Alternative to ILRS method

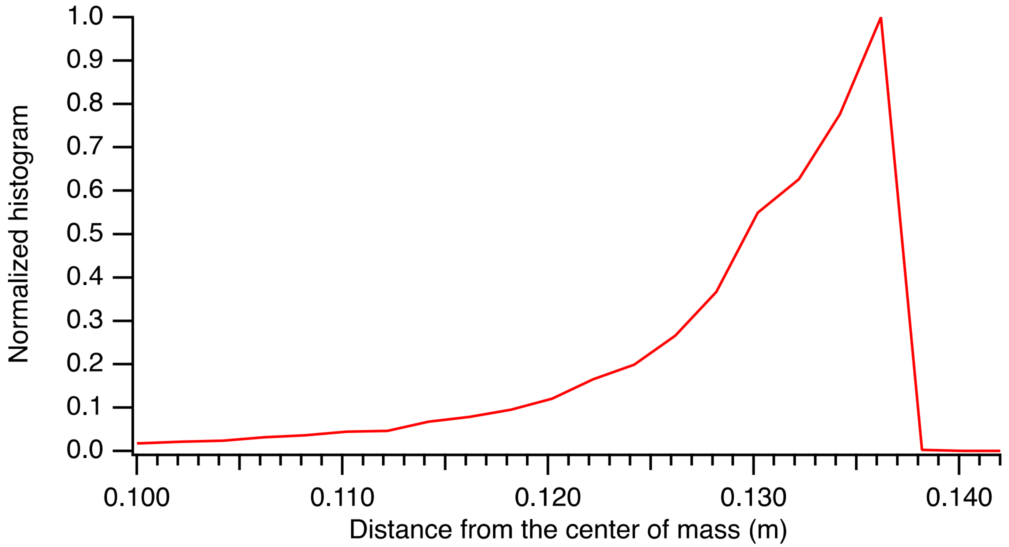
The ILRS method was invented to deal with satellites where there are known thermal gradients or the dihedral angle offsets have not been specified and controlled. In many cases the beam spread of the cube corners is specified as not to exceed a particular divergence. A beam divergence can be converted to an equivalent dihedral angle offset. A thermal gradient has an effect similar to a dihedral angle offset. It can put a curvature on the exiting wavefront.

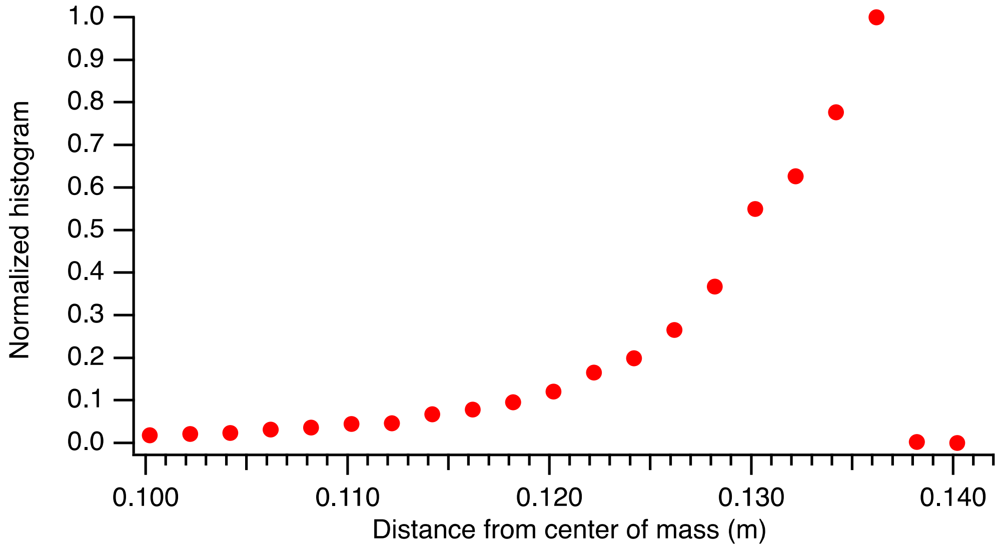
Instead of modeling the signal from a cube corner as a power of the active reflection area, a better approach might be to model the signal with a dihedral angle offset equivalent to the beam divergence due to a thermal gradient and/or unmeasured dihedral angle offsets. This would make it possible to use program TRANSF to calculate the far field cross section and centroid matrices which include the effects of diffraction. The dihedral angle offset could be modified to give the best fit to the experimental data.

I computed the histogram of the Lares-1 satellite in the report "Transfer Function of the LARES Retroreflector Array", February 2015. The presentation “Histograms” gives the histogram of the Lageos satellites. These could be tested to see how they compare with the ILRS method.

The following slide shows the histogram of LARES-1

Lares-1 histogram





The bins have been shifted to coincide with the earliest reflection point at .13719 m. CoM = .1288 m.

Millimeter accuracy SLR bias determination using independent multi-LEO DORIS and GPS-based precise orbits

Eléonore Saquet[1,2], Alexandre Couhert[2,3], Heike Peter[4], Daniel Arnold[5], Flavien Mercier[2,3]

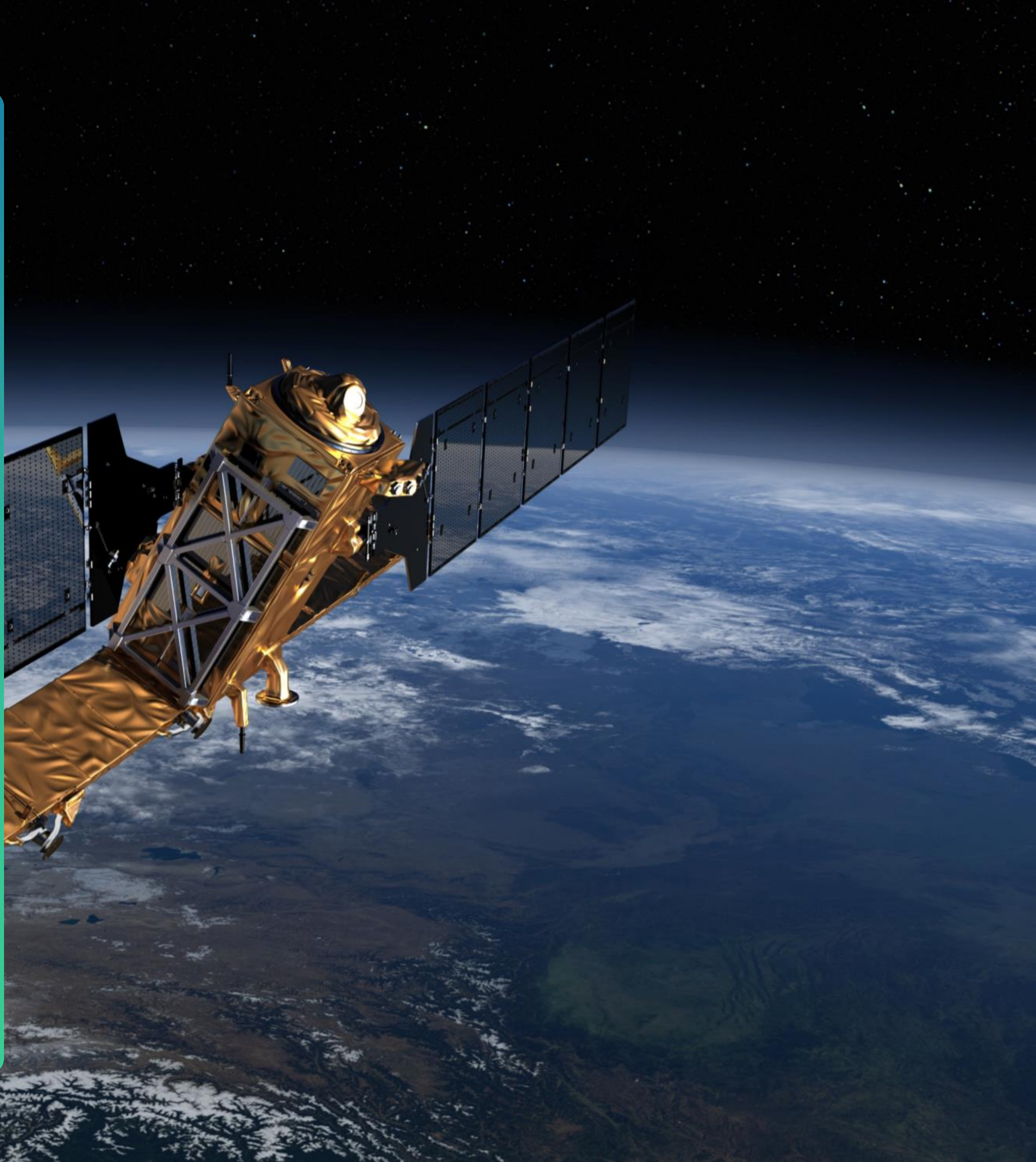
[1] Collecte Localisation Satellites, Toulouse, France

[2] Centre National d'Etudes Spatiales, Toulouse, France

[3] GET-Université de Toulouse (CNES, CNRS, IRD, UPS), Toulouse, France

[4] PosiTim UG, Seeheim-Jugenheim, Germany

[5] Astronomical Institute University of Bern, Switzerland



SLR for satellite altimetry missions

- SLR data is needed to :
  - provide strong tracking information to potentially complement GNSS or DORIS,
  - provide a state-of-the-art independent validation of the orbit accuracy, especially in the radial direction.
- Demanding climate-driven needs: Improve our knowledge of SLR stations corresponding accuracy and eventually reduce systematic errors.

SLR validations of the orbit would need 1 mm RMS short-term accuracy, with long-term stability within 0.1 mm/y decade to monitor the evolution of local sea-level patterns of rise driven by anthropogenic forcing.

Current practice:

- Choose a reduced set of SLR observables from a handful of Core Network (CN) stations considered to have negligible biases,
- Regular Service Reviews (RSRs) by the Copernicus POD Service.

→ New approach to enlarge the SLR stations CN and provide unambiguous SLR range biases.

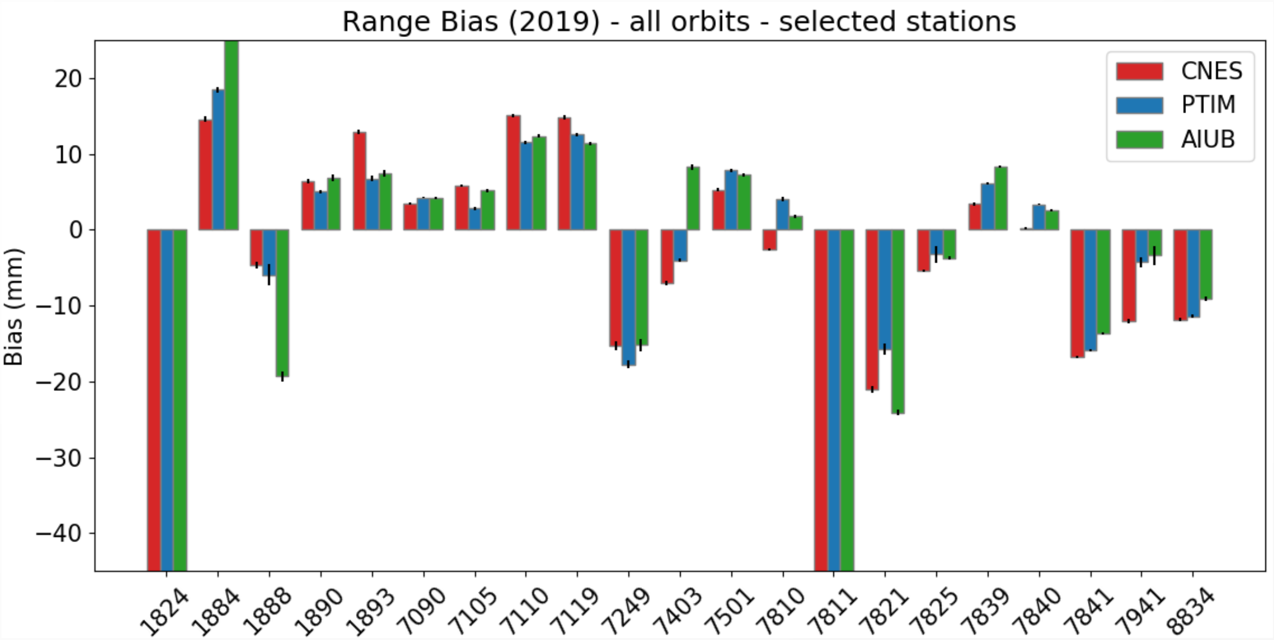
Data and processing methods

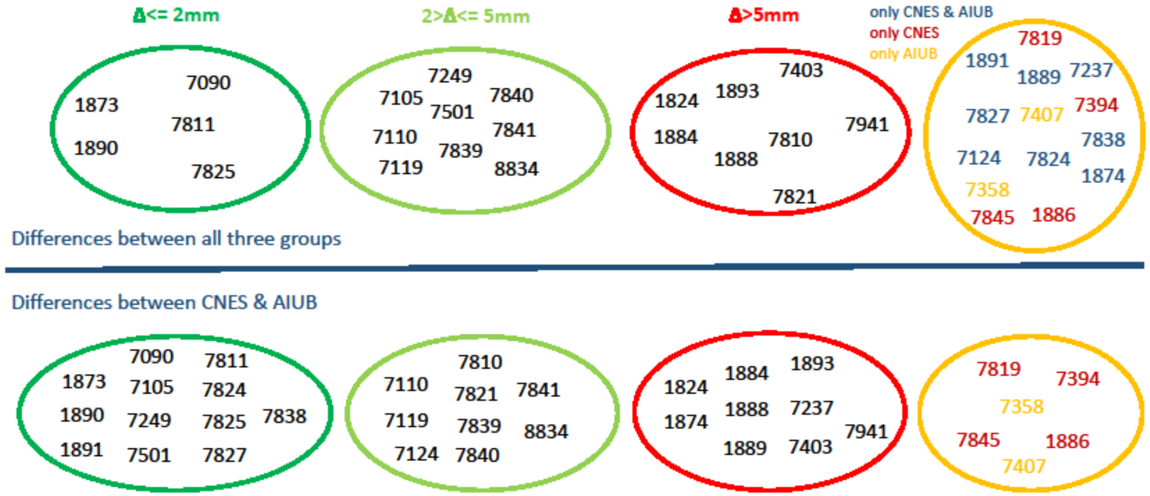
- Satellites involved:
  - Altimetry mission : Jason-2, CryoSat-2, Saral/AltiKa, Jason-3, Sentinel-3A/B
  - Magnetic field mission : Swarm-A/B/C
  - Gravity filed mission : GRACE Follow-On C/D

- 3 POD sofwares involved.
- Validation of SLR measurement corrections performed (models consistency, satellite CoM, LRA optical center locations/corrections,…).
- Determination of independent yearly SLR biases:
  - 1st approach: high elevation observations only (> 50°). RB only estimated,
  - 2nd approach: no elevation cut-off angle. RB + station coordinates estimated.

CLS
COLLECTE LOCALISATION SATELLITES

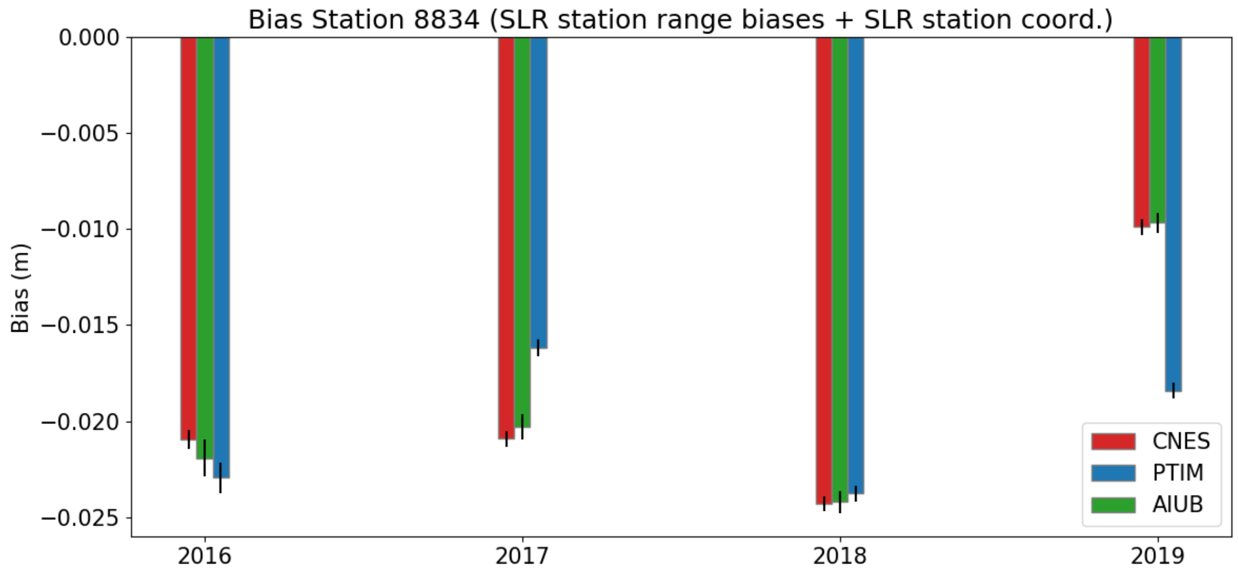
1st approach

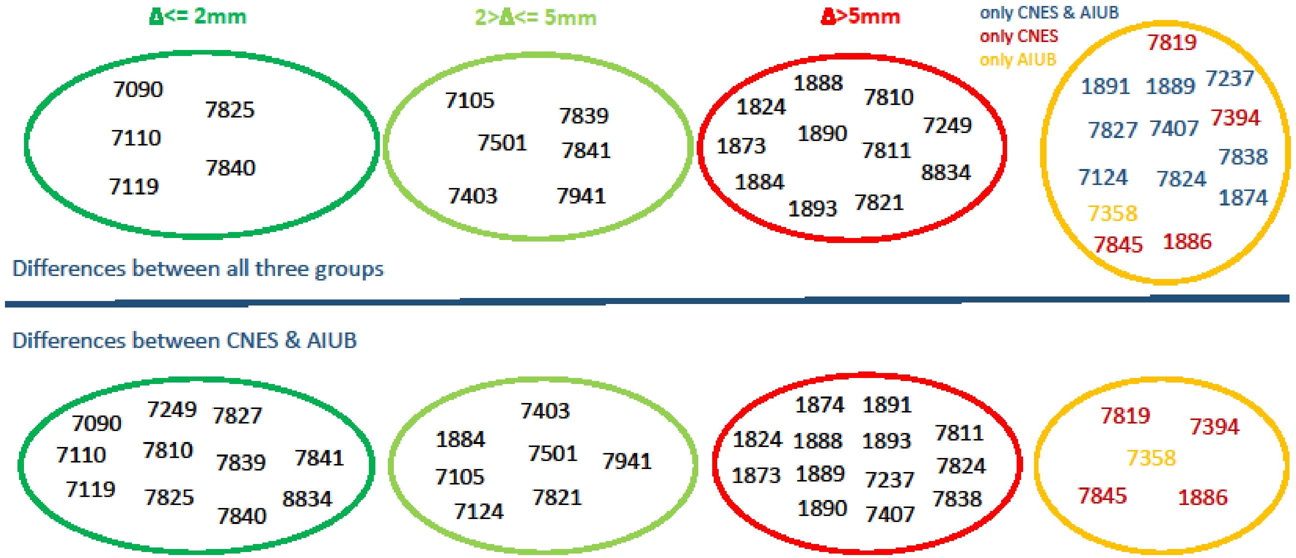




CNES and AIUB agree within 2 mm for 12 stations

2nd approach





CNES and AIUB agree within 2 mm for 11 stations

CLS COLLECTE LOCALISATION SATELLITES

Assessment of aliased orbit errors

RB estimates comparison:

- solving for range biases and station coordinates with no elevation cut-off angle,
- solving for range biases only with an elevation cut-off angle of 50 degrees, where station coordinates corrected with the outcomes of the previous configuration.

For most of the stations: The two types of range bias determinations do not differ by more than <u>2 mm</u>

Comparison of SLR station range biases (mm) obtained in two configurations of choice of elevation cut-off angle (with station coordinate modeling errors removed in the high-elevation approach) to assess aliased orbit errors. The red tags indicate the stations and years for which the estimated coordinates differ by more than 2 cm from the a priori SLRF2014 ones.

Station	2016		2017		2018		2019	
	$E > 10°$	$E > 50°$	$E > 10°$	$E > 50°$	$E > 10°$	$E > 50°$	$E > 10°$	$E > 50°$
1824	79.7	81.5	-31.4	5.2	-10.9	-5.0	21.8	25.2
1873	3.3	3.4	0.5	3.1	15.8	22.9	15.3	24.1
1874	N.A.	N.A.	-10.6	-12.4	-19.2	-20.1	-24.3	-22.0
1884	164.0	168.3	198.0	197.0	198.7	198.8	193.5	193.4
1886	N.A.	N.A.	-108.8	-110.3	-113.5	-113.8	-113.6	-116.6
1888	N.A.	N.A.	6.8	6.6	-9.8	-11.0	-7.7	-7.6
1889	N.A.	N.A.	6.2	5.0	6.5	6.0	13.2	12.2
1890	N.A.	N.A.	7.0	6.8	19.0	19.9	14.2	14.1
1891	N.A.	N.A.	16.5	17.6	15.5	15.4	14.9	16.7
1893	-66.8	-67.7	-57.7	-57.6	-53.0	-52.8	-41.4	-40.4
7090	3.5	2.9	2.1	1.7	2.6	2.3	3.1	2.8
7105	-10.5	-10.8	-8.0	-8.2	-7.6	-7.2	-10.2	-10.0
7110	1.0	0.9	-0.2	-0.3	0.0	0.3	1.1	1.2
7119	11.3	10.7	11.6	11.2	12.5	12.3	8.5	7.9
7124	-15.1	-16.6	-6.8	-7.4	-7.9	-8.3	-16.1	-16.6
7237	8.1	7.4	5.9	6.0	8.4	8.7	13.8	14.1
7249	13.0	13.3	0.0	0.4	-8.1	-10.4	-3.2	-2.7
7394	N.A.	N.A.	7.8	7.4	8.0	7.7	7.0	8.2
7403	13.8	15.2	11.6	15.1	11.6	11.6	13.0	11.8
7407	N.A.	N.A.	10.4	6.1	9.9	8.1	16.4	17.2
7501	-3.1	-3.4	1.0	1.0	3.8	4.8	5.8	5.9
7810	0.5	0.0	5.4	4.6	6.4	6.1	8.5	7.6
7811	-4.8	-3.5	-9.1	-10.0	-15.3	-14.8	-6.6	-5.7
7819	N.A.	N.A.	2.6	2.9	-6.2	-2.1	14.7	14.3
7821	-12.3	-13.1	1.7	3.3	-2.4	-3.5	-6.5	-8.5
7824	-6.7	-6.8	N.A.	N.A.	N.A.	N.A.	-28.7	-33.3
7825	5.5	5.4	7.3	7.4	2.2	1.9	3.0	3.1
7827	N.A.	N.A.	1.7	1.8	3.7	4.8	3.9	4.0
7838	-9.0	-10.1	-13.3	-14.0	-21.7	-22.5	-71.8	-73.1
7839	4.4	5.1	7.4	8.0	12.4	13.0	13.7	14.9
7840	-2.2	-2.3	-2.6	-2.7	-2.0	-1.9	-1.2	-1.3
7841	4.4	4.4	1.9	1.7	2.9	2.5	-0.3	-0.5
7845	-16.7	-18.3	-9.4	-10.2	N.A.	N.A.	-1.7	-6.6
7941	-7.0	-8.0	-5.6	-6.1	-4.3	-4.5	-4.6	-5.8
8834	-21.3	-21.4	-21.4	-21.5	-24.5	-24.5	-10.3	-10.0

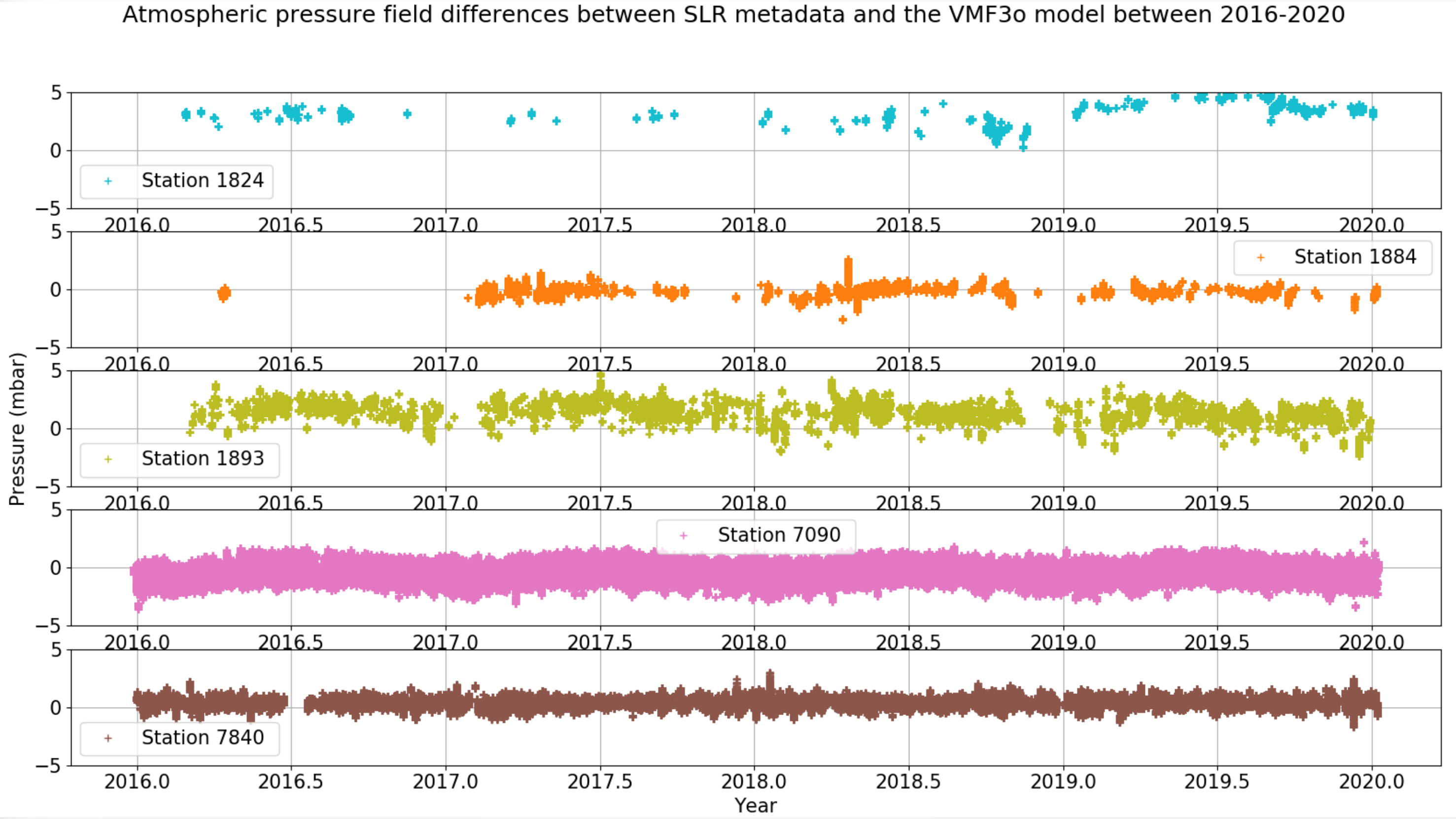
Note. E = Elevation; *N.A.* = Not Available.

Barometer measurement errors ?

Comparison between the atmospheric pressure fields (1884, 1893, 1824, 7090 and 7840) with the VMF3o troposphere delay model for satellite laser ranging (Boisits et al., 2020).

Stations 1824 and 1893: residual offsets between the pressure data and the VFM3o model (max 7 mm and 4 mm resp. troposphere delay differences in the zenith direction).

⇨ Larger biases are probably not caused by barometer measurement errors.



Conclusion

- Independent validation (using different satellite groups and software packages) of the SLR station range biases derived on a yearly basis down to the 2-mm level !
- New CN with 11 to 12 stations at the 2-mm level (18-21 at the 5-mm level).
- Such SLR station range biases could be determined by ILRS ?

Questions to NESC

NESC Meeting 16th November 2023

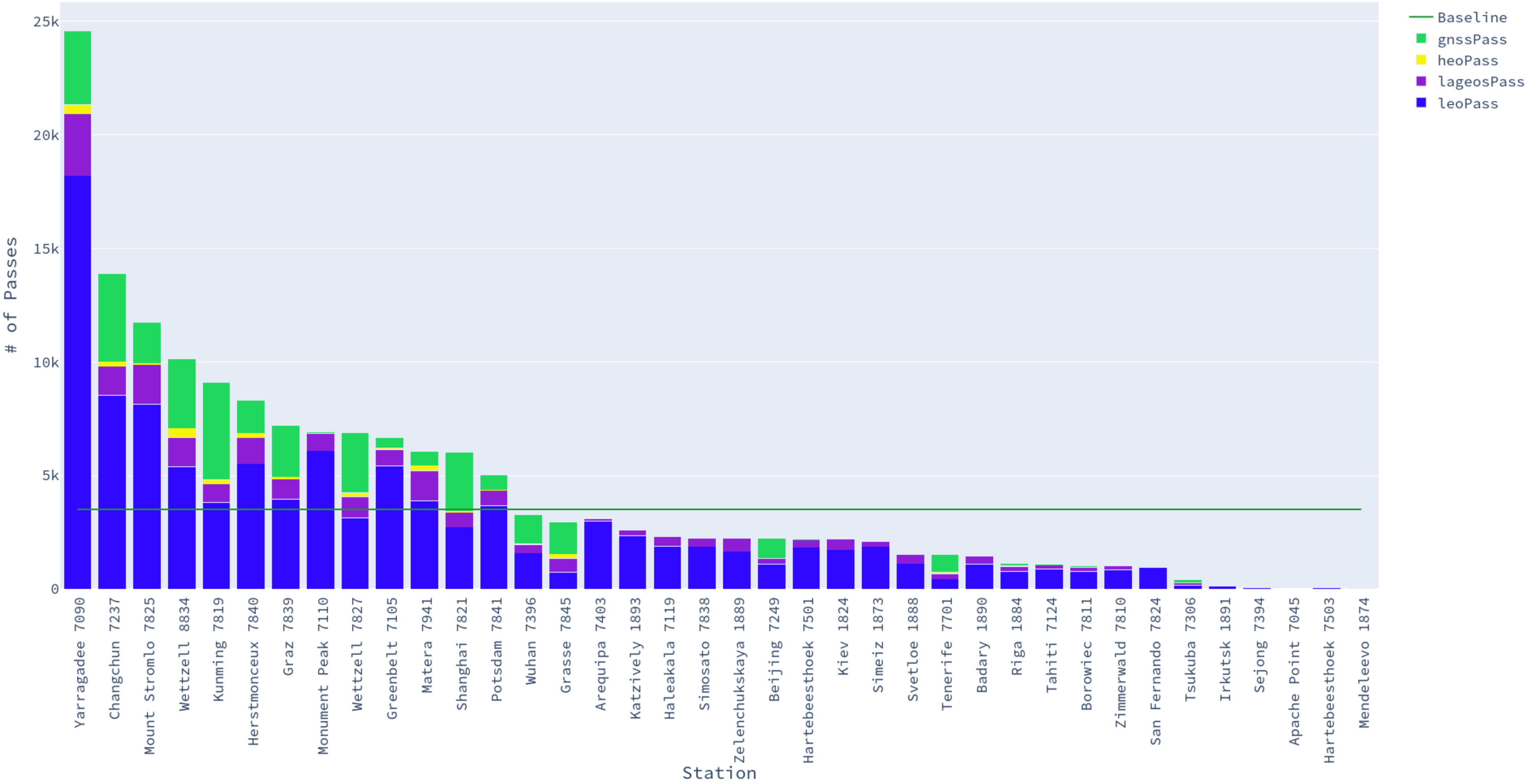
Feedback to Stations

- Do ILRS stations get the feedback they need to improve?
- There are a number of QC providers.
  - Is the information provided in good time?
- Are stations responsive to detections of range bias or time bias?

Station Performance

- Do we understand why some stations are far more productive than others??

Total Number of Passes (All Satellites)
(2022-11-01 to 2023-10-31)



Support for Stations

- Is the ILRS community able to help stations that are not performing?
- How can we approach stations that are not contributing enough?
- How do we share best practice?

Expectations for Stations

- Are under-performing SLR stations in the ILRS network expected to improve?
- What could the NESC do to help?
- Could the NESC identify stations for our focussed attention?
  - What questions do we ask these stations?
  - Could a plan be made?

?

NESC Meeting 16th November 2023

Changing the Dome of the ZIML station– Some Episodes of a Long Story…

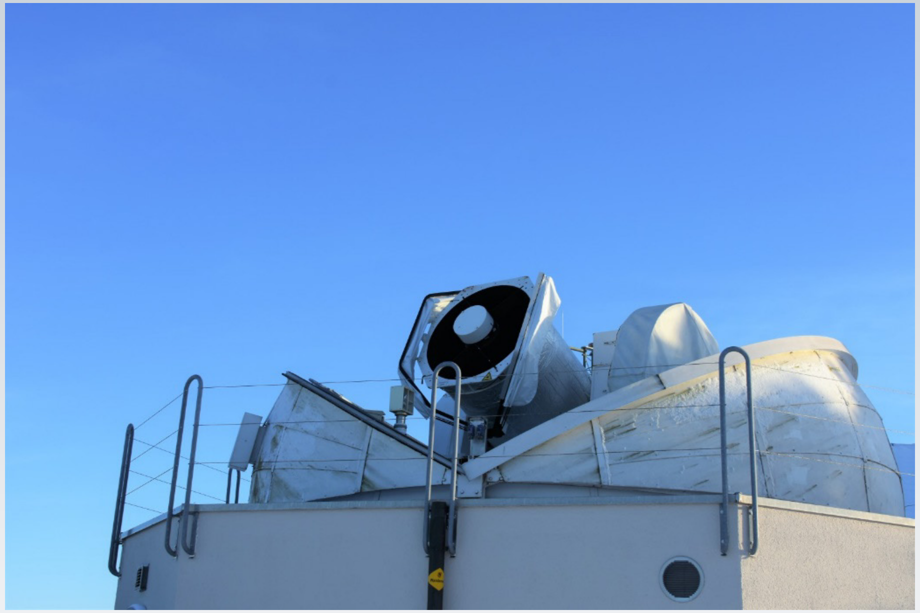
T. Schildknecht, Pierre Lauber

Astronomical Institute, University of Bern, Switzerland

New Dome for the ZIMLAT SLR System (ZIML)

Why a new dome?

- daylight SLR measurements were not efficient in automated mode as the pointing of the telescope was inaccurate due to thermal stress
- safety issues with dome
- solution: replace the all-sky dome with a slit dome to better protect the telescope mount and the tube from direct sunlight (reduce thermal stress)
- Disadvantages
  - need high-speed slit dome
  - need to slave dome to telescope



New Dome for the ZIMLAT SLR System (ZIML)

Not just a new dome but…

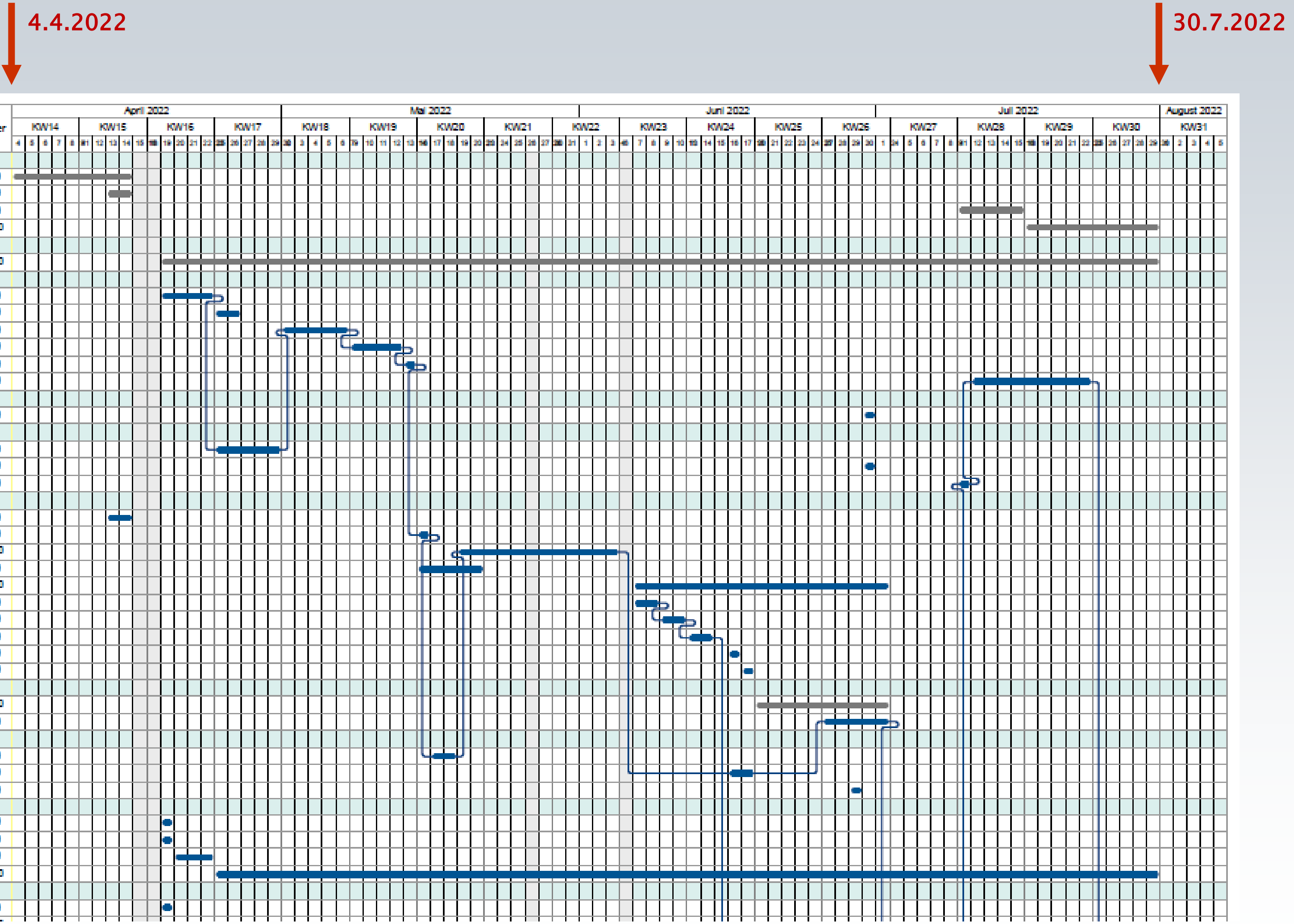
- entire building to be refurbished, in particular the thermal insulation and the roof
- new thermal control for the Coudé room
- new central unit for the cooling of the laser and the electronics racks
- new central UPS (in the garage)

Timeline (original)

- SLR and optical operations stopped in February 2022
- dome and building ready by July 2022

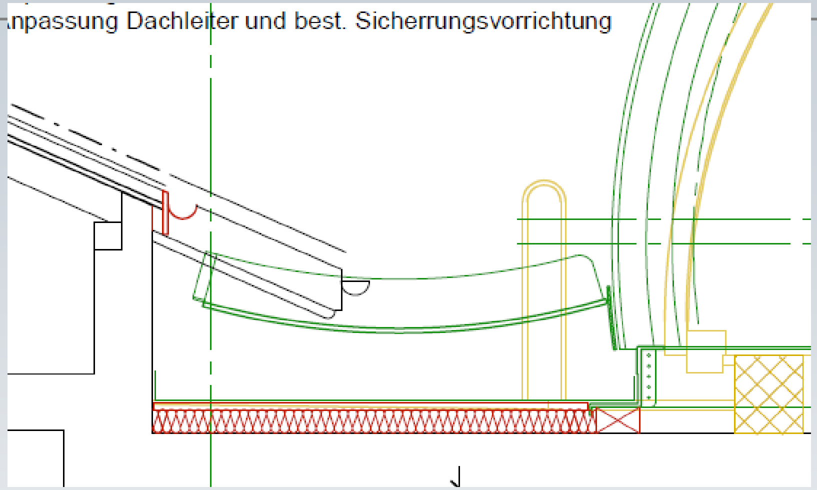
New Dome for the ZIMLAT SLR System (ZIML)

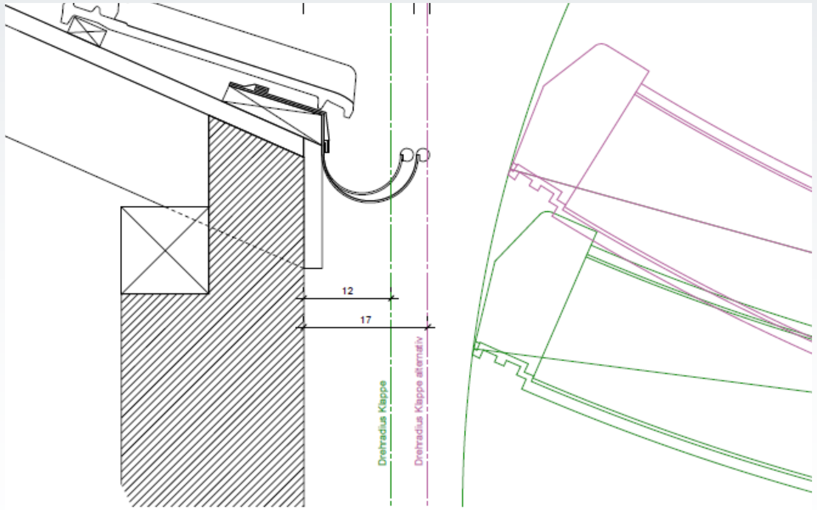
	BKP	Aktivitätsname	Unternehmer	Start	Ende	Dauer
1		Leistungen Betrieb				
2		Ausserbetriebnahme, Geräte schützen		04.04.22	14.04.22	9.00
3		Laser / Lasertisch schützen durch Remund Holzbau		13.04.22	14.04.22	2.00
4		Geräte Auspacken		11.07.22	15.07.22	5.00
5		Inbetriebnahme Kuppel		18.07.22	29.07.22	10.00
6		Bauphase				
7		Baustart bis Bauende		19.04.22	29.07.22	72.00
8	211	Baumeisterarbeiten	Ramseier			
9		Hecke, Aushub Fassadensockel, Sockeldämmung		19.04.22	22.04.22	4.00
10		Kernbohrungen		25.04.22	26.04.22	2.00
11		Demontagen, Abbrüche		02.05.22	06.05.22	5.00
12		Fräsarbeiten Dachrand und Kuppelring		09.05.22	12.05.22	4.00
13		Ausbesserungen Betondecke		13.05.22	13.05.22	1.00
14		Umgebungsarbeiten		12.07.22	22.07.22	9.00
15	211.0	Pneukran	Frutiger			
16		Montage neue Kuppel		30.06.22	30.06.22	1.00
17	211.1	Gerüste	Schwarz			
18		Montage Fassadengerüst, Notdach		25.04.22	29.04.22	5.00
19		Demontage Notdach		30.06.22	30.06.22	1.00
20		Demontage Fassadengerüst		11.07.22	11.07.22	1.00
21	214	Montagebau in Holz	Remund			
22		Laser und Lasertisch schützen, Bautüren		13.04.22	14.04.22	2.00
23		Montage Kuppelring		16.05.22	16.05.22	1.00
24		Dachaufbau		19.05.22	03.06.22	11.00
25		Anpassungen Dach Wohngebäude inkl. Spengler		16.05.22	20.05.22	5.00
26		Aussendämmung Fassade, Eternit		07.06.22	01.07.22	19.00
27		Fassadenelement, Abbruch und Montage		07.06.22	08.06.22	2.00
28		Aussentüre, Abbruch und Montage		09.06.22	10.06.22	2.00
29		Wand- und Deckenverkleidung Zwischenbau		13.06.22	14.06.22	2.00
30		Abdeckung Fenster innen		16.06.22	16.06.22	1.00
31		Deckel Auszugstreppe		17.06.22	17.06.22	1.00
32	224	Bedachungsarbeiten (Kuppel)	Baader			
33		Zeltfenster Baader		20.06.22	01.07.22	10.00
34		Montage Kuppel		27.06.22	01.07.22	5.00
35	224	Bedachungsarbeiten (Abdichtung)	Loder			
36		Dampfbremse Dach		17.05.22	18.05.22	2.00
37		Abdichtung Dach, Flüssigkunststoff		16.06.22	17.06.22	2.00
38		Abdichtung Dach, Anschlüsse an Kuppel		29.06.22	29.06.22	1.00
39	230	Elektroanlagen	Burkhalter			
40		Kältegeräte abhängen		19.04.22	19.04.22	1.00
41		Bauprovisorium		19.04.22	19.04.22	1.00
42		Demontagen Kuppel, Zwischenbau		20.04.22	22.04.22	3.00
43		Elektrische Installationen		25.04.22	29.07.22	68.00
44	245	Klimaanlagen	Roth / KTZ			
45		Demontage Kältegeräte		19.04.22	19.04.22	1.00



New Dome for the ZIMLAT SLR System (ZIML)

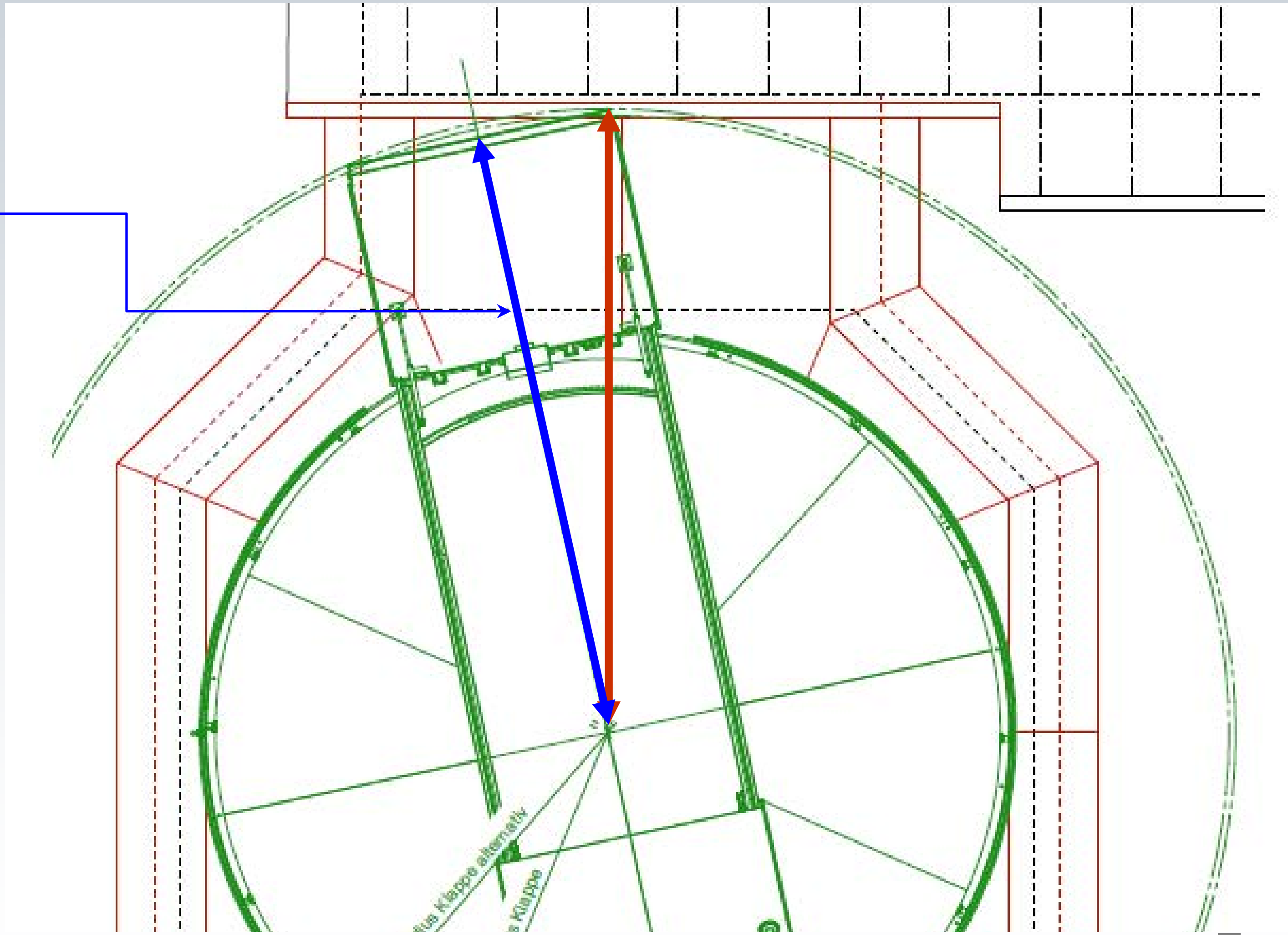
- Flap of new dome would hit the roof...
- First solution:
  - s/w and h/w interlocks assure minimum elevation of flap in critical azimuth region...
  - implemented
  - finally considered as too complex and unsafe...
- Second solution
  - roof adapted, new gutter installed





New Dome for the ZIMLAT SLR System (ZIML)

- Hmm, something went wrong…
- wrong radius taken!
  → change roof again!



Dismounting the old dome

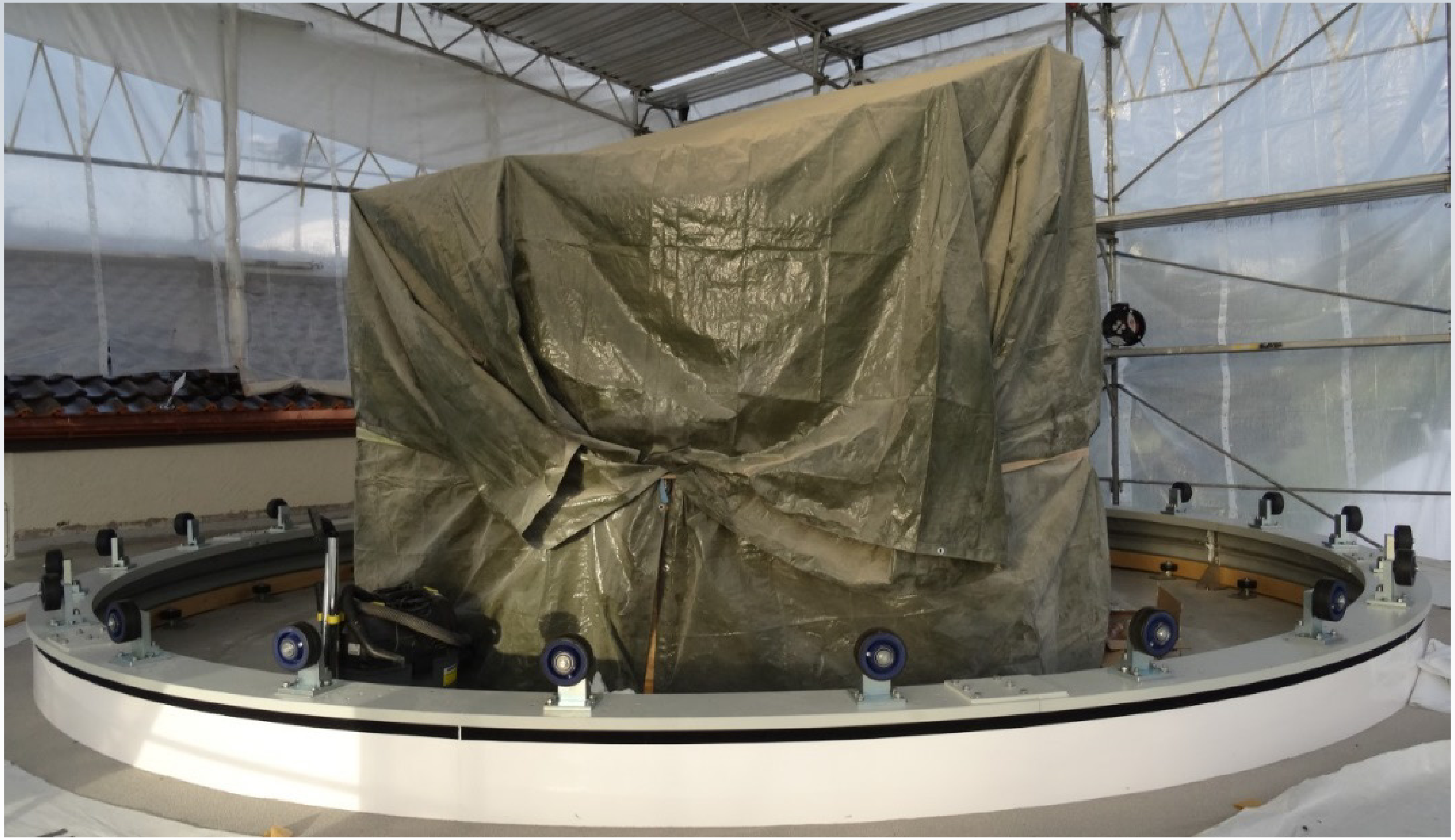
- **Protecting ZIMLAT, removing old dome**

New Dome for the ZIMLAT SLR System (ZIML)

Protecting ZIMLAT, further protection…

New Dome for the ZIMLAT SLR System (ZIML)

Protecting ZIMLAT, further protection…



New Dome for the ZIMLAT SLR System (ZIML)

June 24, 2022, finally, the new dome…

June 24, 2022, finally, the new dome…

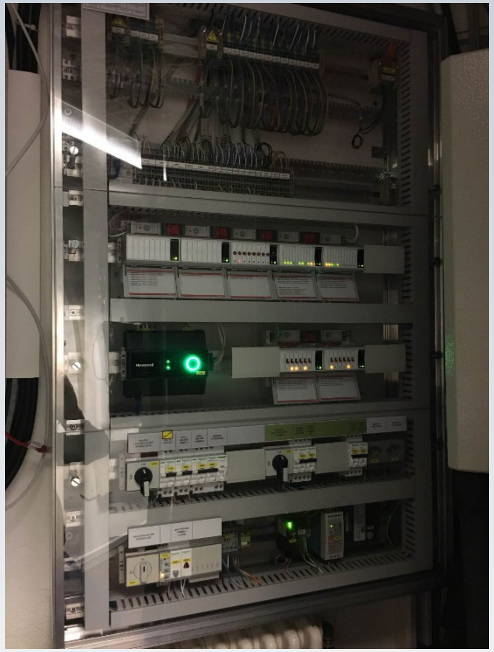
New Dome for the ZIMLAT SLR System (ZIML)

June 24, 2022, finally, the new dome…

New Cooling / Air Conditioning System

Outer devices

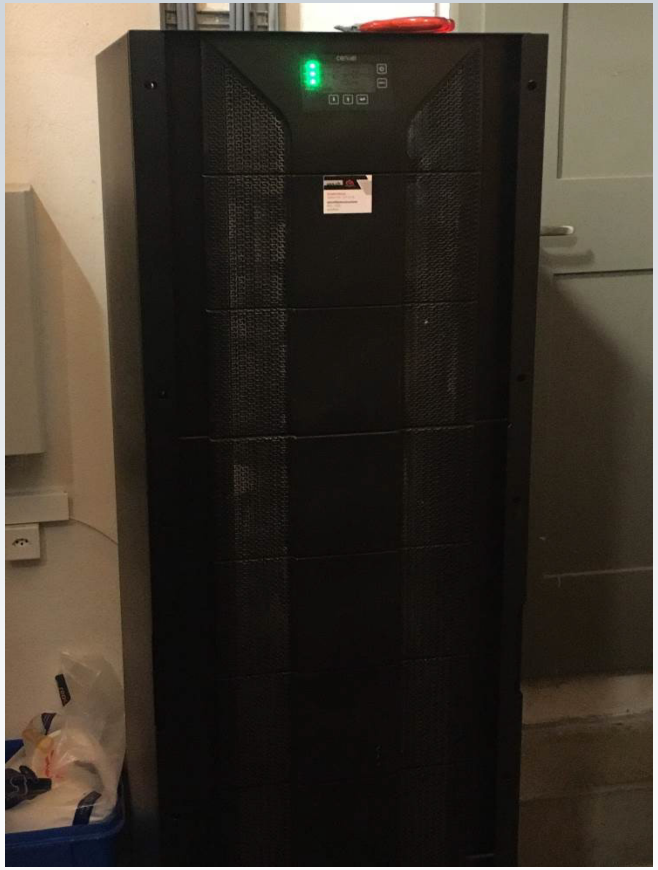
Inner devices



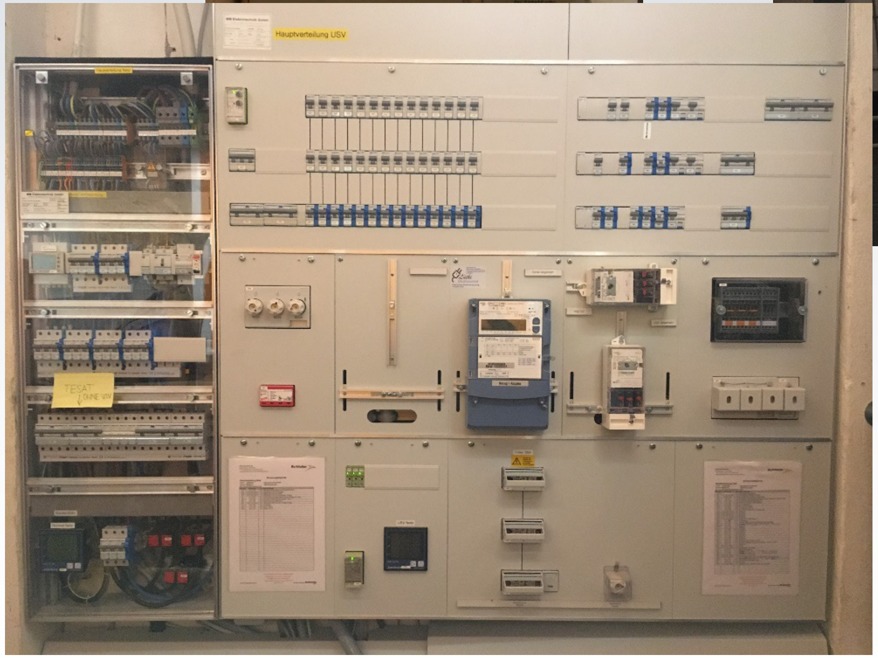
Control unit

New UPS, new Current Distribution, …

UPS 230VAC for entire station



UPS 24VDC for SLR



Compressor

New Dome for the ZIMLAT SLR System (ZIML)

Timeline (effective)

- SLR and optical operations stopped in February 2022
- dome installed on June 24 2022
- dome and building ready by November 2022 (3 months delay)

→ dome operational and optical observations resumed 4.11.2022

Restarting the Laser (Sept 2022)

- failure of rotating shutter (22.2.2022, repaired 9.6.2022)
- failure of the MASER → master frequency unit changed to quartz (6.9.2022)
- several failures of the new cooling/air condition system
  → 17°C and 30°C instead of 22°C @ laser
  → >30°C @ electronics racks
- failure of laser cooling unit → repaired (6.10.2022)

Restarting the SLR Sytem

Restarting the Laser

- NO laser output (7.10.2022)
- Failure analysis:
  - 100 MHz oscillator working
  - no 100 MHz input trigger from oscillator seen by the laser Master pulse distribution unit
    → suspicion that RF output from oscillator was too low
  - analysis of the oscillator
    → 180 mW instead of 230 mW@1064 nm (measured 2013)

→ hypothesis: oscillator output too low
→ get oscillator serviced
(custom made model, replacement not available, company changed owner,...)

Restarting the SLR Sytem

Restarting the Laser (cont.)

- Oscillator:
  - order to service the oscillator (23.12.2022)
  - oscillator shipped to company (18.1.2023)
  - oscillator “repaired” and shipped back to Zimmerwald (15.3.2023)
    → 216 mV @ 1064 (36ps instead of 58ps before)

Laser Master pulse distribution unit still not working (17.3.2023)!

- failure analysis…
  - reconfiguration required…?
  - internal 24V power unit failed (21.3.2023 works with lab power unit)
  - 24V power unit replaced (30.3.2023)

On-site Service from Thales required to adjust laser

Restarting the SLR Sytem

Restarting the Laser (cont.)

- second failure of the laser cooling unit (6.4.2023)
  - trials to repair the cooling unit on site…
  - preparation of paperwork (export…)
  - cooling unit shipped to company (20.4.2023)
  - → cooling unit back at Zimmerwald 27.6.2023

On-site Service by Thales 11./12.7.2023

  - 2mJ @532 instead of 8mJ (18mJ @1064)
  - first LAGEOS returns @21° elevation (13.7.2023)!!!
  - → why only 2mJ @532 (SHG seems ok…)

- Failure of the several additional units in the transmit path (4.8.2023)
  - failure of the beam attenuator drive
  - failure of the divergence adjustment drive
  - → SLR out of service (safety reasons)
  - → workaround for attenuator and divergence drives, successful LAGEOS pass (1.9.2023)

Murphy's Law…

- 1.9.2023 Flap damaged
  crash with agricultural tractor trailer
- 14.9.2023 Flap replaced

13.10.2023 ZIML Operational Again!

- Regular SLR observation (16.9.2023 onwards; LEO including LAGEOS)
- 13.10.2023: Released from quarantine (first observation July 13 2023)
  → ZIML data has been validated
  → ZIML contributing to ILRS on a regular basis
- Data Quality
  - same as before February 2022:

2023 Evaluation

LAGEOS 1

QC L1 78106821	PREC EST [mm]	RANGE BIAS [mm]
Mean	2.6	1.8
STD	1.5	6.8
RMS	3.0	6.9
Passes	31	31

LARES2

QC L2 78106821	PREC EST [mm]	RANGE BIAS [mm]
Mean	3.3	0.2
STD	1.5	8.0
RMS	3.6	7.8
Passes	18	18

2017 Evaluation

LAGEOS 1

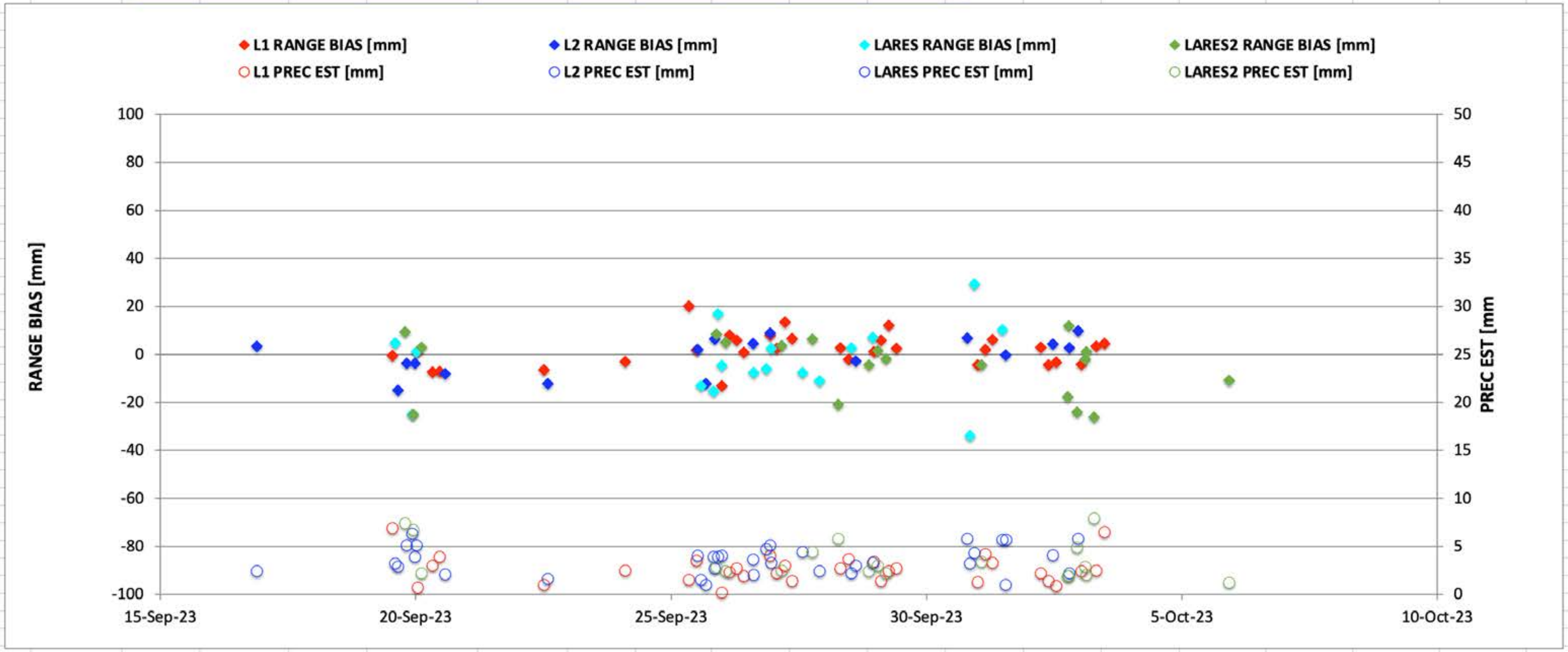
78106821 L1	PREC EST [mm]	RANGE BIAS [mm]
Mean	2.9	14.4
STD	0.8	6.9
RMS	3.0	15.9
Point	34	34

LARES

78106821 LR	PREC EST [mm]	RANGE BIAS [mm]
Mean	6.3	13.6
STD	3.0	28.4
RMS	7.0	31.0
Point	25	25

- Remaining issues:
  - Laser power at ~2mJ instead of ~8mJ
    → MEO (GNSS) are difficult to track
    → need service from Laser manufacturer (Thales)
  - limited number of observers to maintain 24/7 operations
    → recruiting/training of student observers ongoing

Qualification Results



QC L1 78106821	PREC EST [mm]	RANGE BIAS [mm]
Mean	2.6	1.8
STD	1.5	6.8
RMS	3.0	6.9
Passes	31	31

QC L2 78106821	PREC EST [mm]	RANGE BIAS [mm]
Mean	3.3	0.2
STD	1.5	8.0
RMS	3.6	7.8
Passes	18	18

QC LR 78106821	PREC EST [mm]	RANGE BIAS [mm]
Mean	3.8	-3.0
STD	1.3	14.7
RMS	4.1	14.6
Passes	18	18

QC R2 78106821	PREC EST [mm]	RANGE BIAS [mm]
Mean	3.6	-4.6
STD	2.0	12.4
RMS	4.1	12.9
Passes	19	19


Thanks for listening!