# 1887 BAIL Analysis

Baikonur, Kazakhstan

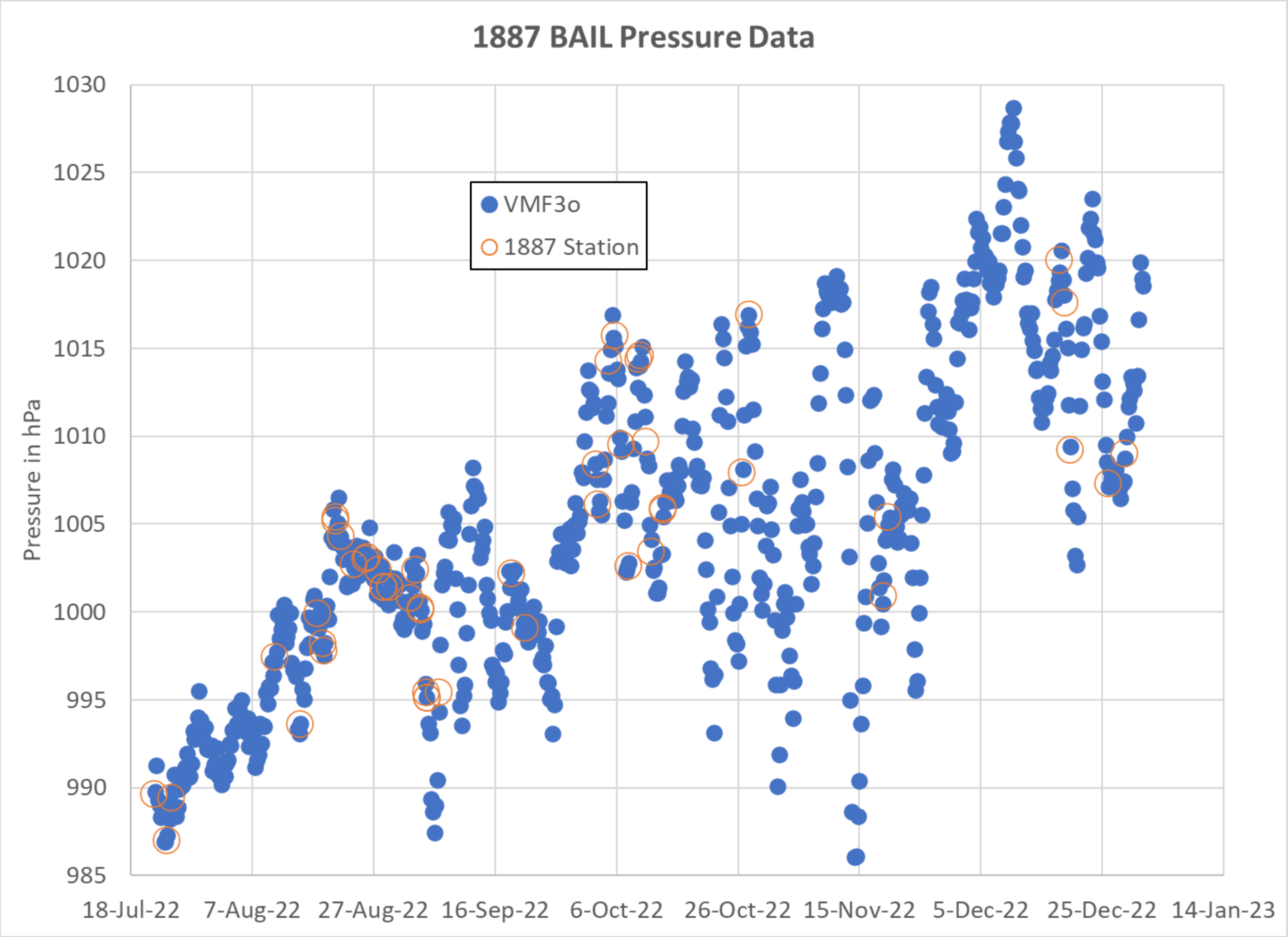
Van Husson

ILRS Quality Control Board (QCB)

20-January-2023

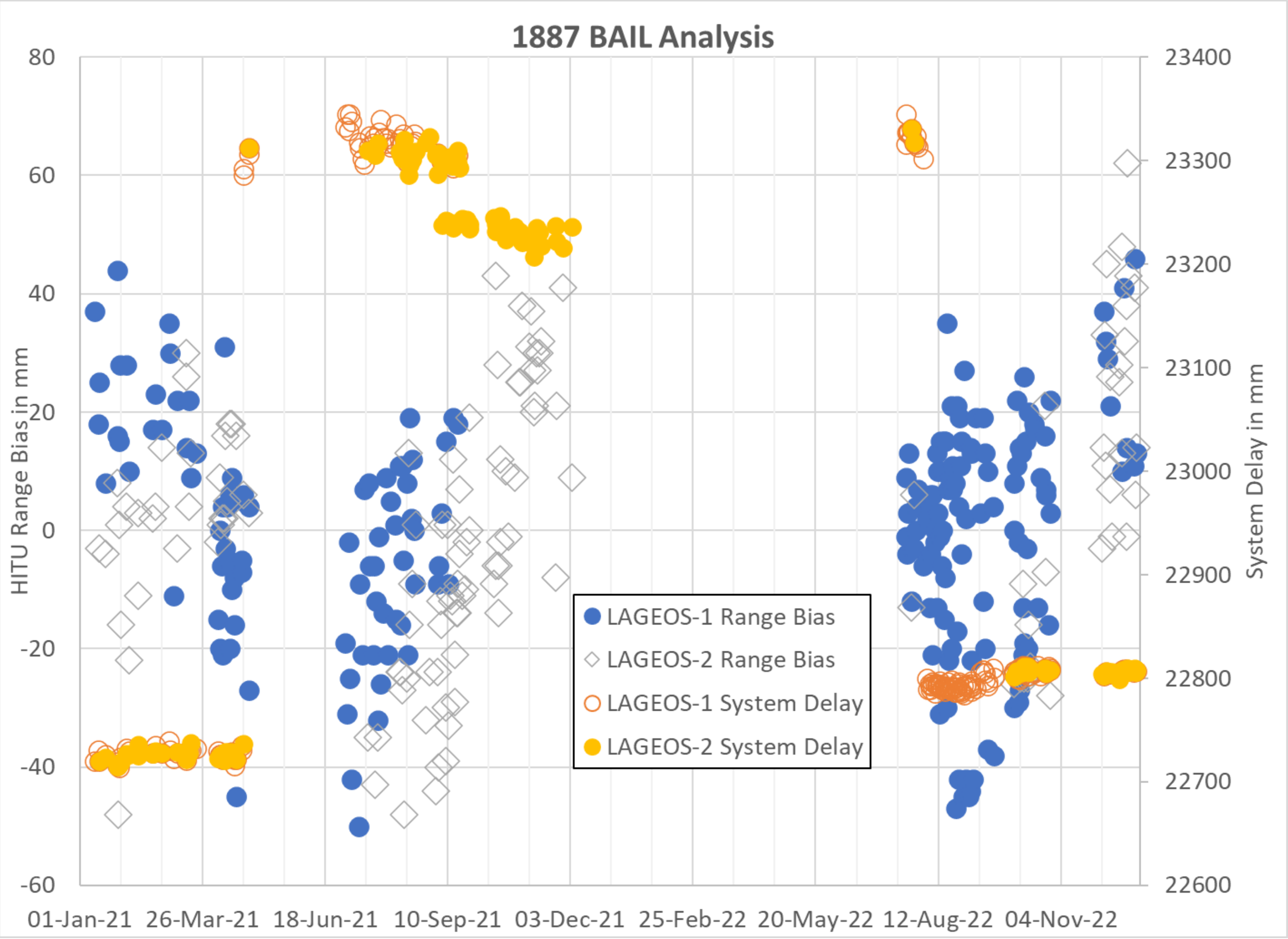
Peraton

# 1887 BAIL Barometric Analysis



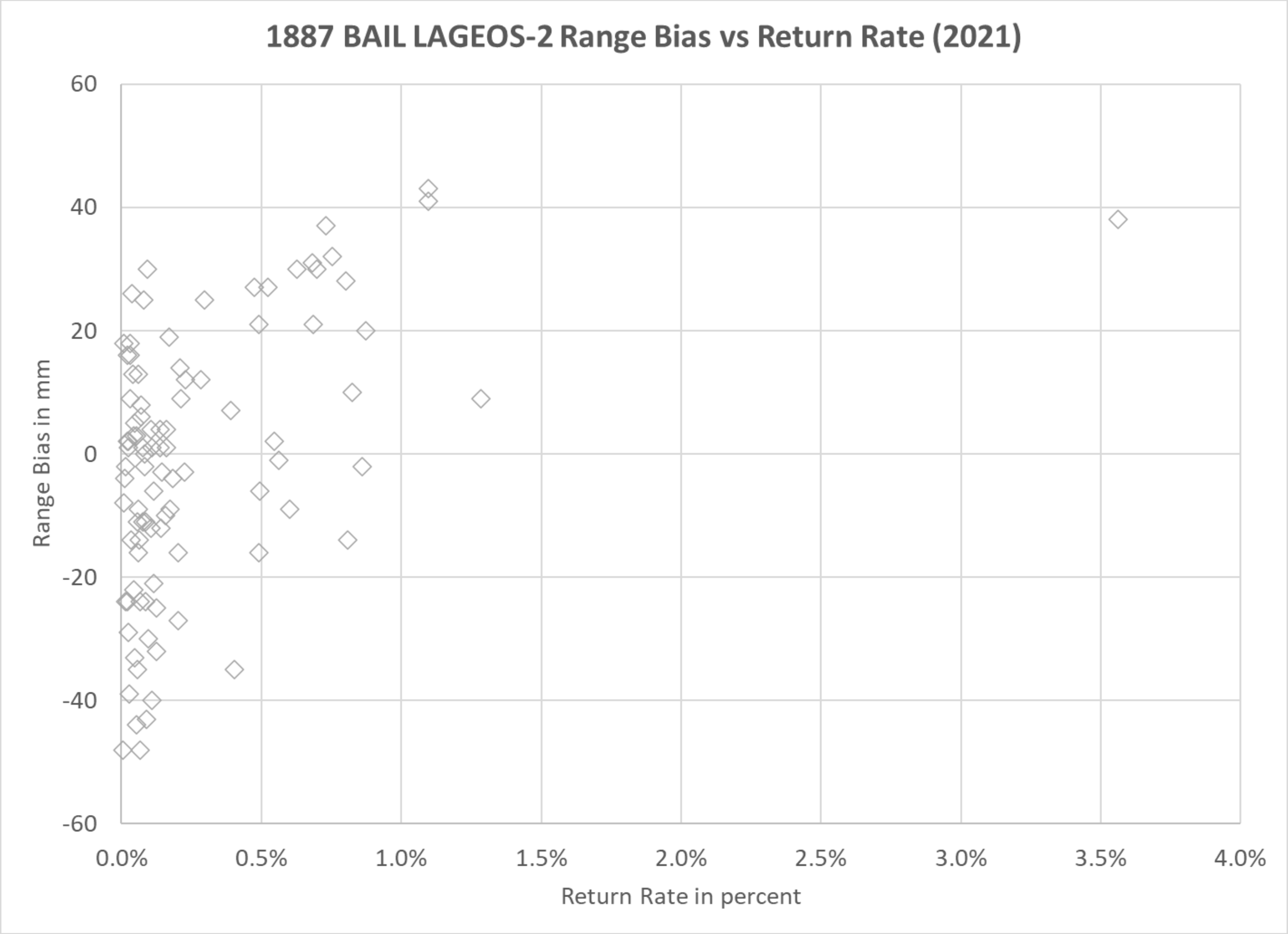

- Station pressures agree with VMF3o data; therefore, we can rule out a change in range bias is due to a barometric error

# 1887 HITU Range Biases and System Delays



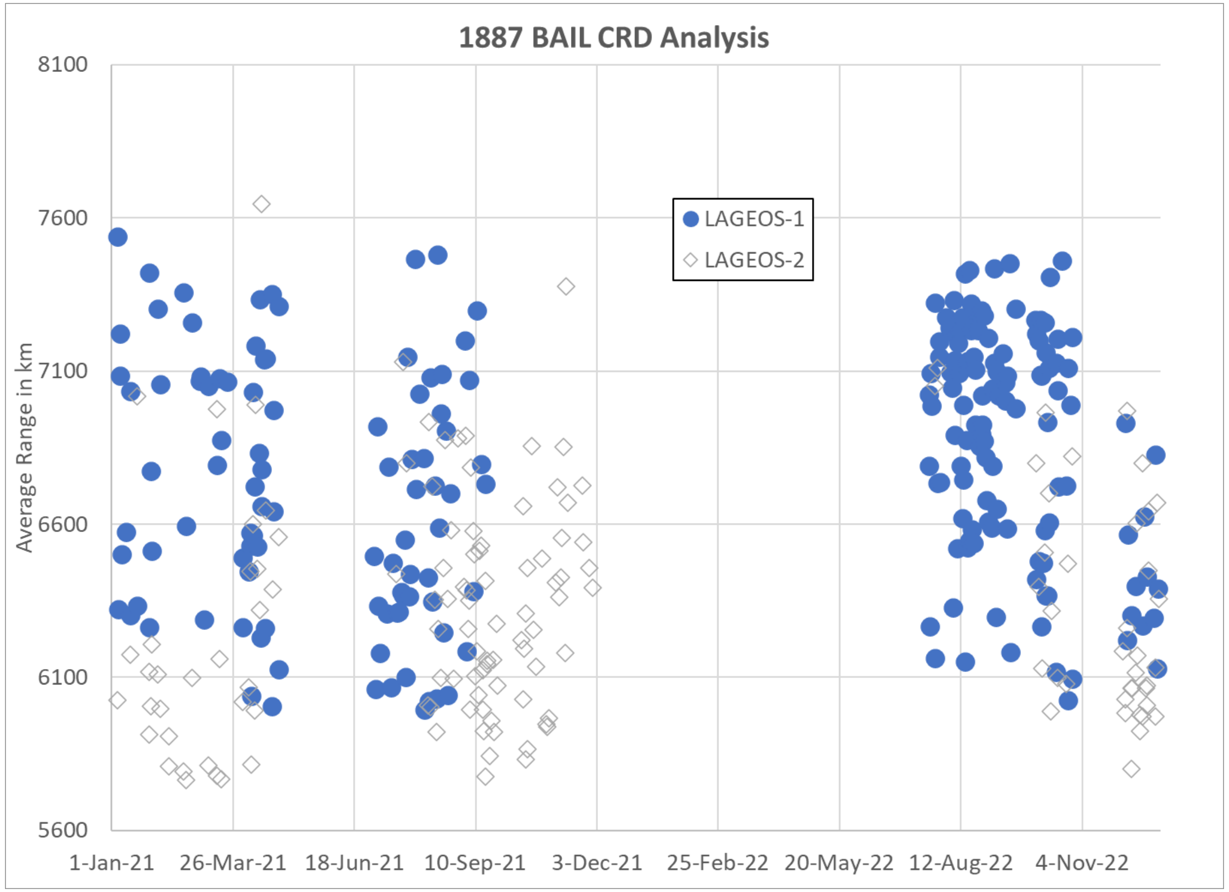

- HITU LAGEOS range bias and system delay on the right and left axes; respectively, since 1-Jan-2021
- 1887 BAIL data in 2022 is in quarantine after a several month break in tracking
- HITU range biases show the same trend as JCET range biases
- 2 to 3 cm changes in their LAGEOS range bias have occurred in 2021 and again in late 2022

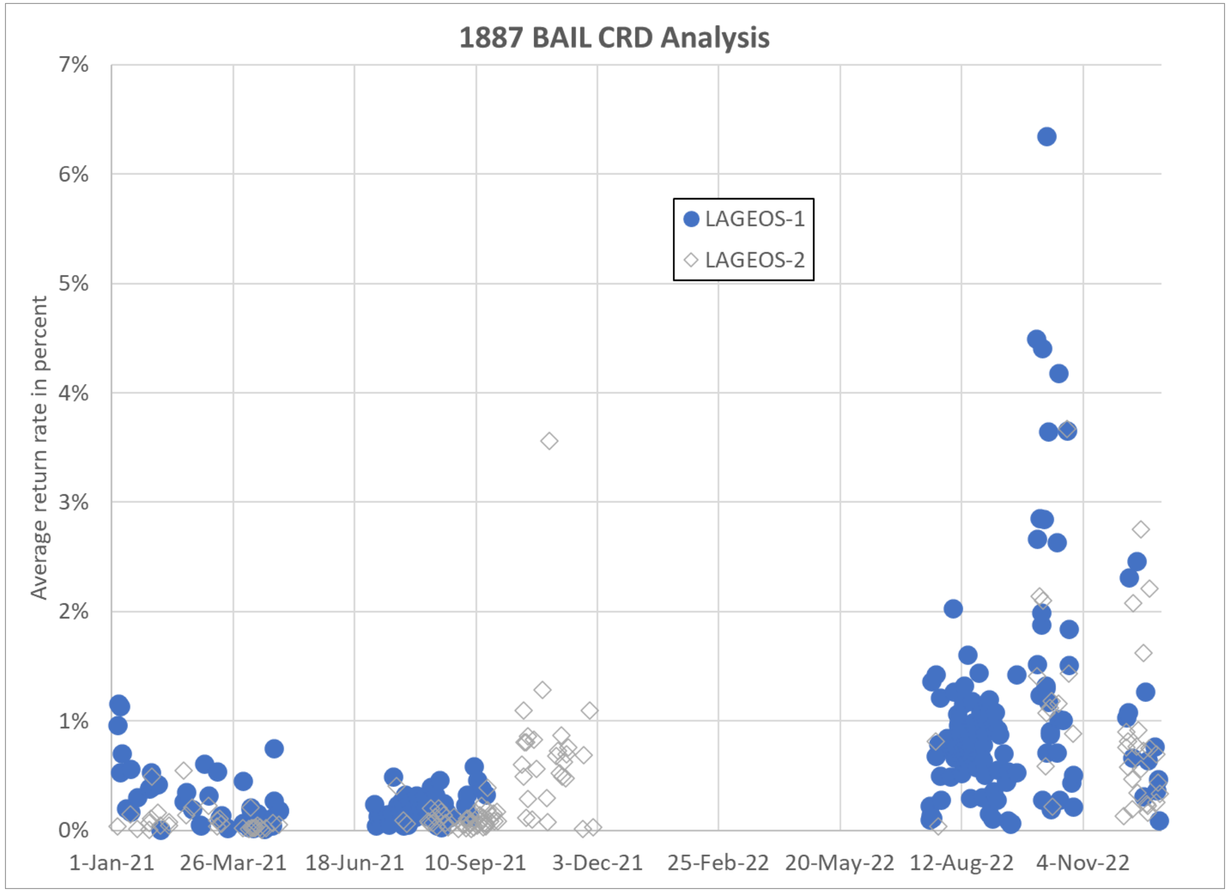
# 1887 BAIL Range Bias Vs Return Rate




- As the return rate increases, the range bias moves positive
- Return rate is an approximation of signal strength

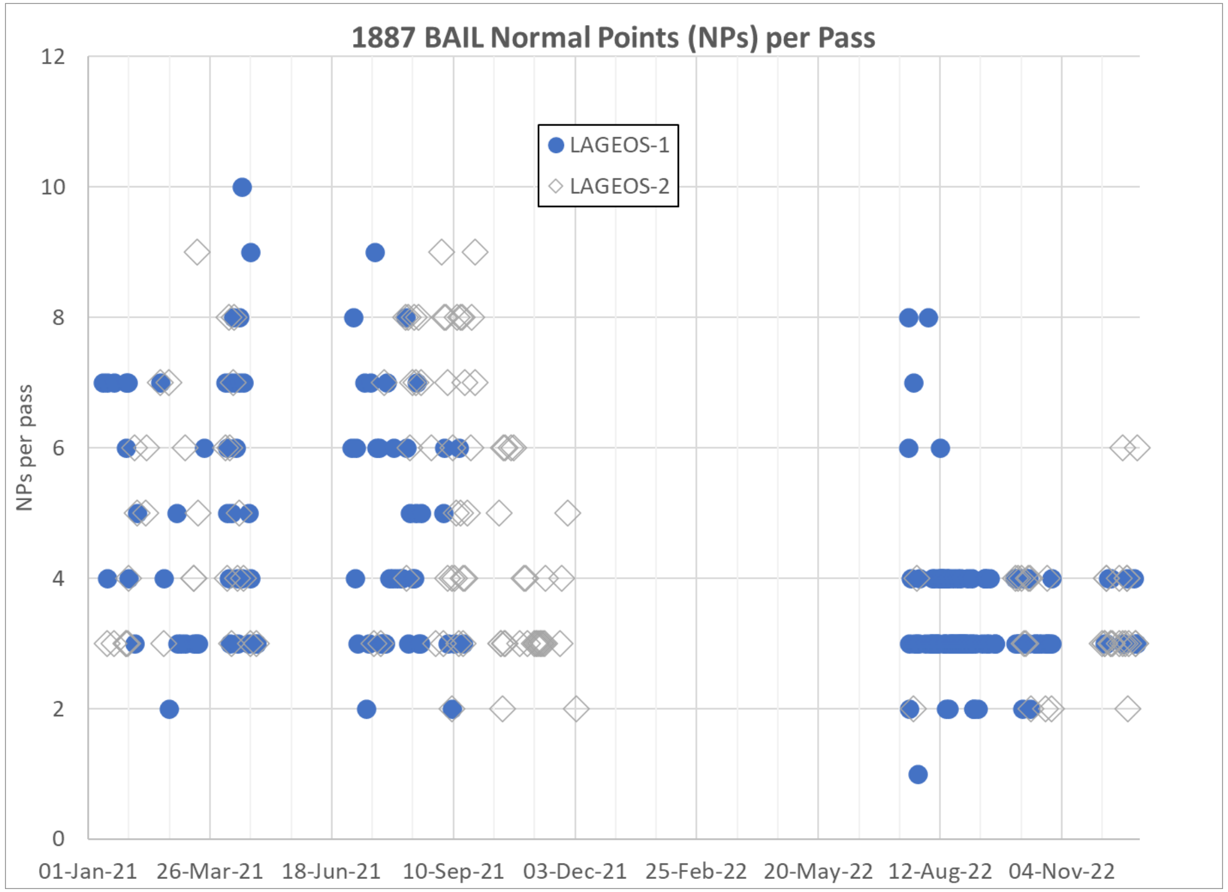
# 1887 CRD Analysis (Average Range and Return Rate)

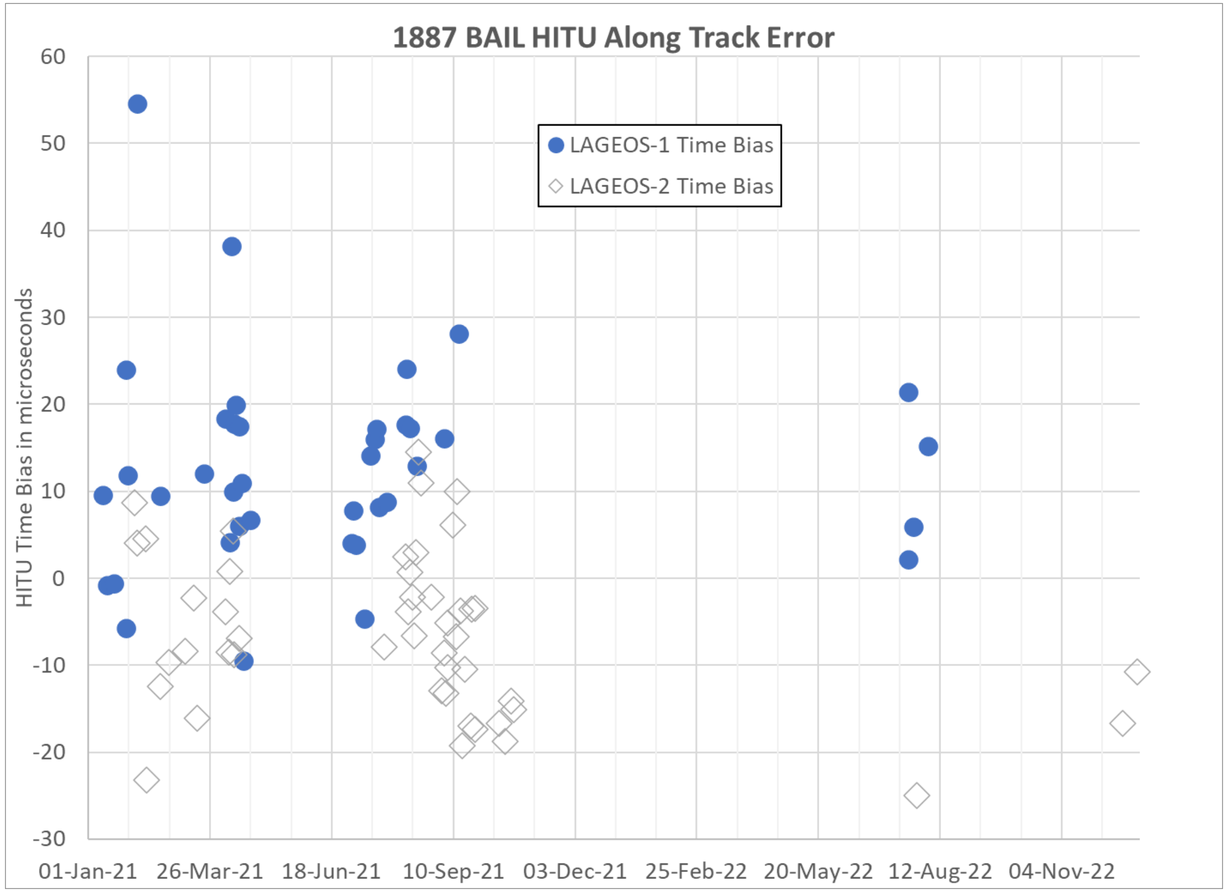



- **1887 LAGEOS Average Range and return rate on the left and right chart; respectively**

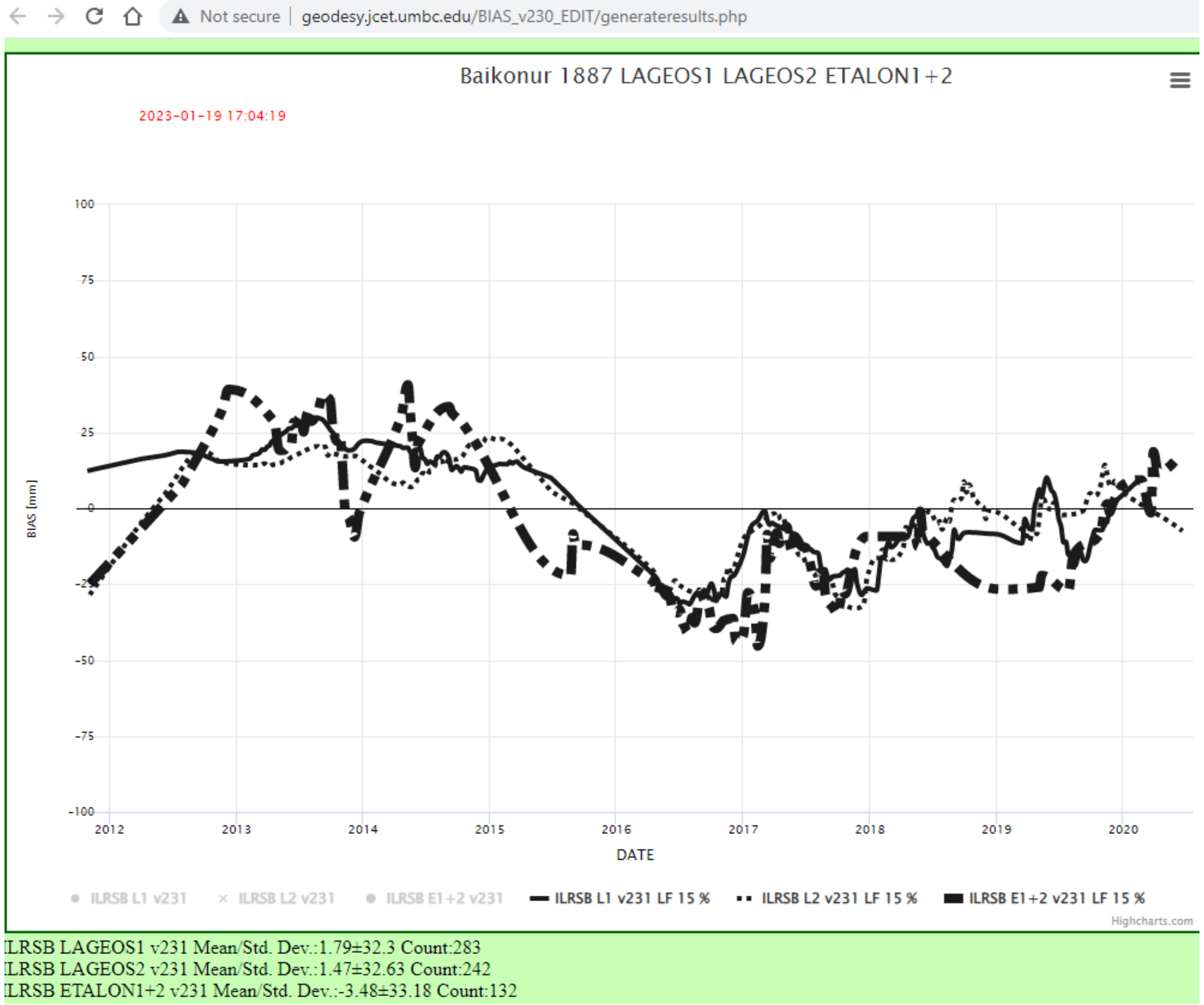
# 1887 BAIL NPs per Pass and Along Track Error (Orbital Time Bias)



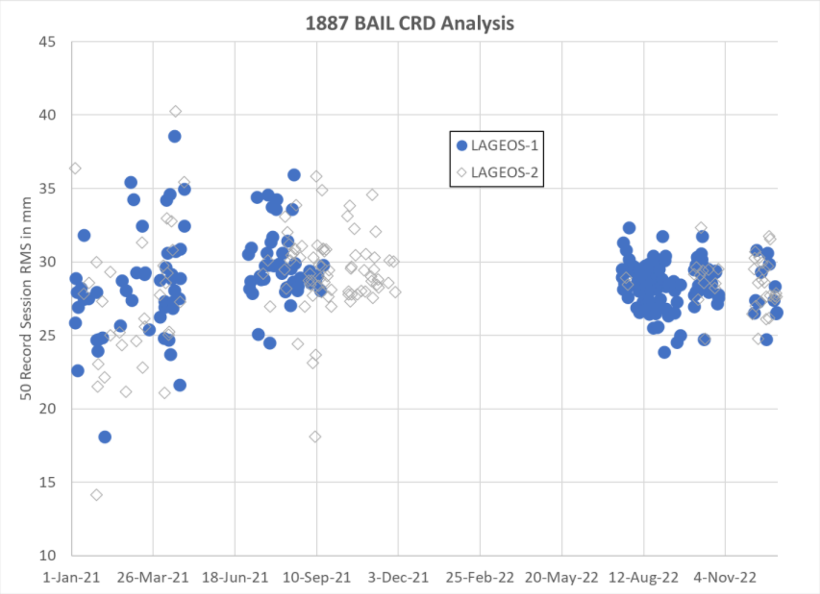

- **1887 LAGEOS NPs per pass and HITU time bias estimates on the left and right charts; respectively**
- **In mid August 2022, there has been a noticeable decline in the number of NPs per pass and why some passes have no time bias estimate**
- **The HITU along track error differences between LAGEOS 1 and 2 indicate the ITRF2014 1887 coordinates are not very accurate in latitude and/or longitude**

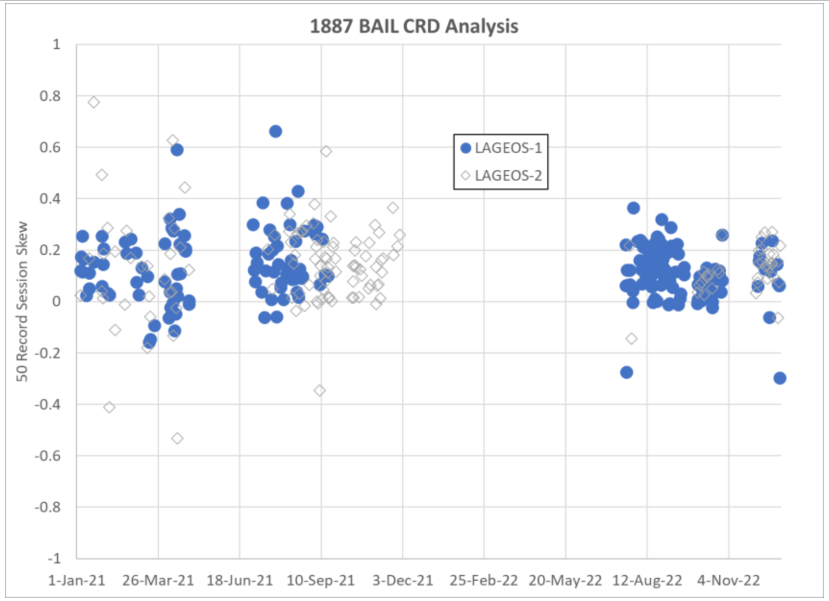
# 1887 BAIL SSEM Range Biases

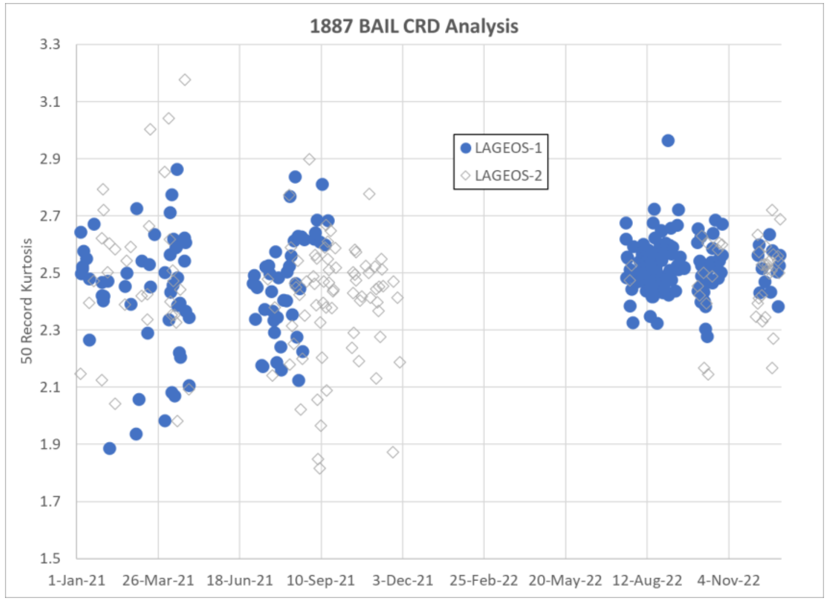


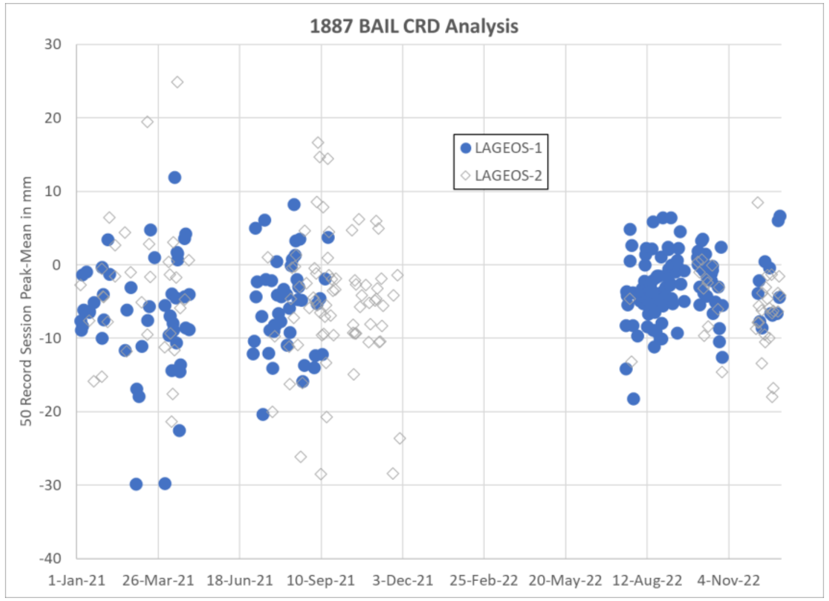

- **SSEM results indicate there have been several cm swings in the 1887 range biases**

# 1887 BAIL LAGEOS NP Moments and Peak minus Mean



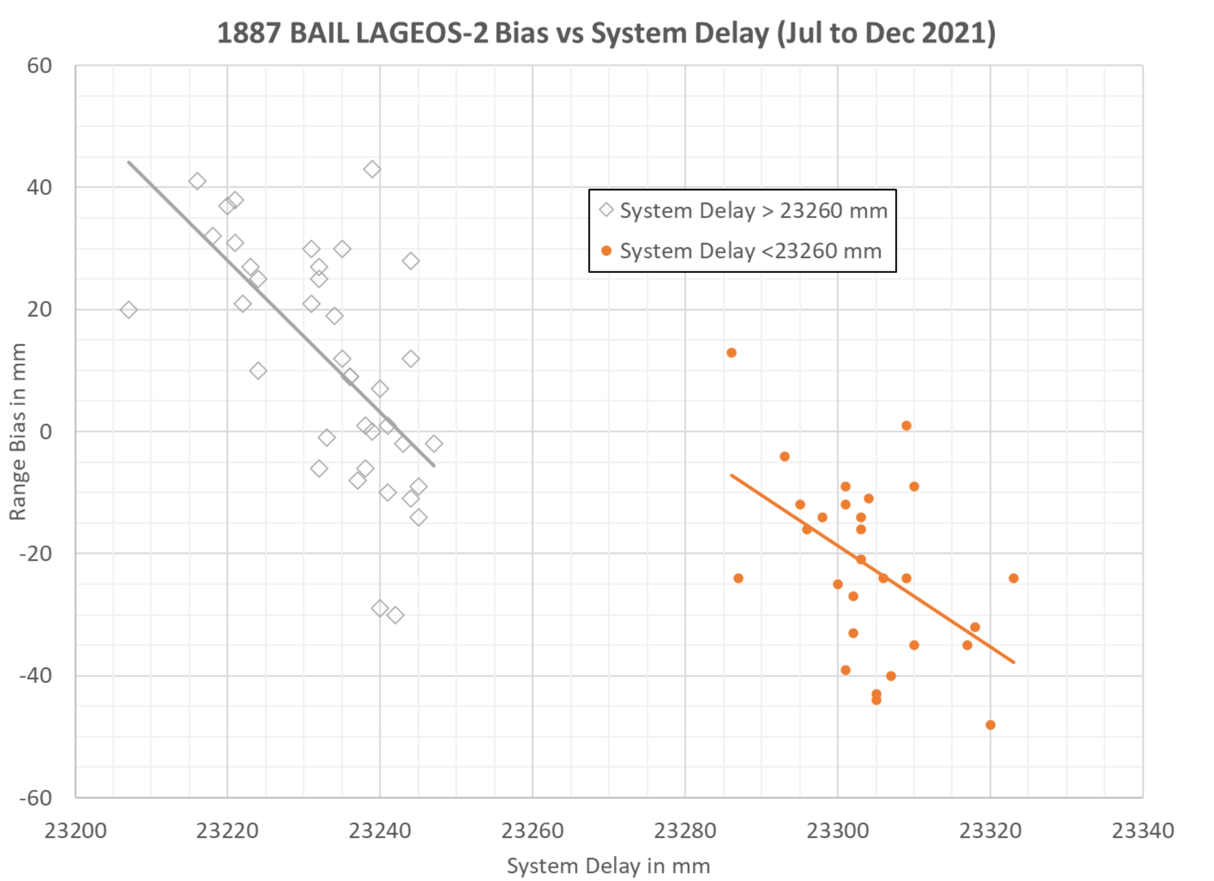



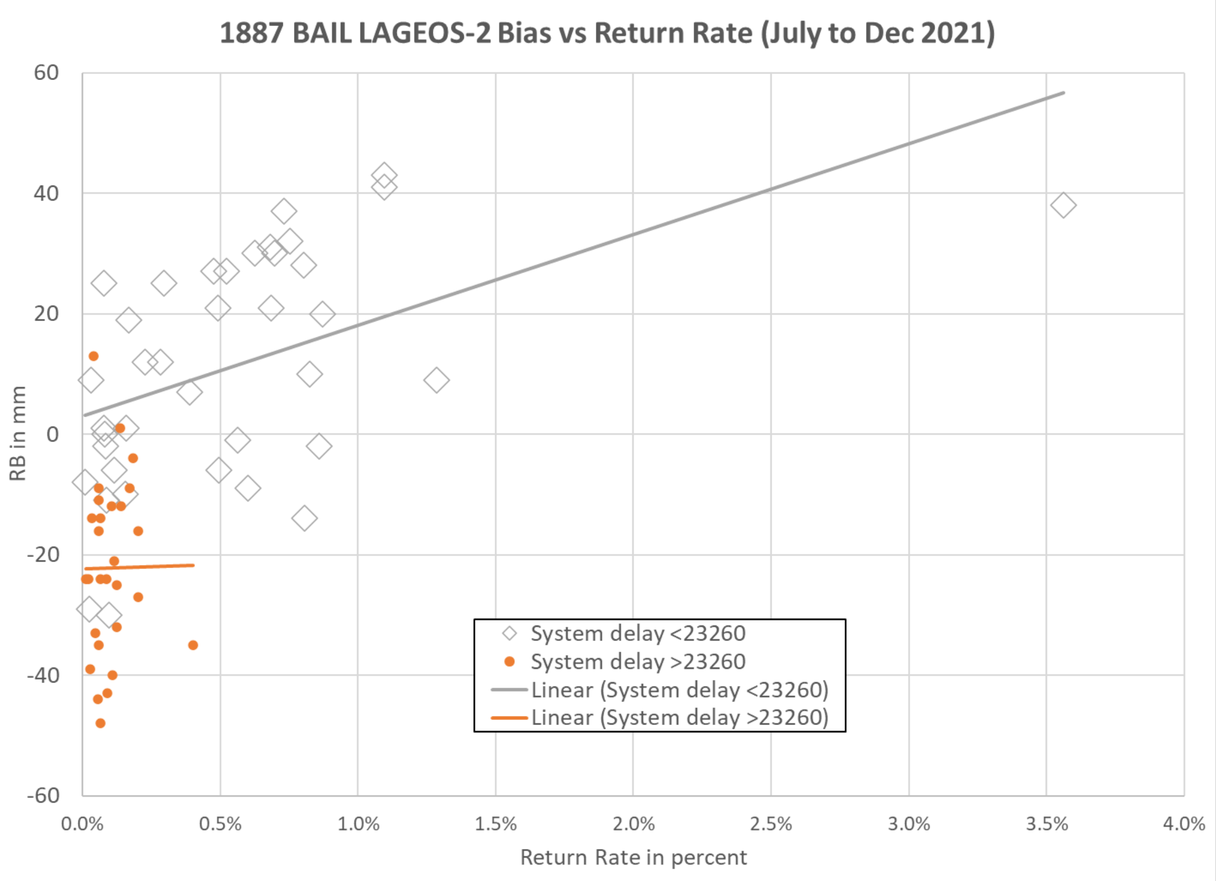




- **Single shot session RMS, session skew, session kurtosis and session peak minus mean on the top left chart, top right chart, lower left chart and lower right chart; respectively.**
- **All the moments and the peak minus mean values have less scatter than before.**

# 1887 BAIL LAGEOS-2 Analysis (July to Dec 2021)




| System Delay | System Delay Average in mm | Range Bias Average in mm | Range Bias Standard Deviation in mm | Average return rate |
|---|---|---|---|---|
| <23260 mm | 23233.4 | 11.3 | 19.0 | 0.5% |
| > 23260 mm | 23304.1 | -22.2 | 14.6 | 0.1% |
| Delta | -70.7 | 33.4 | 4.4 | 0.4% |

# Baikonur 1887 QC Evaluation

E. C. Pavlis & M. Kuzmicz-Cieslak

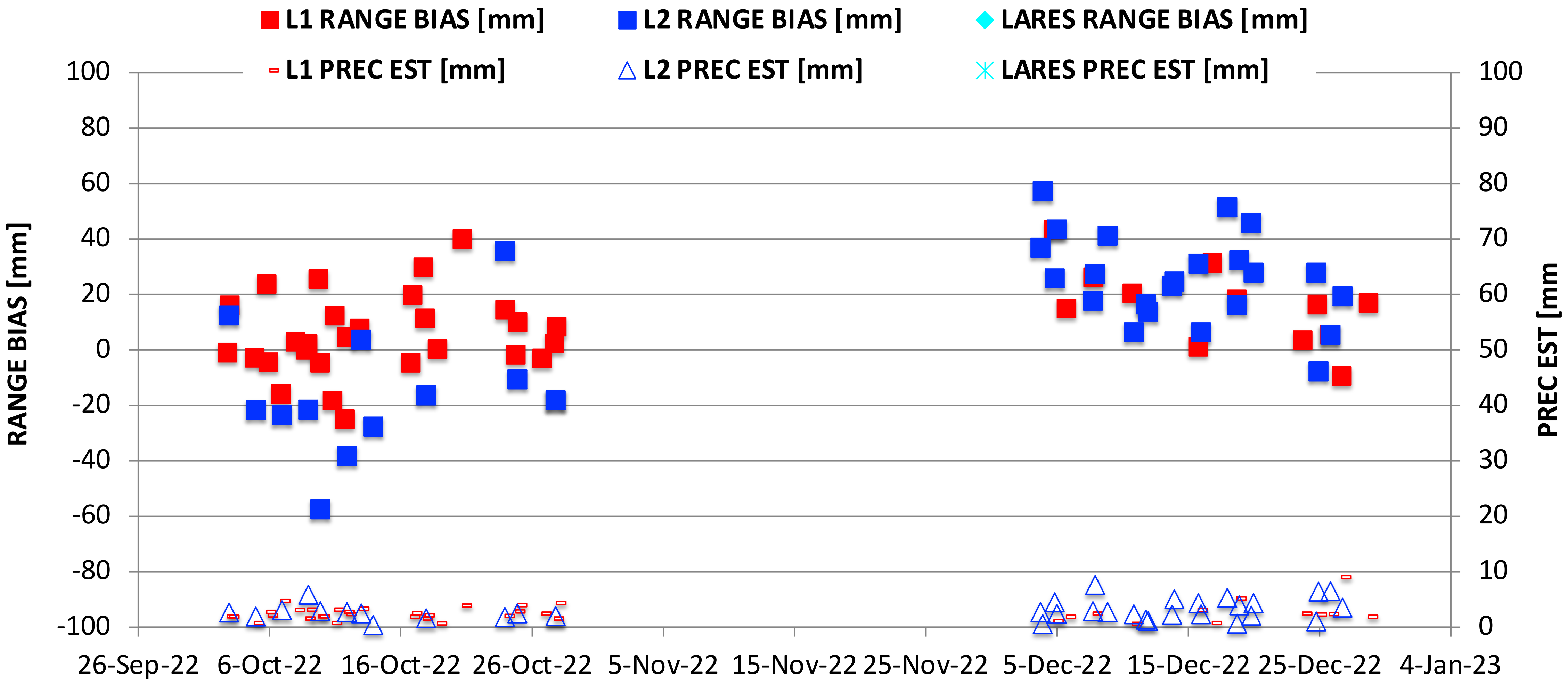
GESTAR II/UMBC

January 7, 2023

# Baikonur 1887 – Fall 2022 QC Results

| L1 18879701 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 2.5 | 8.3 |
| STD | 1.5 | 15.0 |
| RMS | 2.9 | 17.0 |
| Passes | 40 | 40 |

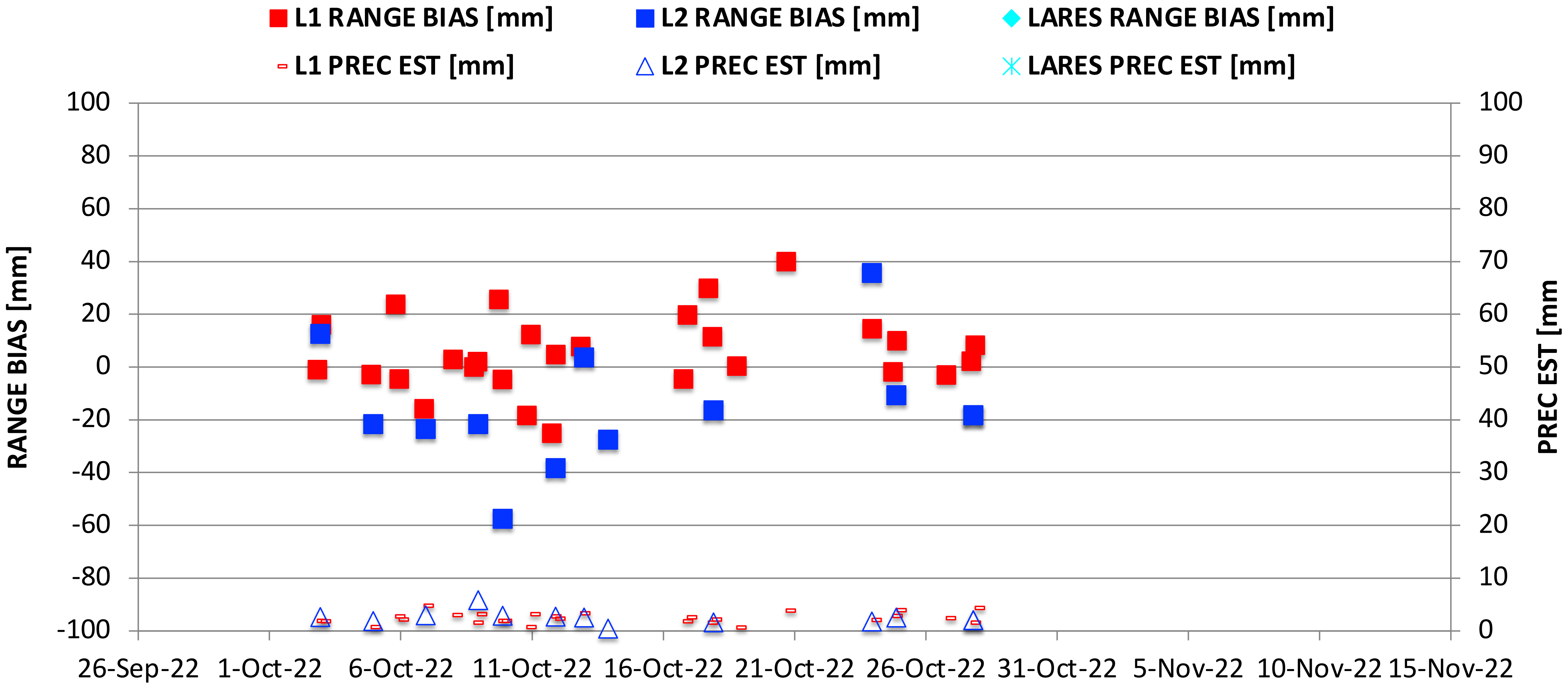
| L2 18879701 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 3.0 | 10.8 |
| STD | 1.8 | 27.3 |
| RMS | 3.4 | 28.9 |
| Passes | 36 | 36 |



# Baikonur 1887 – Sept.-Oct. 2022 QC Results

| L1 18879701 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 2.4 | 10.0 |
| STD | 1.0 | 20.1 |
| RMS | 2.6 | 22.1 |
| Passes | 31 | 31 |

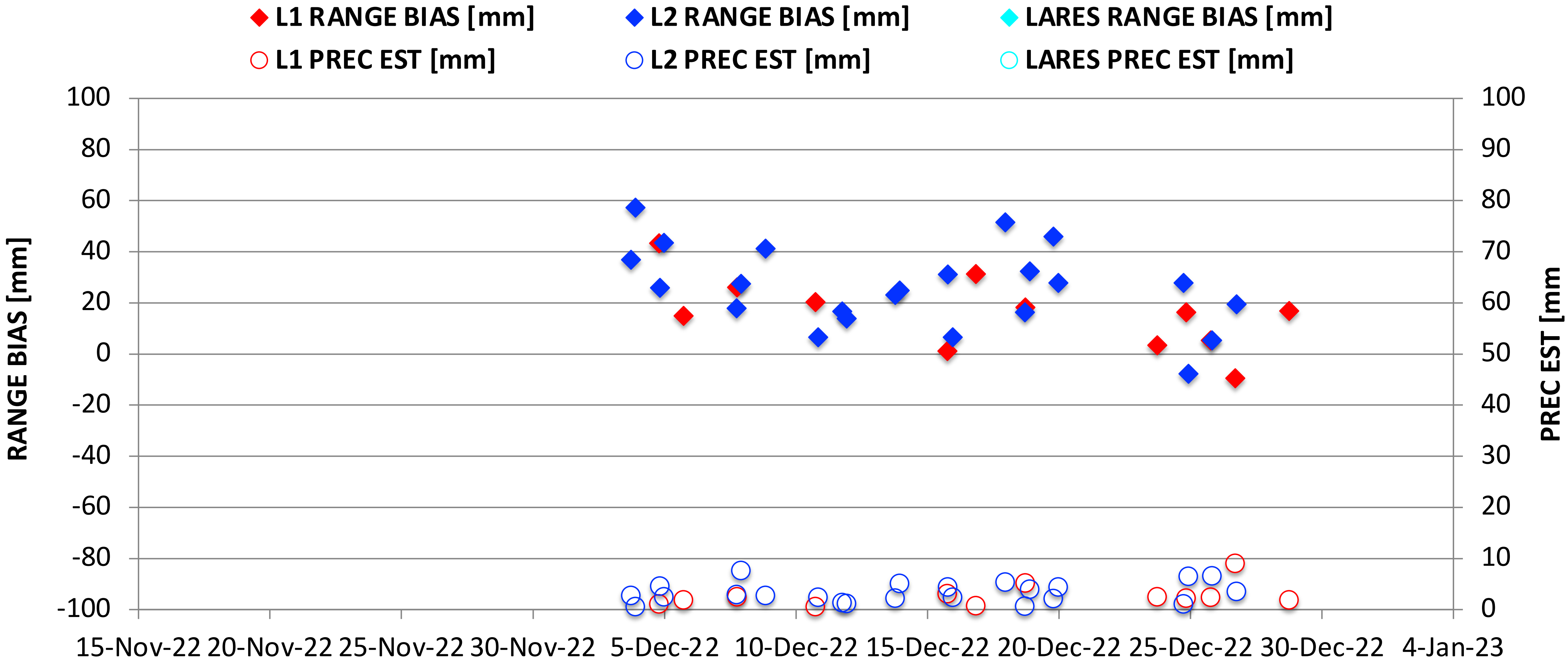
| L2 18879701 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 2.4 | -15.5 |
| STD | 1.2 | 23.1 |
| RMS | 2.7 | 27.1 |
| Passes | 13 | 13 |



# Baikonur 1887 – Dec. 2022 QC Results

| L1 18879701 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 2.7 | 15.6 |
| STD | 2.3 | 14.3 |
| RMS | 3.5 | 20.7 |
| Passes | 12 | 12 |

| L2 18879701 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 3.3 | 25.6 |
| STD | 2.0 | 15.8 |
| RMS | 3.8 | 30.0 |
| Passes | 23 | 23 |




| BIAS [mm] HartRAONASA 7501 LAGEOS |
|---|
| Mean/Std. Dev.: -3.00 ± 13.83 Count: 74 |


| BIAS [mm] HartRAONASA 7501 LAGEOS2 |
|---|
| Mean/Std. Dev.: 1.10 ± 7.44 Count: 74 |


| BIAS [mm] HartRAONASA 7501 ETALON1 |
| --- |
| Mean/Std. Dev.: 6.64 ± 21.82 Count: 46 |


| BIAS [mm] HartRAONASA 7501 ETALON2 |
|---|
| Mean/Std. Dev.: 24.43 ± 151.94 Count: 53 |

# ITRF2020 SLR Scale Analysis

Van S. Husson

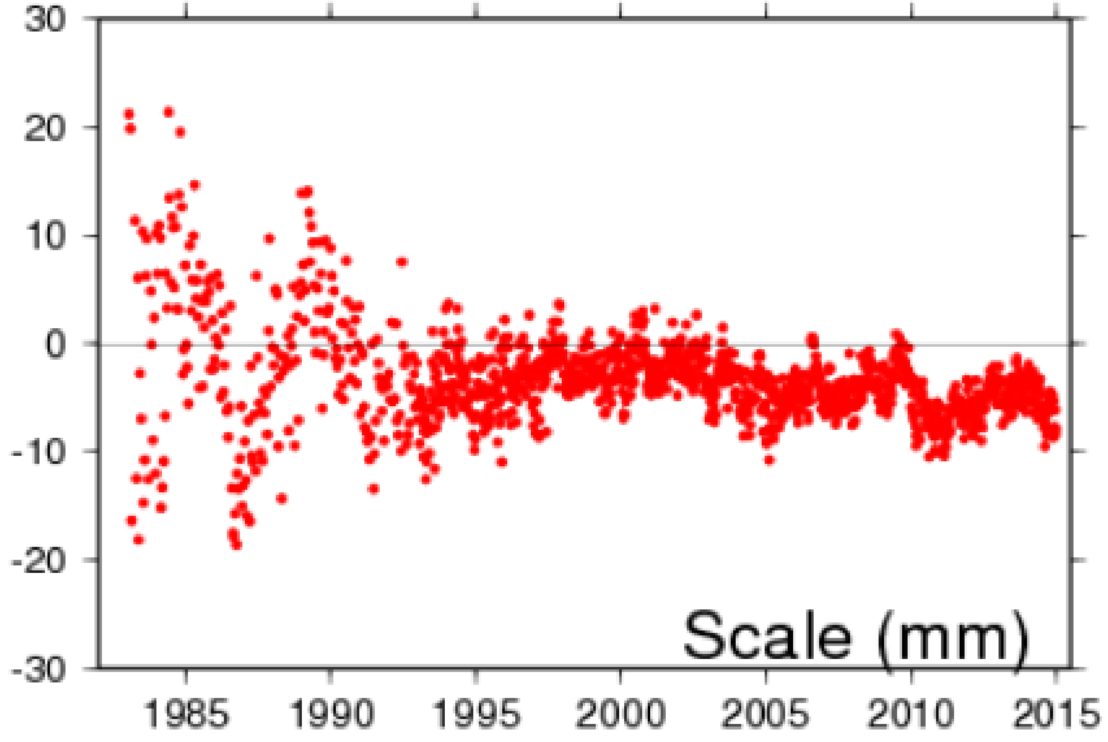
vhusson@peraton.com

ILRS Quality Control Board

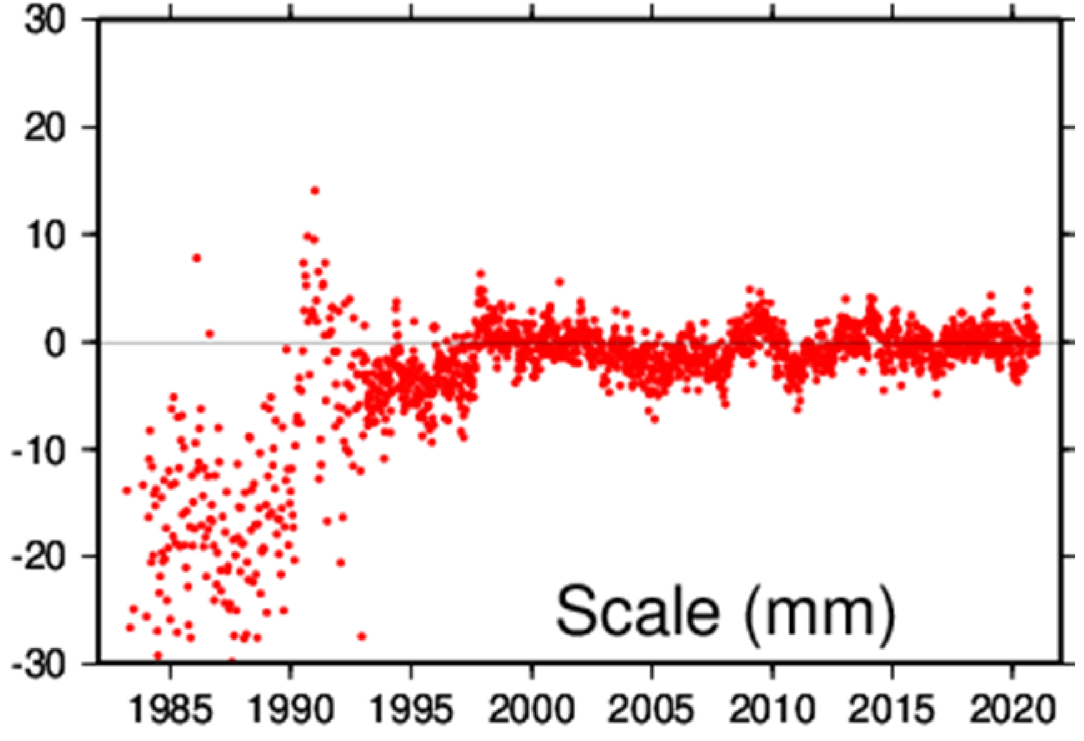
18-Jan-2023

# ITRF2014 and ITRF2020 SLR Scales

## ITRF2014 SLR Scale




## ITRF2020 SLR Scale

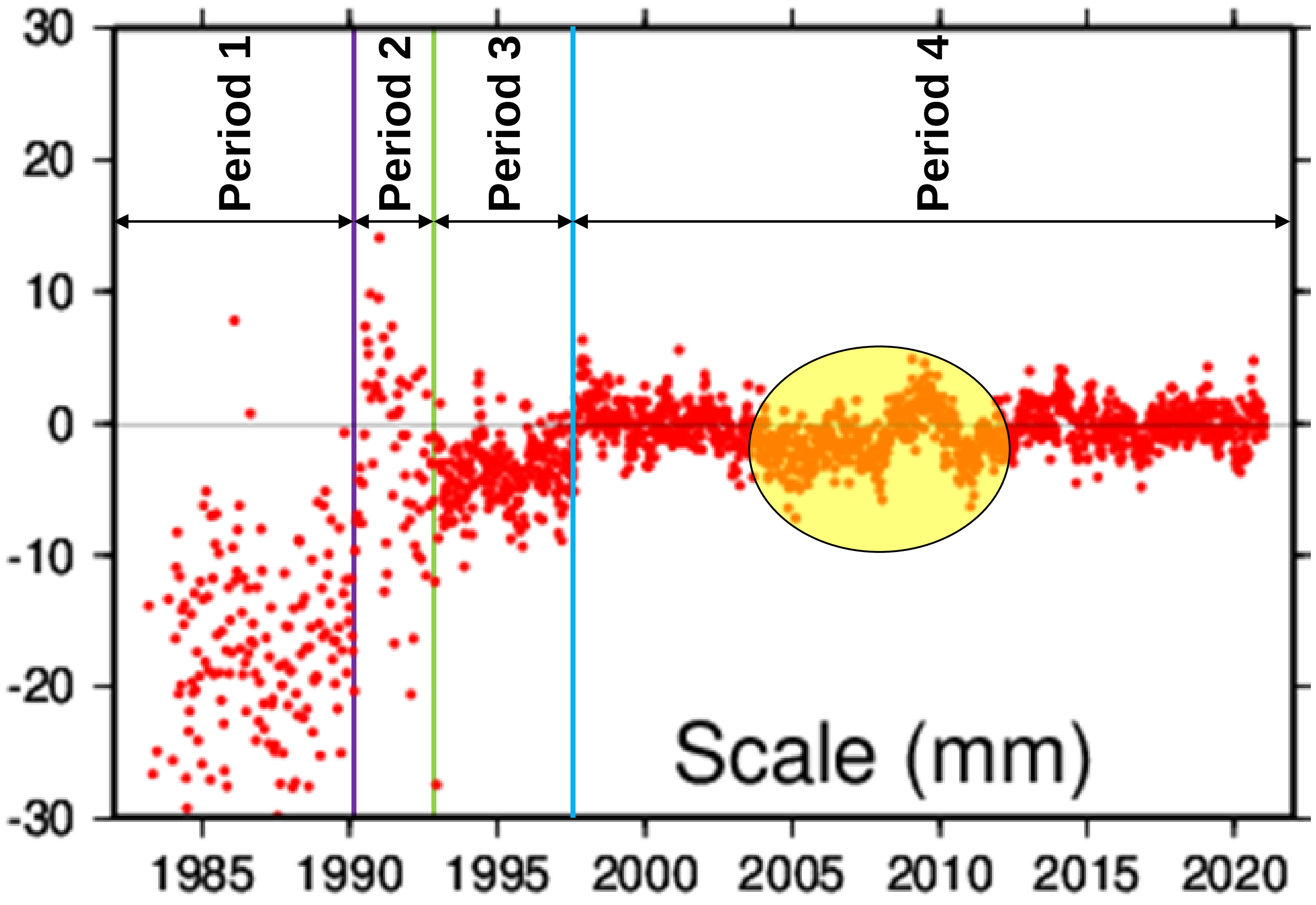



- ❑ **ITRF2020 scale residuals since July 1997 are centered around zero. The ITRF2020 scale estimates have some systematic variations**

# Potential Causes of Systematics in the SLR ITRF2020 Scale Results

- **Changes in the satellite constellation**
- **Poor spatial and temporal tracking coverage from the ILRS Core sites**
- **Unmodelled systematic errors (tropospheric, epoch, signal strength, counter non-linearities, frequency) in the Core sites**

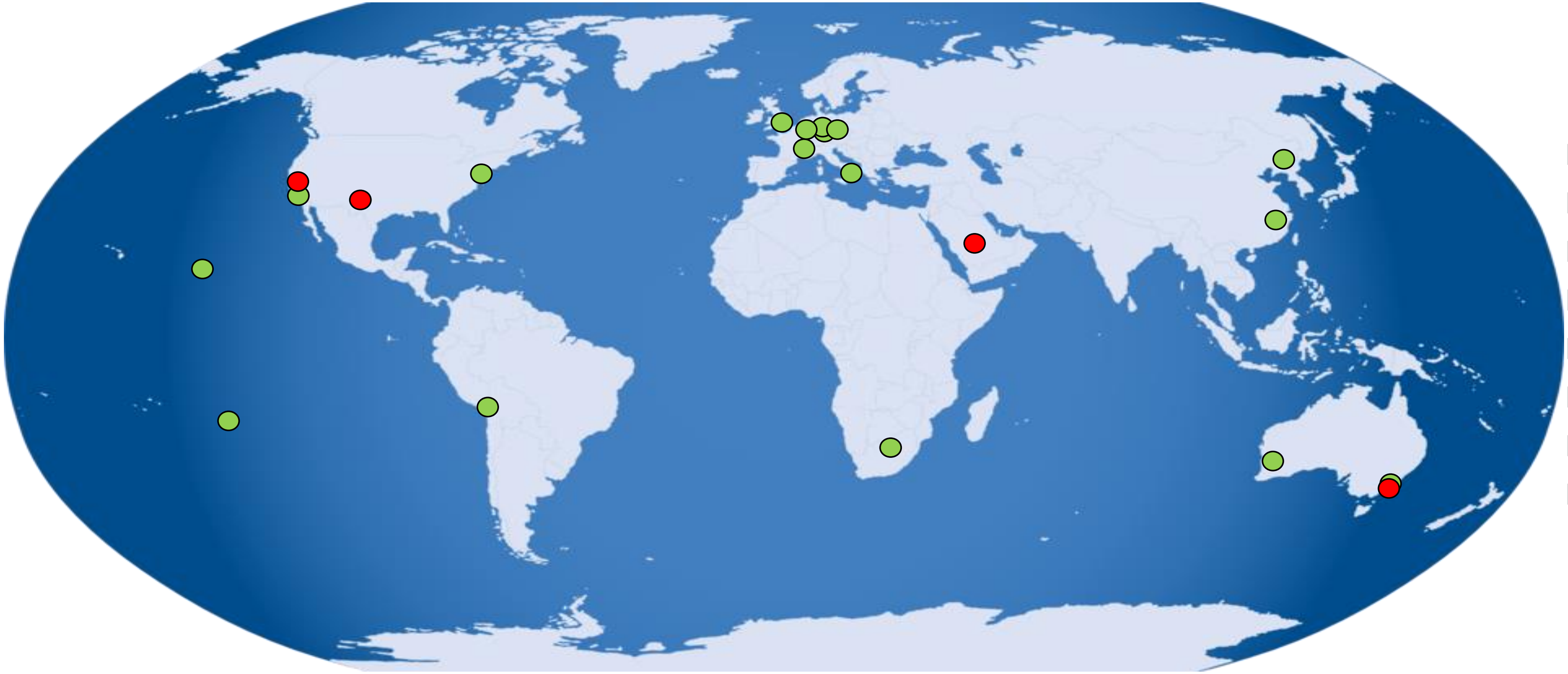
# ITRF2020 SLR Scale Estimates and Satellites




- **Four distinct periods, 1st three periods are due to changes in the satellite constellation**
- **Period 1: LAGEOS-1 only (1983 to early March 1990)**
  - Scale estimates mostly negative
- **Period 2: Etalon -1 and -2 added (early March 1990 to November 1992)**
  - Scale estimates distributed around zero, but slightly negative
- **Period 3: LAGEOS-2 added (November 1992 to July 1997)**
  - Scale estimates mostly negative, decrease in scatter
- **Discontinuity in the scale estimates in July 1997**
- **Period 4: no change in satellites (July 1997 to end of 2020)**
  - Scale estimates scattered around zero with some systematics (2004 to 2011)

# Analysis of LAGEOS and Etalon Tracking from Core Sites

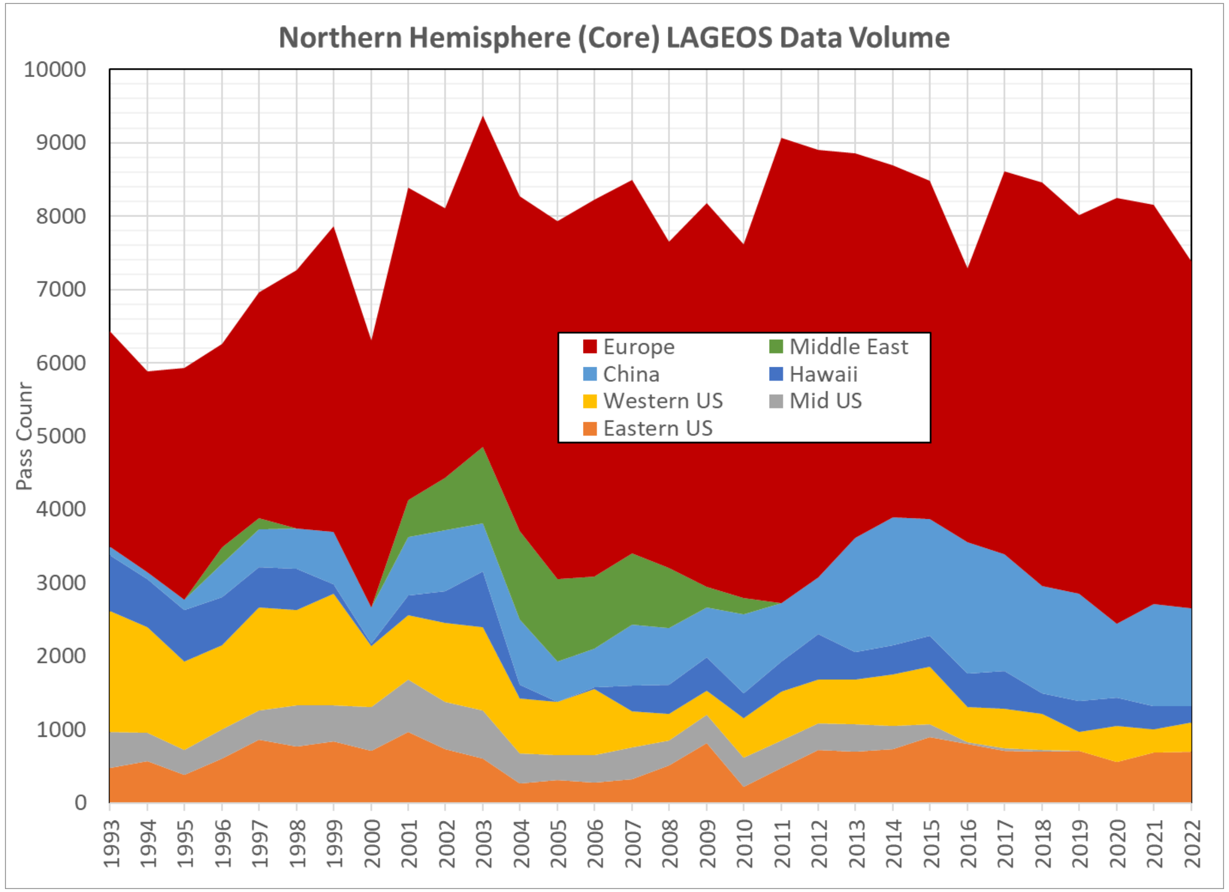
# ITRF2020 SLR Core Site Locations

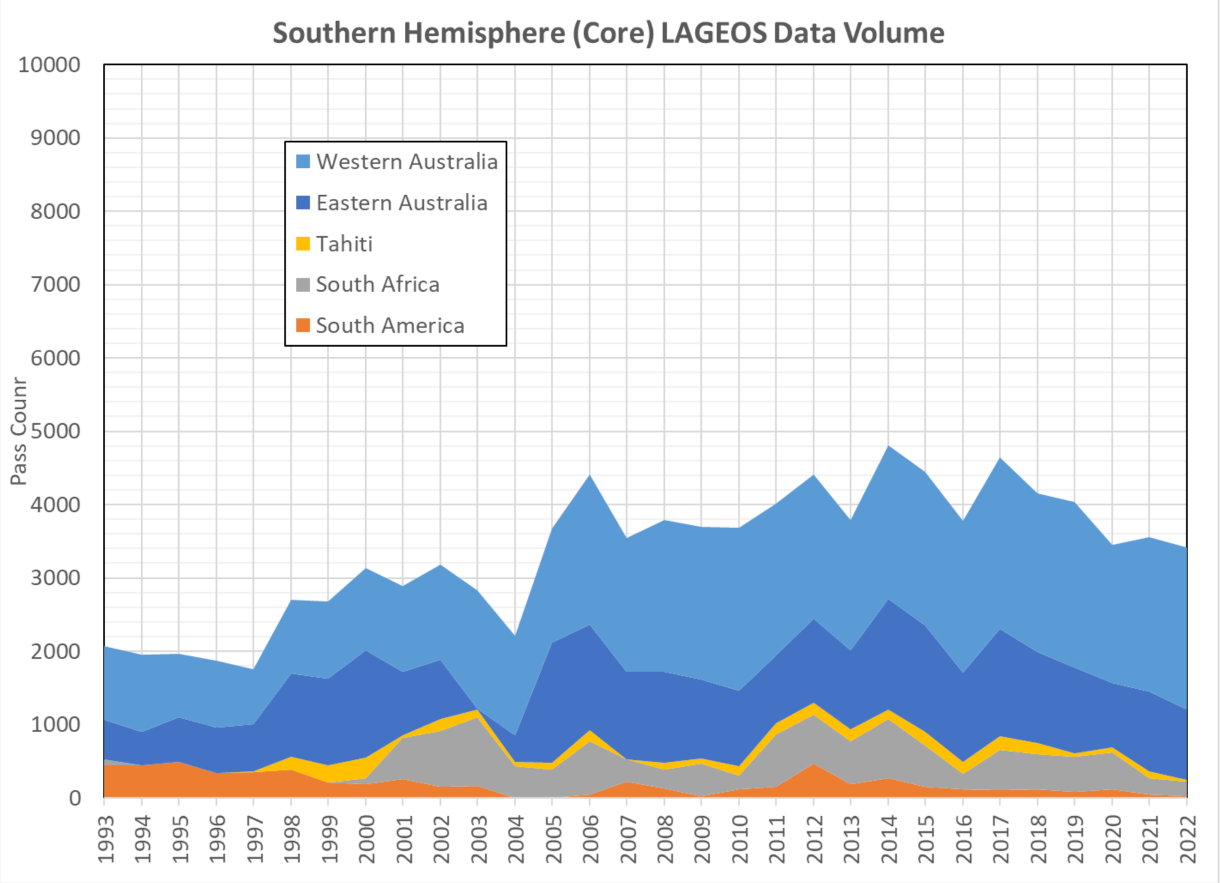


- 4 N. American sites
- 1 S. American site
- 2 Pacific sites
- 3 Australian sites
- 2 Chinese sites
- 1 Middle Eastern site
- 1 African site
- 7 European sites

**Sites in RED (Quincy, McDonald, Riyadh, Orroral Valley) currently don't have SLR systems**

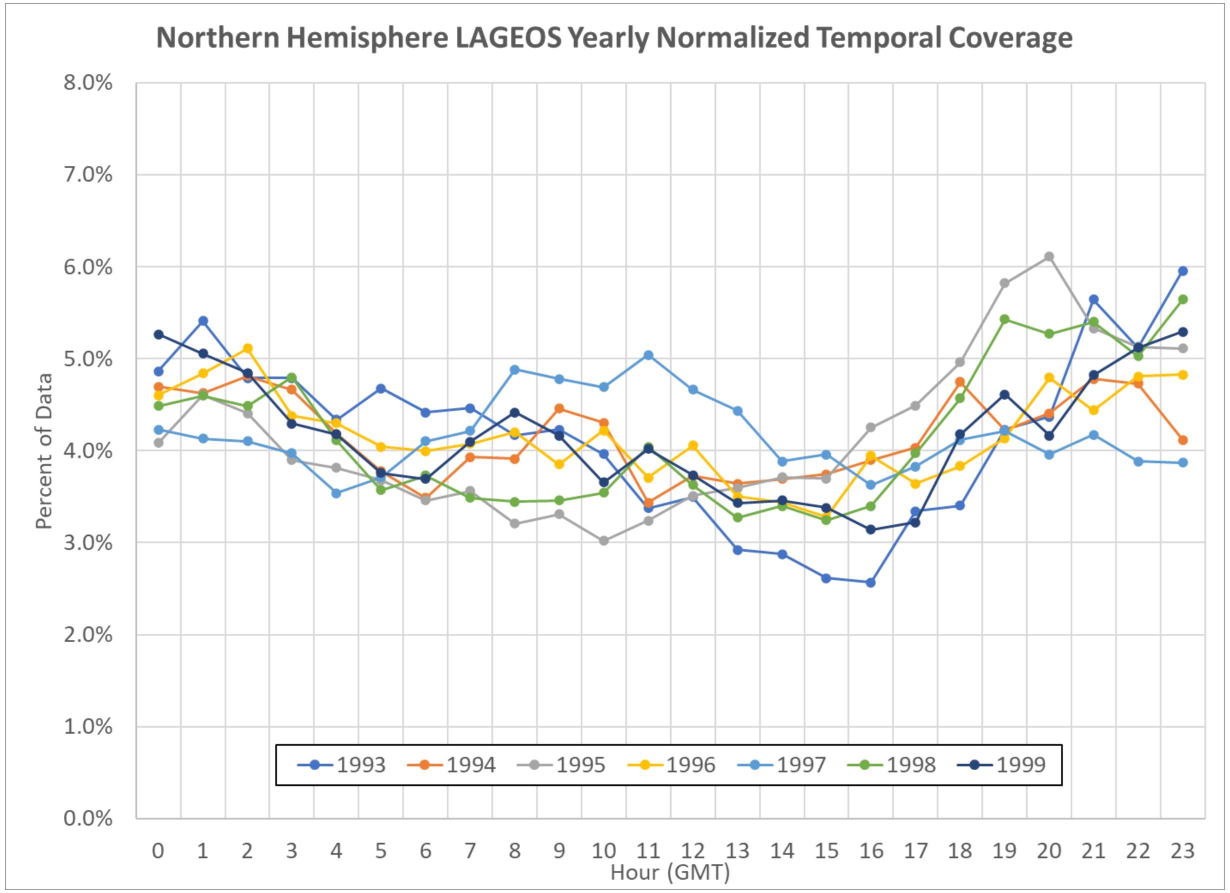
# LAGEOS (-1, -2) Yearly Pass Totals by Hemisphere

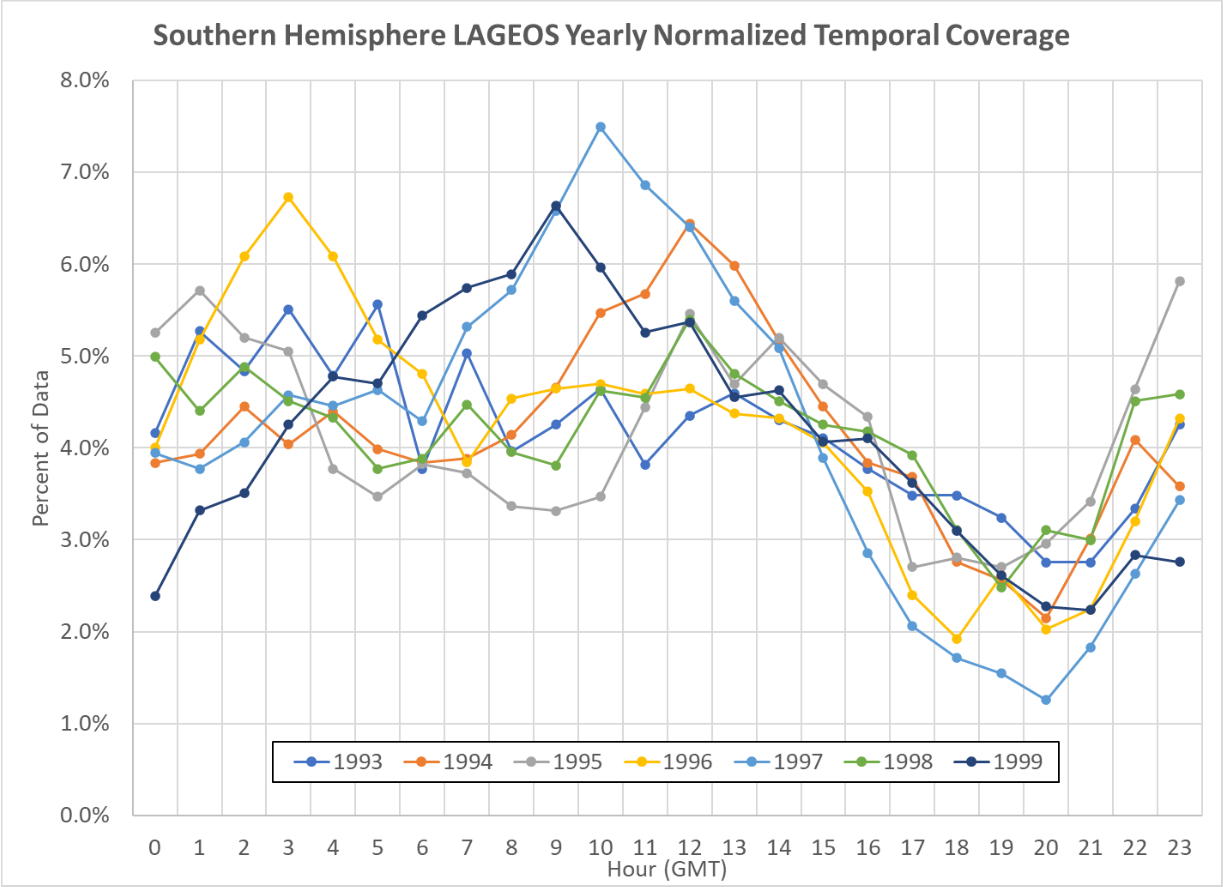



- ❑ Stacked areas charts of yearly LAGEOS pass totals from the Core Sites (Northern and Southern hemispheres)
- ❑ There is 2 to 3x more LAGEOS data from the Northern Core Sites than the Southern Core Sites

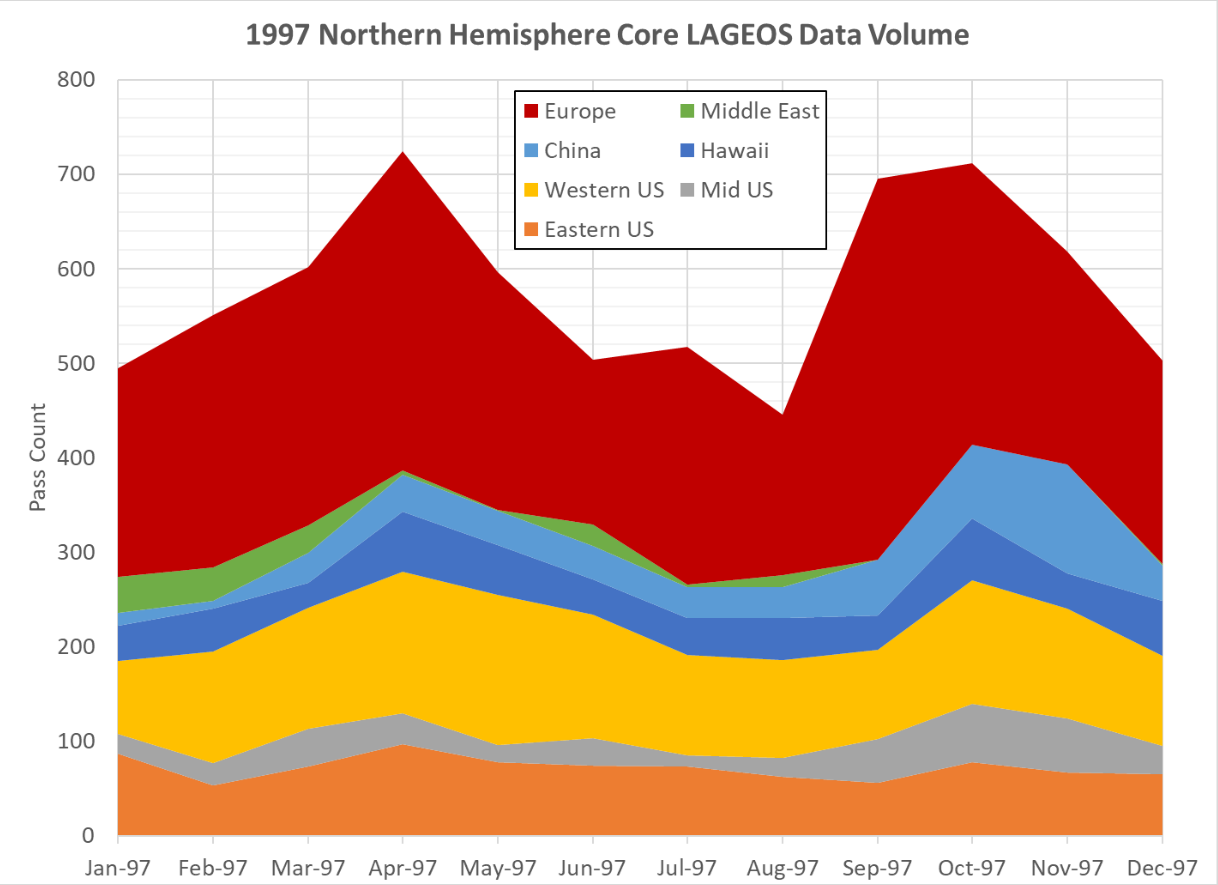
# LAGEOS Yearly Normalized Core Site Temporal Coverage

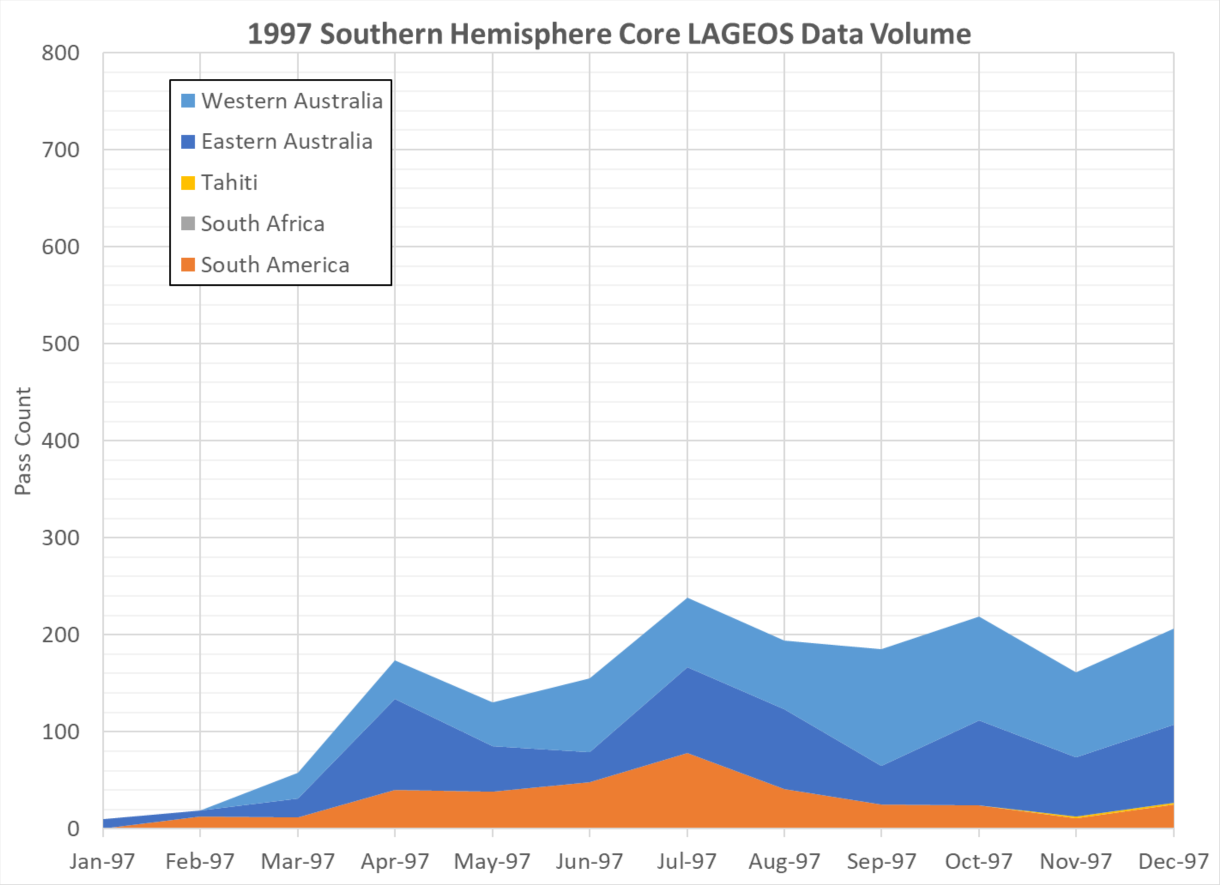



- **The southern hemisphere has more temporal variations than the northern hemisphere in the years 1993-1999**
- **The year 1997 (the light blue series on the right chart) had the most temporal variation in the southern hemisphere. 1997 is the year where the discontinuity appeared in the SLR Scale**

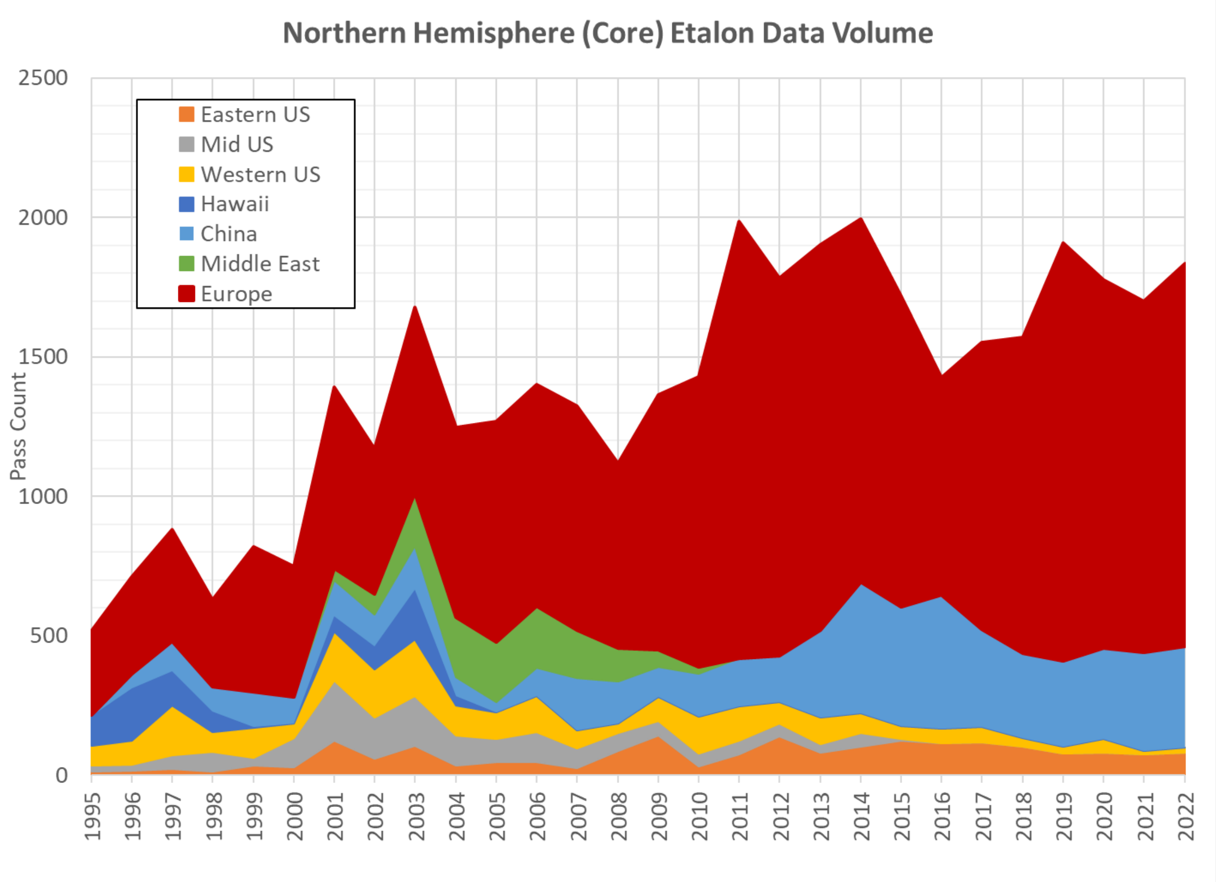
# LAGEOS (-1, -2) 1997 Monthly Pass Totals by Hemisphere

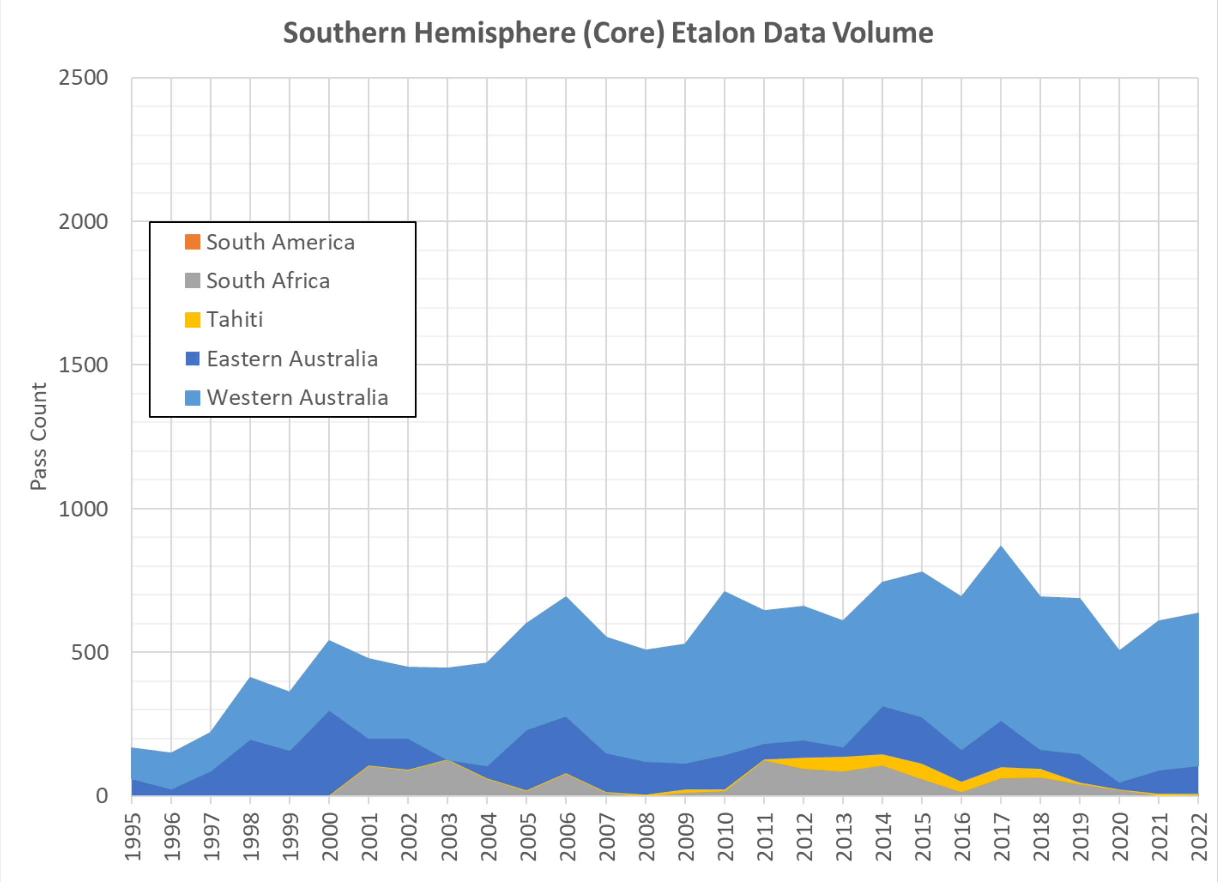



- **Stacked areas charts of LAGEOS1997 Monthly pass totals from the Core Sites (Northern and Southern hemispheres)**
- **Only data from 3 southern hemisphere sites in 1997 and two were Australian (7834 ORRL and 7090 YARL) Southern hemisphere LAGEOS data peaked in July 1997, which coincides with the change in SLR scale**

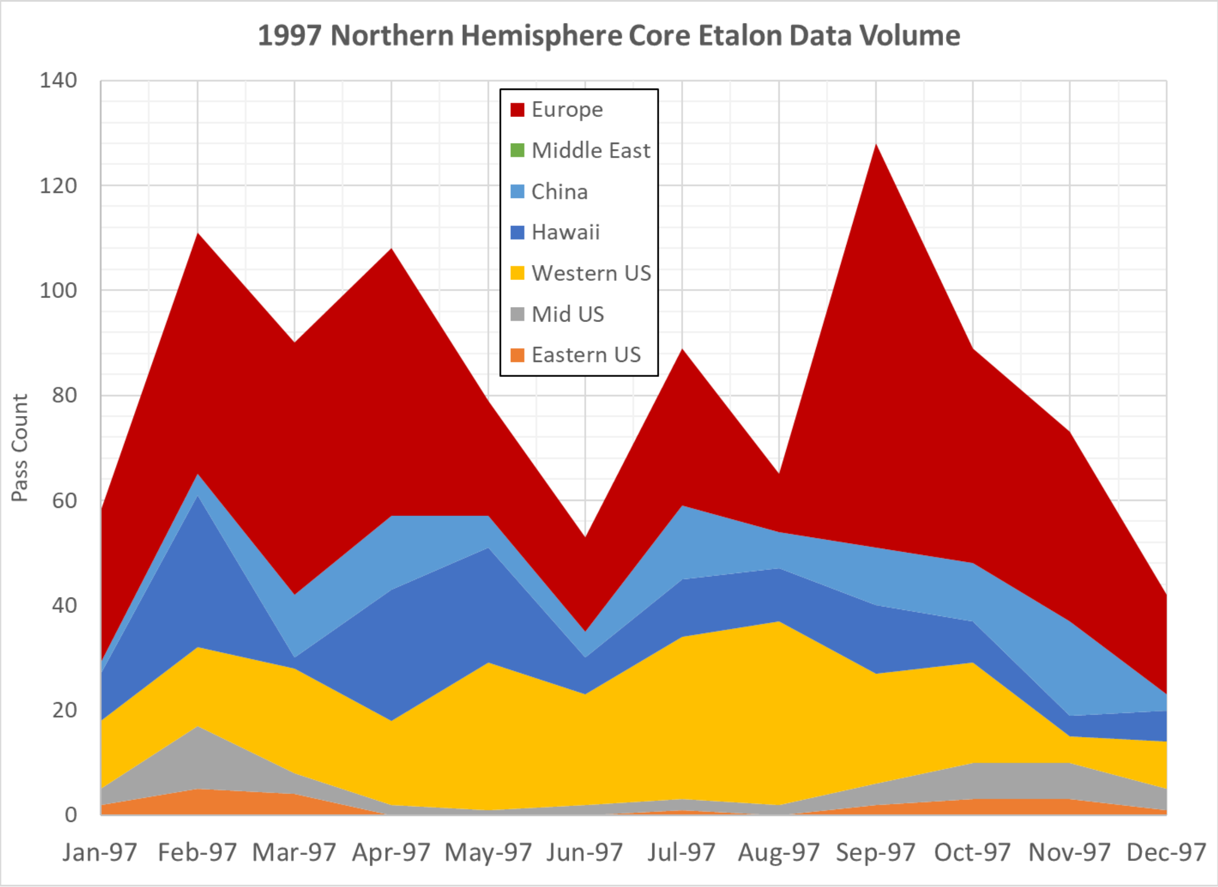
# Etalon (-1, -2) Yearly Pass Totals by Hemisphere

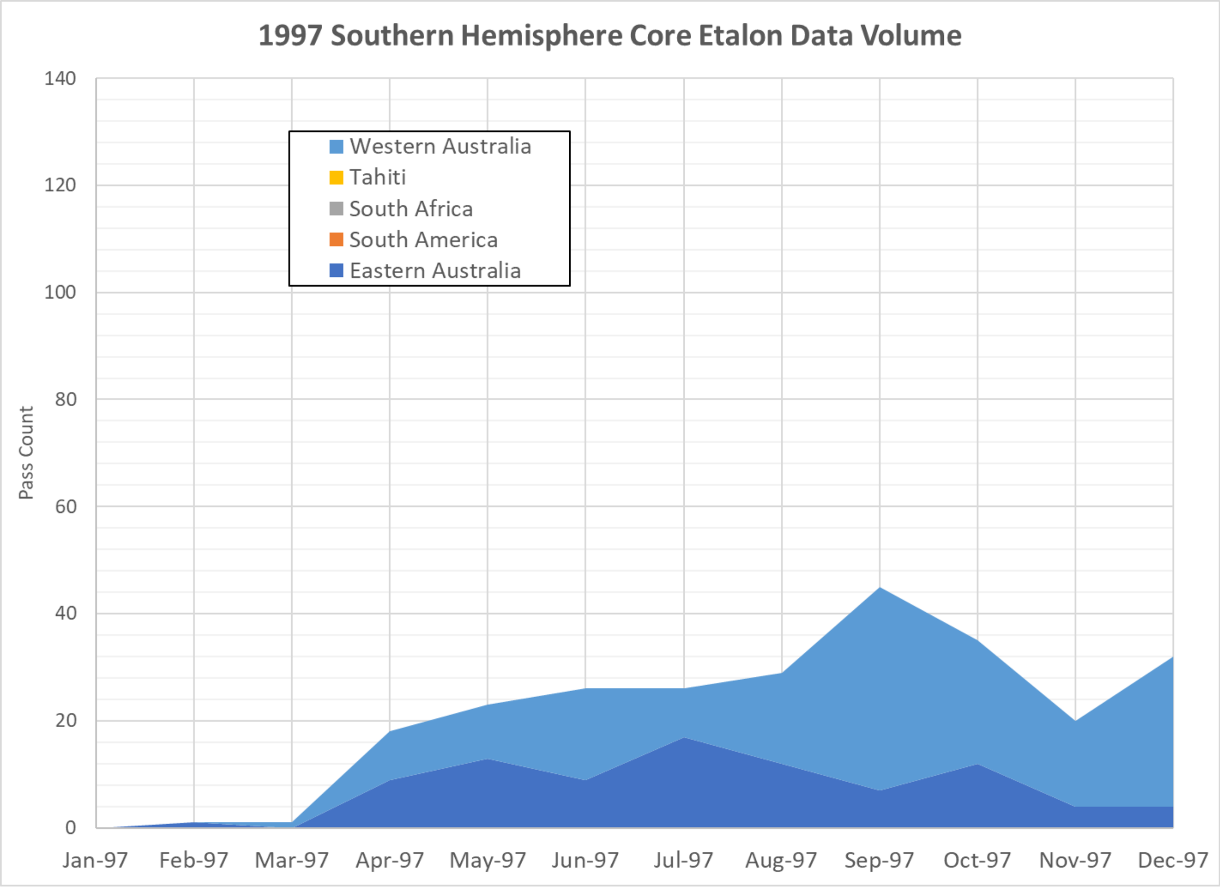



- **Stacked areas charts of yearly Etalon pass totals from the Core Sites (Northern and Southern hemispheres)**
- **There is 2 to 4x more Etalon data from the Northern Core Sites than the Southern Core Sites**

# Etalon (-1, -2) 1997 Monthly Pass Totals by Hemisphere




- ❑ **Stacked areas charts of Etalon1997 Monthly pass totals from the Core Sites (Northern and Southern hemispheres)**
- ❑ **Only data from 2 southern hemisphere sites in 1997 and both were Australian (7834 ORRL and 7090 YARL)**

# Systematic Errors

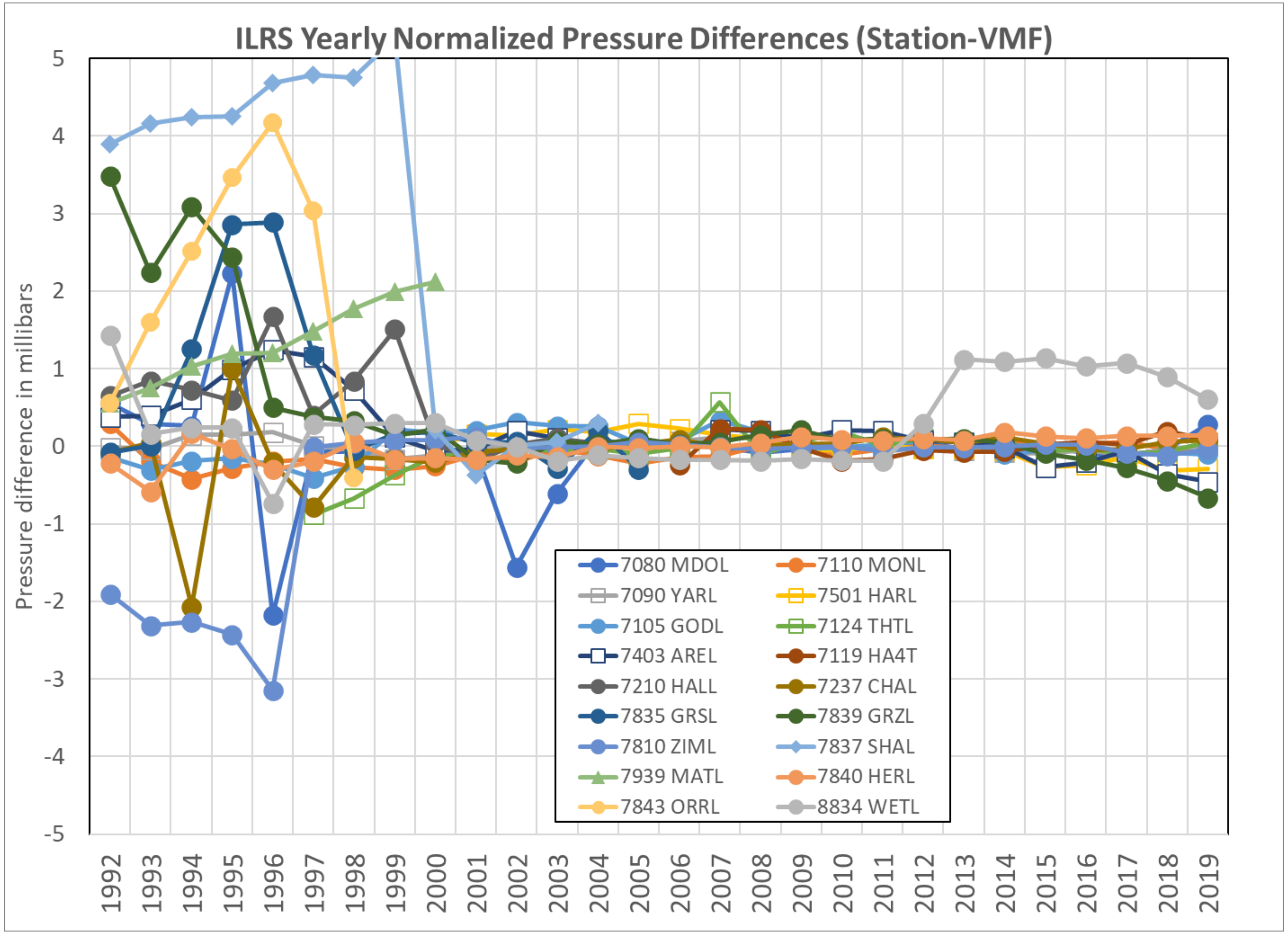
# Core Sites in 1997 and their System Components and Changes

| Location | Barometer | GPS Steered | Detector | Timer | System Changes in 1997 |
|---|---|---|---|---|---|
| McDonald, TX USA | Setra | No | MCP | TD811 + UT Timer | 27-Aug-97: Crystal Oscillator replaces Cesium |
| Monument Peak, CA, USA | MET3 | No | MCP | HP5370B | |
| Yarragadee, Australia | MET3 | No | MCP | HP5370B | Jan-Feb 1997: Controller Computer Upgrade, no data |
| Greenbelt, MD USA | MET3 | No | MCP | HP5370B | |
| Quincy, CA USA | MET3 | No | MCP | HP5370B | 10-May-1997: last pass |
| Arequipa, Peru | Setra | No | MCP | HP5370B | |
| Haleakala, Hawaii | unknown | No | MCP | HP5370B | |
| Graz, Austria | MET3 | Yes | CSPAD | HP5370B & multi SR620 | 1997: Many counter, time and frequency changes |
| Changchun, China | unknown | unknown | PMT | HP5370B | Jan-Feb 1997: No data;<br>18-Aug-1997: C-SPAD replaces PMT, new MET, new time and frequency device, new survey |
| Shanghai, China | China | unknown | SPAD | HP5370B | 01-Oct-1997: installed crystal oscillator |
| Grasse, France | unknown | unknown | PMT | SR620 | 04-Sep-1997: CSPAD installed, CoM changed by 3.3mm |
| Herstmonceux, United Kingdom | Nimbus | Yes | SPAD | SR620 | 17-Apr-1997: new cal target<br>04-Jun-1997 new MET<br>22-Oct-1997: swapped SPADs |
| Zimmerwald, Switzerland | Digiquartz | Yes | PMT | SR620 | 01-Jan-1997: Laser change 532 to 423, 1.8 mm CoM change, new MET<br>Jan-Jun 1997: only 9 LAGEOS passes<br>01-Jul-1997: Crystal oscillator installed<br>21-Dec-1997: changed to internal calibration; 2 detectors (PMT and SPAD) in use<br>Note: No ITRF2020 residuals in 1997 |
| Wettzell, Germany | Digiquartz | unknown | MCP & SPAD | unknown | |
| Orroral Valley, Australia | Weathertronics | Yes | PMT, APD, SPAD | Event Timer | 02-Mar-1997: has 3 different detectors (PMT, APD and SPAD1)<br>15-Apr-1997: new APD installed |
| Riyadh, Saudi Arabia | Weathertronics | Yes | CSPAD | EOS Event Timer | |
| Potsdam, Germany | Druck | Yes | PMT | SR620 | |

| Legend |
|---|
| * |
| ** |
| *** |
| **** |
| ***** |

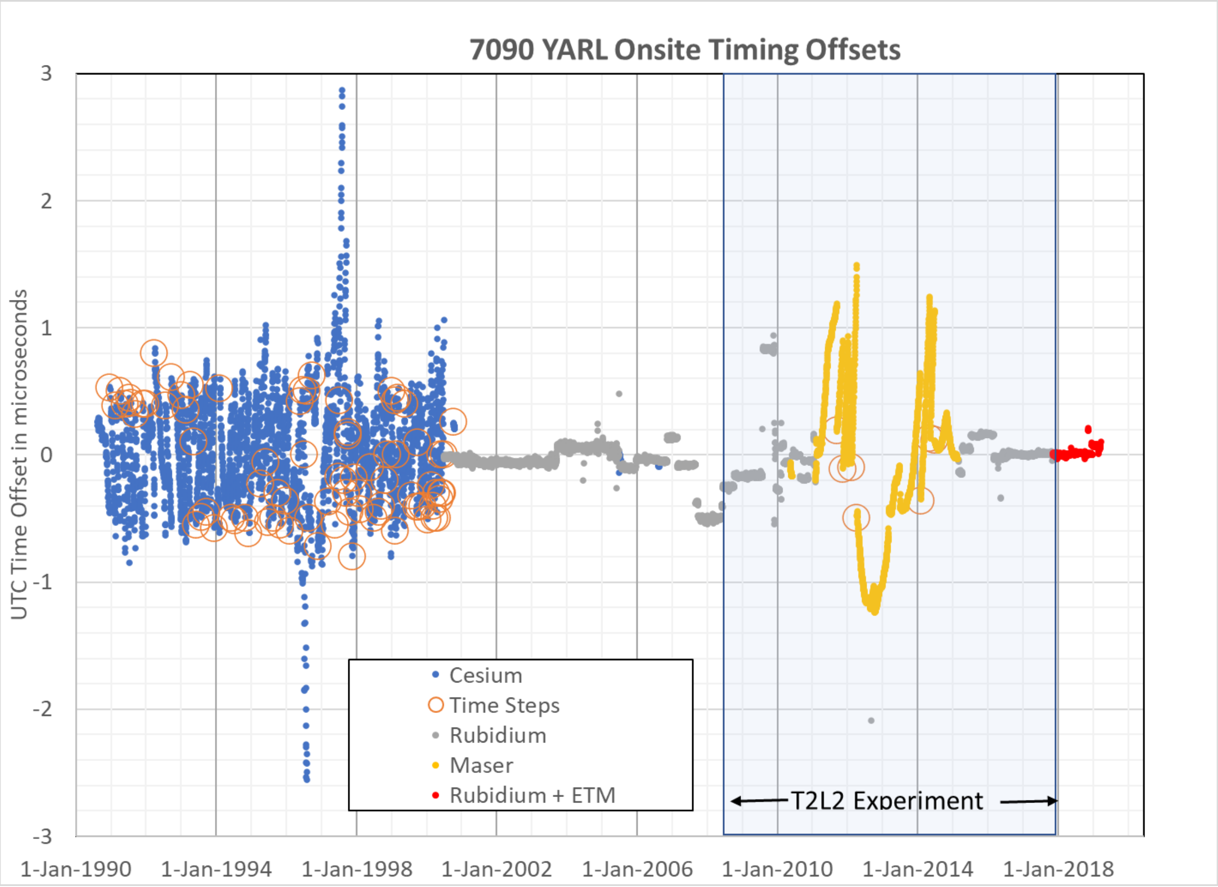
- **Listed here are key hardware components of the core sites in 1997 than can induce systematic errors (Tropospheric, Epoch, Signal Strength, Timer Non-linearities)**
- **Legend: The lighter the shade of green, the increased potential for systematics**

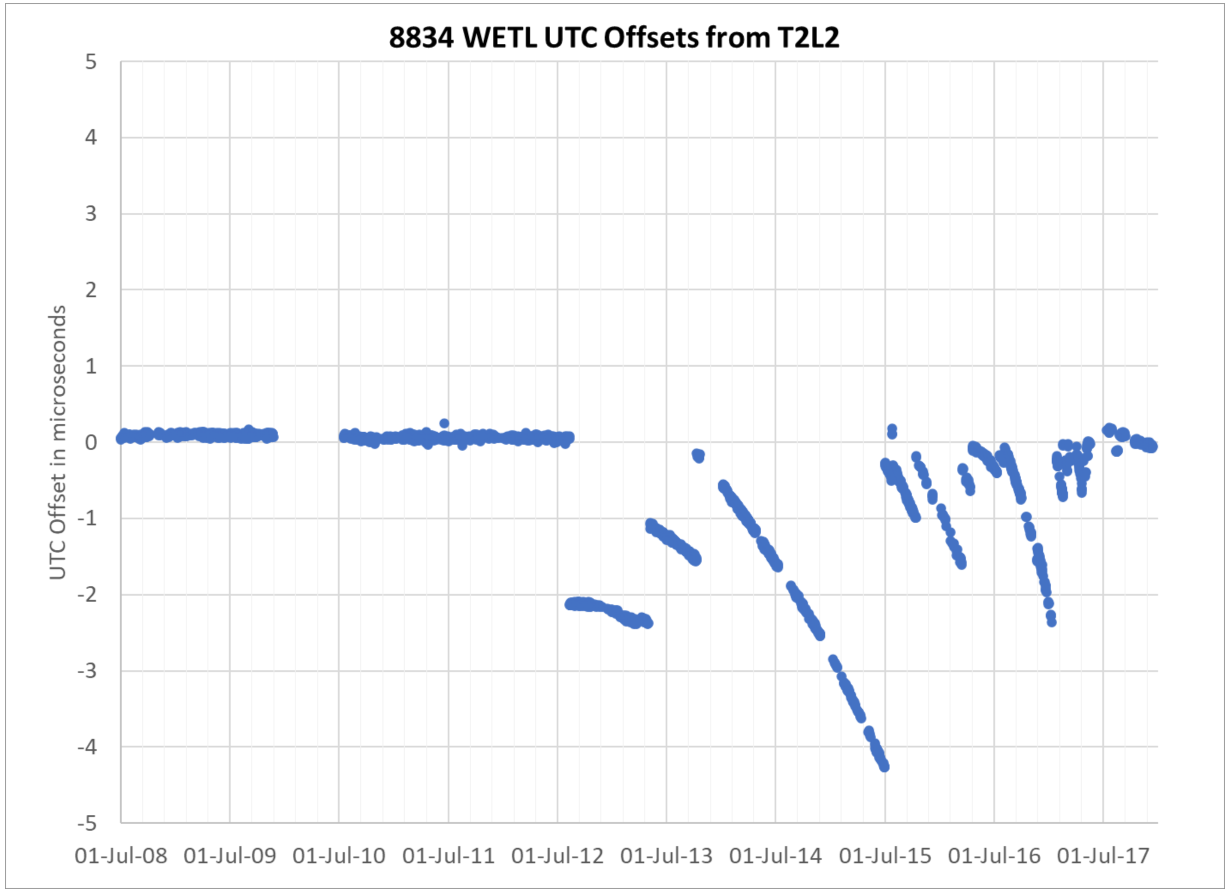
# Tropospheric Biases in SLR Core Sites




- 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

# Epoch Errors

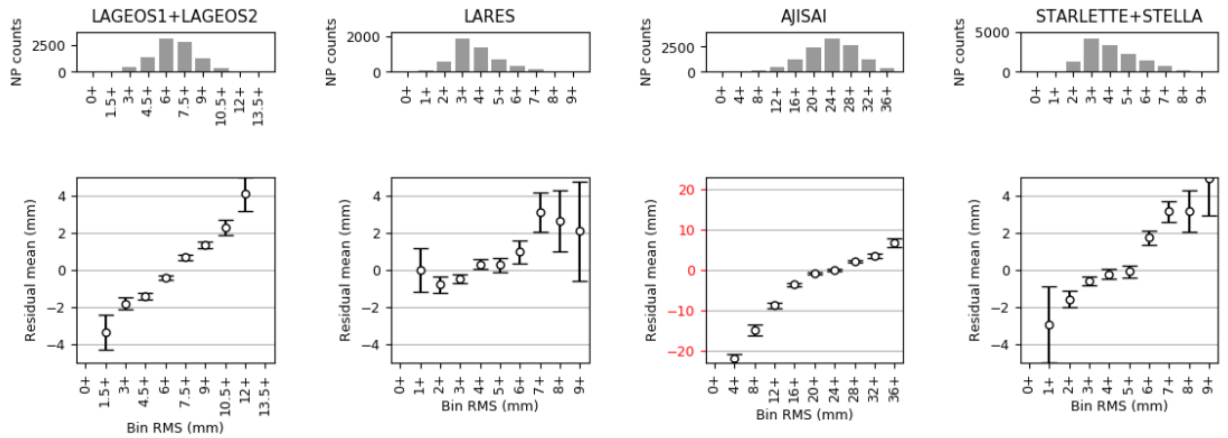


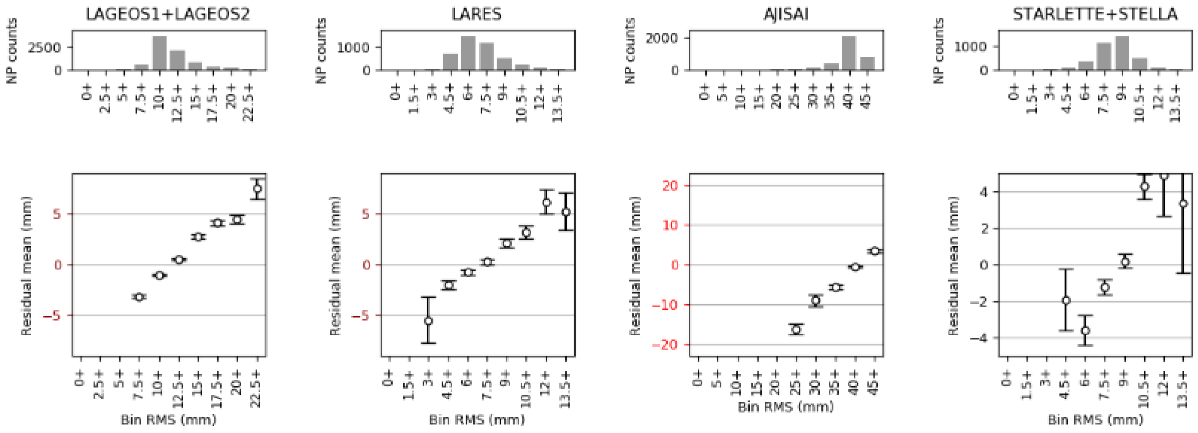

- **7090 and 8834 epoch errors are based on onsite timing data and Time Transfer by Laser Link (T2L2) data (Exertier et al., 2017; https://doi.org/10.1016/j.asr.2017.05.016 ); respectively**
- **Some frequency devices were/are synched to GPS and some were/are not**
- **7090 epoch were distributed around 0, but not 8834. Are the accuracy of epochs known before and after T2L2?**

# Detector Systematics

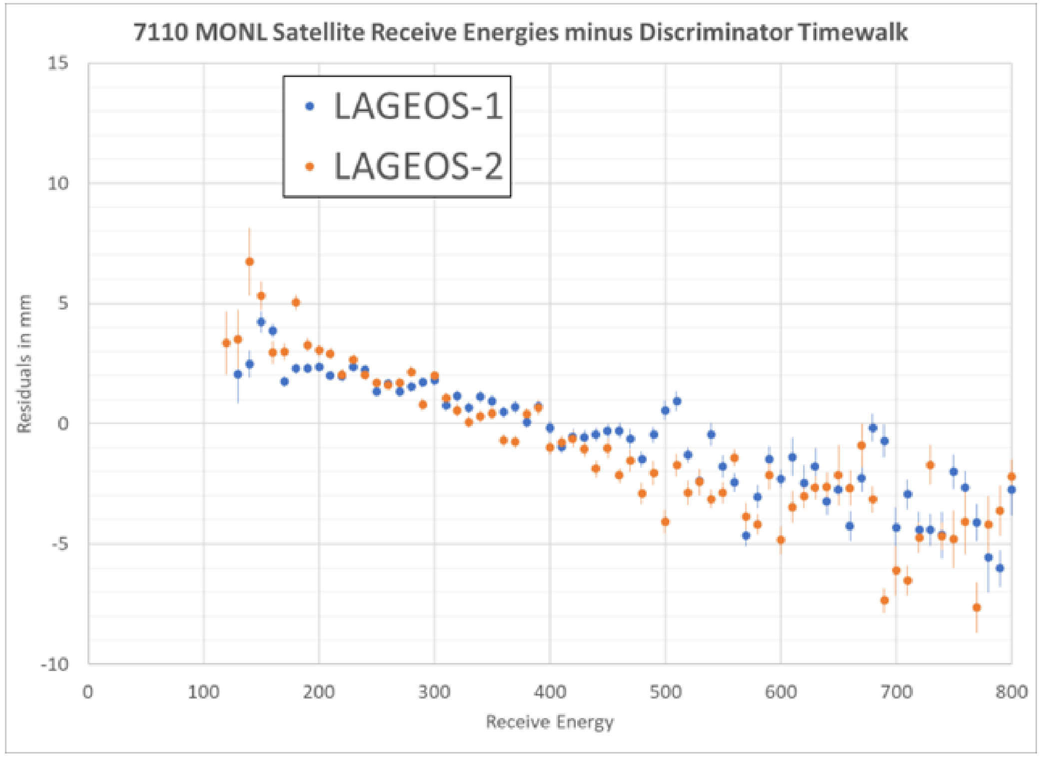
7825: wrt Single-Shot RMS **Mt. Stromlo: C-SPAD**




7840: wrt Single-Shot RMS **Herstmonceux: SPAD**

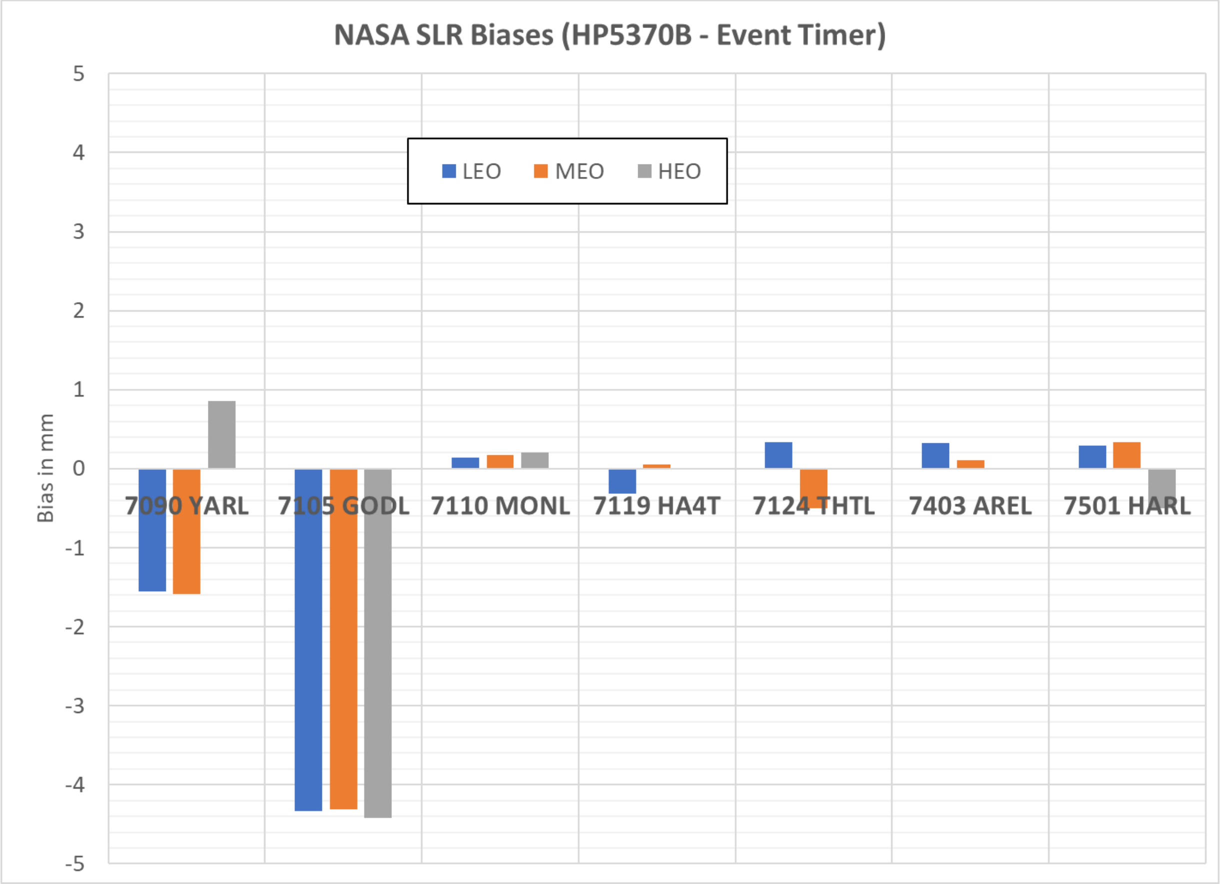


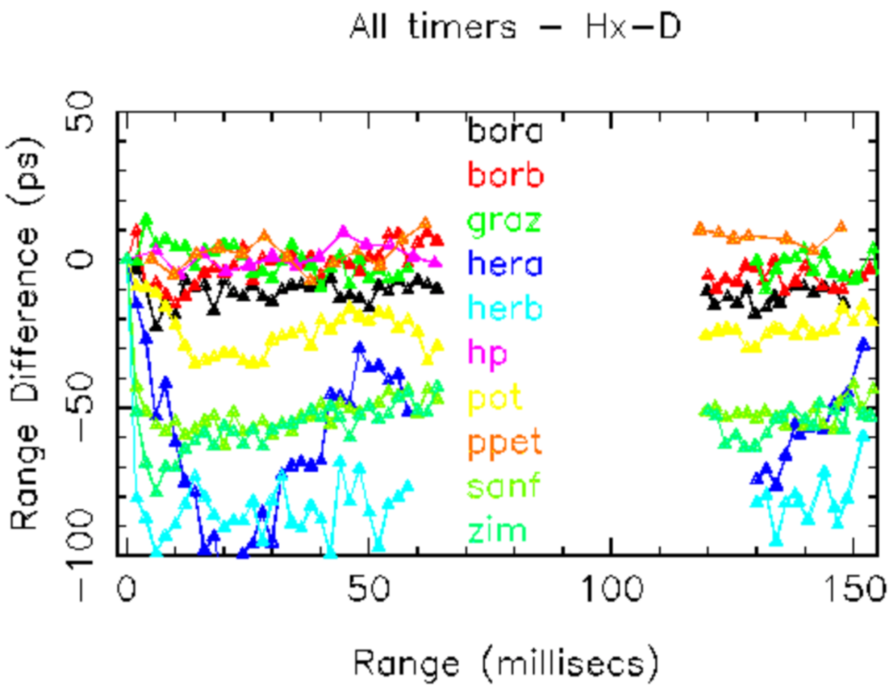

**Monument Peak: MCP-PMT**




- **SPAD (Otsubo, 2018) and MCP-PMT detector systematics on the left and right; respectively**

# Timer Systematics




- **HP5370B (Varghese et al., 2019) and SR620 (Gibbs et al., 2002) Time Interval Unit (TIU) range biases on the left and right; respectively**

# Conclusions

- **Items one and two below have had the most significant impact on ITRF2020 SLR Scale results**
  1. Changes in the SLR satellite constellation
  2. Spatial and temporal tracking outages from the ILRS Core sites
  3. Unmodelled systematic errors (e.g. tropospheric, epoch, amplitude variations, counter non-linearities) in the Core sites

# LAGEOS-2 minus LAGEOS-1 SSEM Range Bias Differences

Van Husson

ILRS Quality Control Board (QCB)

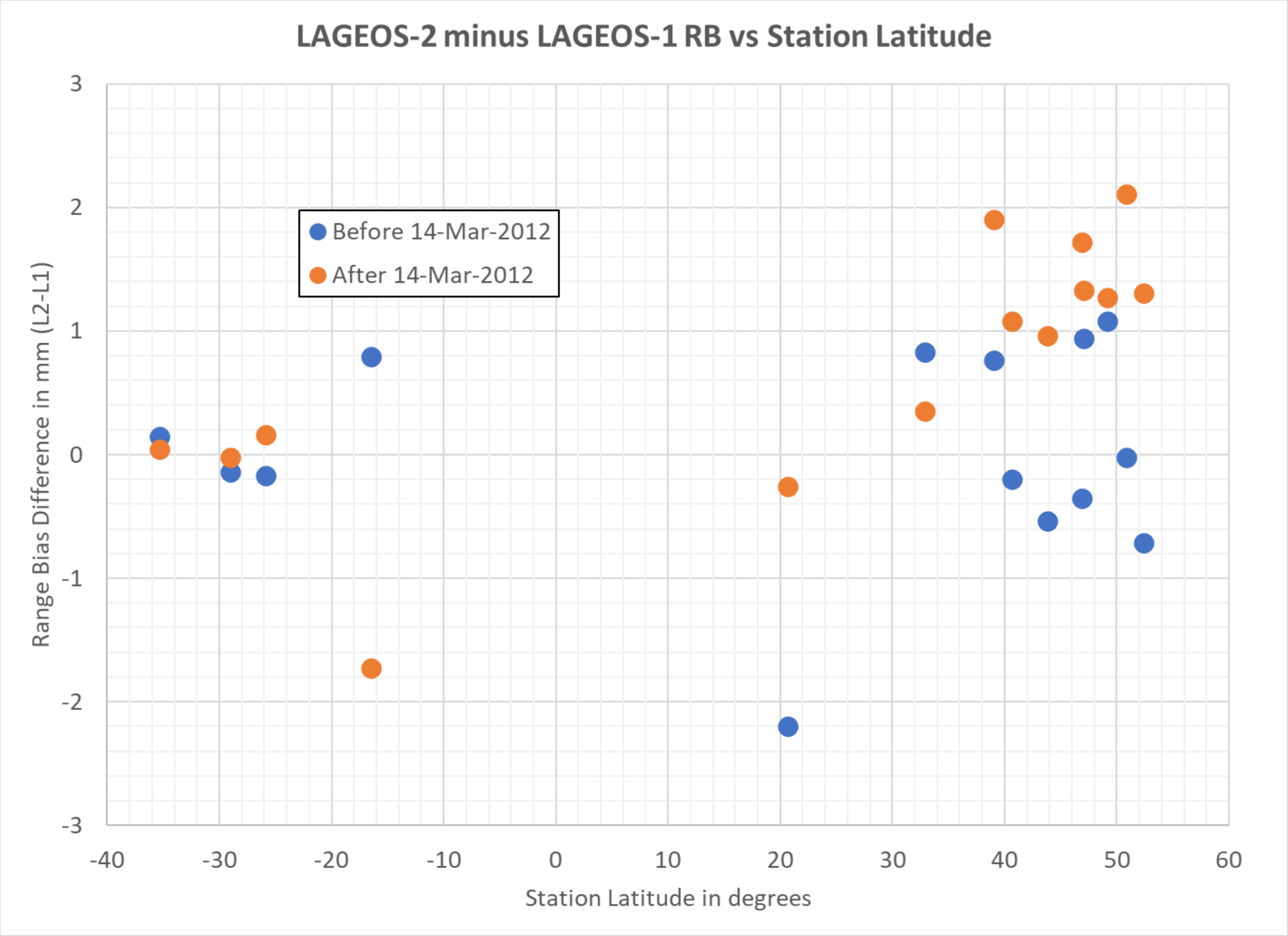
18-January-2023

Peraton

# Introduction

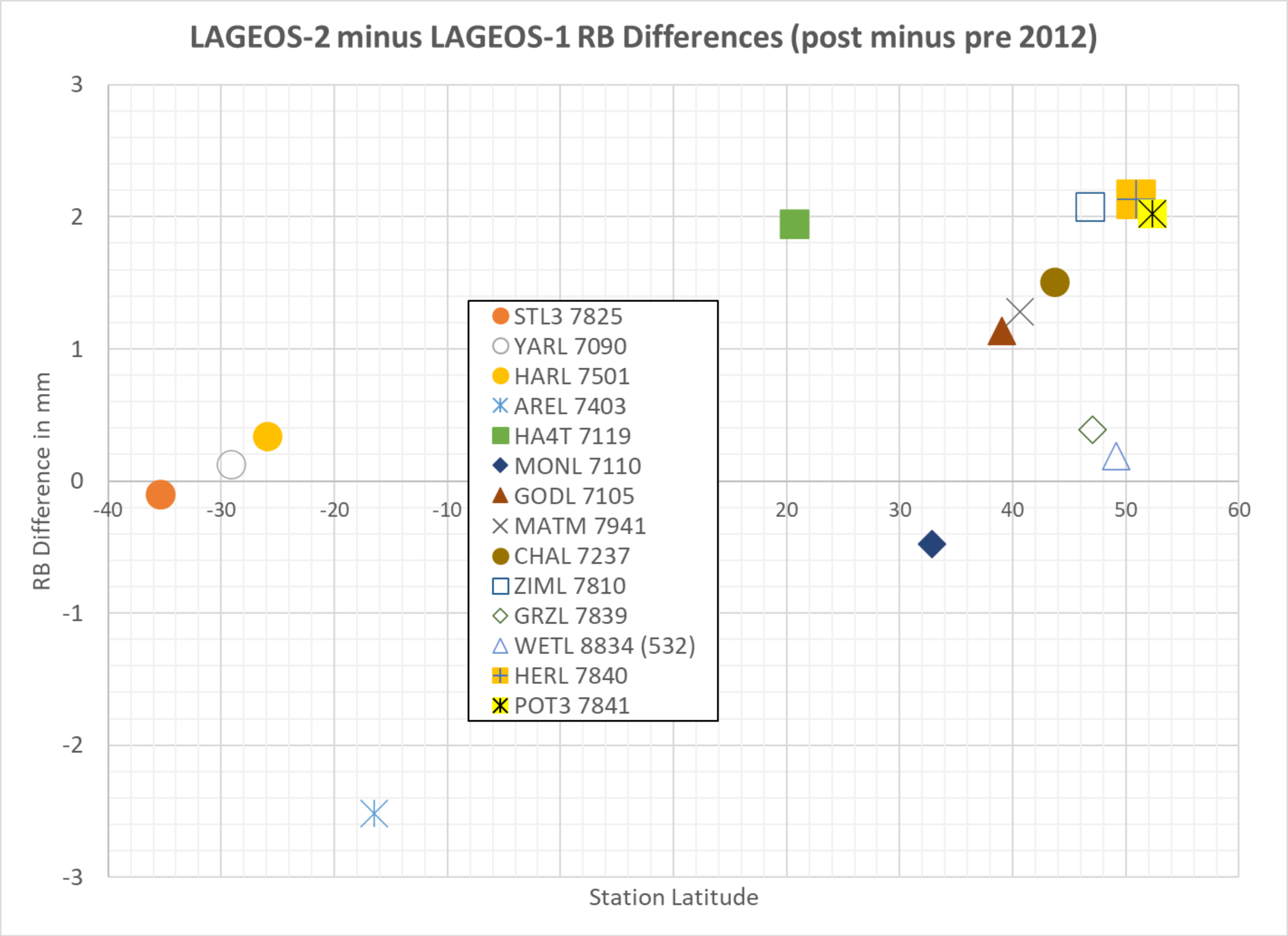
- At the May 2020 QCB meeting, Peter showed that the residual patterns and the higher moments are different between LAGEOS-1 and -2
- At the 22nd ILRW in Guadalajara, David Lucchesi presented "Thermal Thrust Perturbations, Spin evolution and the long-term behavior of LAGEOS II Semi-Major axis" in which he stated the LAGEOS-2 semi-major axes changed on March 14, 2012
- In the best performing ILRS stations, LAGEOS-2 range bias estimates were more positive than LAGEOS-1 (Rodriguez et. al., 2018)
- Based on updated CoM Tables [Rodriguez, 2019], the mean CoM difference between LAGEOS-1 and -2 is 0.7 mm for all ILRS stations. LAGEOS-1 always has a larger correction (i.e. more biased toward the leading edge)
- Our NASA MOBLAS stations have observed that LAGEOS-2 signal strengths have gotten weaker relative to LAGEOS-1 for the past several years. However; for several years post LAGEOS-2 launch, LAGEOS-2 returns were stronger than LAGEOS-1

# LAGEOS-2 minus -1 SSEM Range Biases (RB)




- With the current LAGEOS CoM corrections, L2 minus L1 SSEM RB differences prior to March 2012 were mixed (some positive and some negative)
- Post March 2012 the L2 minus L1 SSEM RB differences after gotten more positive for the northern hemisphere stations except one

# LAGEOS-2 minus -1 SSEM Range Biases (RB) (con't)




- **Here are the difference in L2 minus L1 (post-March 2012 minus pre-March 2012)**
- **For 11 out of 14 stations, the differences got more positive**
- **Notes:**
  - GRZL 7839 implemented 20 mm Leading Edge (LE) rejection criteria on 5-Feb-2008
  - Are the results from the two sites closest to the equator (AREL and HA4T) outliers?
  - WETL 8834 changed lasers (532 to 1064 nm) and detectors on 6-Jun-2019. This data was not included in the analysis. Based on very limited dataset (i.e. 1 year), the L2 – L1 SSEM RB difference post laser change was +3.2 mm.

# Discussion

- The change in the LAGEOS-2 semi major axes appears to have caused some systematic mm level range bias differences between LAGEOS-1 and -2. Are these range bias changes in the orbital analysis, the stations or a combination?
- Why have the LAGEOS-2 signal strengths gotten weaker over time relative to LAGEOS-1? Would weaker LAGEOS-2 returns influence the LAGEOS-2 minus LAGEOS-1 range bias differences?

# Riga 1884 Status

E. C. Pavlis & M. Kuzmicz-Cieslak

GESTAR II/UMBC

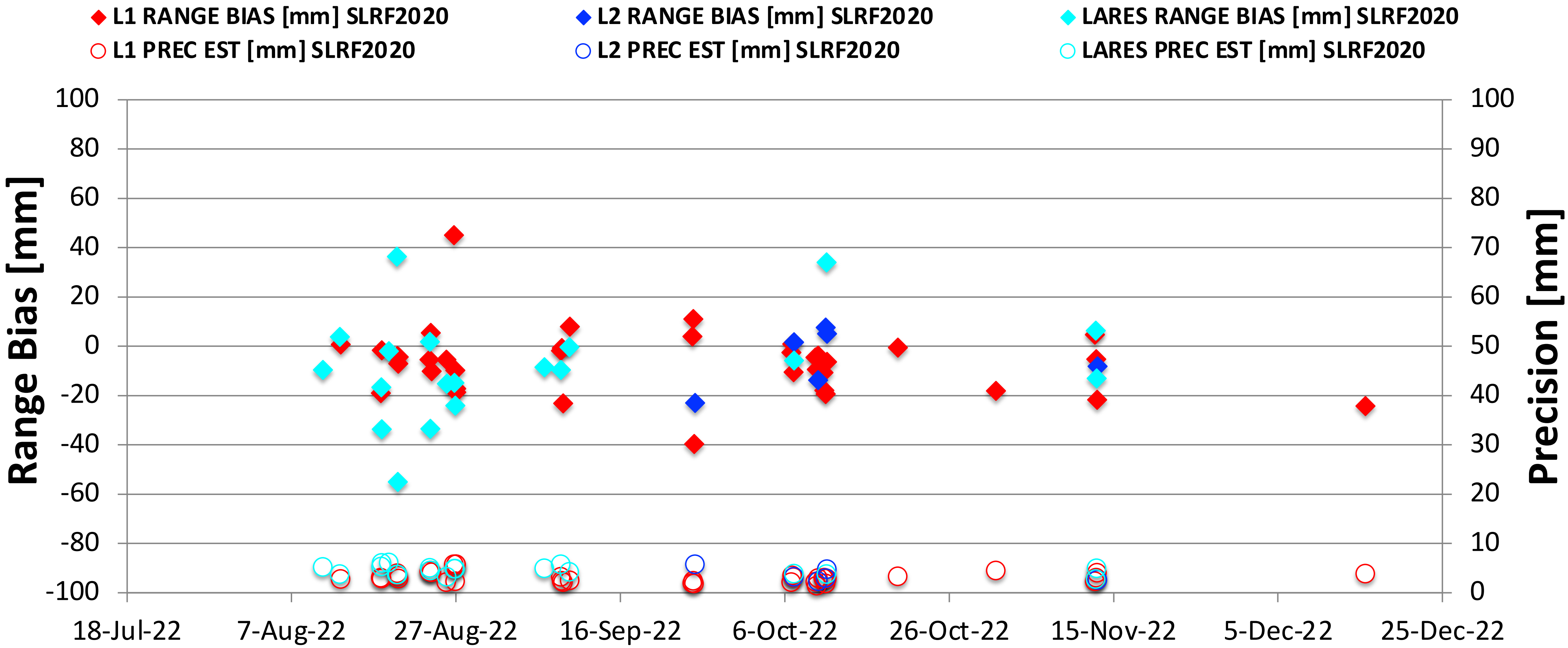
January 5, 2023

# LAGEOS 1 LARES LAGEOS 2

| L1 18844401SLRF2020 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 3.1 | -6.6 |
| STD | 1.1 | 13.6 |
| RMS | 3.3 | 14.9 |
| Passes | 37 | 37 |

| LR 18844401SLRF2020 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 4.5 | -8.4 |
| STD | 1.0 | 21.4 |
| RMS | 4.6 | 22.5 |
| Passes | 19 | 19 |

| L2 18844401SLRF2020 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 3.6 | -5.2 |
| STD | 1.3 | 11.9 |
| RMS | 3.8 | 12.1 |
| Passes | 6 | 6 |



# SOS Wettzell 7827 Evaluation

E. C. Pavlis & M. Kuzmizc-Cieslak
GESTAR II/UMBC

January 12, 2023

# LAGEOS 1 LARES LAGEOS 2

| L1 78272201 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 2.1 | 11.9 |
| STD | 1.5 | 13.4 |
| RMS | 2.6 | 17.9 |
| Passes | 131 | 131 |

| LR 78272201 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 2.8 | 14.6 |
| STD | 1.6 | 26.7 |
| RMS | 3.2 | 30.3 |
| Passes | 94 | 94 |

| L2 78272201 | PREC EST [mm] | RANGE BIAS [mm] |
|---|---|---|
| Mean | 1.9 | 7.8 |
| STD | 1.5 | 13.4 |
| RMS | 2.4 | 15.5 |
| Passes | 78 | 78 |