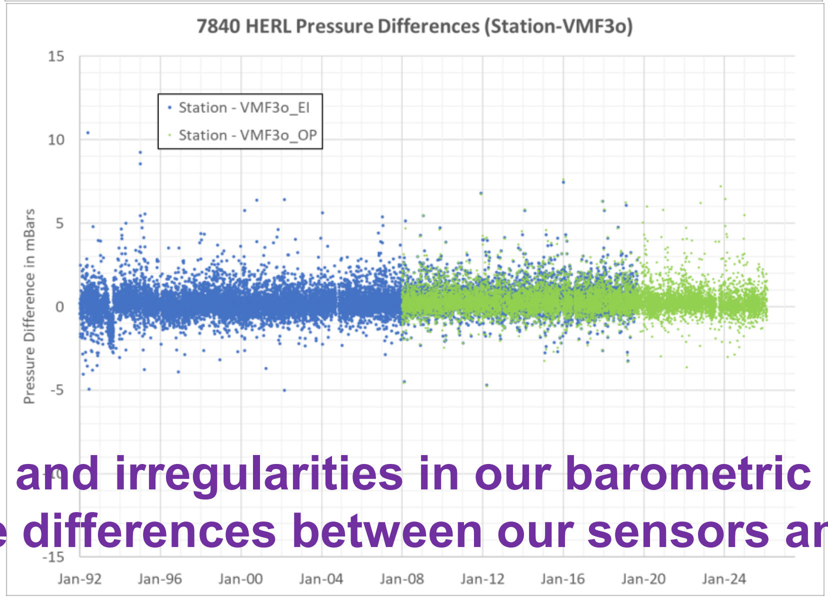
Six-Hour Barometric Differences (Station – VMF3o)
Six Examples from ILRS Core Sites

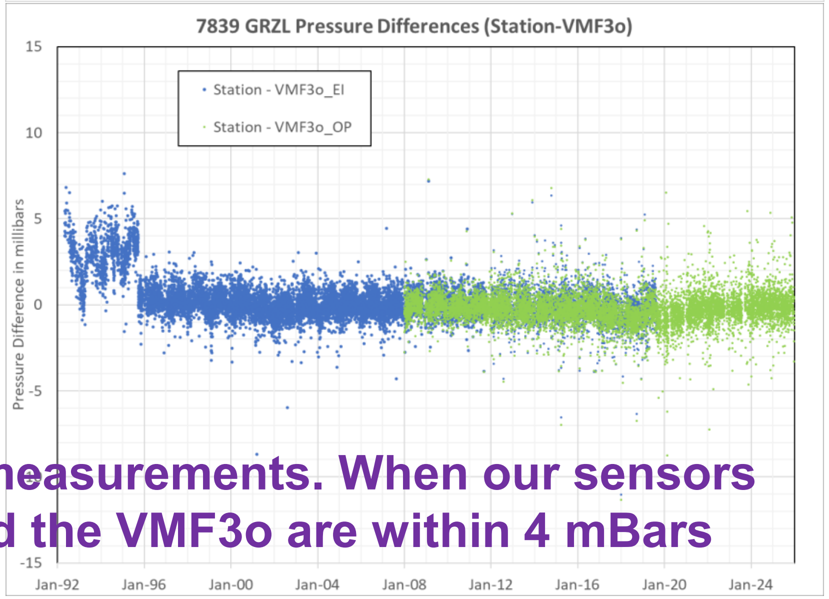










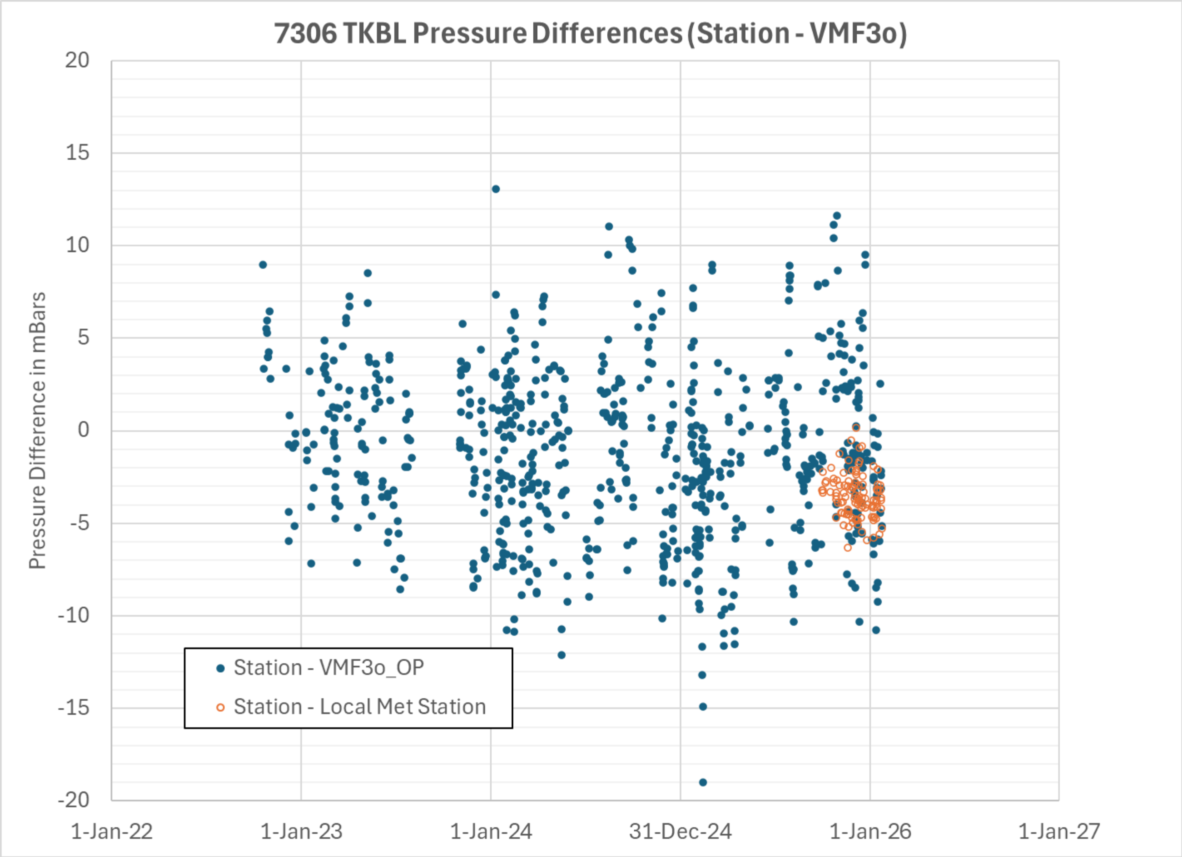


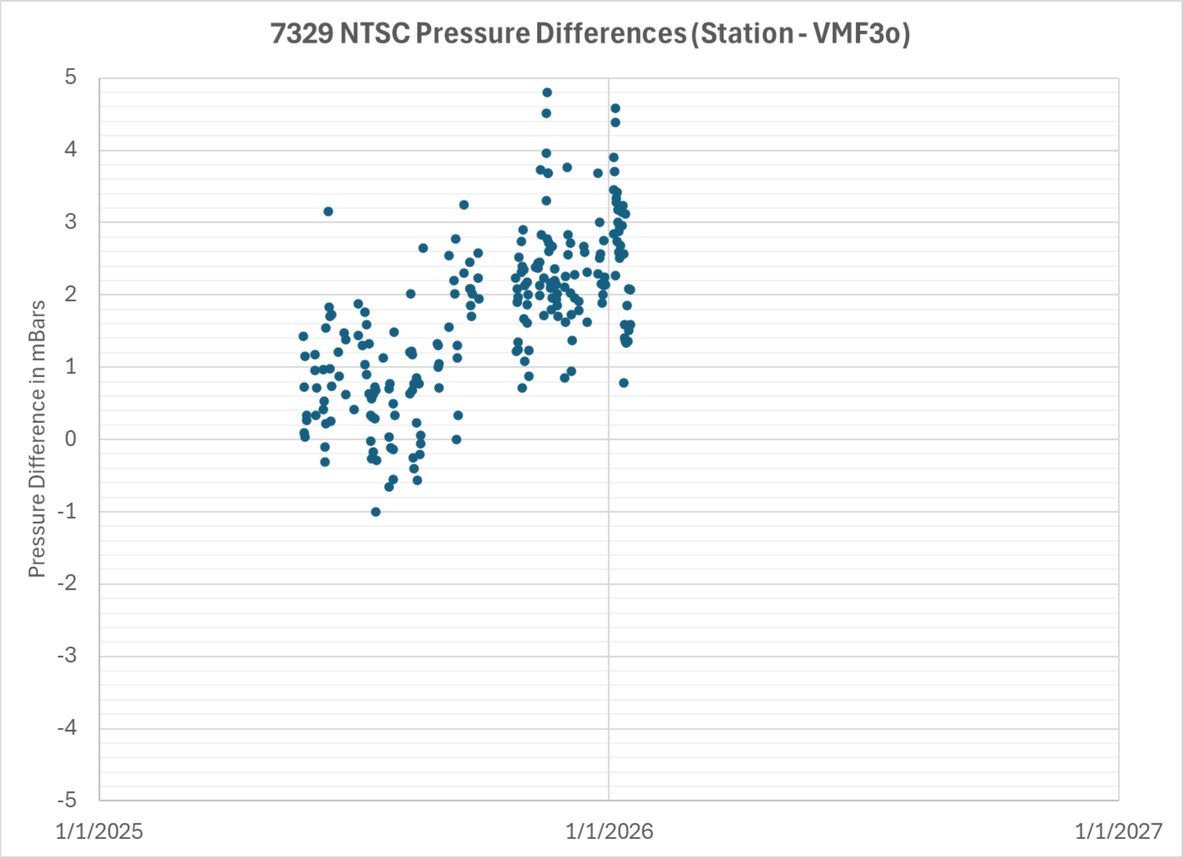
The VMF3o data can detect outliers and irregularities in our barometric measurements. When our sensors are properly calibrated, >99% of the differences between our sensors and the VMF3o are within 4 mBars

New AutoQC Using VMF3o_OP Data

- **In January 2026, the NASA SLR DOC implemented a new data integrity check to automatically flag, for further investigation, any six-hour period where the difference between the average six-hour pressures from the station and the VMF3o exceeds 4 mBars**
  - Twenty-five out of 1957 six-hour differences (station minus VMF3o) for January and February 2026 were flagged (1.3%)
    - One from Simeiz (1873): positive alarm, the mean difference between the Simeiz pressures and the VMF is -3 mBars
    - Twenty from Tsukuba (7306): false alarms, VMF3o data is suspect
    - Two From Xian (7329): inconclusive
    - Two from Simosato (7838): positive alarm, caused by frozen pressure for 3 hours on 8-Feb-2026 from 20:51 to 23:50
- **In February 2026, I was asked to peer review a paper titled** “Diagnosis strategy of abnormal on-site barometric pressure for SLR tropospheric delay correction” **written by our Chinese colleagues. In the paper, they automatically compare SLR pressures to Numerical Weather Model (NWM) derived pressures and auto correct SLR pressure measurements if the pressure difference exceeds 4 mBars**

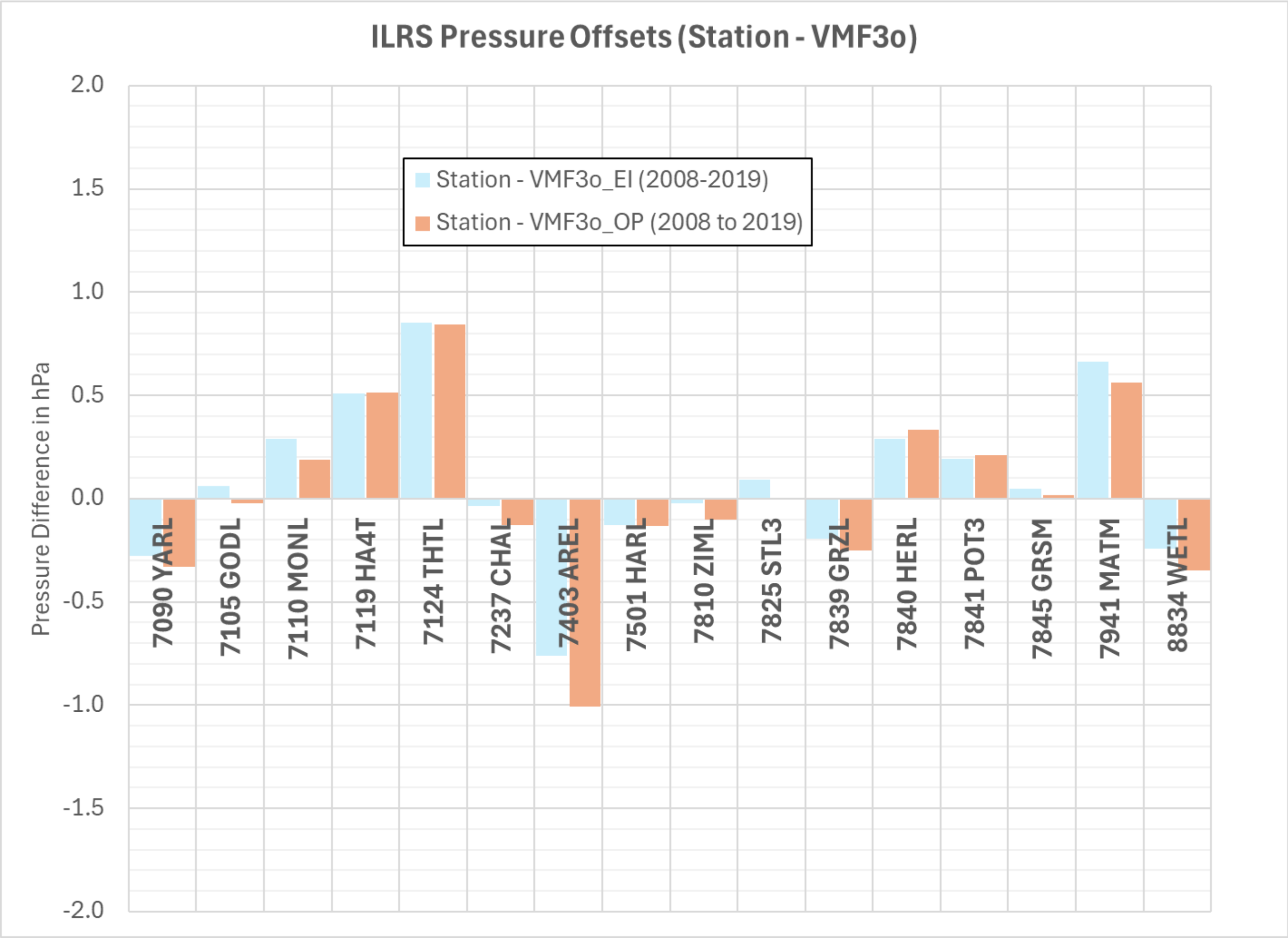
7306 TKBL and 7329 NTSC Pressures Differences (Station minus VMF3o_OP)





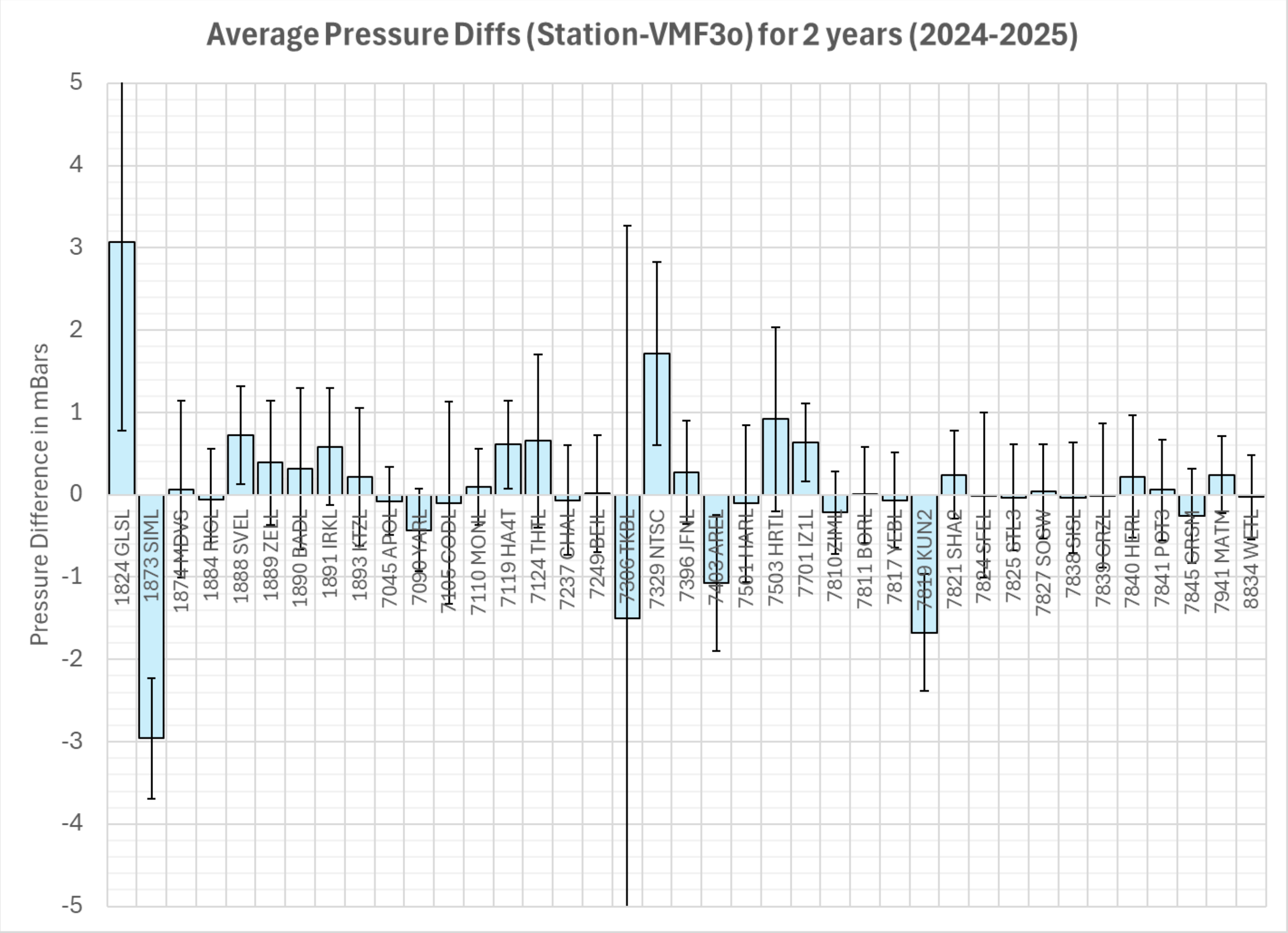
- ❑ **Tsukuba (7306) pressure differences (Station – VMF3o) have a large scatter, but data from a local Tsukuba weather bureau has reduced scatter suggesting an issue with the VMF3o data for that site**
- ❑ **Xian (7329) pressure differences (Station – VMF3o) appear to have a discontinuity. Needs further investigation**

What is the absolute accuracy of VMF3o_EI and VMF3o_OP Data?



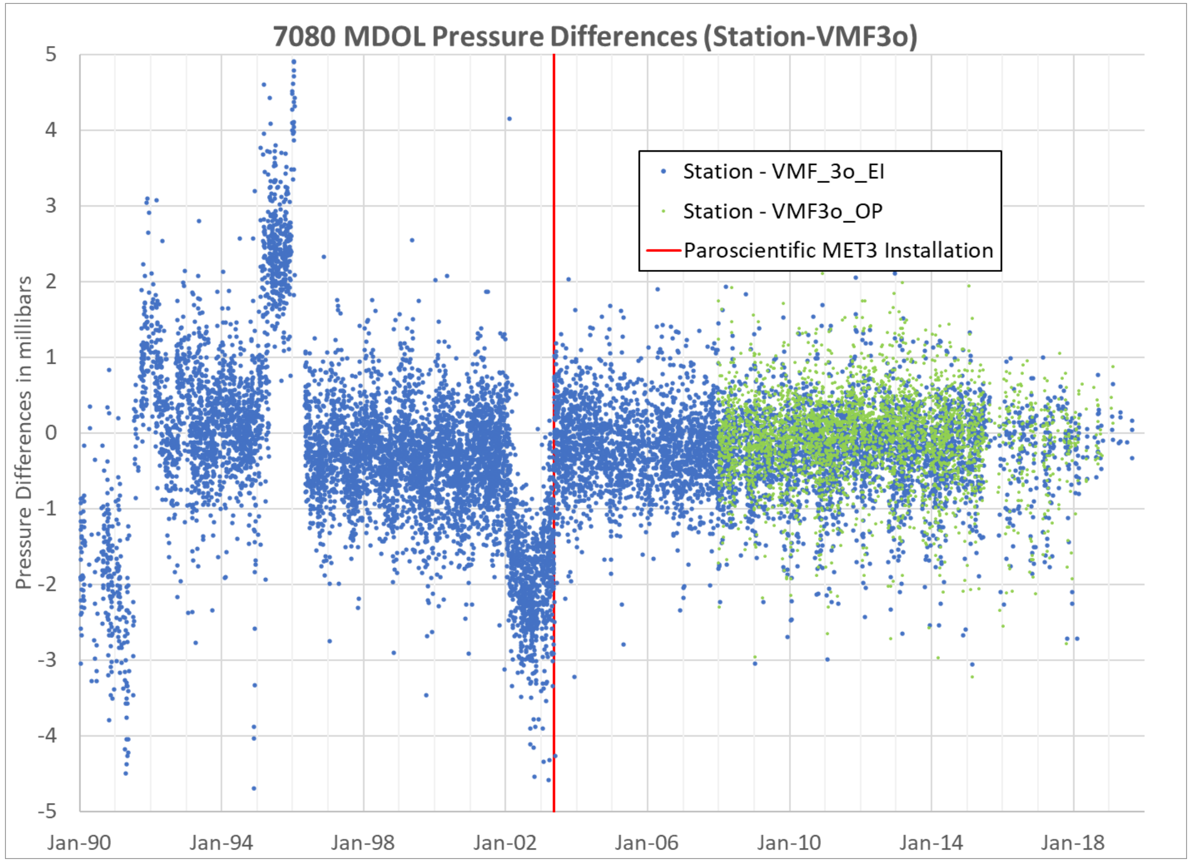
- Plotted here are the mean barometric pressure differences between the active sixteen ILRS Core stations and the two VMF3o categories, VMF3o_EI and VMF3o_OP for a 12-year span (2008-2019)
- The aggregate pressure differences between the two VMF3o categories and our stations are within a few tenths of a hPa
- For twelve of the 16 sites, the barometric differences are less than 0.4 hPa. Stations 7119 and 7124 are on small islands in the Pacific Ocean. Is VMF3o data less accurate for sites near large bodies of water?
- Based on the first VMF3o paper (https://link.springer.com/article/10.1007/s00190-020-01385-5), there are semidiurnal variations with an amplitude of less than 3 hPa for stations 7090 and 7839
- There are many ways to aggregate the six-hour pressure differences to identify trends

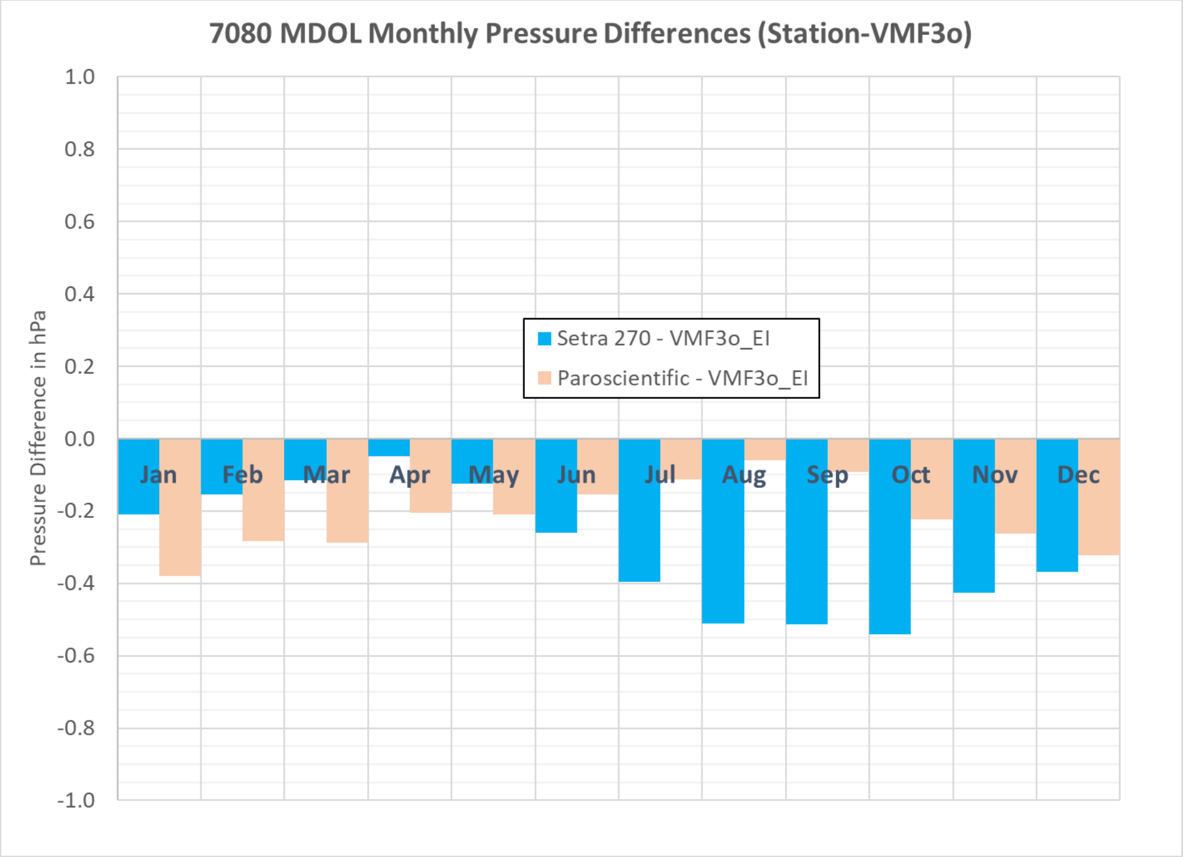
Average Six-Hour Differences (Station minus VMF3o_OP) for the ILRS Network (2024 and 2025)



- **Six out of 39 sites have pressure differences exceeding 1 mBar on average**
  - Our two newest sites, Xian (7329) and Tsukuba (7306). Tsukuba (7306) differences have a high standard deviation
  - Golosiiv (1824) and Simeiz (1873). Golosiiv (1824) differences have a high standard deviation
  - Arequipa (7403) and Kunming (7819)
- **According to the sensor specifications for Golosiiv (1824) and Kunming (7819), the barometric accuracy is only +/- 1 mBar**
- **There appears to be an issue with the accuracy of the VMF3o data for Tsukuba and possibly Xian**

7080 MDOL Seasonal Differences between the Barometer and VMF3o

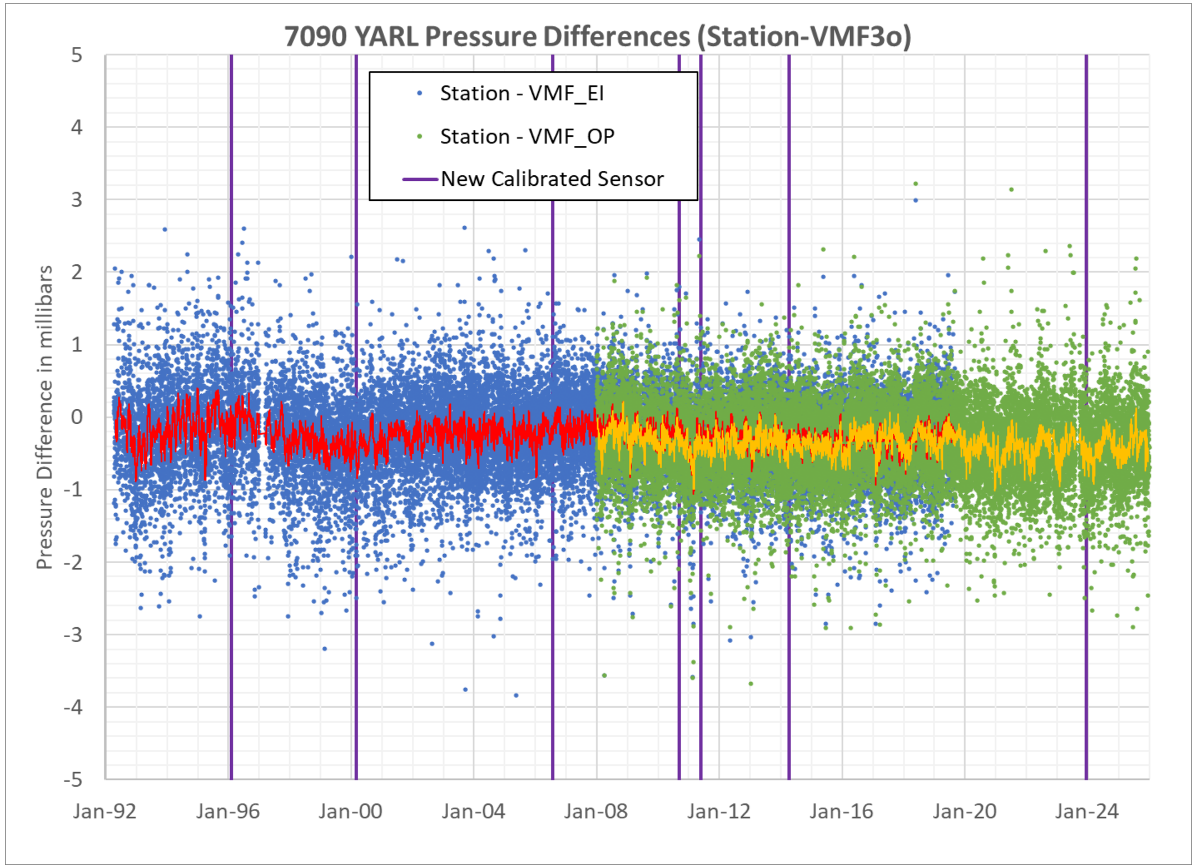


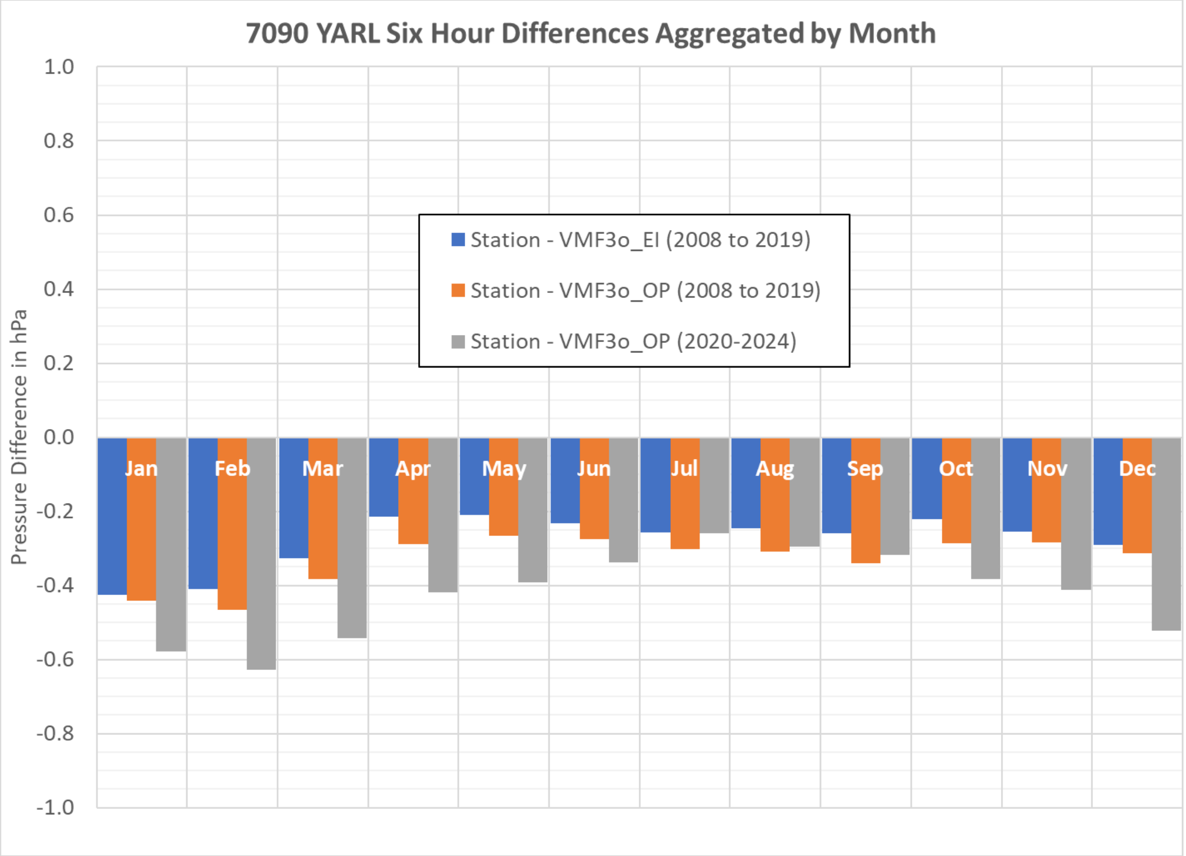


Seasonal Peak-to-Peak Variations	
Setra 270 - VMF3o_EI	MET3 - VMF3o_EI
0.49	0.32

- **On 17-May-2003, the Setra 270 Sensor was replaced with the Paroscientific MET3 which reduced the seasonal variations in the pressure differences**

7090 YARL Seasonal Differences between the Barometer and VMF3o



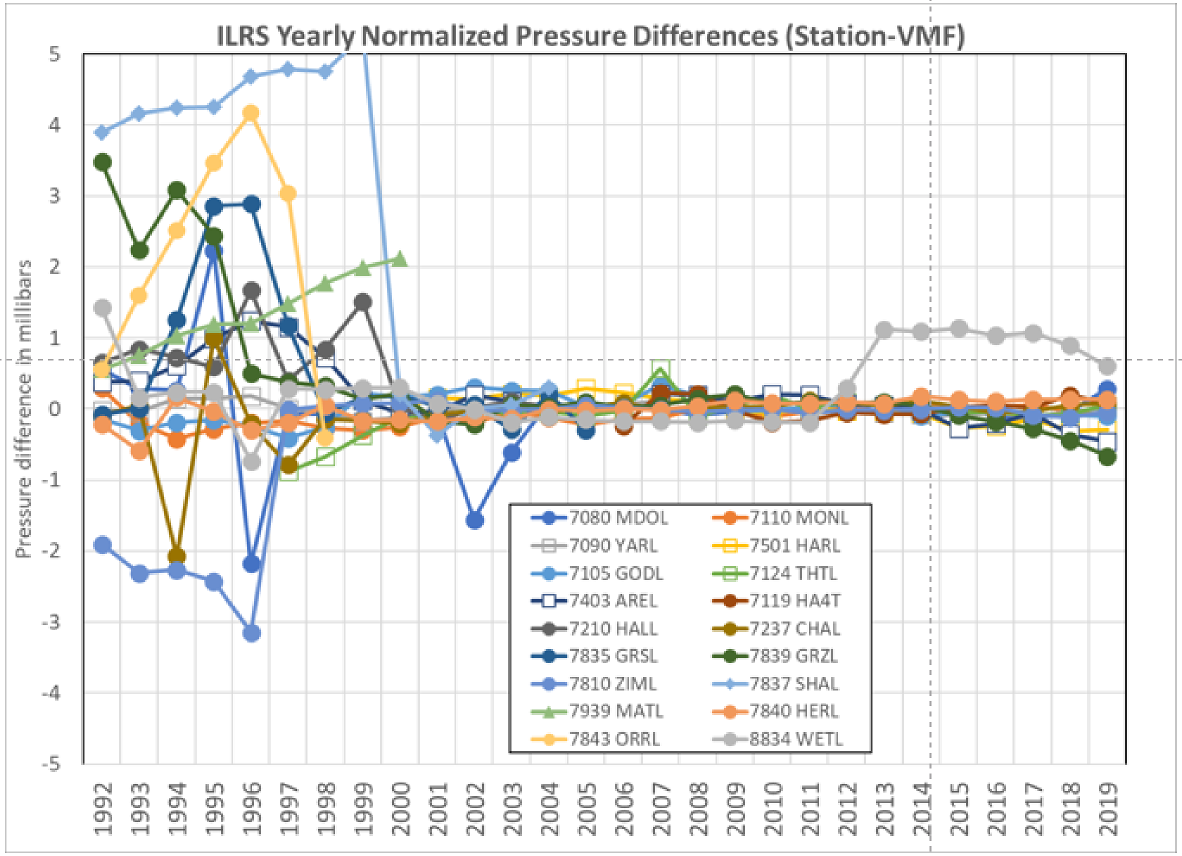


Seasonal Peak-to-Peak Variations		
Station - VMF3o_EI (2008-2019)	Station - VMF3o_OP (2008-2019)	Station - VMF3o_OP (2020-2025)
0.21	0.20	0.37

- The seasonal variations in the station minus VMF3o_OP differences have increased perhaps starting in 2017

Yearly Aggregation of the Six-Hour Differences

Tropospheric Biases in SLR Core Sites



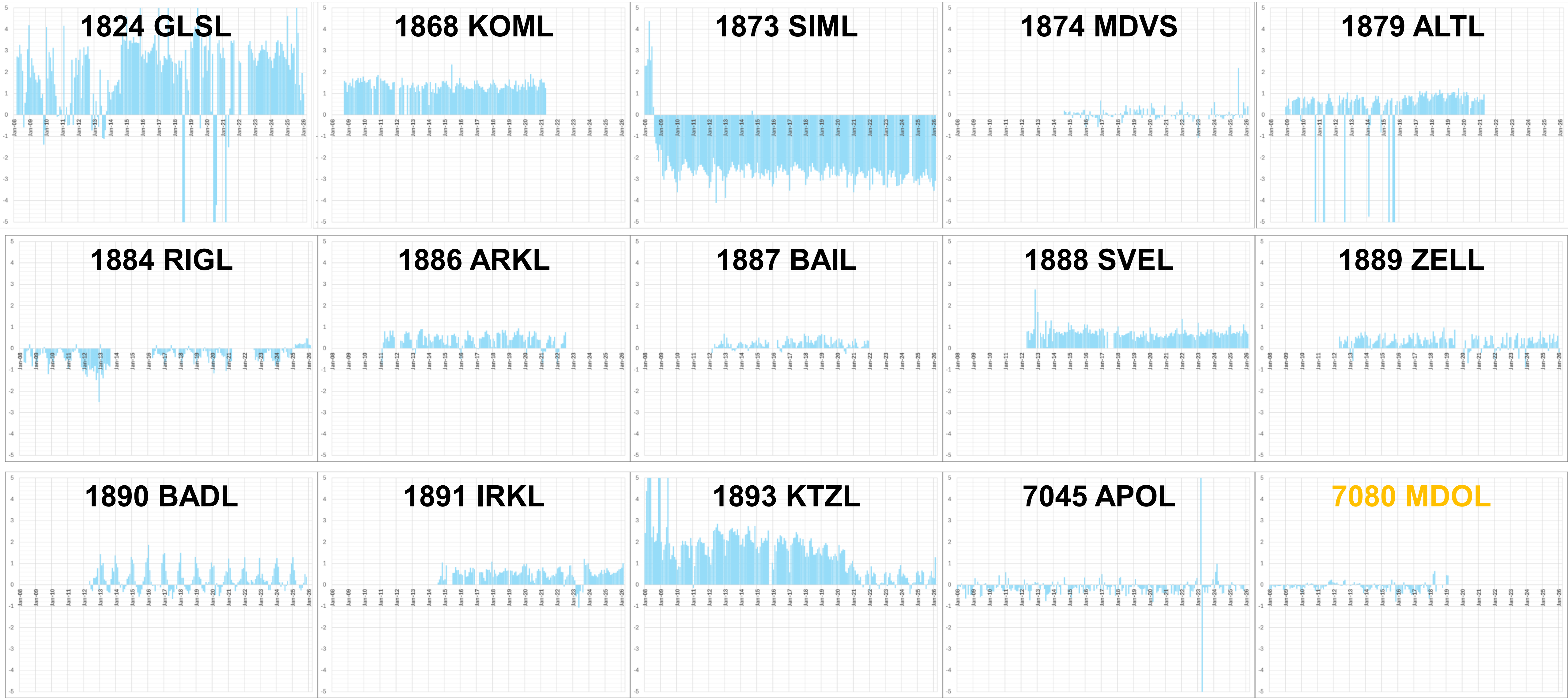
- A yearly time series of barometric errors in our core sites from 1992 to August 2019 based on comparing station's barometric data to the Vienna Mapping Function for optical frequencies (VMF3o)
- VMF3o is based on Numerical Weather Models (NWMs) provided by the European Centre for Medium-Range Weather Forecasts (Boisits et al., 2020) DOI:10.1007/s00190-020-01385-5

ILRS QCB 18-Jan-2023

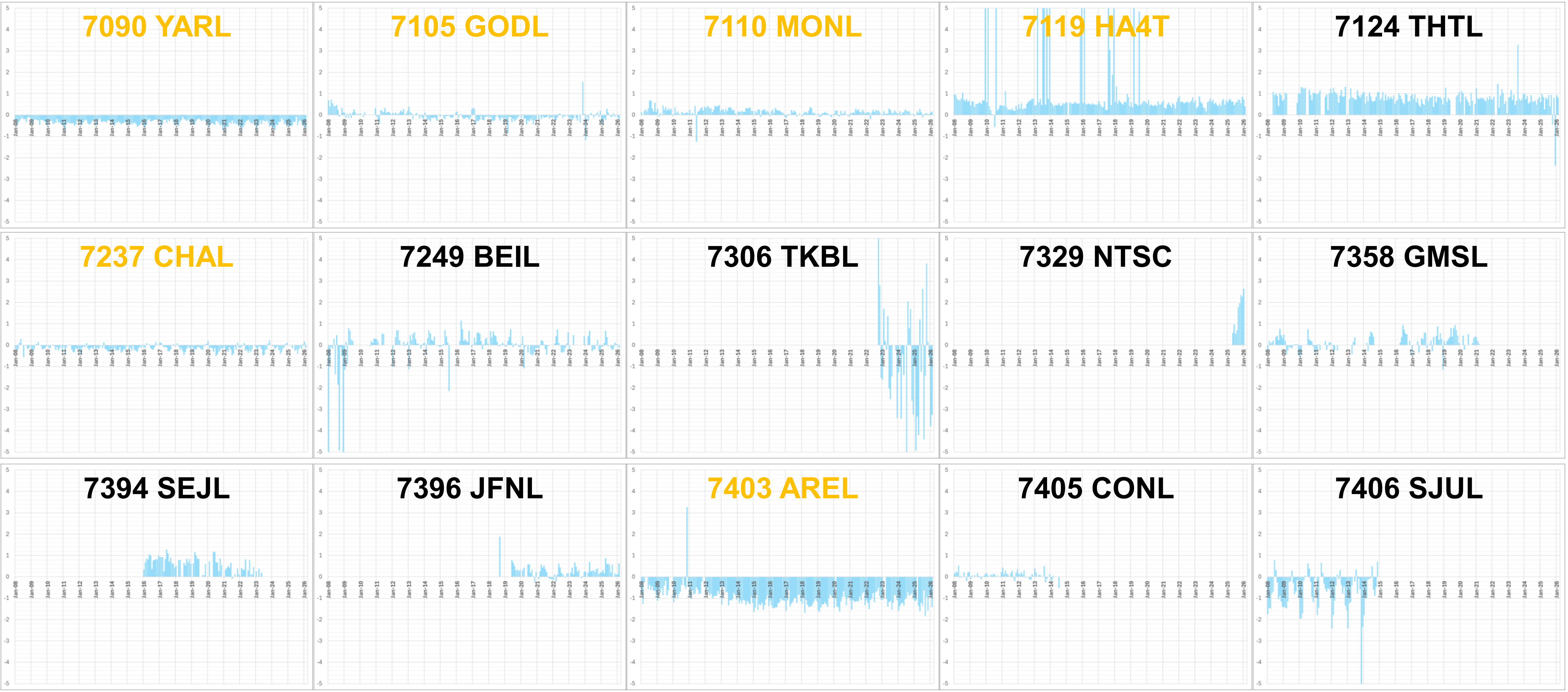
14

- This slide was presented to the ILRS QCB in Jan-2023. This analysis was based on the original VMF3o_El data
- As more accurate barometric sensors were deployed, the accuracy of the barometric and range data improved
- If you look closely, you will notice the discontinuity in the Wettzell 8834 data starting in 2012, when the height difference between the sensor and the SRP was not modelled. Also notice the drift in the Gras 7839 barometric pressure starting in 2015. Both stations reprocessed their data to remove these errors

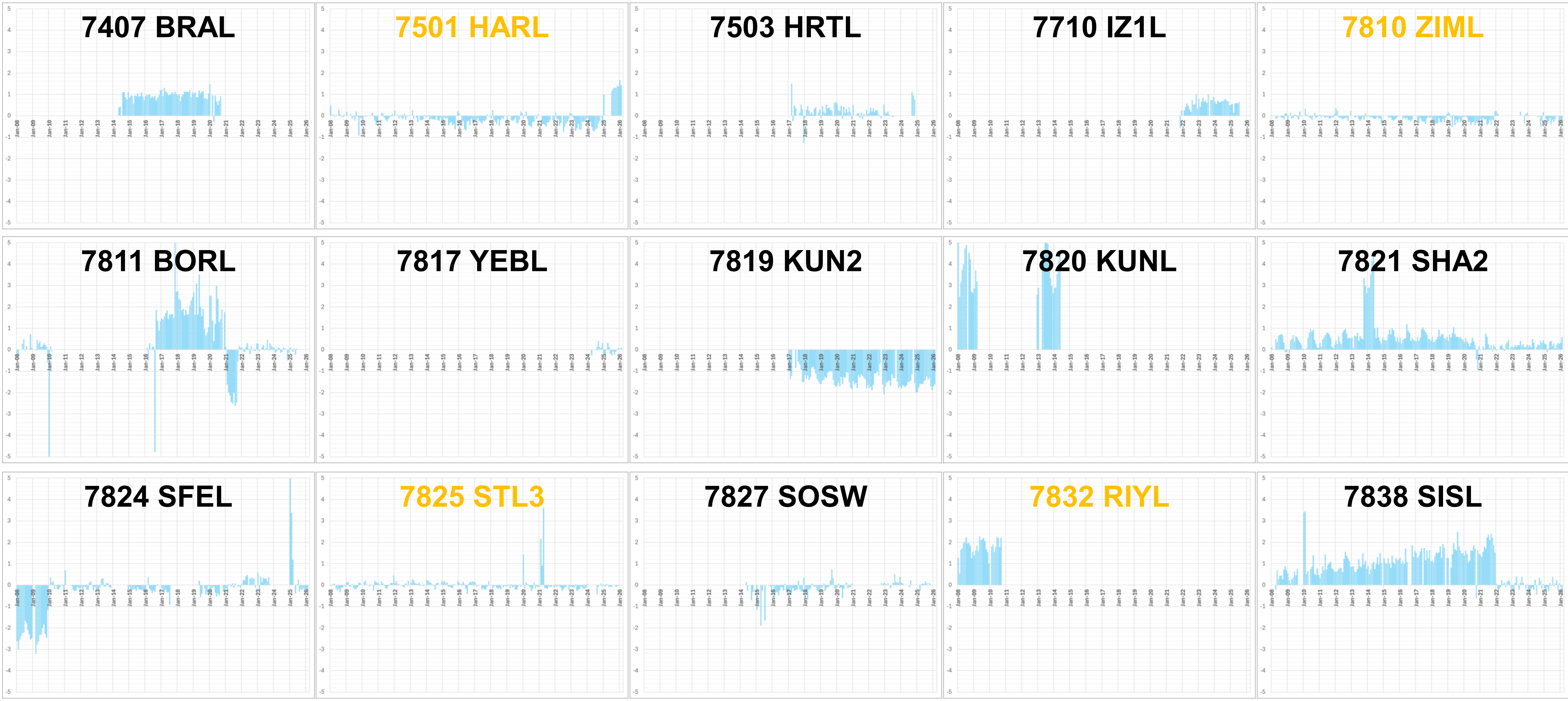
Monthly Pressure Differences in mBars (Station minus VMF3o_OP)



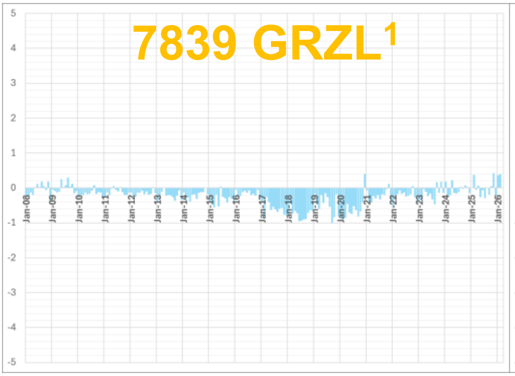
Monthly Pressure Differences in mBars (Station minus VMF3o_OP)

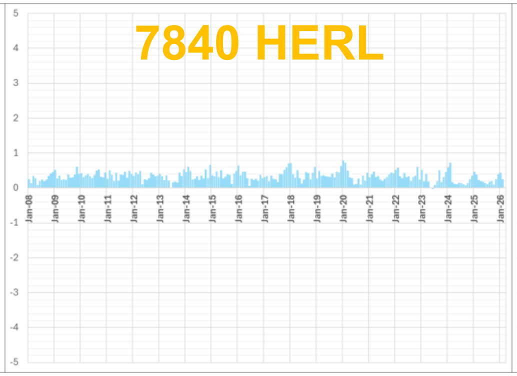


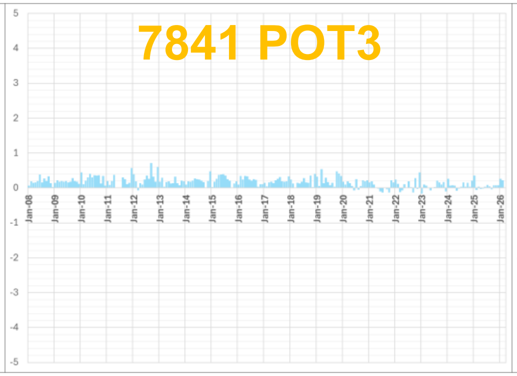
Monthly Pressure Differences in mBars (Station minus VMF3o_OP)

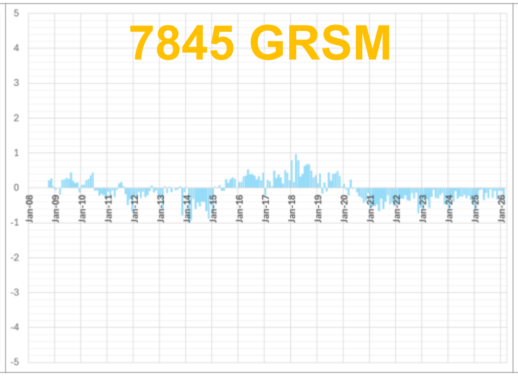


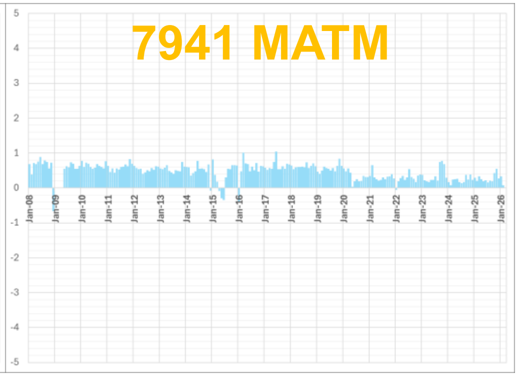
Monthly Pressure Differences in mBars (Station minus VMF3o_OP)

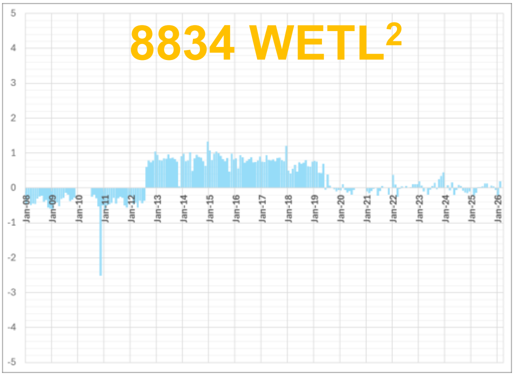












- ❑ *Footnote 1: 7839 GRZL results were based on a mixture of the original pressures and the corrected pressures*
- ❑ *Footnote 2: 8834 WETL results were based on the original pressures*

Meteorological Data Processing and Handling from Cradle to Grave?

CRD 20 Meteorological Record Format

3.4. Meteorological Record

This data record contains a minimal set of meteorological data. At least one record must appear in the data file.

3.4.1. Format:

1. A2(1-2) Record Type (= "20")
2. F18.12 Seconds of day (typically to 1 milllisec precision).
3. F7.2 Surface pressure (millibar)
4. F6.2 Surface temperature in degrees Kelvin
5. F4.0 Relative humidity at the surface in %
6. I1 Origin of values

   0=measured values (written whenever a value changes “significantly”)

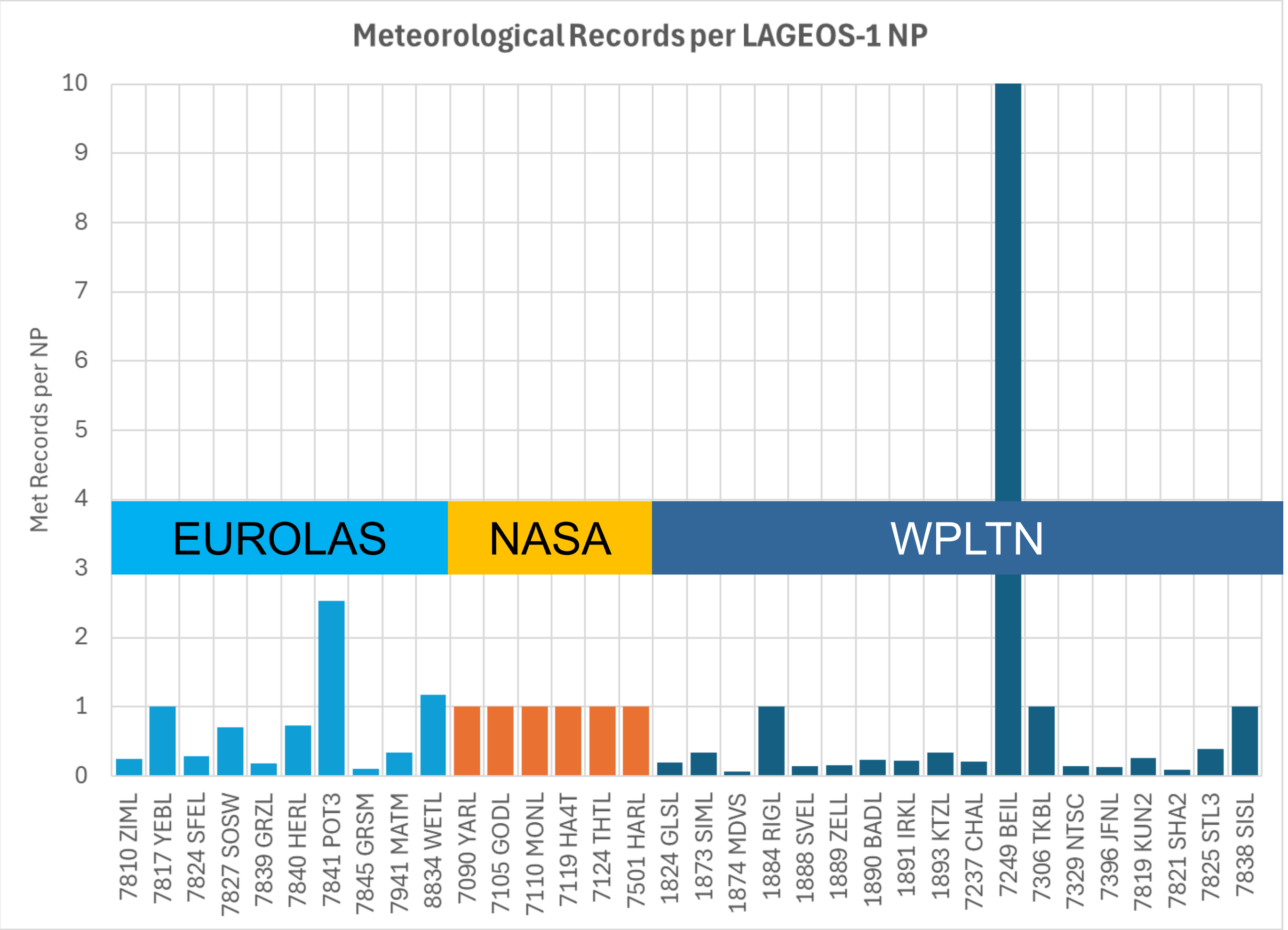
   1=interpolated values applicable at the time (seconds of day) given in this record

3.4.2. Notes

Meteorological records should only be written when one of the fields changes “significantly”. As a minimum, a new record should be written whenever pressure changes by 0.1mB, the temperature changes by 0.1 K, or when the humidity changes by 5%. The time (seconds of day) of an interpolated record should match the time in the following normal point record.

Since meteorological records may be submitted in blocks and not interspersed with the normal point or range records, it is recommended that the meteorological records be accumulated and interpolated to the times needed (e.g., times of normal points or full rate records).

20 Meteorological Data Records Per LAGEOS-1 NPs (September 2025 to January 2026)



- ❑ **The legacy SLR formats (CSTG and MERIT II) included meteorological data in each NP record, so there was no need to interpolate/extrapolate**
- ❑ **The number of CRD 20 meteorological records per LAGEOS NP is diverse across the ILRS network (0.06 to 10)**
- ❑ **NASA SLR sites share the same data reduction software**
- ❑ **Having a meteorological record per each NP eliminates the possibility of an interpolation error by the data analysts**
  - ➢ Should the stations adopt this as a best data reduction process?

Conclusions/Actions/Questions

- **The NASA SLR DOC has implemented three new automated weekly barometric checks to flag**
  - When the six-hour differences (station – VMF3o) in barometric pressure exceed +/- 4 mBars
  - When potential frozen pressures are detected
  - When there are inexplicable changes in barometric pressure within a CRD
- **Station operators need to ensure their meteorological measurements are being updated. Station needs to update your station change histories after a meteorological sensor calibration or replacement**
- **Calibrated barometric sensors are inherently more accurate than the VMF3o data. The VMF3o data, for most sites, when aggregated yearly is accurate to at least 0.4 to 0.6 mBars**
- **Are the seasonal trends in the six-hour differences (station – VMF3o) in the sensor and/or the VMF3o? If feasible, it is better to locate the barometric sensor in a controlled environment?**
- **Aggregating the six-hour pressures differences (station – VMF3o) can detect sudden jumps and drifts in our barometric measurements**
- **Would any of the six-hour VMF3o barometric differences be useful on the ILRS website?**
- **Should algorithms for the ILRS DHF be developed to fix legacy barometric errors?**
- **Should there be a standard for how stations report their meteorological data? Should only one meteorological data record per CRD be flagged as a data integrity issue?**

Status of the Borowiec SLR Station

Paweł Lejba

ILRS Networks and Engineering Standing Committee

April 16, 2026

Comparison of the PMT’s

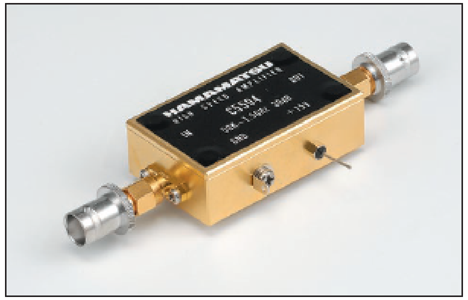
PARAMETER	**PMT H5023**	**PMT H6533**
Manufacturer	Hamamatsu	Hamamatsu
Tube size	25mm	25mm
Spectral Response Range	300 to 650nm (peak 420nm)	300 to 650nm (peak 420nm)
QE at PEAK	10%	23%
Nominal Gain	1×10^6	5.0×10^6
Anode to Cathode Supply Voltage	-2200V	-2200V
Rise Time	0.6ns	0.7ns
Time Transit Spread	0.16ns	0.16ns
Amplifier	C5594-22 (36dB)	C5594-22 (36dB)

HAMAMATSU

PHOTON IS OUR BUSINESS

HIGH SPEED AMPLIFIER UNIT C5594 SERIES

The C5594 series is designed for photomultiplier tubes (PMTs), especially fast time response PMTs.
This unit has high gain of 36 dB and wide frequency bandwidth of 50 kHz to 1.5 GHz, which can accurately amplify the PMT pulse output. Therefore it is well-matched to the application of Time Correlated Single Photon Counting (TCSPC) for fluorescence life time measurement with MCP-PMT and various time response measurements with PMT.



C5594-44

FEATURES

- Frequency bandwidth: 50 kHz to 1.5 GHz
- Current-to-voltage conversion factor: 3.15 mV/μA at 50 Ω load resistance
- Non-inverting output
- Selectable signal input / output connectors

SPECIFICATIONS

Parameter		C5594-12	C5594-22	C5594-44	Unit
Frequency bandwidth (-3 dB)		50 kHz to 1.5 GHz			—
Voltage gain ①		36 (Approx. 63 times)			dB
Current-to-voltage conversion factor ①		3.15			mV/μA
Rise time	Typ.	0.23			ns
Input polarity		Positive / Negative			—
Amplifying method		Non-inverting output			—
Input / output impedance		50			Ω
Recommended load resistance		50			Ω
Maximum output signal voltage ①		+0.8 / -2.5			V Min.
Noise figure ①	Typ.	5			dB
Signal connector	Input	SMA-P	SMA-R	BNC-R	—
Signal connector	Output	SMA-R	SMA-R	BNC-R	—
Power supply voltage		+12 to +16			V
Max. power supply voltage		+17			V
Power supply current ②	Max.	95			mA
Operating ambient temperature ③		0 to +40			°C
Storage temperature ③		-15 to +60			°C
Weight		Approx. 70	Approx. 70	Approx. 90	g

①Load resistance: 50 Ω
②Power supply voltage: +15 V
③No condensation

Figure 1: Typical frequency response

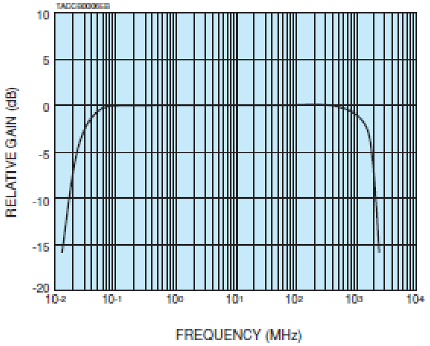
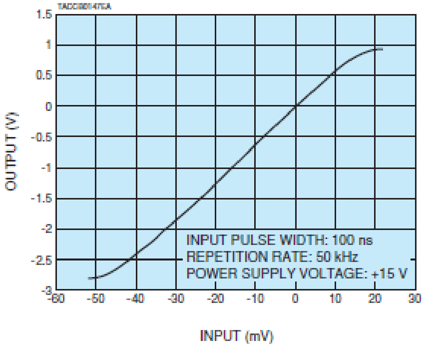
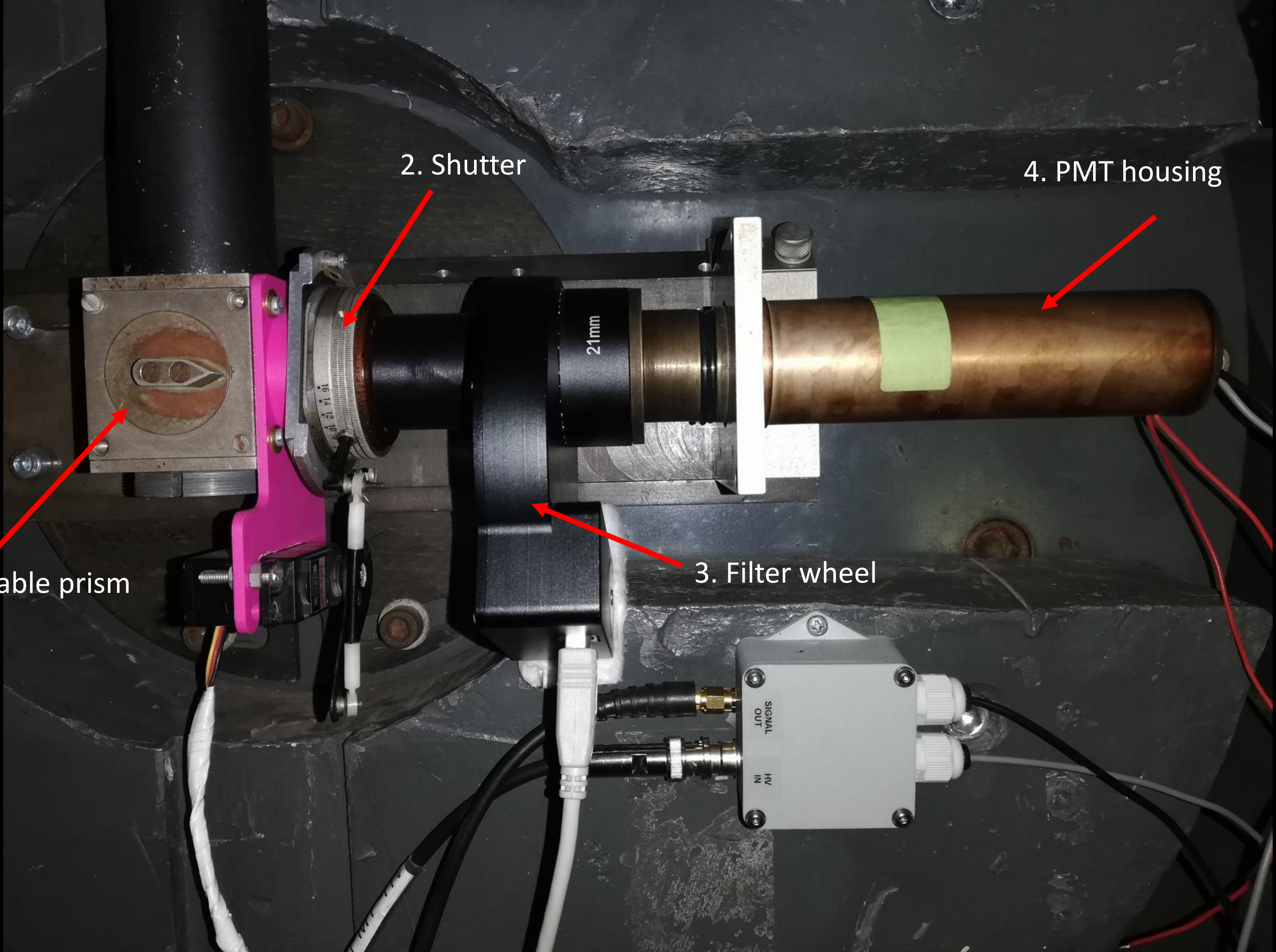
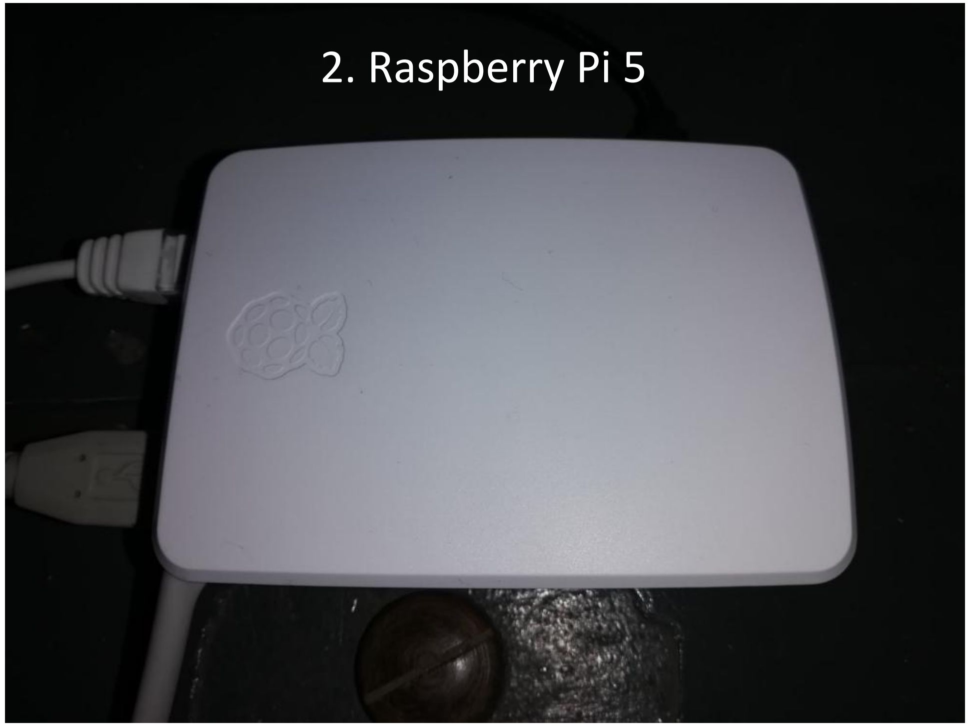


Figure 2: Input-output characteristics

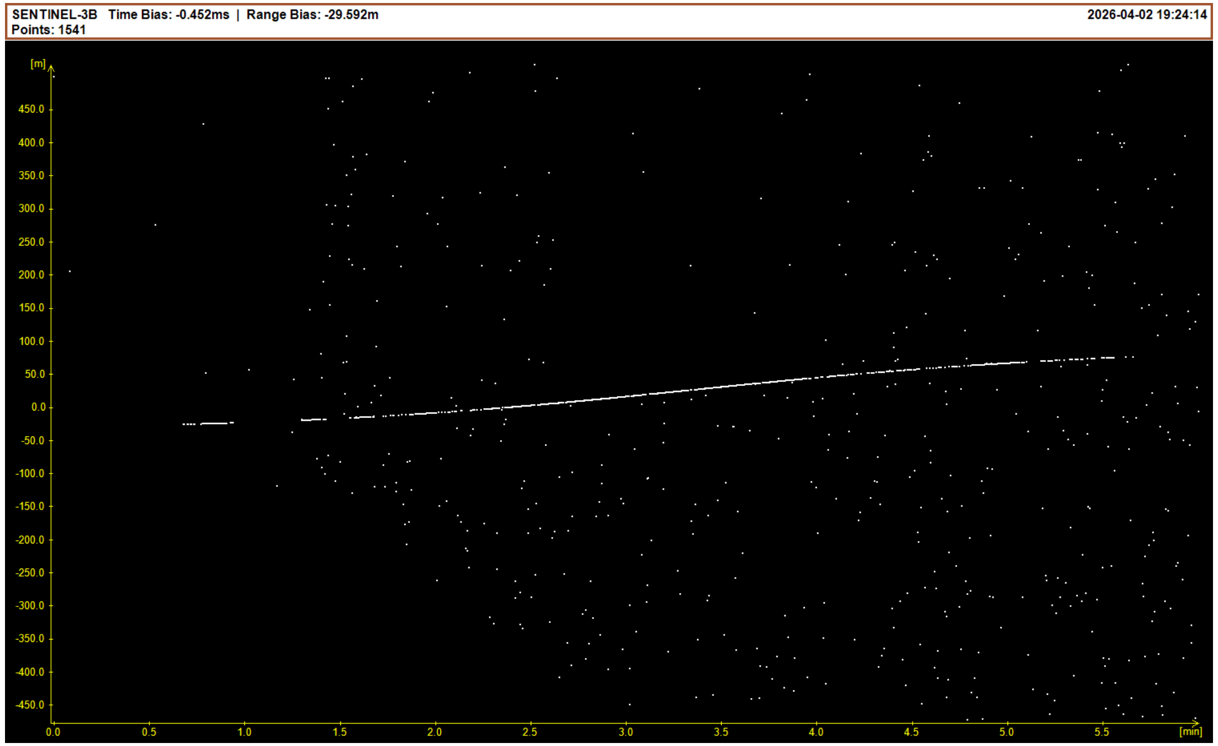


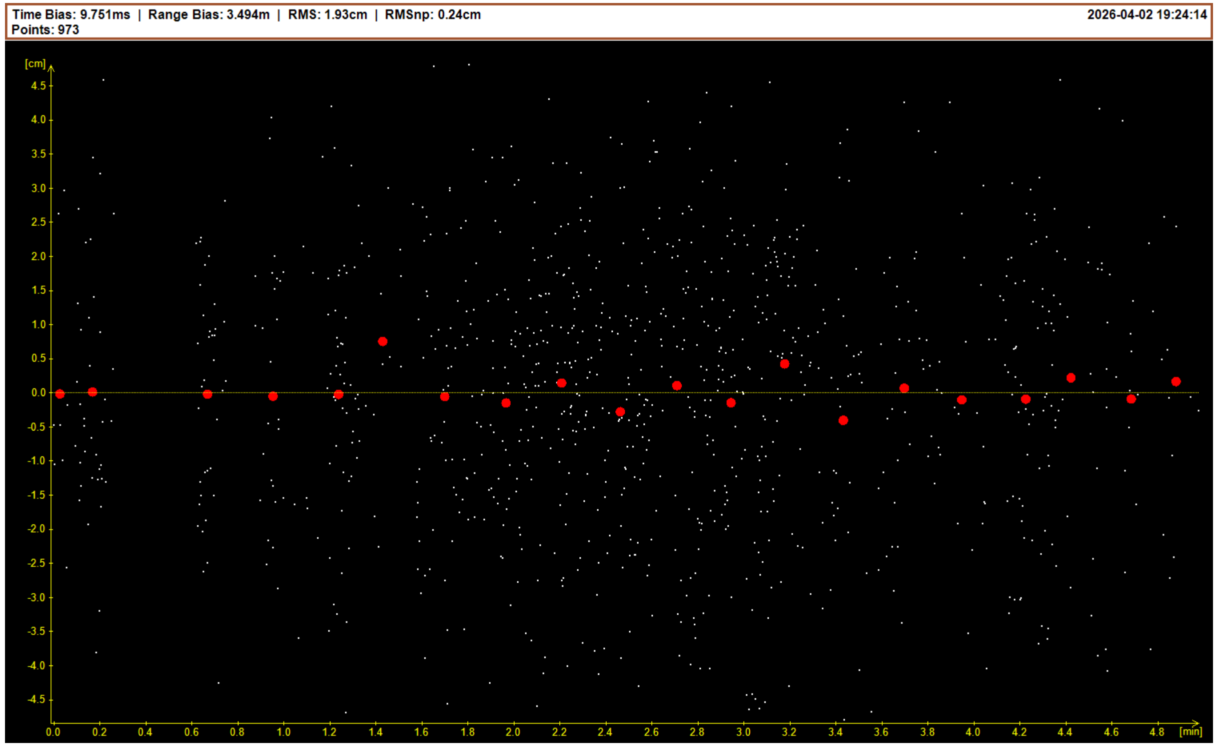

1. Movable prism
2. Shutter
3. Filter wheel
4. PMT housing
21mm
SIGNAL OUT
HV IN


1. HV power supply
Eurotek
International
HIGH VOLTAGE
POWER SUPPLY
VOLTAGE
KV

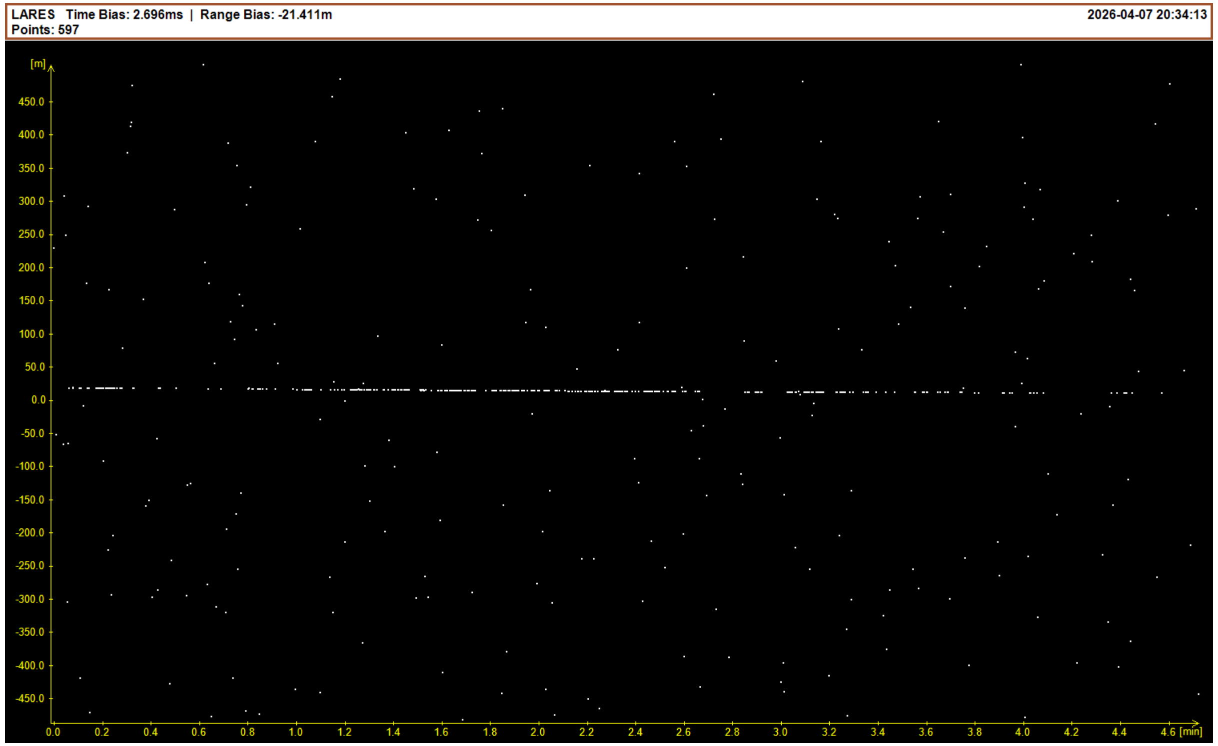

2. Raspberry Pi 5

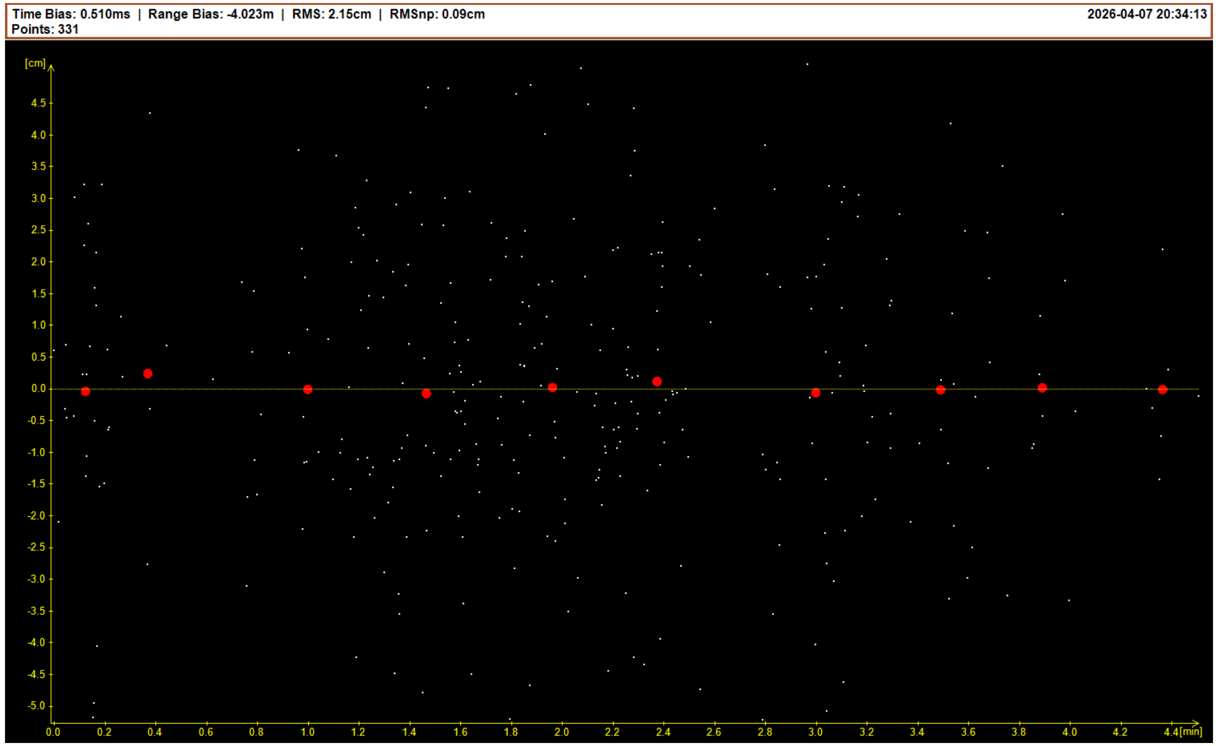
SENTINEL-3B (973 returns, 20 NP, pass RMS 1.93cm)



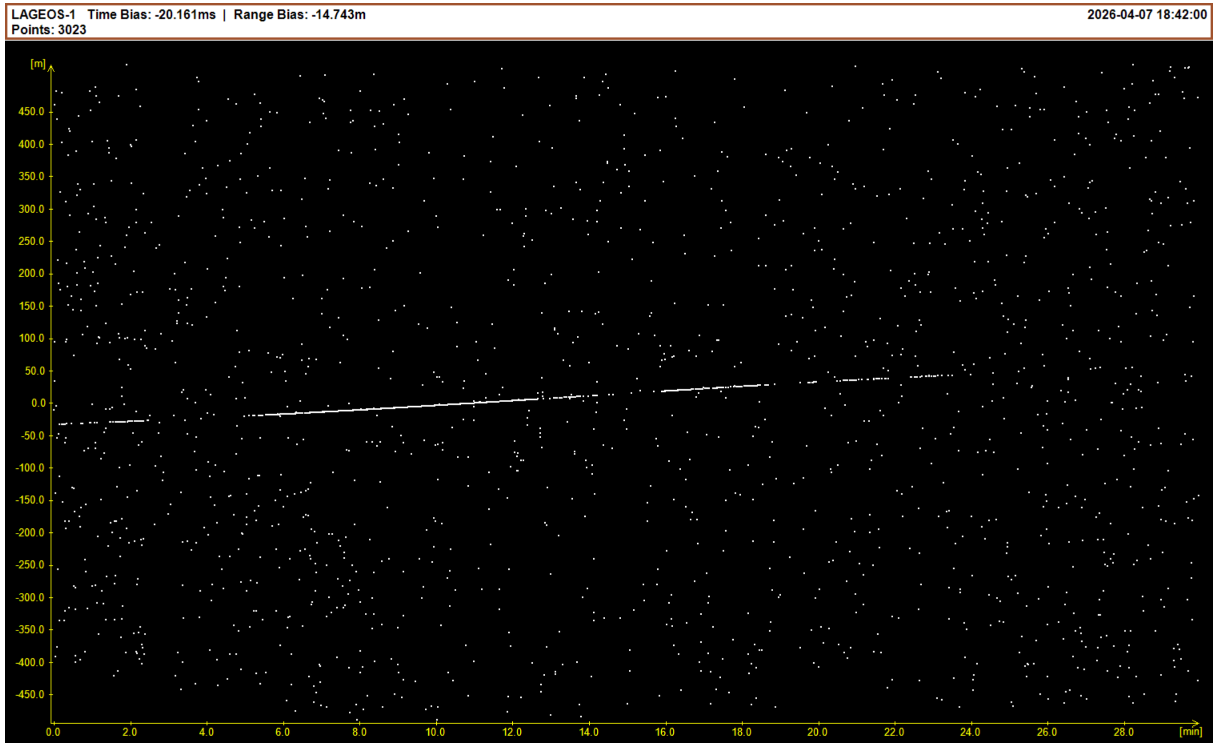


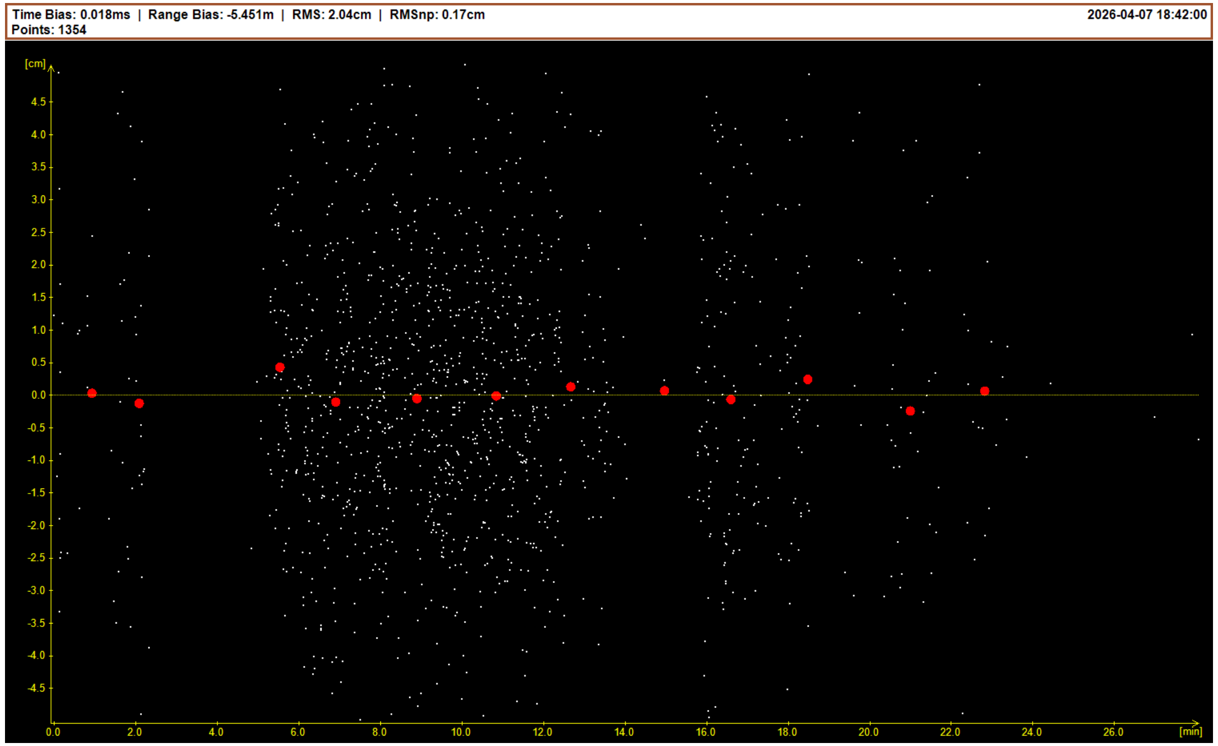
LARES-1 (331 returns, 10 NP, pass RMS 2.16cm)





LAGEOS-1 (1354 returns, 12 NP, pass RMS 2.04cm)



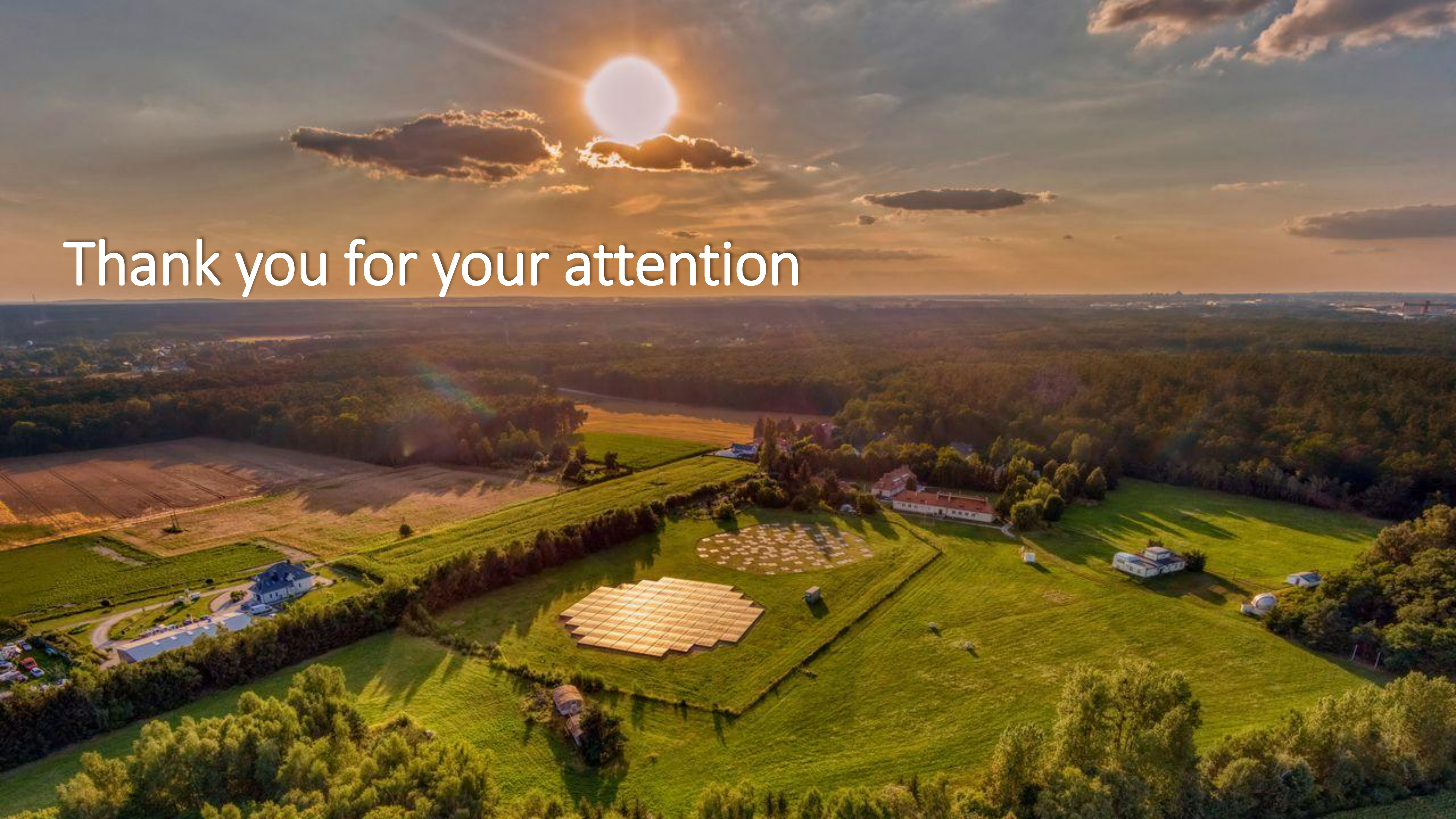


Observational statistics – April 2-9, 2026

OBJECT GROUP	EPHEMERIS LENGTH [H:M:S]	OBSERVATION TIME [H:M:S]	OBSERVED PASSES	HIT TIME [H:M:S]	TRACKED PASSES	TOTAL RETURNS	TOTAL NP	MEAN RMS [cm]
ALL	04:00:15	02:46:42	24	02:17:31	24	14407	211	19.07
ILRS	03:34:14	02:24:05	17	02:02:10	17	13410	155	2.34
DEBRIS	00:26:01	00:22:37	7	00:15:22	7	997	56	59.7
Nonactive	00:11:35	00:08:26	3	00:07:19	3	611	22	11.19
Rockets	00:14:26	00:14:11	4	00:08:03	4	386	34	96.08

Summary

- New PMT detector was installed
- New filter wheel was installed
- Quarantine Procedure according to the ILRS criteria

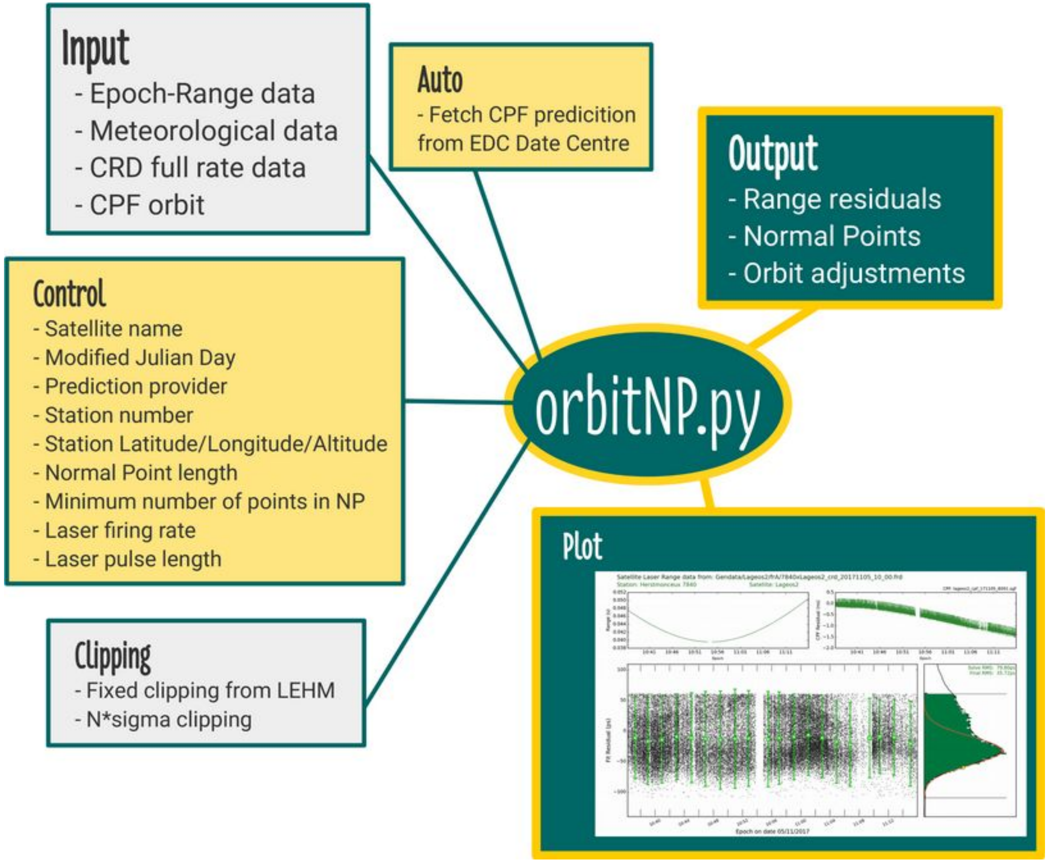

Thank you for your attention

orbitNP.py 1.3

Matthew Wilkinson

orbitNP.py

orbitNP.py was first made freely available to download in **2018**.



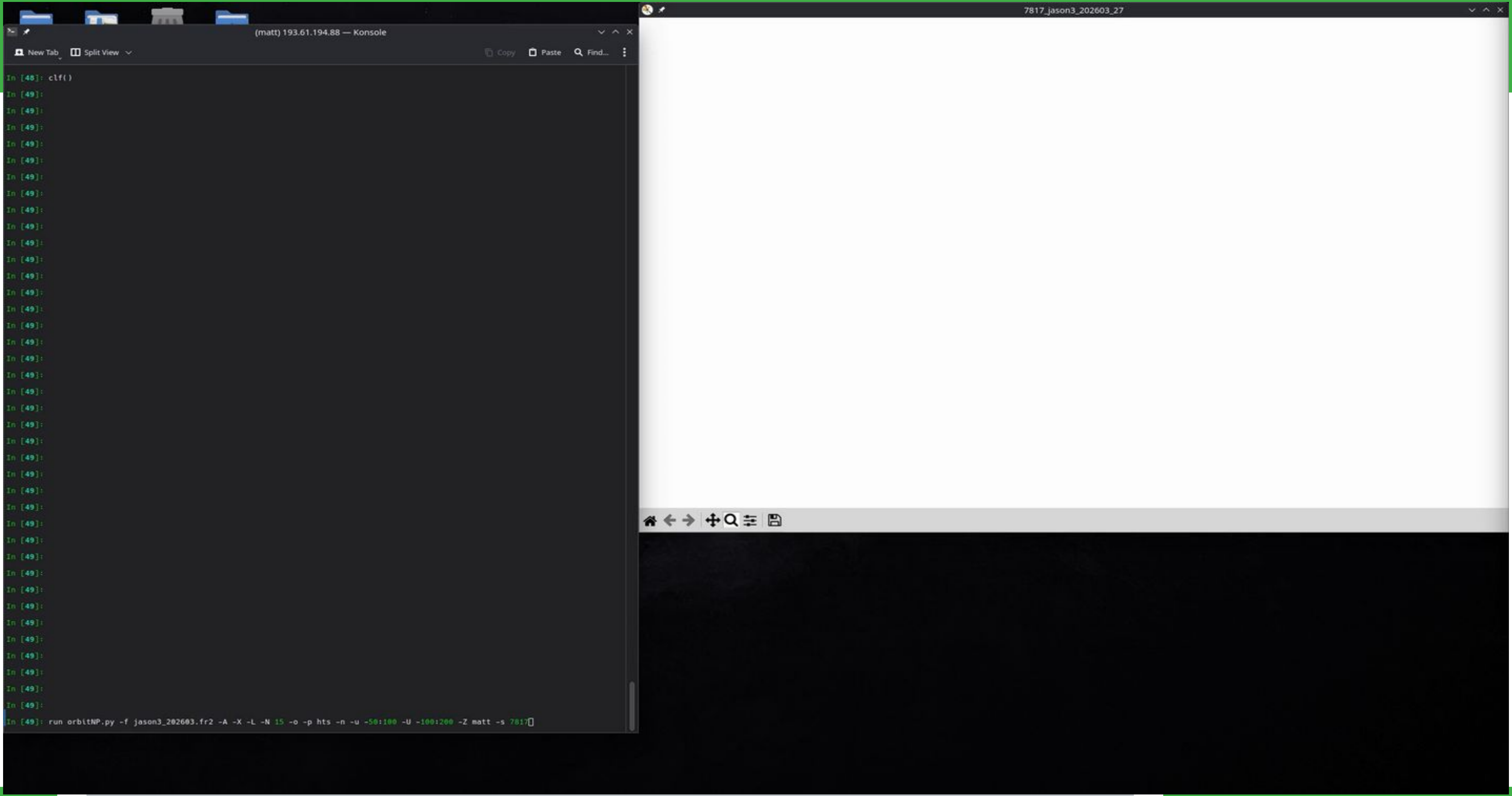
orbitNP.py

orbitNP.py is written in **Python3** to process SLR observations.

It takes 2-way ranges and produces flattened observed-computed (O-C) range residuals by solving for along track and radial corrections to a reference orbit CPF prediction.

The flattened residuals are then averaged in bins and time stamped to form precise **normal points**.

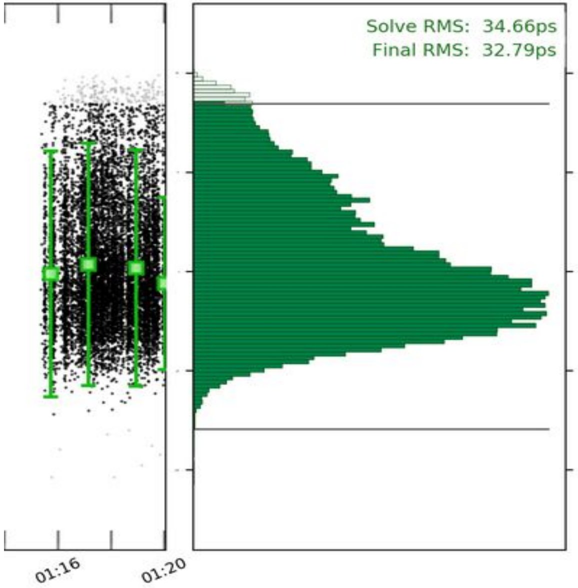
Results from orbitNP.py can be compared with those generated at the station.



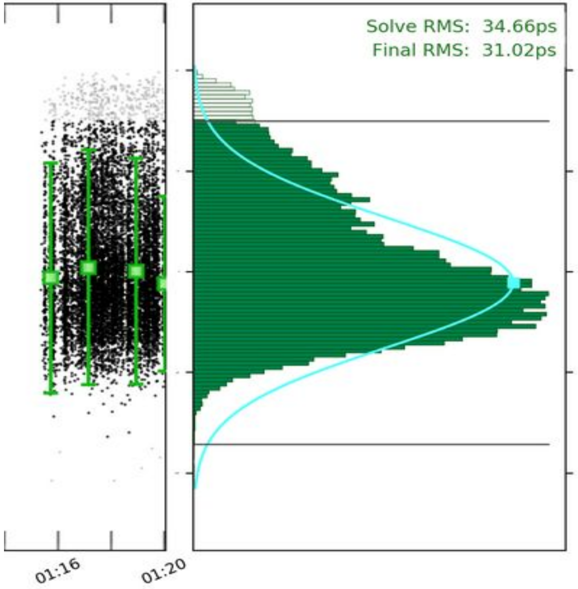
(matt) 193.61.194.88 — Konsole
New Tab
Split View
Copy
Paste
Find...
In [48]: clf()
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]:
In [49]: run orbitNP.py -f jason3_202603.fr2 -A -X -L -N 15 -o -p hts -n -u -50:100 -U -100:200 -Z matt -s 7817
7817_jason3_202603_27

Clipping

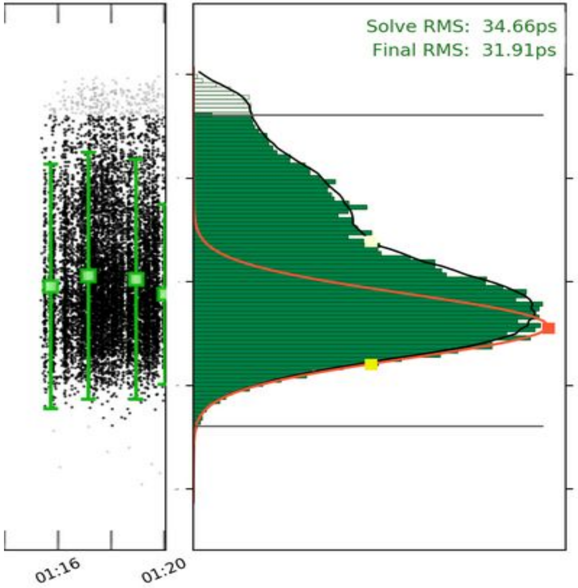
Iterative Mean, 2.5*sigma



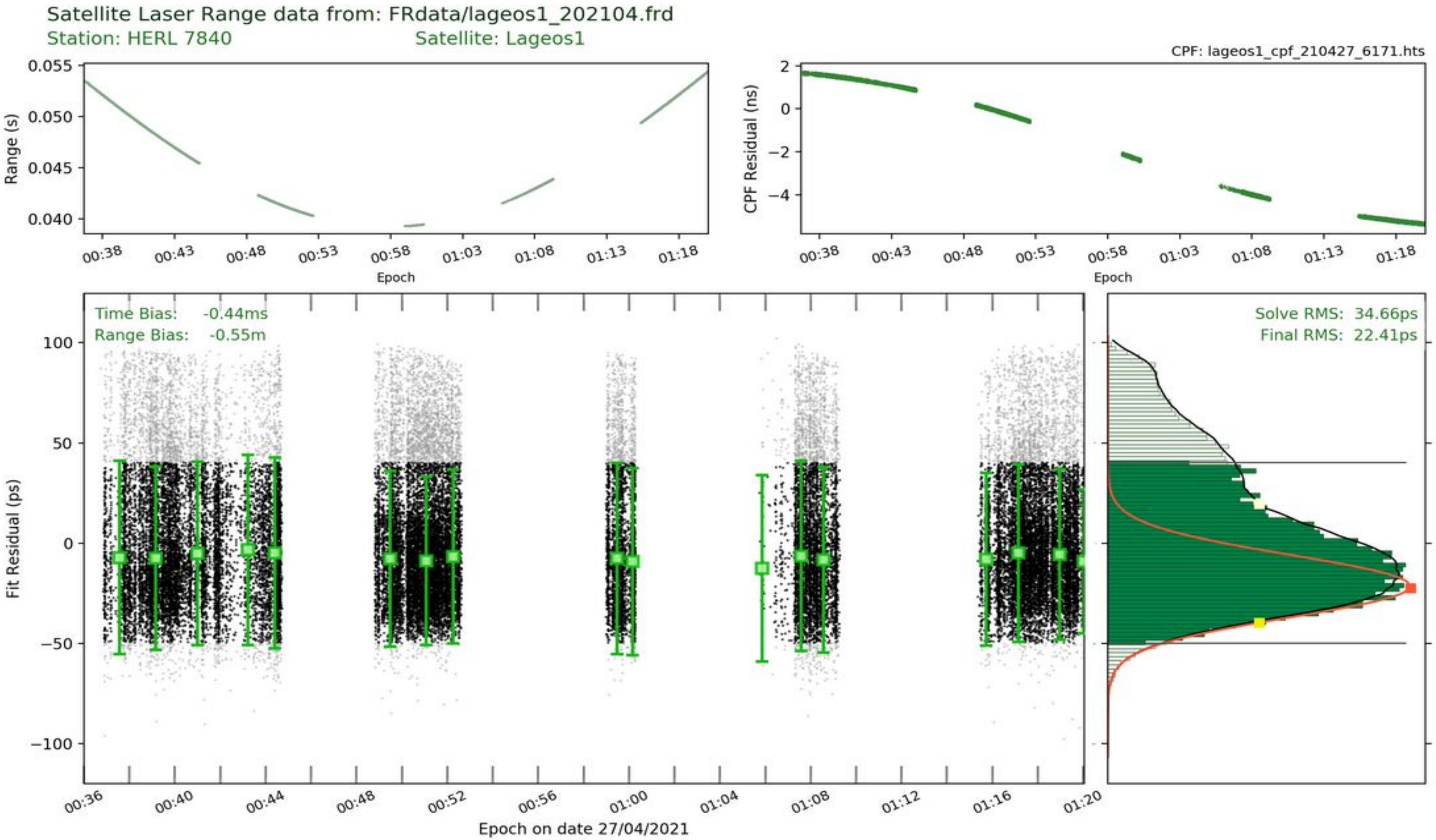
Gauss Peak, 2.5*sigma



Fixed clipping from LEHM



2 Level Clipping



orbitNP.py 1.3 -updates

Version 1.3

-- Include CDDIS as a source for automatic cpf predictions and crd downloads. EARTHDATA login details requested and stored locally in .earthdatalogin file.

-- Attempt to download fr2 full-rate file from Data Center if does not exist on drive.

-- Downloads CDDIS full-rate data files that are gzipped.

-- Clipping varies depending on the incident angle for GNSS flat LRA. This results in relatively wider acceptance at low elevations.

-- Jpeg output option.

-- Read and output receive amplitude records.

-- Allow dynamic axes labelling for matplotlib plots.

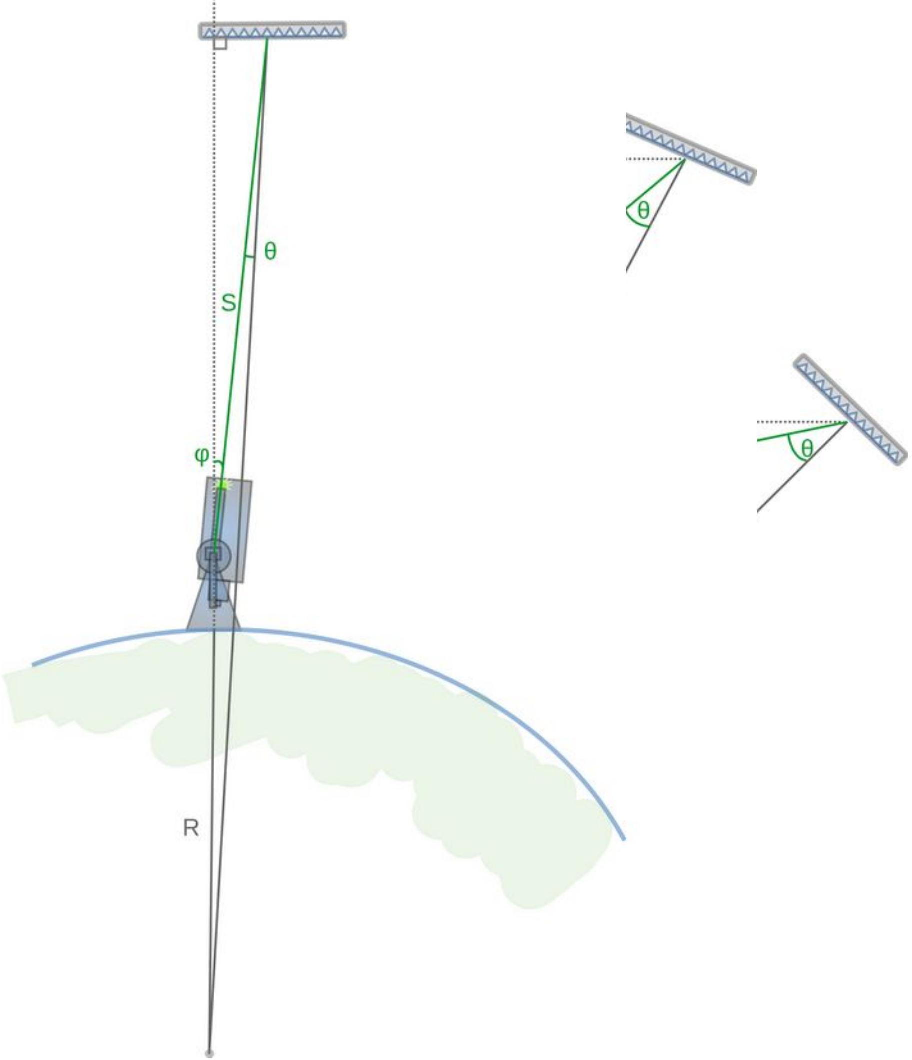
-- Specify output folder name to save plots.

-- Search local CPF folder

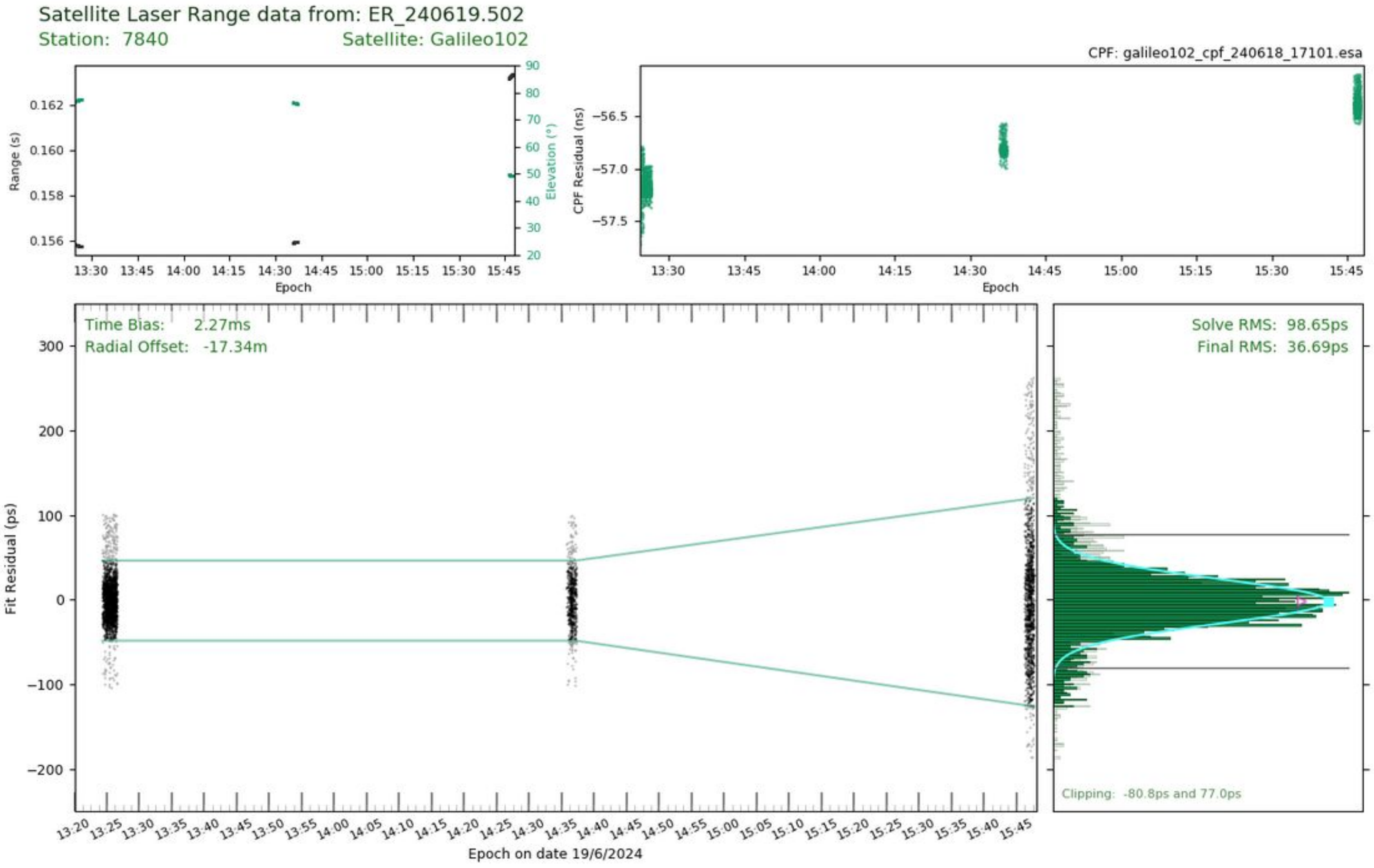
orbitNP.py 1.3 -updates

$$\theta = arcsin\left(\frac{R}{S}sin\left(arctan\left(\frac{Ssin(\varphi)}{R + Scos(\varphi)}\right)\right)\right)$$

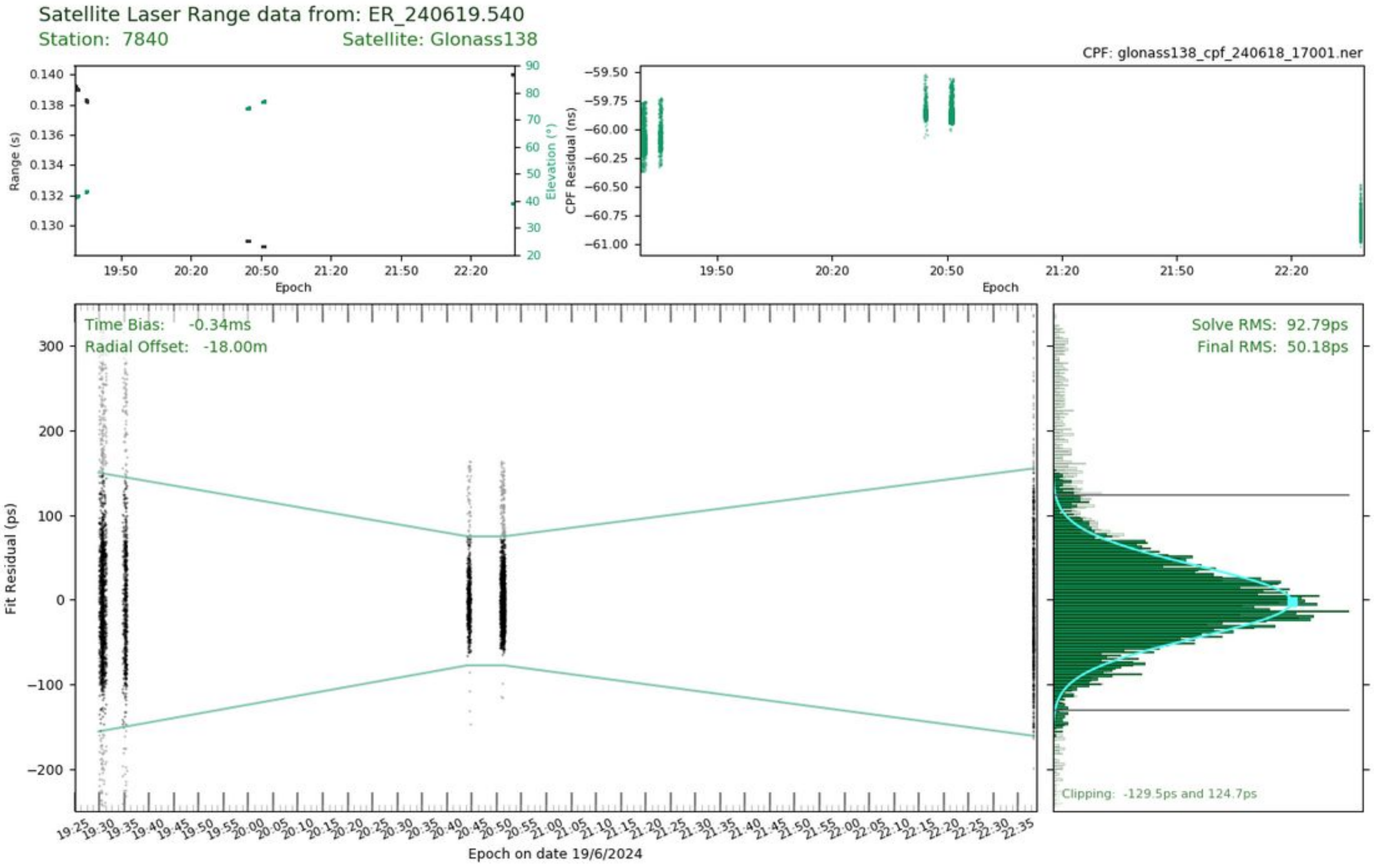
R = Earth's radius
S = Satellite range
φ = Zenith angle



Elevation Clipping



Elevation Clipping



orbitNP.py 1.3 -updates

Version 1.3

-- Include CDDIS as a source for automatic cpf predictions and crd downloads. EARTHDATA login details requested and stored locally in .earthdatalogin file.

-- Attempt to download fr2 full-rate file from Data Center if does not exist on drive.

-- Downloads CDDIS full-rate data files that are gzipped.

-- Clipping varies depending on the incident angle for GNSS flat LRA. This results in relatively wider acceptance at low elevations.

-- Jpeg output option.

-- Read and output receive amplitude records.

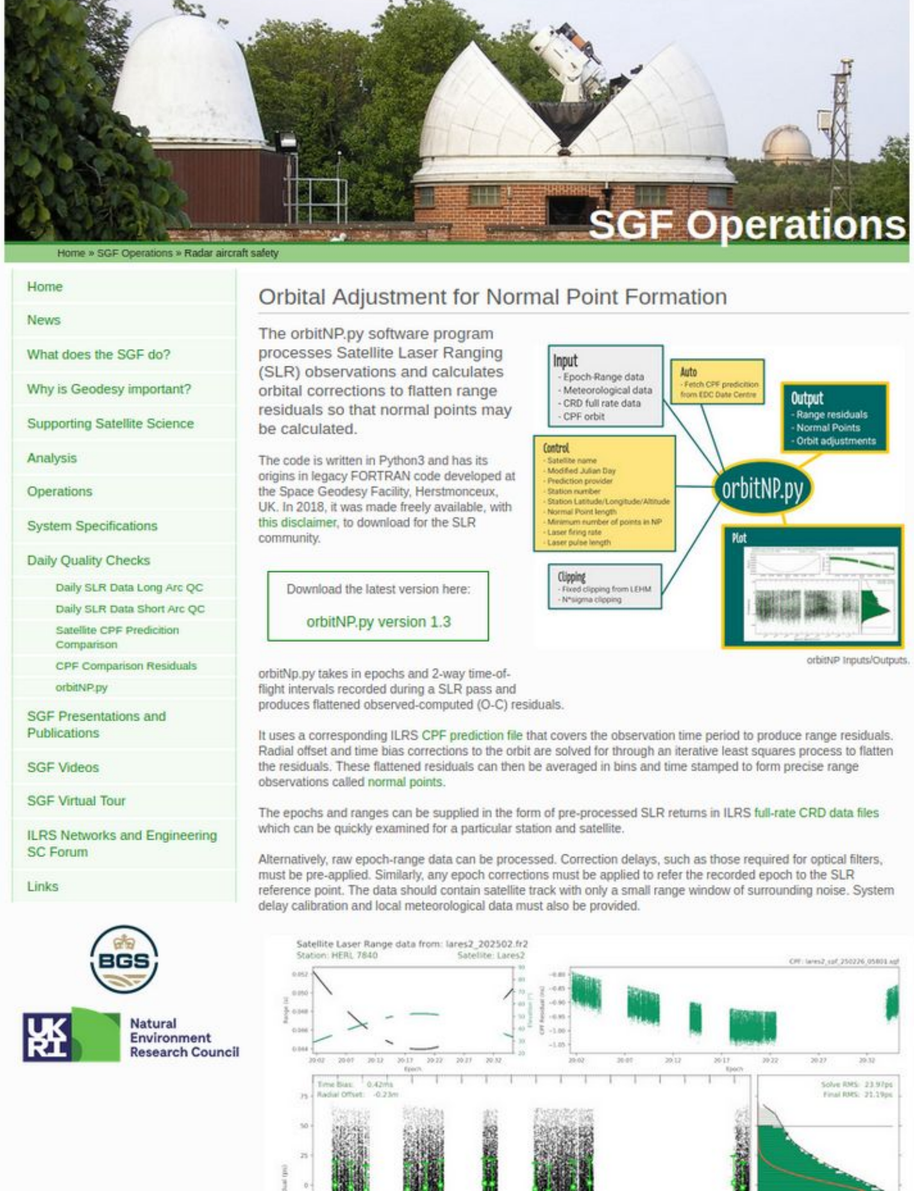
-- Allow dynamic axes labelling for matplotlib plots.

-- Specify output folder name to save plots.

-- Search local CPF folder

orbitNP.py 1.3 -download

http://sgf.rgo.ac.uk/qualityc/orbitNP.html



SGF Operations

Home » SGF Operations » Radar aircraft safety

Home

News

What does the SGF do?

Why is Geodesy important?

Supporting Satellite Science

Analysis

Operations

System Specifications

Daily Quality Checks

Daily SLR Data Long Arc QC

Daily SLR Data Short Arc QC

Satellite CPF Prediction Comparison

CPF Comparison Residuals

orbitNP.py

SGF Presentations and Publications

SGF Videos

SGF Virtual Tour

ILRS Networks and Engineering SC Forum

Links

Orbital Adjustment for Normal Point Formation

The orbitNP.py software program processes Satellite Laser Ranging (SLR) observations and calculates orbital corrections to flatten range residuals so that normal points may be calculated.

The code is written in Python3 and has its origins in legacy FORTRAN code developed at the Space Geodesy Facility, Herstmonceux, UK. In 2018, it was made freely available, with this disclaimer, to download for the SLR community.

Download the latest version here:

orbitNP.py version 1.3

orbitNP Inputs/Outputs.

orbitNp.py takes in epochs and 2-way time-of-flight intervals recorded during a SLR pass and produces flattened observed-computed (O-C) residuals.

It uses a corresponding ILRS CPF prediction file that covers the observation time period to produce range residuals. Radial offset and time bias corrections to the orbit are solved for through an iterative least squares process to flatten the residuals. These flattened residuals can then be averaged in bins and time stamped to form precise range observations called normal points.

The epochs and ranges can be supplied in the form of pre-processed SLR returns in ILRS full-rate CRD data files which can be quickly examined for a particular station and satellite.

Alternatively, raw epoch-range data can be processed. Correction delays, such as those required for optical filters, must be pre-applied. Similarly, any epoch corrections must be applied to refer the recorded epoch to the SLR reference point. The data should contain satellite track with only a small range window of surrounding noise. System delay calibration and local meteorological data must also be provided.

BGS

UKRI Natural Environment Research Council