7090 YARL Analysis

ILRS QCB
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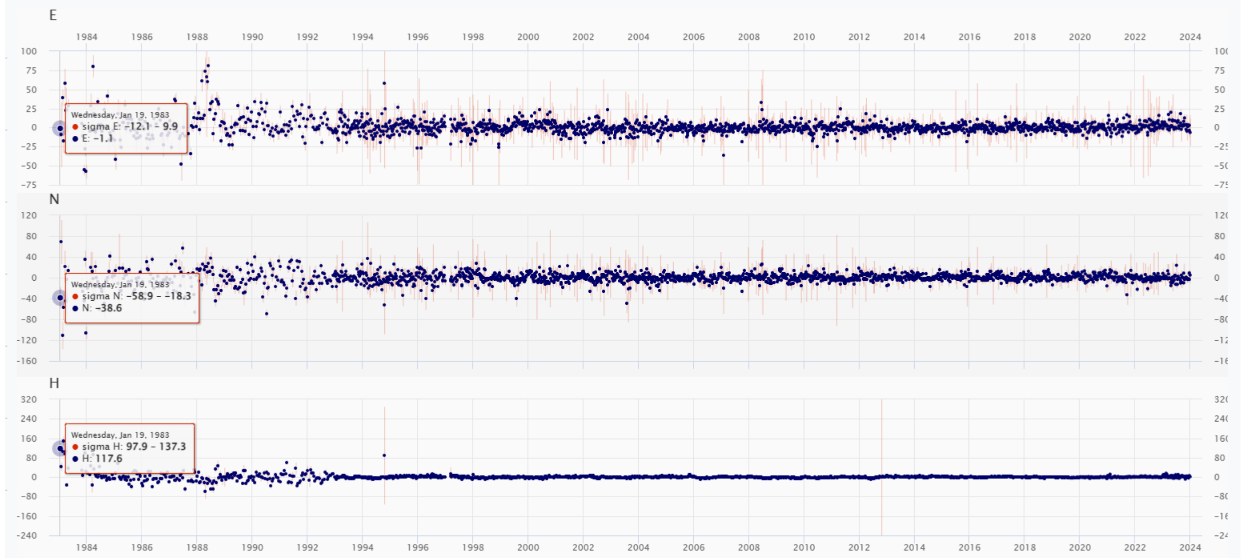
7090 YARL ITRF2020_U2023 Weekly Station Residuals



- **Top Chart: ITRF Station residuals (East, North, Up) since 1-Jan-1983. The residual scatter improved after LAGEOS-2 was added in late 1992**
- **Botton Chart: Zoom-in of the top chart. The 7090 Up residuals since January 2023 have larger scatter with larger error bars than before**
- **What might be the root causes:**
  - Degradation in data yield
  - Degradation in data quality
  - Something in the data analysis/data handling
  - Or a combination of factors

7090 YARL Data Yield (passes and normal points)

7090 YARL LAGEOS-1 Data Yield per Hour per Year

GMT	Local	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	8	4.0%	3.1%	5.2%	4.0%	1.3%	3.3%	1.4%	2.0%	3.4%	1.0%	2.8%	3.9%	2.3%	2.5%	4.8%	3.0%	2.9%	4.5%	3.0%	3.7%	4.4%	3.4%	3.6%	3.7%	3.4%	4.2%	3.7%	2.6%	4.5%	3.4%	3.4%	5.6%
1	9	5.5%	3.3%	6.1%	5.5%	1.3%	4.9%	1.8%	0.7%	2.9%	0.8%	2.4%	1.9%	1.2%	2.8%	6.0%	2.1%	2.6%	6.0%	2.4%	2.4%	5.1%	3.0%	2.9%	5.0%	3.2%	4.0%	4.3%	3.5%	4.3%	2.9%	4.7%	5.1%
2	10	4.8%	4.9%	4.2%	5.3%	2.9%	2.2%	1.4%	1.6%	2.5%	0.7%	1.6%	1.4%	0.2%	2.4%	4.3%	2.3%	2.8%	5.9%	2.8%	3.6%	6.2%	2.0%	2.0%	4.8%	2.9%	3.8%	4.6%	3.6%	4.4%	3.5%	3.5%	4.1%
3	11	5.9%	3.1%	4.0%	5.7%	3.1%	3.3%	1.9%	2.3%	2.7%	1.1%	1.5%	1.7%	2.3%	3.0%	3.9%	2.4%	3.7%	6.5%	2.2%	2.4%	4.8%	2.3%	2.1%	5.5%	3.1%	2.6%	6.0%	3.6%	3.8%	4.9%	4.6%	3.0%
4	12	6.9%	3.1%	2.8%	4.4%	2.6%	2.0%	3.5%	2.3%	3.2%	1.5%	1.2%	1.1%	1.8%	2.1%	4.9%	3.0%	3.8%	5.2%	2.4%	2.3%	5.2%	2.6%	2.3%	6.2%	2.8%	3.1%	6.2%	3.9%	2.8%	5.2%	3.9%	2.7%
5	13	6.0%	2.9%	1.4%	5.5%	2.9%	2.7%	5.6%	3.4%	3.0%	3.2%	0.8%	1.4%	2.2%	2.8%	2.5%	3.2%	2.8%	4.8%	2.6%	2.7%	4.2%	2.6%	3.4%	5.1%	2.3%	3.5%	6.7%	3.0%	2.9%	6.1%	3.4%	2.6%
6	14	3.5%	3.8%	2.6%	5.3%	4.5%	1.8%	4.4%	3.3%	2.9%	5.0%	1.2%	1.4%	2.5%	2.9%	3.2%	3.8%	4.0%	4.2%	3.4%	2.5%	3.9%	3.6%	3.1%	4.1%	2.9%	3.7%	5.2%	2.8%	3.1%	5.8%	2.5%	2.8%
7	15	5.9%	2.7%	2.6%	2.5%	4.2%	4.1%	7.4%	4.9%	4.0%	7.6%	2.2%	2.6%	2.8%	2.2%	2.6%	5.0%	3.4%	3.9%	4.0%	3.7%	4.0%	3.5%	2.8%	4.7%	4.0%	4.0%	5.6%	3.7%	2.8%	6.0%	3.0%	2.9%
8	16	4.0%	4.5%	2.8%	2.3%	5.8%	4.3%	7.6%	4.4%	5.1%	7.8%	2.8%	2.9%	5.7%	2.8%	3.1%	5.4%	3.0%	2.9%	6.4%	3.2%	3.6%	5.6%	3.6%	4.4%	4.4%	3.3%	4.3%	3.8%	3.8%	4.6%	2.9%	3.5%
9	17	2.9%	5.4%	1.9%	4.6%	6.8%	4.7%	7.4%	5.4%	5.6%	8.7%	4.1%	4.9%	6.8%	3.4%	4.2%	5.8%	3.1%	3.4%	5.9%	3.5%	3.0%	5.4%	3.6%	4.1%	4.8%	3.6%	4.0%	3.5%	3.7%	5.1%	2.9%	4.7%
10	18	3.1%	5.6%	3.3%	3.4%	7.9%	4.7%	7.9%	5.6%	6.4%	8.3%	5.8%	5.6%	7.6%	4.0%	4.4%	7.2%	3.0%	3.0%	6.8%	3.8%	4.3%	5.7%	3.7%	3.4%	5.9%	3.9%	3.5%	3.9%	3.8%	4.8%	3.3%	3.6%
11	19	4.0%	6.7%	5.2%	4.0%	7.3%	5.9%	6.9%	9.0%	5.6%	6.9%	6.6%	7.8%	8.6%	4.1%	4.7%	6.2%	3.9%	3.8%	6.3%	3.7%	4.3%	7.3%	3.7%	4.7%	6.3%	3.9%	4.1%	6.0%	4.1%	3.8%	5.7%	3.9%
12	20	3.7%	7.8%	5.2%	4.9%	8.1%	5.1%	6.2%	7.4%	4.9%	7.4%	6.6%	6.3%	6.9%	5.5%	3.9%	6.1%	3.8%	3.1%	6.4%	4.0%	4.4%	6.9%	4.0%	4.0%	6.3%	3.6%	3.5%	6.6%	4.5%	4.7%	6.0%	3.7%
13	21	4.4%	6.5%	3.1%	5.1%	6.8%	3.9%	4.8%	7.2%	5.1%	6.0%	8.1%	4.3%	6.3%	6.0%	4.2%	5.5%	4.9%	3.6%	5.6%	4.1%	4.2%	5.8%	4.3%	4.0%	5.7%	3.4%	3.4%	6.8%	3.6%	3.3%	7.3%	4.6%
14	22	4.0%	5.8%	6.8%	5.3%	6.8%	4.1%	5.5%	7.9%	3.9%	6.2%	7.8%	5.7%	5.6%	5.9%	4.1%	4.6%	4.7%	3.8%	5.4%	4.4%	3.6%	5.6%	5.0%	3.7%	5.9%	3.8%	3.0%	5.9%	3.3%	3.5%	6.4%	3.3%
15	23	4.9%	4.2%	4.7%	6.1%	5.5%	6.3%	5.6%	7.7%	4.9%	4.9%	8.6%	5.7%	4.4%	6.2%	3.2%	4.5%	5.6%	3.1%	4.7%	6.1%	4.0%	5.2%	5.1%	4.7%	5.2%	3.7%	3.5%	6.1%	4.2%	3.5%	5.8%	3.7%
16	24	4.4%	5.4%	5.2%	5.5%	5.0%	5.1%	5.6%	6.7%	5.2%	5.0%	6.6%	4.0%	4.6%	7.0%	3.5%	3.9%	5.7%	4.4%	3.8%	5.1%	3.9%	4.5%	5.2%	3.4%	5.0%	3.7%	4.0%	5.7%	4.0%	4.2%	5.5%	3.3%
17	1	4.2%	3.3%	3.8%	3.8%	4.2%	5.3%	4.2%	4.9%	3.7%	4.1%	5.9%	4.0%	5.1%	6.1%	4.0%	4.3%	6.2%	2.8%	3.8%	6.1%	3.9%	4.4%	5.9%	4.1%	4.3%	5.0%	3.5%	4.6%	4.2%	4.1%	5.4%	4.2%
18	2	4.0%	2.9%	3.3%	3.8%	2.9%	5.3%	3.7%	3.1%	4.2%	2.9%	3.9%	3.3%	4.7%	5.6%	3.1%	3.7%	6.5%	3.8%	3.9%	6.8%	3.9%	3.9%	6.1%	3.3%	4.1%	5.9%	4.1%	4.1%	4.1%	3.4%	3.7%	4.9%
19	3	3.1%	1.6%	5.4%	2.5%	2.9%	5.3%	2.1%	3.4%	3.5%	3.1%	4.2%	5.4%	5.6%	5.9%	4.4%	3.9%	5.8%	4.1%	3.9%	6.0%	3.6%	3.1%	6.4%	4.1%	3.3%	6.0%	3.8%	3.9%	5.9%	4.6%	4.8%	5.3%
20	4	2.7%	2.7%	4.2%	3.8%	1.8%	4.5%	1.4%	2.3%	5.7%	2.7%	4.2%	7.2%	3.4%	4.9%	4.9%	4.0%	5.4%	4.4%	3.8%	6.5%	3.2%	3.7%	6.3%	3.3%	4.0%	5.8%	3.5%	3.1%	5.9%	3.7%	3.9%	5.8%
21	5	2.7%	4.3%	6.6%	1.7%	1.6%	3.5%	1.2%	1.6%	4.7%	2.4%	5.1%	5.8%	3.5%	5.1%	5.1%	3.1%	4.6%	3.7%	3.6%	5.0%	3.8%	3.8%	5.5%	3.4%	3.6%	5.8%	2.8%	2.9%	5.9%	3.5%	3.0%	5.9%
22	6	2.2%	3.1%	4.5%	1.7%	1.8%	4.1%	1.2%	1.8%	3.5%	1.4%	3.5%	6.4%	3.0%	3.4%	5.1%	3.9%	3.9%	4.9%	4.1%	4.6%	4.2%	3.3%	5.3%	2.5%	3.7%	4.9%	3.5%	2.5%	5.4%	2.5%	2.0%	5.8%
23	7	3.1%	3.3%	5.2%	3.4%	1.8%	3.7%	1.1%	1.0%	3.4%	1.3%	2.6%	5.3%	2.7%	3.5%	5.7%	3.1%	3.9%	4.4%	3.0%	4.0%	4.3%	2.8%	4.2%	4.2%	3.2%	4.9%	3.2%	3.5%	5.1%	2.9%	2.2%	5.1%
Total Passes		547	552	425	474	381	490	567	610	593	714	862	720	824	1133	944	1112	1134	1193	1116	1061	925	1124	1148	1134	1261	1174	1186	1020	1126	1158	988	967

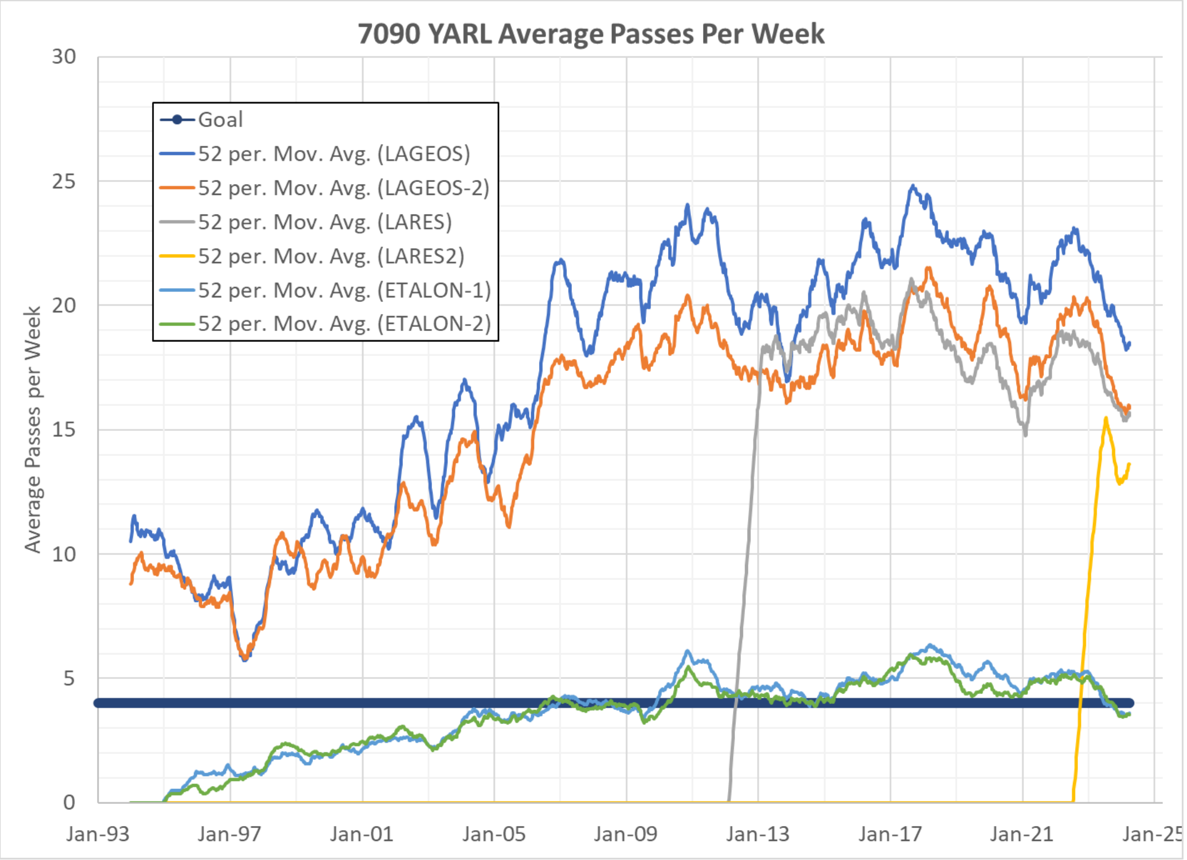
- ILRS goal: 200 LAGEOS-1 passes/year easily exceeded every year. Data yield peaked in 2017. Since 2007, the hourly distribution of LAGEOS-1 passes seem to repeat every 3 years. 15% reduction in passes in 2023 vs 2022

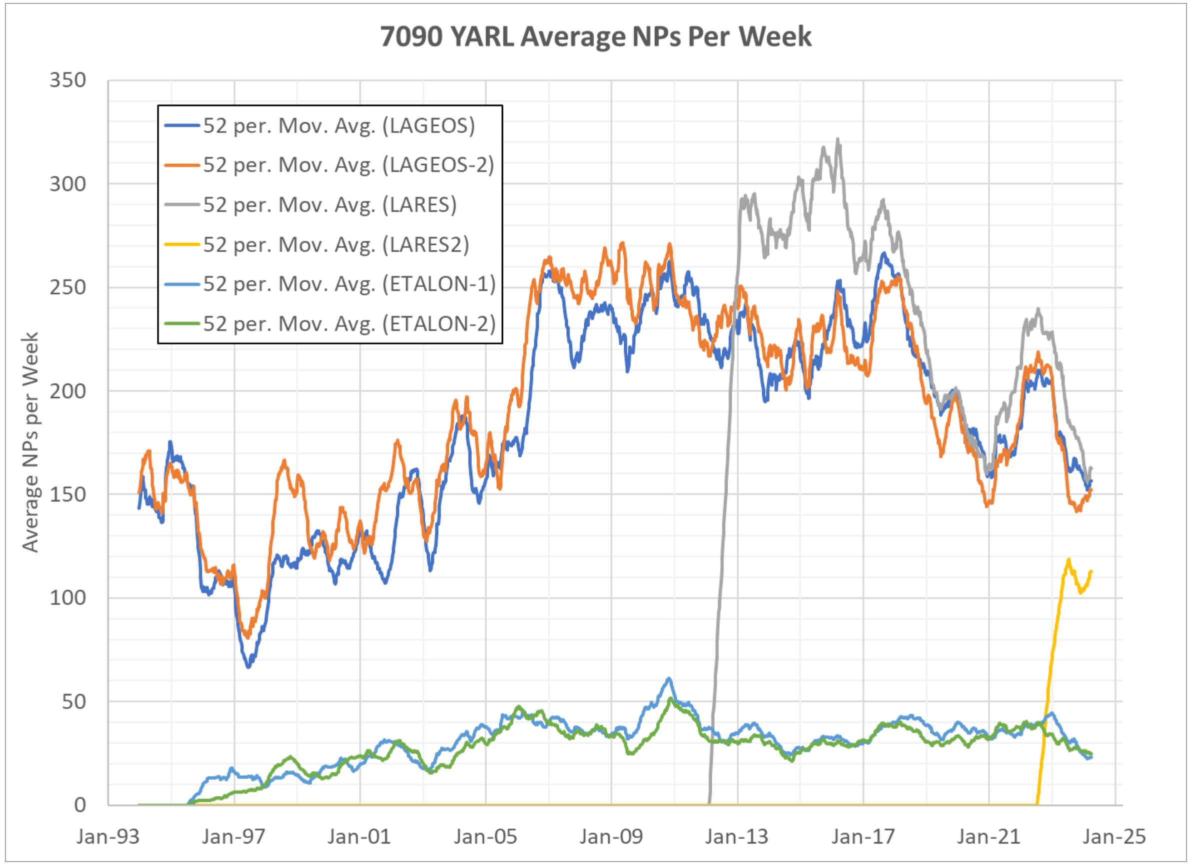
7090 YARL LAGEOS-2 Data Yield per Hour per Year

GMT	Local	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	8	4.2%	4.0%	4.7%	5.8%	3.6%	2.7%	2.7%	2.0%	2.2%	2.1%	3.0%	2.5%	2.5%	3.9%	4.3%	3.2%	3.9%	4.8%	2.5%	4.1%	4.9%	2.9%	3.9%	4.2%	3.5%	5.3%	3.6%	3.7%	4.8%	2.8%	3.8%	4.2%
1	9	6.3%	4.4%	4.7%	5.2%	2.8%	3.4%	1.4%	1.4%	2.2%	1.4%	2.1%	1.9%	1.9%	3.6%	3.3%	3.1%	2.9%	5.1%	2.7%	4.0%	4.5%	2.1%	4.1%	3.4%	3.4%	3.5%	3.4%	4.1%	4.1%	2.9%	4.1%	4.5%
2	10	6.1%	4.2%	4.9%	7.0%	4.4%	3.1%	3.3%	2.5%	1.7%	2.2%	2.6%	1.1%	1.5%	3.1%	3.4%	1.5%	2.7%	5.4%	3.1%	3.5%	4.1%	3.2%	2.8%	3.9%	3.4%	3.1%	4.6%	3.4%	5.1%	4.0%	2.9%	5.8%
3	11	6.1%	4.4%	3.5%	4.3%	2.8%	2.7%	2.5%	1.6%	2.2%	2.4%	2.4%	1.6%	3.2%	2.6%	4.5%	4.2%	2.6%	4.8%	2.8%	3.0%	3.1%	2.7%	3.0%	4.2%	4.1%	4.1%	3.8%	3.1%	4.3%	3.7%	2.6%	4.1%
4	12	4.4%	3.8%	2.6%	4.7%	4.1%	3.3%	4.1%	2.3%	3.1%	2.9%	2.0%	1.6%	1.8%	3.3%	3.2%	2.9%	2.5%	4.9%	2.8%	2.5%	4.6%	3.0%	3.6%	5.3%	2.8%	3.7%	4.2%	4.1%	3.9%	4.2%	2.9%	4.9%
5	13	4.4%	3.6%	2.3%	2.7%	4.1%	2.7%	4.9%	3.1%	2.9%	3.5%	2.5%	1.9%	2.1%	2.7%	4.3%	3.9%	2.6%	4.5%	3.6%	3.8%	3.9%	3.4%	3.2%	4.3%	3.6%	4.5%	3.9%	4.2%	4.3%	3.4%	2.0%	4.2%
6	14	4.2%	4.6%	1.4%	3.1%	5.0%	3.1%	5.6%	4.5%	4.1%	4.8%	1.5%	1.7%	3.2%	2.4%	3.9%	3.3%	3.4%	4.3%	4.1%	2.5%	3.6%	3.3%	3.1%	4.5%	4.4%	3.6%	4.8%	2.2%	4.7%	4.2%	3.0%	4.6%
7	15	4.4%	3.6%	2.3%	2.5%	6.1%	4.0%	6.6%	6.1%	5.2%	4.8%	4.1%	3.6%	2.9%	2.8%	3.8%	4.6%	3.2%	5.1%	5.0%	3.2%	3.9%	3.8%	3.7%	5.1%	3.6%	3.8%	5.2%	4.0%	4.1%	4.4%	3.0%	3.6%
8	16	3.9%	5.0%	2.3%	3.1%	5.2%	3.8%	6.2%	7.0%	4.3%	8.6%	3.0%	4.4%	5.1%	4.2%	4.5%	5.0%	3.8%	3.7%	4.8%	3.7%	4.6%	4.9%	3.5%	5.3%	4.3%	4.3%	4.9%	3.3%	4.0%	5.1%	3.2%	4.5%
9	17	3.3%	4.2%	2.8%	4.3%	6.6%	4.0%	7.8%	7.6%	4.3%	6.7%	6.1%	4.7%	5.3%	3.6%	4.3%	4.9%	2.8%	4.3%	5.4%	3.5%	4.1%	5.1%	3.5%	4.6%	4.7%	4.3%	4.8%	3.3%	3.8%	4.8%	3.0%	3.7%
10	18	2.4%	7.6%	3.0%	4.0%	6.4%	5.4%	6.0%	6.4%	6.0%	8.3%	4.7%	4.5%	7.3%	4.3%	4.1%	6.2%	4.6%	4.4%	6.1%	3.9%	4.3%	4.4%	5.4%	5.3%	5.2%	3.7%	4.8%	2.6%	3.8%	5.0%	3.8%	4.7%
11	19	2.0%	5.2%	4.2%	3.6%	6.6%	5.9%	7.4%	7.8%	5.9%	6.7%	8.2%	5.6%	6.9%	5.1%	4.0%	5.5%	4.8%	3.8%	5.2%	4.3%	4.6%	5.7%	4.1%	5.2%	4.9%	4.1%	4.9%	4.8%	3.8%	5.2%	4.7%	4.6%
12	20	2.8%	4.0%	5.6%	4.9%	5.0%	4.8%	5.8%	7.4%	4.1%	6.9%	6.1%	6.4%	6.2%	5.5%	4.2%	5.1%	4.7%	4.1%	5.8%	3.8%	4.3%	5.3%	4.7%	4.5%	4.5%	3.9%	4.9%	4.5%	4.1%	5.2%	4.6%	3.0%
13	21	4.6%	5.6%	6.7%	5.6%	4.1%	5.4%	7.2%	7.2%	6.4%	6.6%	6.1%	5.2%	5.6%	4.9%	3.9%	4.1%	4.5%	2.4%	5.1%	5.3%	4.6%	5.7%	4.5%	4.0%	5.4%	5.1%	3.9%	6.1%	3.7%	5.7%	5.8%	4.6%
14	22	4.4%	4.0%	5.6%	4.5%	4.7%	5.0%	4.9%	6.4%	5.9%	6.7%	5.7%	5.0%	5.5%	5.6%	4.3%	4.9%	4.4%	4.2%	5.1%	4.5%	3.6%	5.7%	4.5%	4.2%	5.7%	3.7%	4.4%	4.7%	4.3%	5.0%	4.9%	4.1%
15	23	3.5%	4.6%	6.7%	5.8%	3.3%	6.7%	5.4%	4.7%	5.5%	5.2%	7.0%	6.4%	5.5%	5.1%	4.5%	4.5%	5.6%	3.7%	4.8%	4.5%	4.5%	5.4%	4.4%	3.6%	4.9%	3.9%	4.5%	5.5%	3.6%	3.8%	6.6%	4.7%
16	24	3.9%	4.0%	5.6%	4.9%	4.7%	6.7%	3.9%	4.9%	6.7%	4.1%	5.3%	6.1%	4.1%	6.3%	4.2%	4.1%	5.3%	3.4%	4.7%	4.9%	4.2%	4.9%	4.3%	3.6%	4.5%	3.4%	3.6%	5.1%	4.5%	4.0%	4.6%	2.8%
17	1	3.5%	3.8%	5.8%	3.8%	3.6%	5.6%	3.7%	4.5%	5.0%	3.8%	4.0%	5.0%	4.5%	4.3%	3.7%	4.1%	4.9%	2.8%	4.1%	5.0%	4.2%	5.2%	4.0%	4.1%	4.7%	4.9%	3.7%	5.7%	3.5%	4.2%	5.5%	3.7%
18	2	5.5%	3.2%	5.1%	3.6%	3.3%	4.2%	1.9%	2.9%	4.1%	2.6%	3.4%	3.6%	4.1%	4.3%	4.3%	4.3%	5.7%	4.4%	4.5%	5.3%	4.1%	4.5%	5.7%	4.0%	4.2%	4.2%	4.1%	4.1%	3.5%	3.3%	6.1%	4.2%
19	3	3.7%	3.2%	4.0%	2.9%	2.5%	4.0%	1.9%	2.9%	4.0%	1.6%	4.1%	6.3%	5.3%	6.2%	5.1%	4.2%	5.6%	3.8%	3.7%	6.0%	4.9%	4.7%	4.5%	3.9%	4.3%	5.2%	4.1%	5.4%	4.6%	4.6%	6.0%	3.8%
20	4	4.2%	3.4%	4.4%	2.2%	3.0%	3.3%	1.9%	2.3%	4.1%	1.2%	4.0%	6.1%	4.4%	4.6%	4.7%	4.4%	5.9%	3.9%	4.3%	6.2%	4.3%	3.8%	5.6%	2.9%	4.4%	4.6%	3.9%	4.2%	4.1%	3.6%	4.7%	4.6%
21	5	4.4%	3.2%	3.5%	2.9%	1.9%	3.3%	0.6%	1.8%	3.8%	1.9%	4.4%	6.6%	4.5%	4.3%	3.7%	3.9%	4.8%	3.9%	3.7%	4.6%	3.5%	3.8%	4.5%	3.8%	3.0%	4.6%	3.1%	4.5%	3.9%	4.1%	3.6%	3.5%
22	6	3.7%	3.2%	5.8%	4.3%	2.5%	3.6%	1.9%	1.2%	3.3%	2.6%	4.0%	3.3%	3.4%	3.1%	4.8%	4.1%	4.4%	4.4%	3.4%	4.4%	4.2%	3.1%	4.6%	3.4%	3.5%	4.6%	3.9%	3.7%	4.2%	2.9%	4.8%	4.3%
23	7	4.2%	3.2%	2.6%	4.0%	3.6%	3.4%	2.5%	1.4%	2.6%	2.2%	4.0%	4.9%	3.3%	4.0%	4.9%	4.1%	4.2%	4.2%	2.7%	3.7%	3.3%	3.2%	4.6%	2.5%	3.1%	4.6%	2.7%	4.0%	5.2%	3.9%	3.7%	3.2%
Total Passes		457	500	430	445	362	522	485	512	579	579	758	638	729	922	875	957	957	1027	962	894	861	962	948	943	1080	983	1074	859	975	1054	833	886

- **ILRS goal: 200 LAGEOS-2 passes/year easily exceeded every year. Data yield peaked in 2017. 21% reduction in passes in 2023 vs 2022**

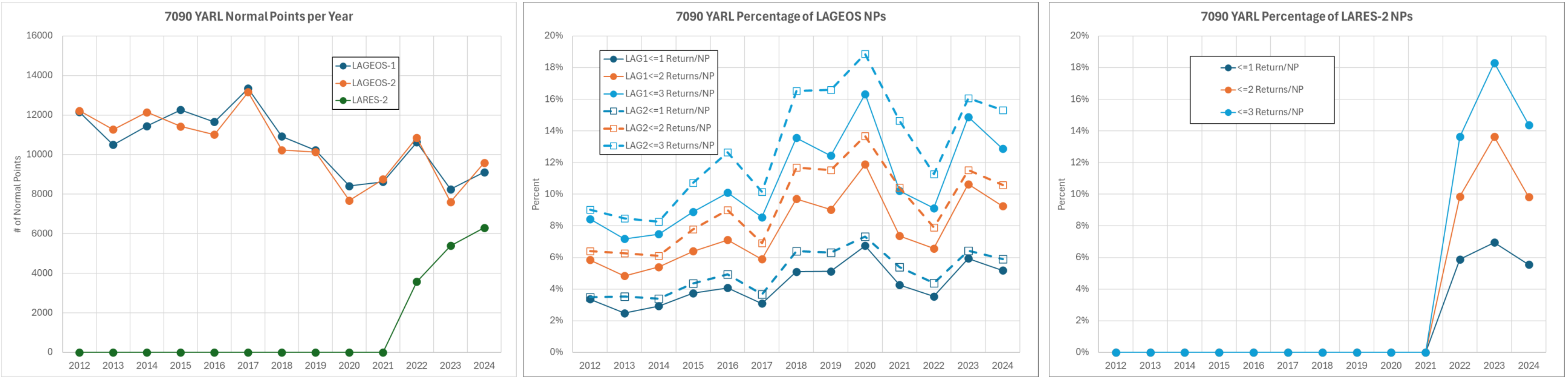
7090 YARL Passes and NPs per GPS Week (52-week running averages)





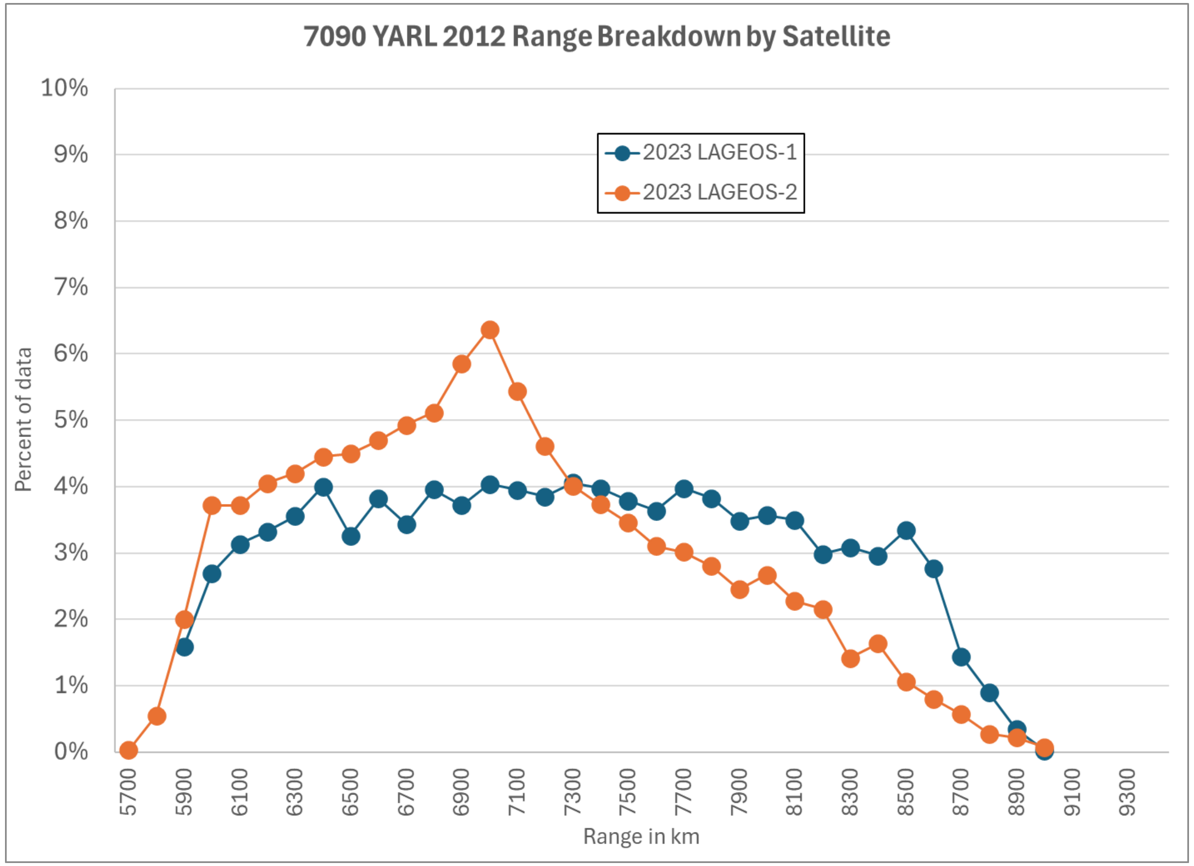
- **An average of 4 passes per week per LAGEOS class satellite will achieve the 200 passes/year goal. LAGEOS-1 and LAGEOS-2 data yield (passes and NPs) started to decline in 2023 but still easily exceeded the ILRS passes/year goal**

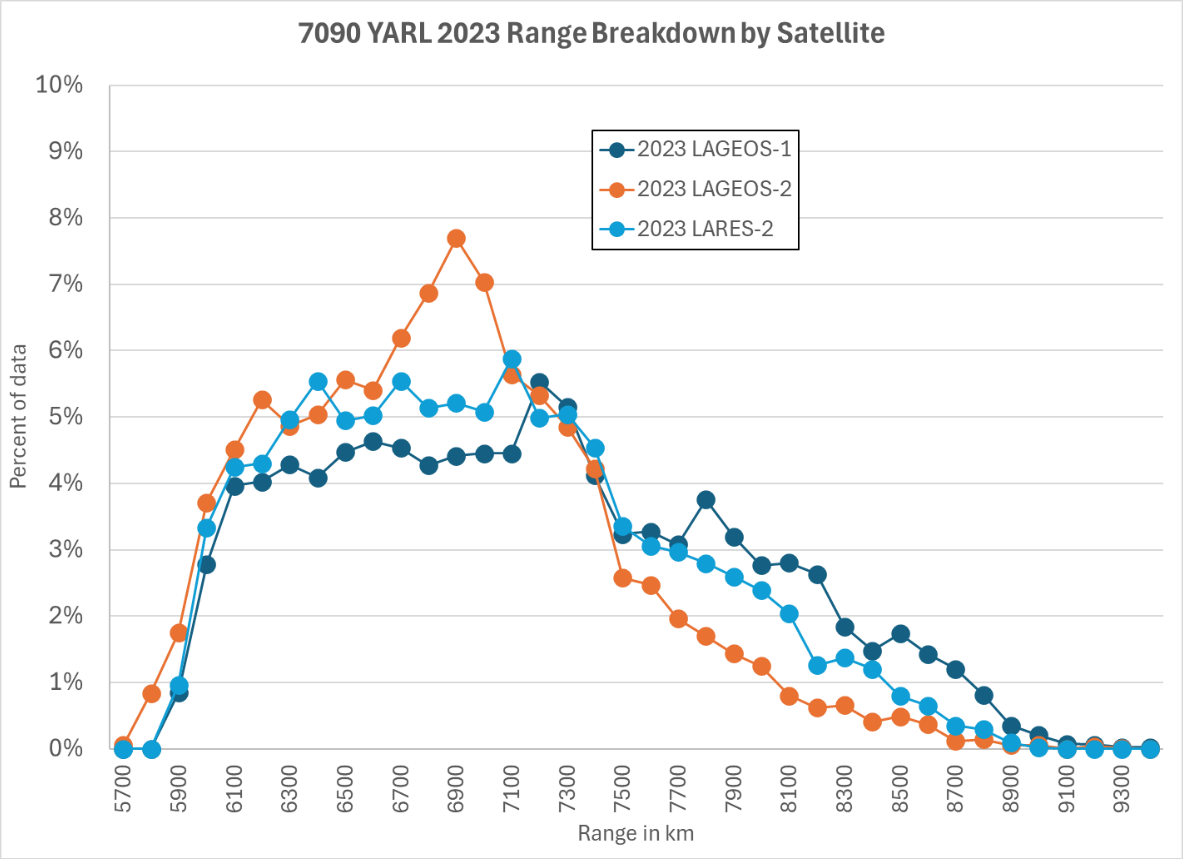
7090 YARL LAGEOS/LARES-2 Normal Point (NP) Statistics by Year



- ❑ **The yearly 7090 LAGEOS NP production was lowest in 2020 and 2023**
- ❑ **While in 2020 and 2023, the highest percentage of weak NPs (<=3 returns per NP) peaked**
- ❑ **LAGEOS-2 and LARES-2 have a higher percentage of weak NPs relative to LAGEOS-1**

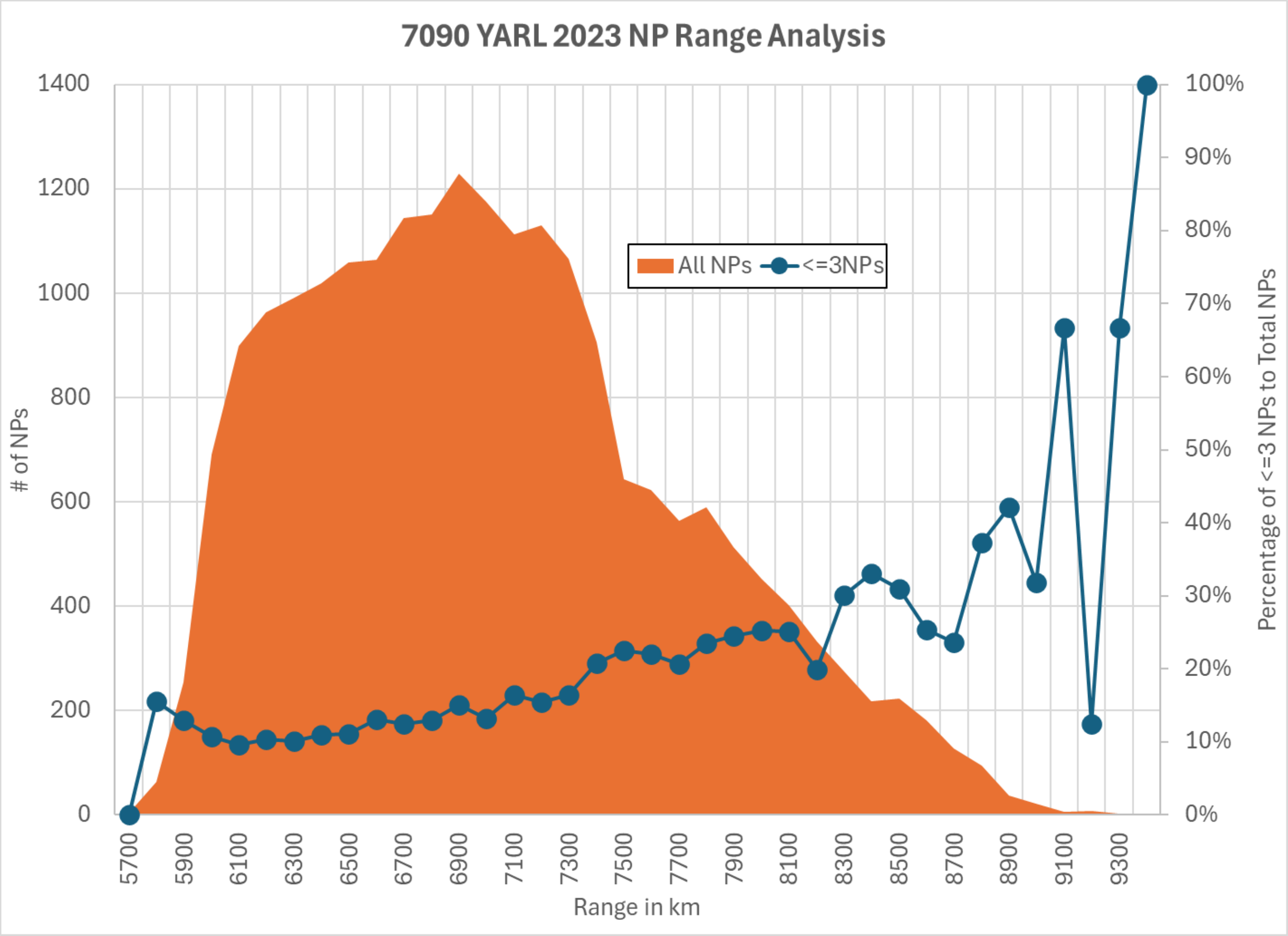
7090 YARL NP Range Analysis
2012 versus 2023





- In 2012, LAGEOS-1 NPs were equally distributed as a function of range, but in 2012 LAGEOS-2 NPs were not
- In 2023, all three satellites (LAGEOS-1, LAGEOS-2 and LARES-2) see a reduction in NPs as a function of range >7300 km

7090 YARL 2023 NP Range Analysis (LAGEOS and LARES-2 Combined)



- ❑ An area chart indicating the distribution of combined LAGEOS and LARES-2 NPs per range
- ❑ Drop off in NP production around 7300 km
- ❑ As the range increases, the percentage of weak NPs increases

John Reis's Conclusions on using NPs based on Few Returns

Conclusions

- There seems to be little consistency in the assigned RMS for low-return NPTs.
  - How exactly *is* the RMS assigned for a single or two-return NPT?
  - Since the uncertainty of a low-return NPT is large, surely the assigned RMS should be correspondingly large.
- The FIT RMS increases from 6.5 to 7.6 mm for 7090, and from 7.6 to 8.5 mm for all stations (an increase in variance of 6.9 mm^2) when low-return NPTs are used.
  - The orbit difference RMS reaches 8 mm (mostly along-track).
  - The low-return NPTs are clearly worse than NPTs with at least 6 (or even 3) returns.
- While the geodetic impact of the low-return NPTs is small, there seems to be good reason to not deliver or use them due to their effect on the orbits.
  - The assigned RMS is unreliable and the analysts do not use it to inform their data weighting in any case. *This is a little worrisome.*
  - If stations continue to deliver low-return NPTs, analysts should consider editing NPTs with only 1 or 2 returns (only a few passes would be lost and these are clearly among the worst ones). *I would strongly recommend adhering to ILRS guidelines for LAGEOS-1/2.*
  - This should become less of a problem with time as high-rep-rate stations come on line (7840, for example, had only a single NPT with less than 6 returns even when the test NPT software was run to allow for NPTs from as few as a single return).

CSR Center for Space Research

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Cockrell School of Engineering

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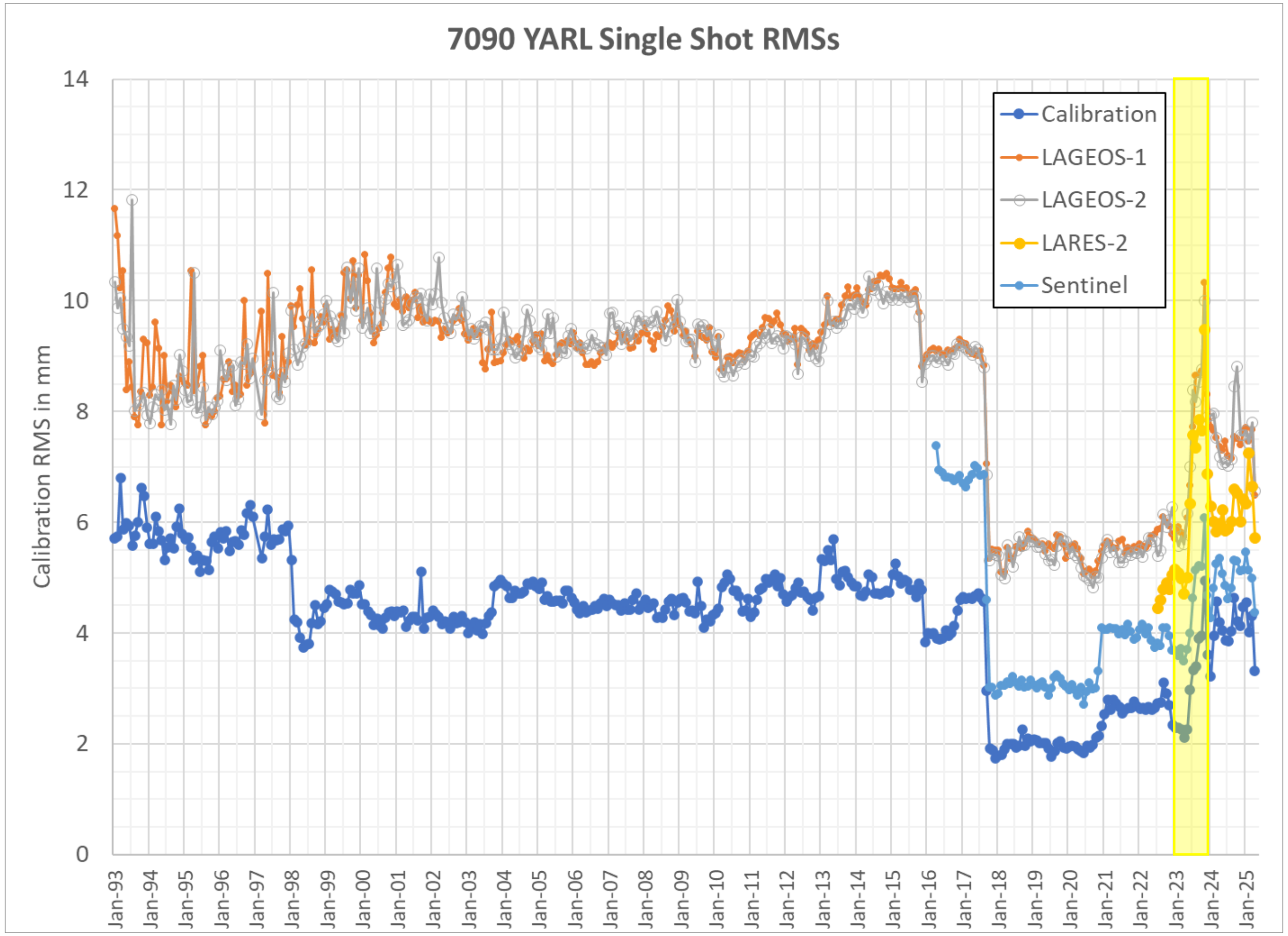
- **John Reis' Conclusion slide from his 24-Sep-2020 QCB presentation on "Analysis of SLR normal points from Herstmonceux open-source normal pointing software"**

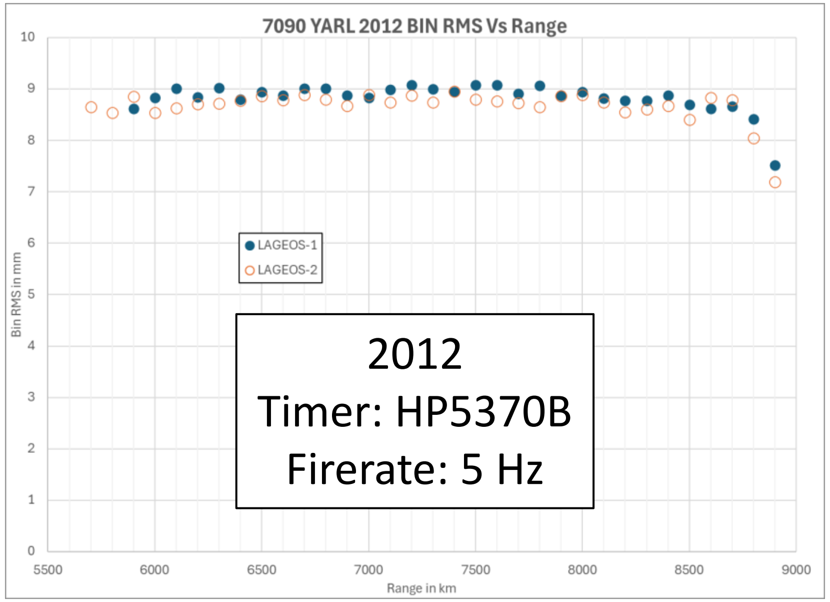
7090 YARL Data Quality (Single Shot RMSs)

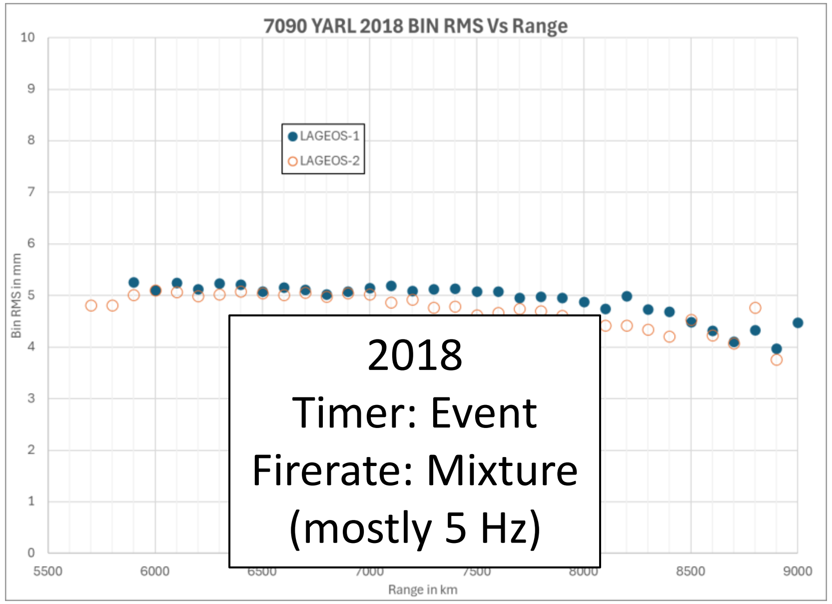
7090 YARL Monthly Single Shot RMSs (satellite and calibrations)

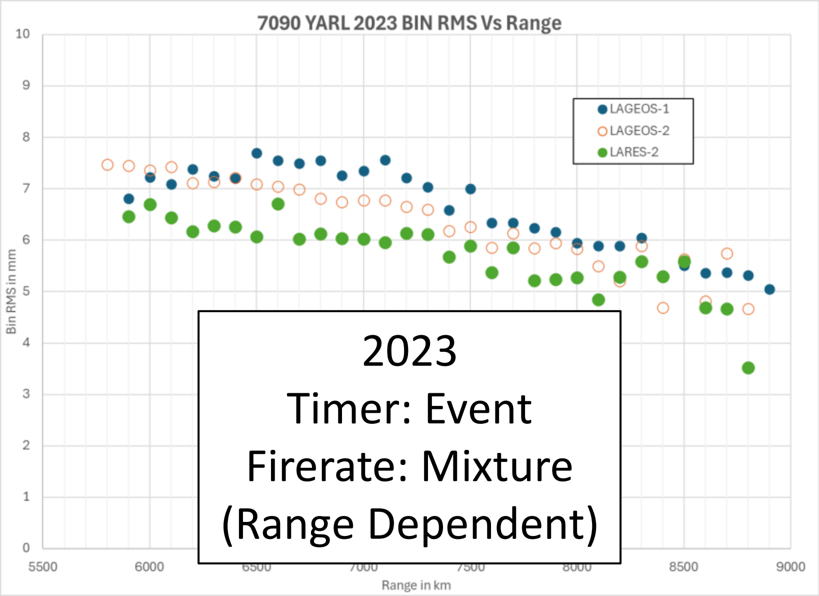


- In January 1998, the HP5370A Time Interval Unit (TIU) failed and was replaced in February 1998 with a HP5370B causing a reduction in calibration RMS. In late November 2015, some maintenance on the HP5370B was performed reducing the single shot RMSs
- In September 2017, the event timer replaced the HP5370B TIU leading to a reduction in single shot RMSs
- RMSs were erratic in 2023. In May 2023, ongoing issues with laser power supply were reported. On 13-Sep-2023 laser running at full power, parasitic lasing eliminated. RMSs peaked in November 2023.
- On 28-Mar-2025, the Active Mode Locking (AML) frequency synthesizer settings were optimized causing a reduction in RMSs
- The RMSs remain elevated versus the initial RMSs post event timer installation. Did the laser issues induce any systematic errors?
- The 7090 YARL event timer installation in Sept 2017 enabled ranging to MEOs and HEOs at 10 and 5Hz; respectively, dependent upon the satellite range

7090 YARL Bin RMS vs Range (2012, 2018, 2023)

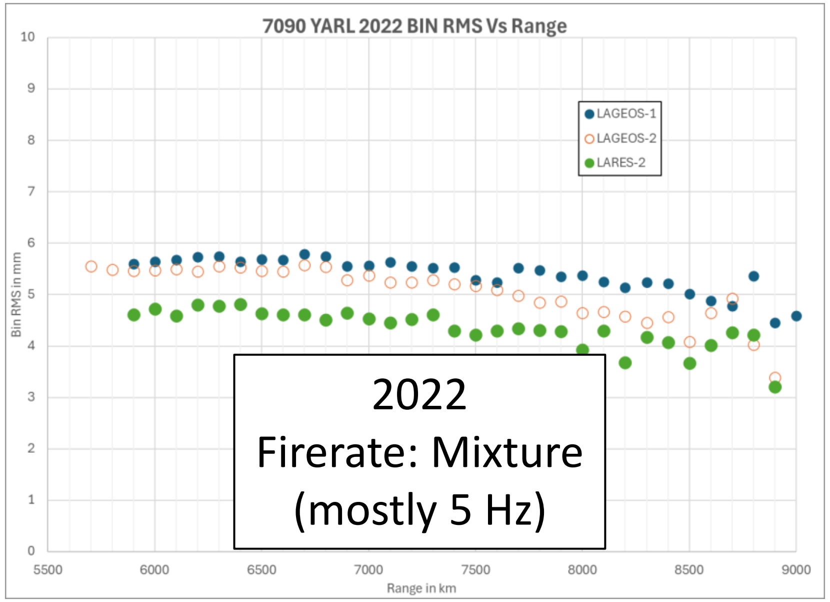


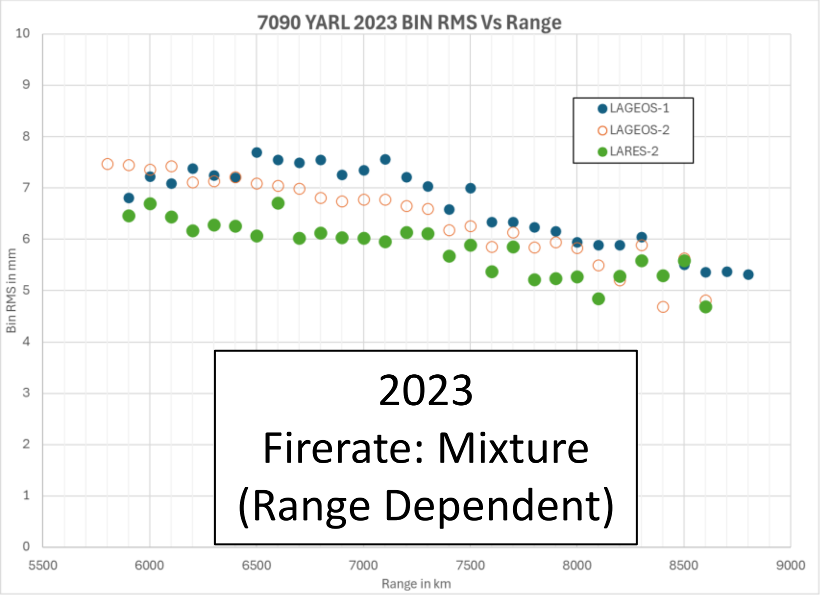


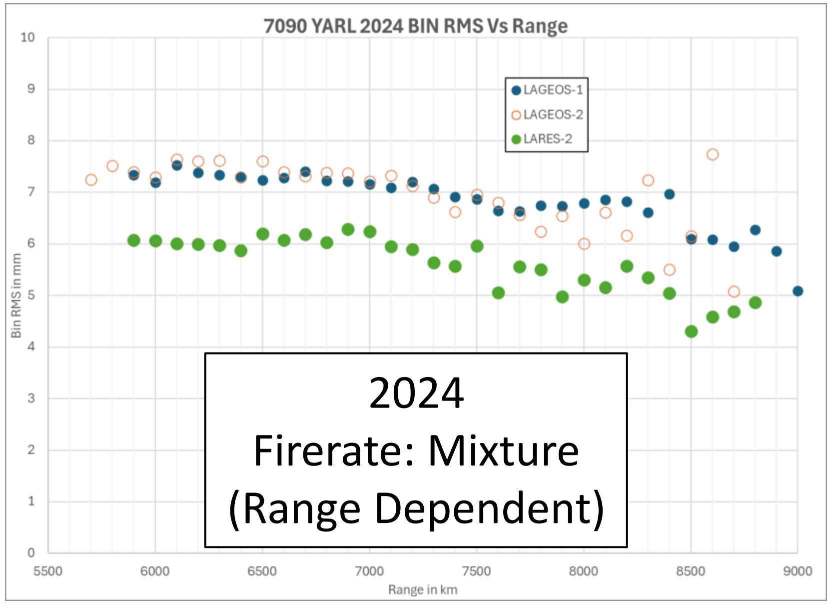


- ❑ **2012: HP5370B Time Interval Unit (TIU) operating a 5 Hz only; consistent Bin RMSs as function of range; LAGEOS-1 RMSs slightly higher than LAGEOS-2 RMSs**
- ❑ **2018: Event Timer operating at both 5 and 10 Hz (predominately 5 Hz); slight downward trend in Bin RMSs starting at 8,000 km; RMSs reduced vs the HP5370B; LAGEOS-1 RMSs slightly higher than LAGEOS-2 RMSs**
- ❑ **2023: Event Timer operating at both 5 and 10 Hz (range dependent, 5 Hz > ~7300 km and 10 Hz < ~7300 km); downward trend in Bin RMSs; LAGEOS-1 RMSs generally higher than LAGEOS-2; LARES-2 RMSs less than LAGEOS-2 RMSs; 2023 RMSs higher than 2018**

7090 YARL Bin RMS vs Range (2022 to 2024)



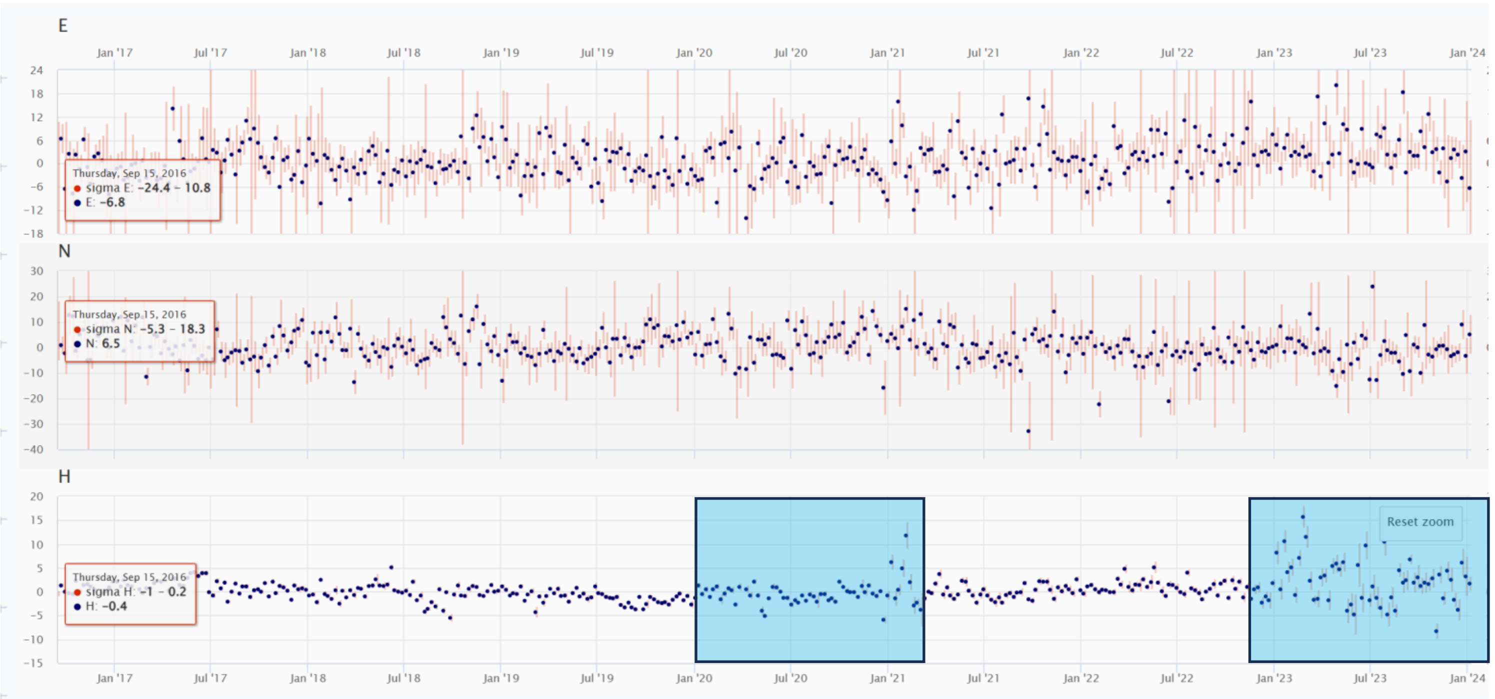




- **2022: Event Timer operating at both 5 and 10 Hz (predominately 5 Hz); Bin RMSs start decreasing around 7,500 km; LAGEOS-1 RMSs slightly higher than LAGEOS-2 RMSs; LARES-2 RMSs less than LAGEOS-2 RMSs**
- **2023: Event Timer operating at both 5 and 10 Hz (range dependent, 5 Hz > ~7300 km and 10 Hz < ~7300 km); downward trend in Bin RMSs; LAGEOS-1 RMSs generally higher than LAGEOS-2; LARES-2 RMSs less than LAGEOS-2 RMSs; 2023 RMSs higher than 2022**
- **2024: Event Timer operating at both 5 and 10 Hz (range dependent, 5 Hz > ~7300 km and 10 Hz < ~7300 km); downward trend in Bin RMSs; LAGEOS-2 RMSs slightly higher than LAGEOS-1 at shorter ranges; LARES-2 RMSs less than LAGEOS-2 RMSs**

7090 YARL Range Biases (RBs) and Data Handling

7090 YARL ITRF2020_U2023 Weekly Residuals (Zoom)



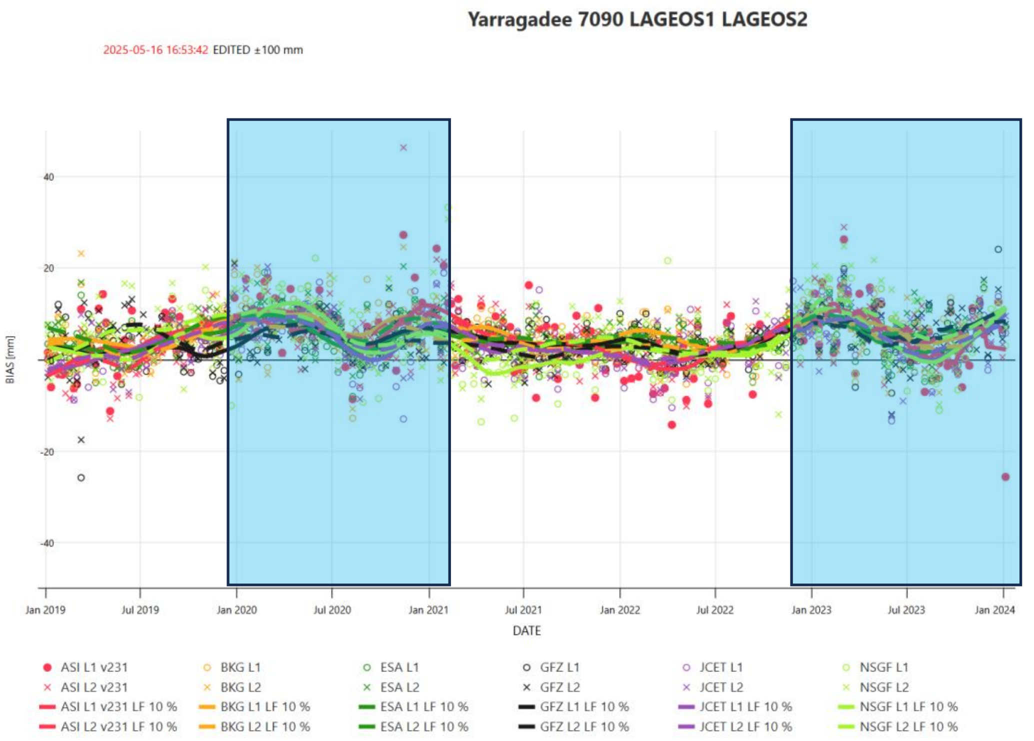
- Station height residuals highlighted in blue is where the LAGEOS-1 and LAGEOS-2 range biases were estimated
- A fixed RB is to be applied for LARES-2
- Assume no bias for Etalon data since day 208, 2014

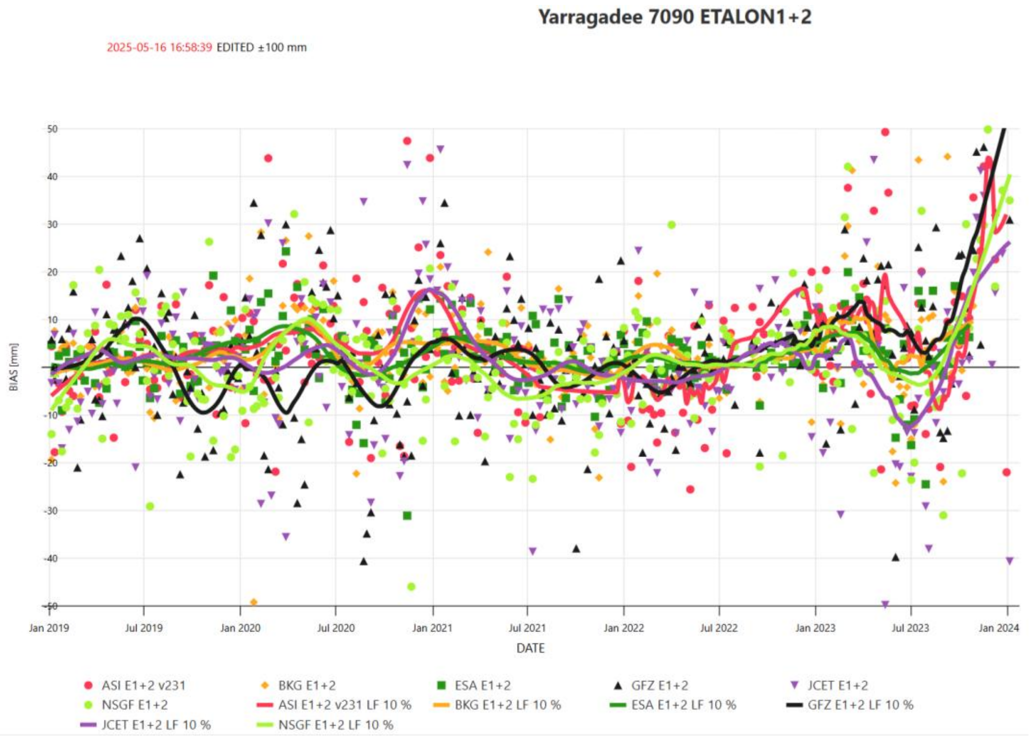
Data Handling File (DHF) sorted by satellite, time

CODE	PT	START_DATE__	END_DATE___	M	__E-VALUE__	STD_DEV	UNIT
7090	51	93:001:00000	96:364:00000	R	3.8	0.3	mm
7090	51	96:364:00000	02:116:00000				
7090	51	02:116:00000	10:059:00000	R	-1.7	0.2	mm
7090	51	10:059:00000	14:208:00000				
7090	51	14:208:00000	19:363:00000	R	2.0	0.2	mm
7090	51	19:356:00000	21:066:00000	E			mm
7090	51	21:066:00000	22:324:00000	R	2.6	0.3	mm
7090	51	22:324:00000	00:000:00000	E			mm
7090	52	93:001:00000	96:364:00000	R	2.9	0.3	mm
7090	52	96:364:00000	02:116:00000				
7090	52	02:116:00000	10:059:00000	R	-1.5	0.2	mm
7090	52	10:059:00000	14:208:00000				
7090	52	14:208:00000	19:363:00000	R	2.2	0.2	mm
7090	52	19:356:00000	21:066:00000	E			mm
7090	52	21:066:00000	22:324:00000	R	3.2	0.3	mm
7090	52	22:324:00000	00:000:00000	E			mm
7090	67	22:212:00000	00:000:00000	R	3.6	0.3	mm
7090	53	93:001:00000	99:185:00000	E			mm
7090	53	99:185:00000	03:201:00000				
7090	53	03:201:00000	14:208:00000	R	-7.8	0.3	mm
7090	53	14:208:00000	00:000:00000				
7090	54	93:001:00000	99:185:00000	E			mm
7090	54	98:135:00000	03:201:00000				
7090	54	03:201:00000	14:208:00000	R	-7.8	0.3	mm
7090	54	14:208:00000	00:000:00000				

DHF Legend	
PT: Satellite ID	M: DHF Code
51: LAGEOS-1	R: Applied Fixed RB
52: LAGEOS-2	E: Estimate RB
67: LARES-2	Assume No RB
53: Etalon-1	(note: not in DHF)
54: Etalon-2	

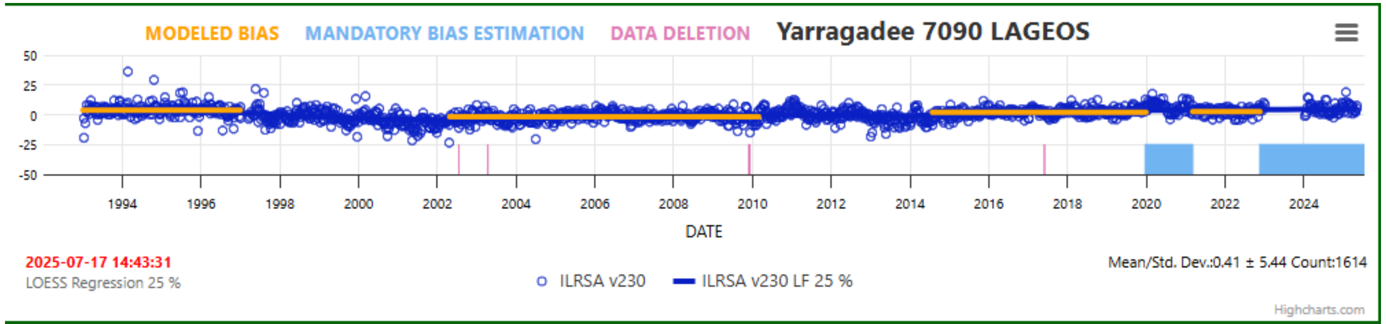
7090 YARL SSEM RB Estimates (since January 2019)

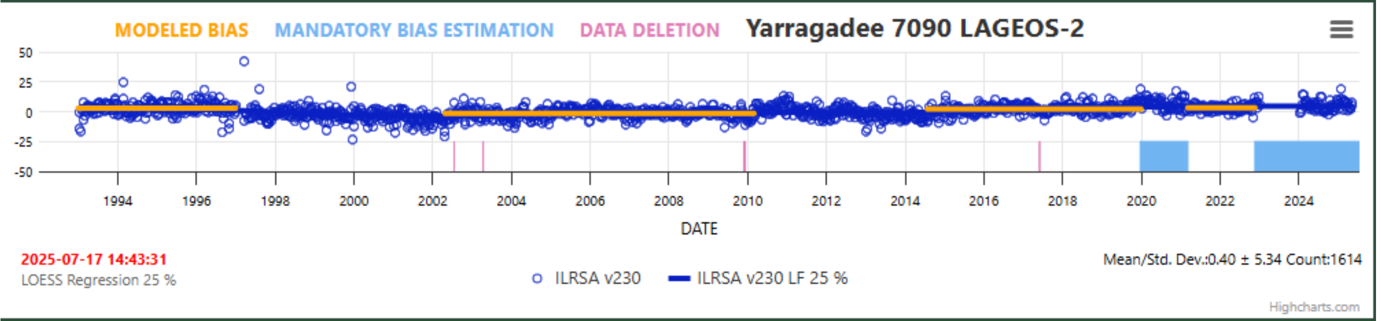


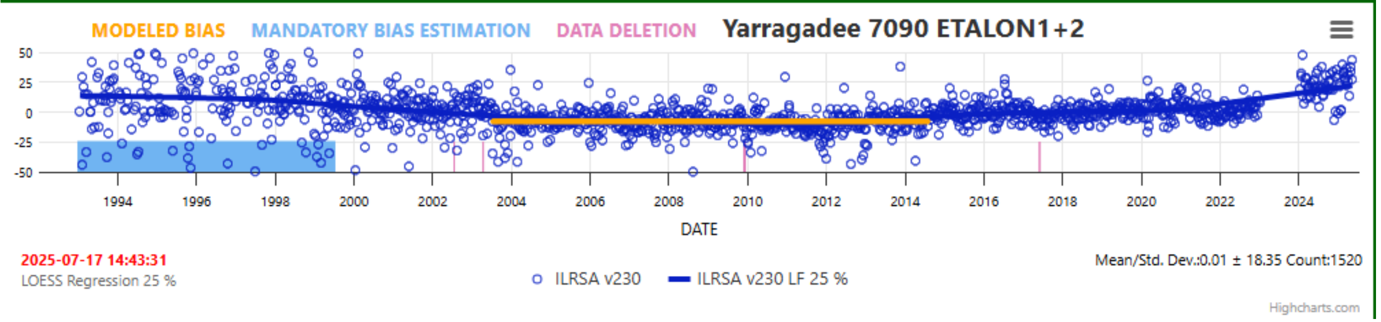


- The two periods where LAGEOS (-1,-2) RBs are estimated are highlighted in blue on the left chart
- The Etalon RBs, starting in 2023, appeared to be drifting upwards, but based on the DHF, assume no Etalon RB since 27-Jul-2014. Note: the high sensitivity laser receiver used to track Etalon was replaced on 21-Oct-2023

7090 YARL SSEM-X RBs (V230+V280 Product)

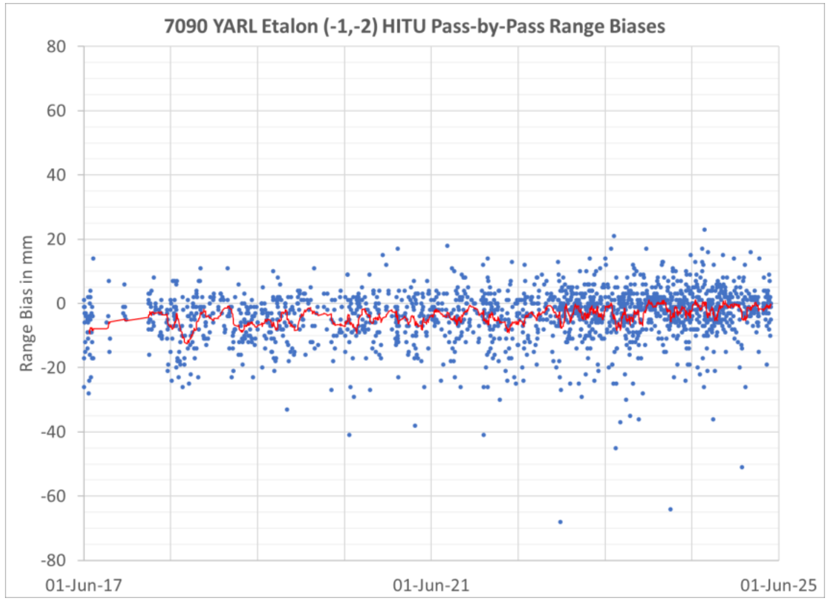


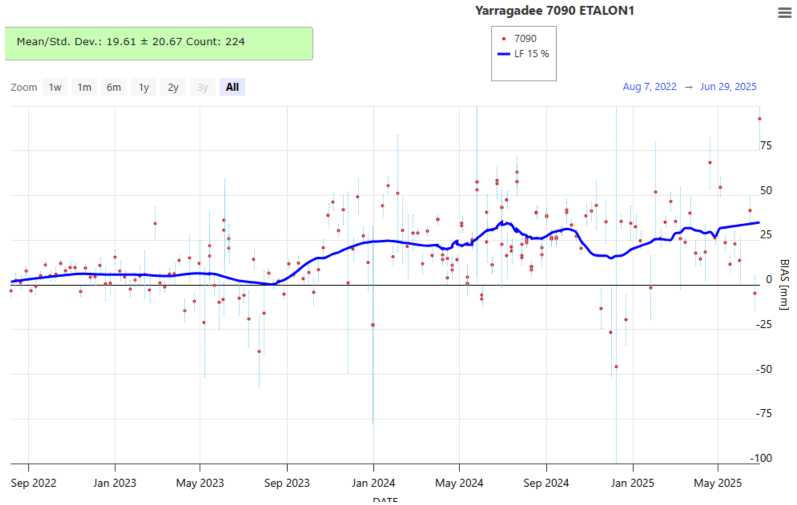


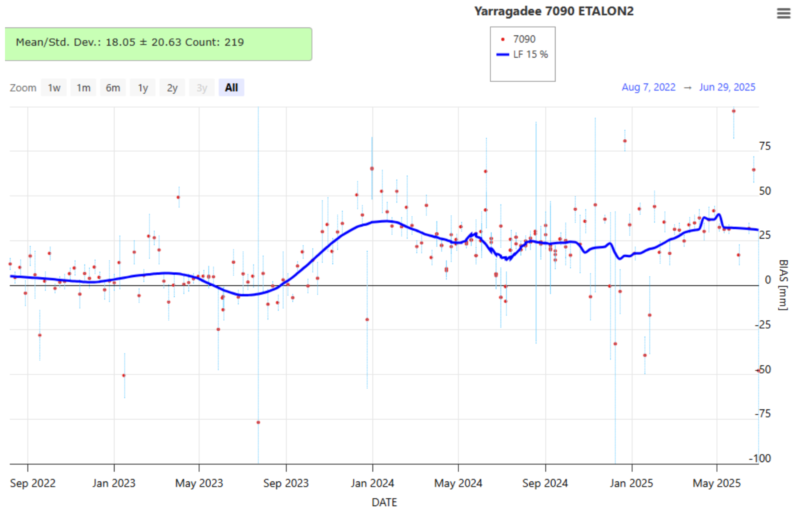


- Here are the SSEM-X 7090 YARL weekly time series of LAGEOS-1, LAGEOS-2 and Etalon RBs
- The 7090 Etalon RBs in 2024 are biased by more than +20 mm
- Since the 2023 results were not available in the JCET DB, was the Etalon RB change instantaneous or gradual?

7090 YARL Etalon Range Bias Comparisons

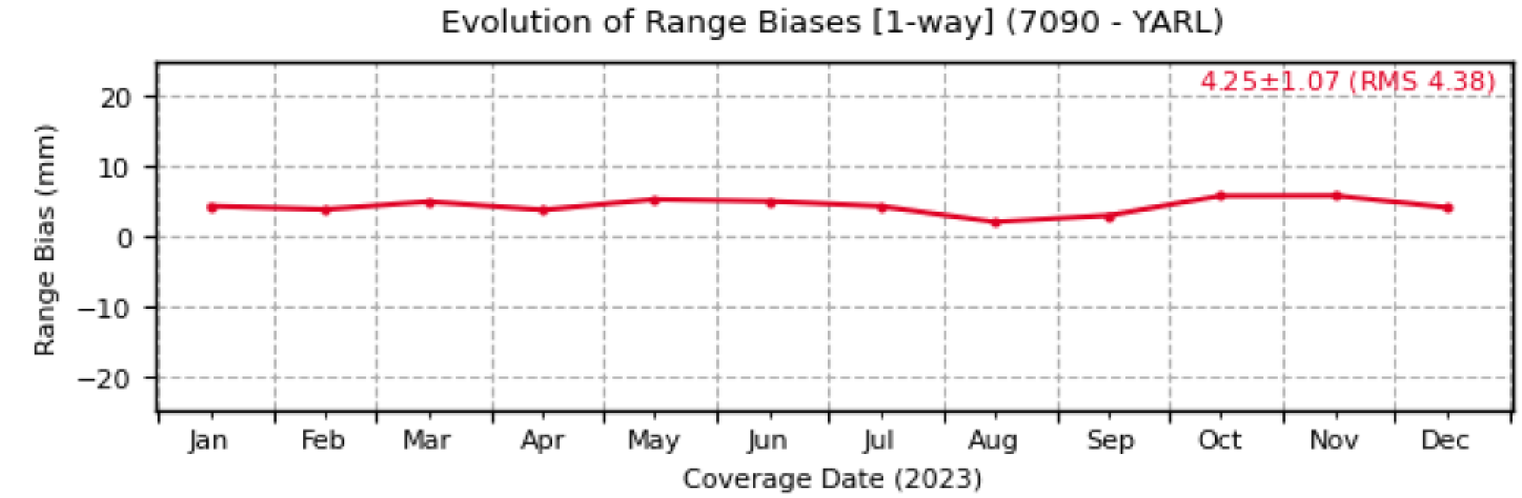


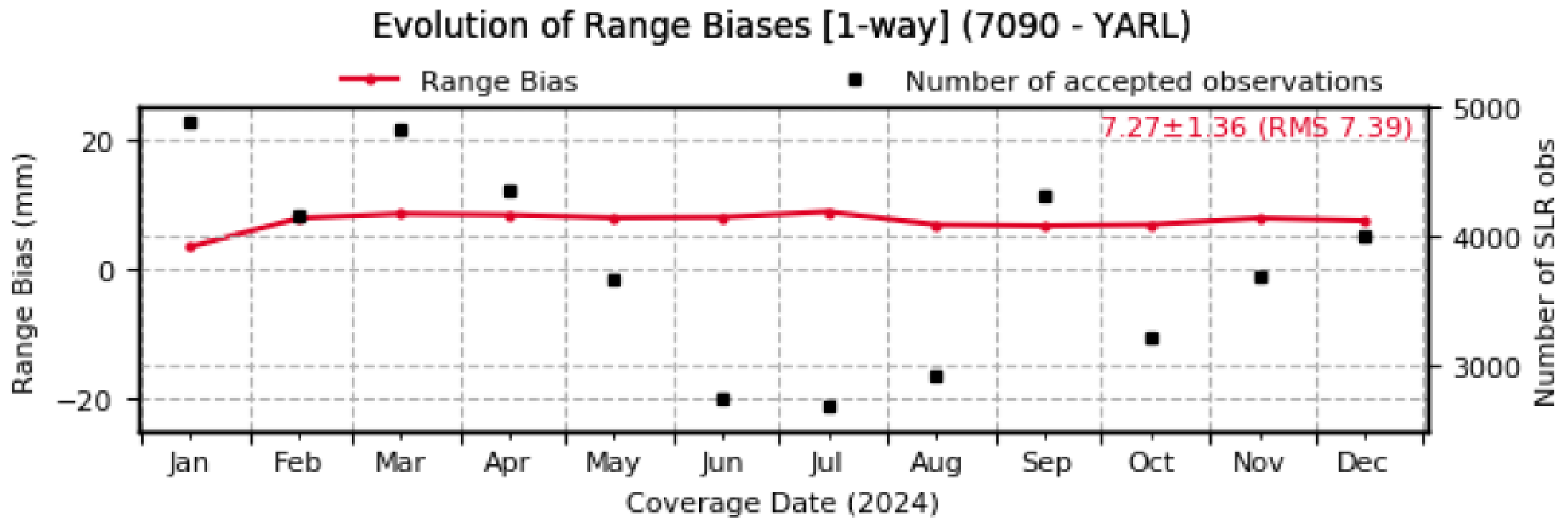




- **Left chart are HITU 7090 Etalon (-1,-2) pass-by-pass range biases using ITRF coordinates. No obvious change in the bias**
- **Middle and right chart are JCET weekly Etalon-1 and -2 RB estimates; respectively, using ITRF2020 coordinates**
- **JCET, SSEM-X and SSEM Etalon results exhibit an ~+25mm change in the 7090 RB, that coincides when a new secondary receiver chain was implemented on 21-Oct-2023. However; the HITU Etalon RB results do not. The HITU Etalon orbits must have absorbed this RB change. >99% of the Etalon NPs in the southern hemisphere came from Australia with Yarragadee providing 87% of the total southern hemisphere NPs**

7090 YARL GMV Sentinel Range Biases in 2023 and 2024





- The mean GMV 7090 Sentinel (-3A,-3B, -6A) yearly RBs in 2023 and 2024 were +4.25 and +7.27 mm; respectively, with RB stabilities of 1.07 and 1.36 mm
- RB Summary:
  - 7090 LAGEOS (-1,-2); Sentinel (-3A,-3B,-6A) and Etalon RBs in 2023 and 2024 are all positive
  - What is/are the root cause(s) of these RBs

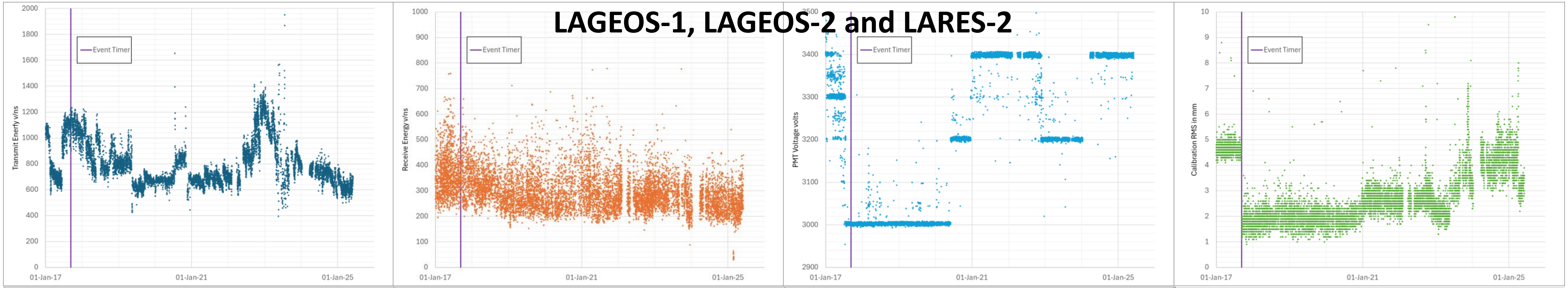
7090 YARL
Systematic Error Sources

Potential Error Sources:

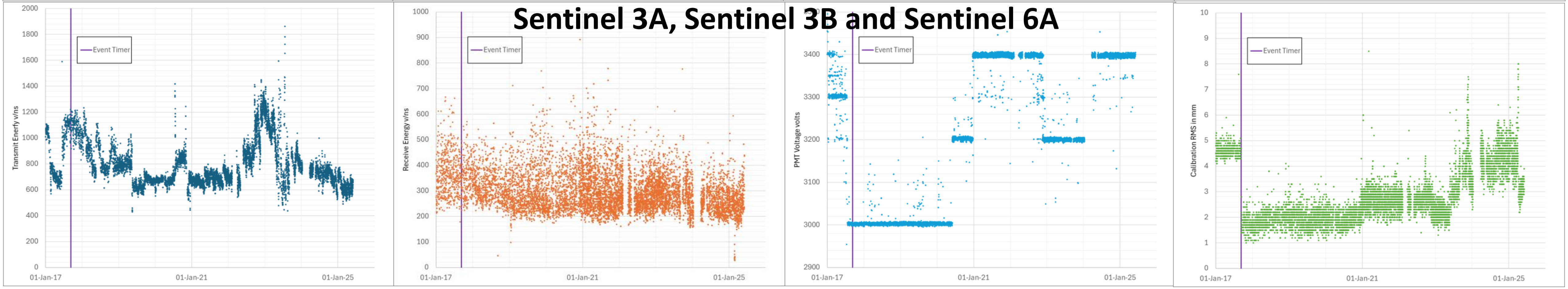
Calibration, Tropospheric, Local Survey

Calibration Data Analysis (LAGEOS/LARES-2 and Sentinel)

LAGEOS-1, LAGEOS-2 and LARES-2



Sentinel 3A, Sentinel 3B and Sentinel 6A

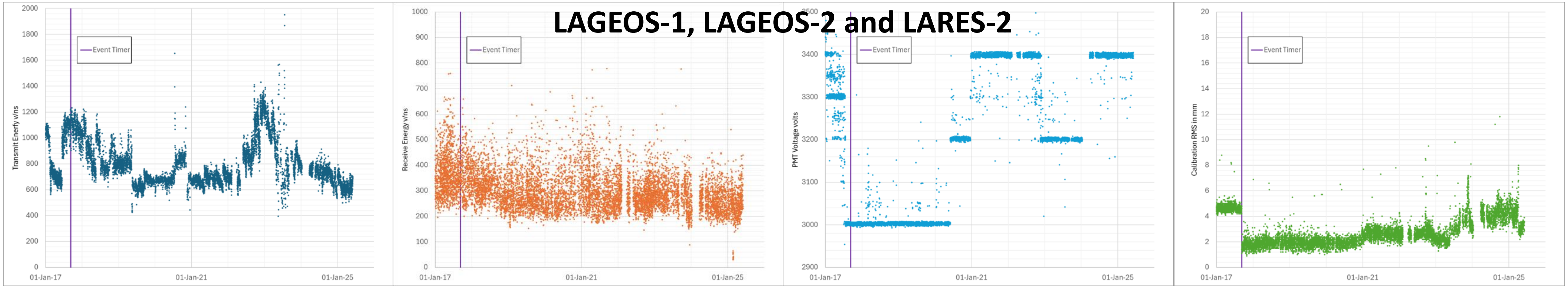


Legend	
Transmit Energy	PMT Voltage
Receive Energy	Calibration RMS

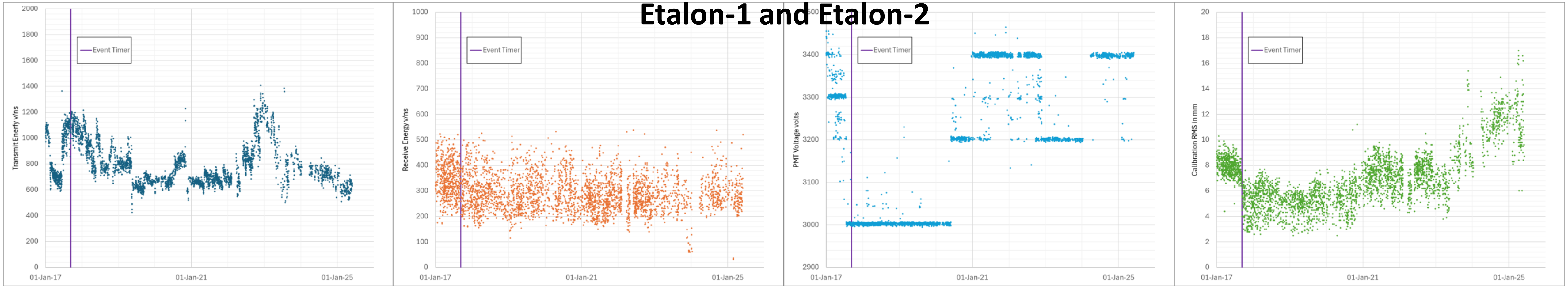
- **The calibration RMS is dependent upon the transmit energy; the receive energy, the PMT Voltage; the detector and the time-of-flight device. To maximize NASA SLR data yield one calibration is applicable to LEOs and MEOs, while a second calibration is applied to HEOs.**

Calibration Data Analysis (LAGEOS/LARES-2 and Etalon)

LAGEOS-1, LAGEOS-2 and LARES-2



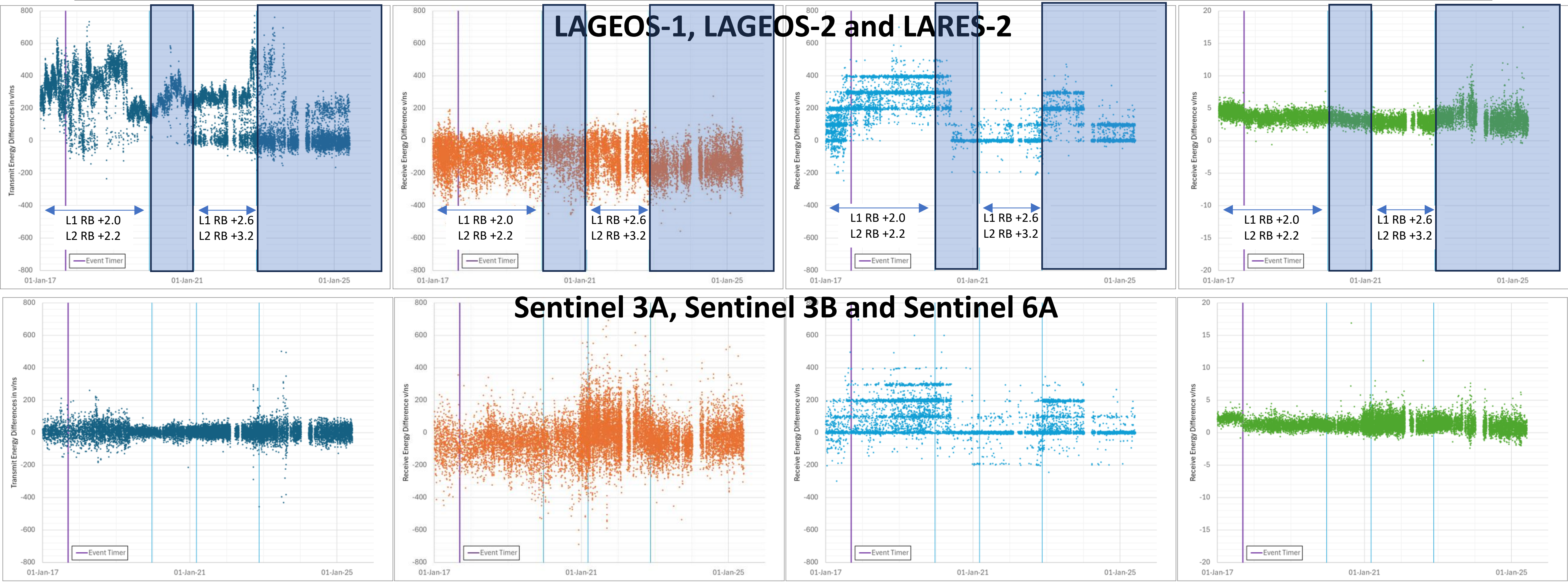
Etalon-1 and Etalon-2



Legend	
Transmit Energy	PMT Voltage
Receive Energy	Calibration RMS

- ❑ **The calibration RMS is dependent upon the transmit energy; the receive energy, the PMT Voltage; the detector and the time-of-flight device. To maximize NASA SLR data yield one calibration is applicable to multi-satellites, except Etalon**

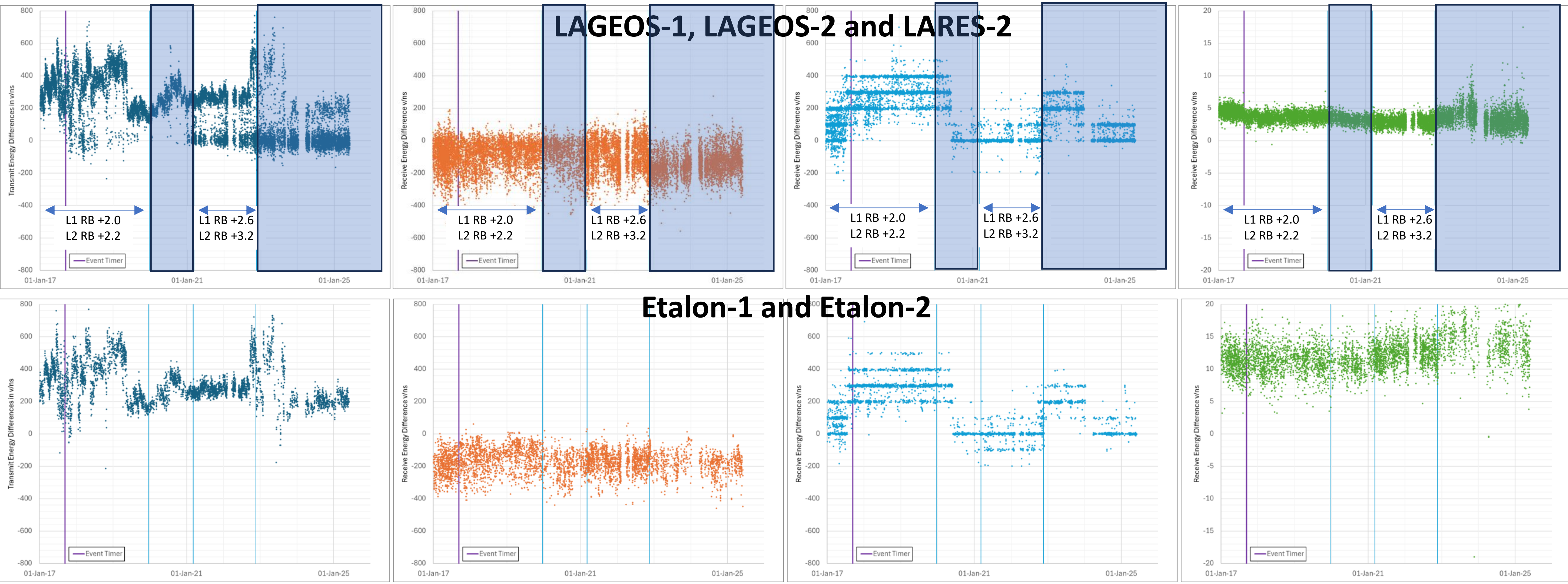
How well is the Satellite Data Calibrated? (Satellite minus Calibration)



Legend	
Transmit Energy	PMT Voltage
Receive Energy	Calibration RMS

- ❑ **In general, Sentinel data is better calibrated in terms of laser transmit energy, receive energy and PMT Voltage. Periods highlighted in blue is where LAGEOS RBs were estimated**

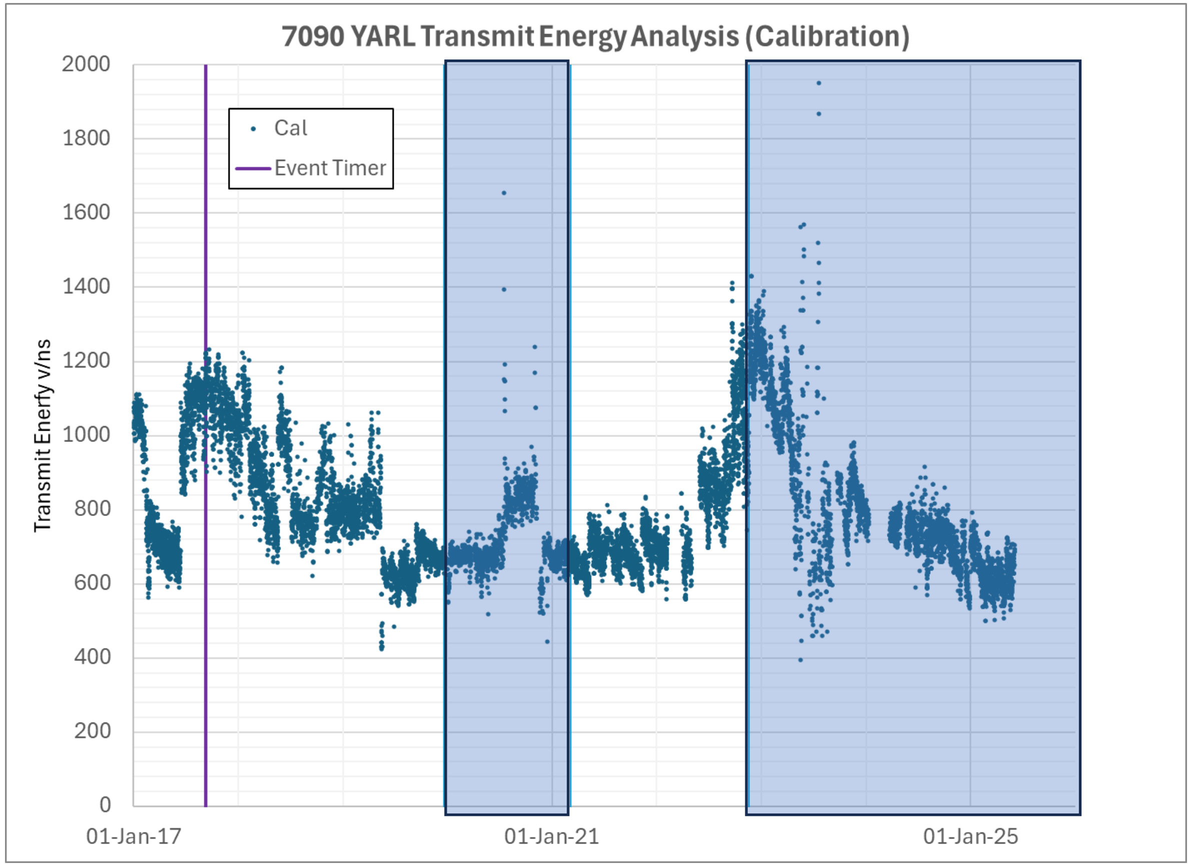
How well is the Satellite Data Calibrated? (Satellite minus Calibration)

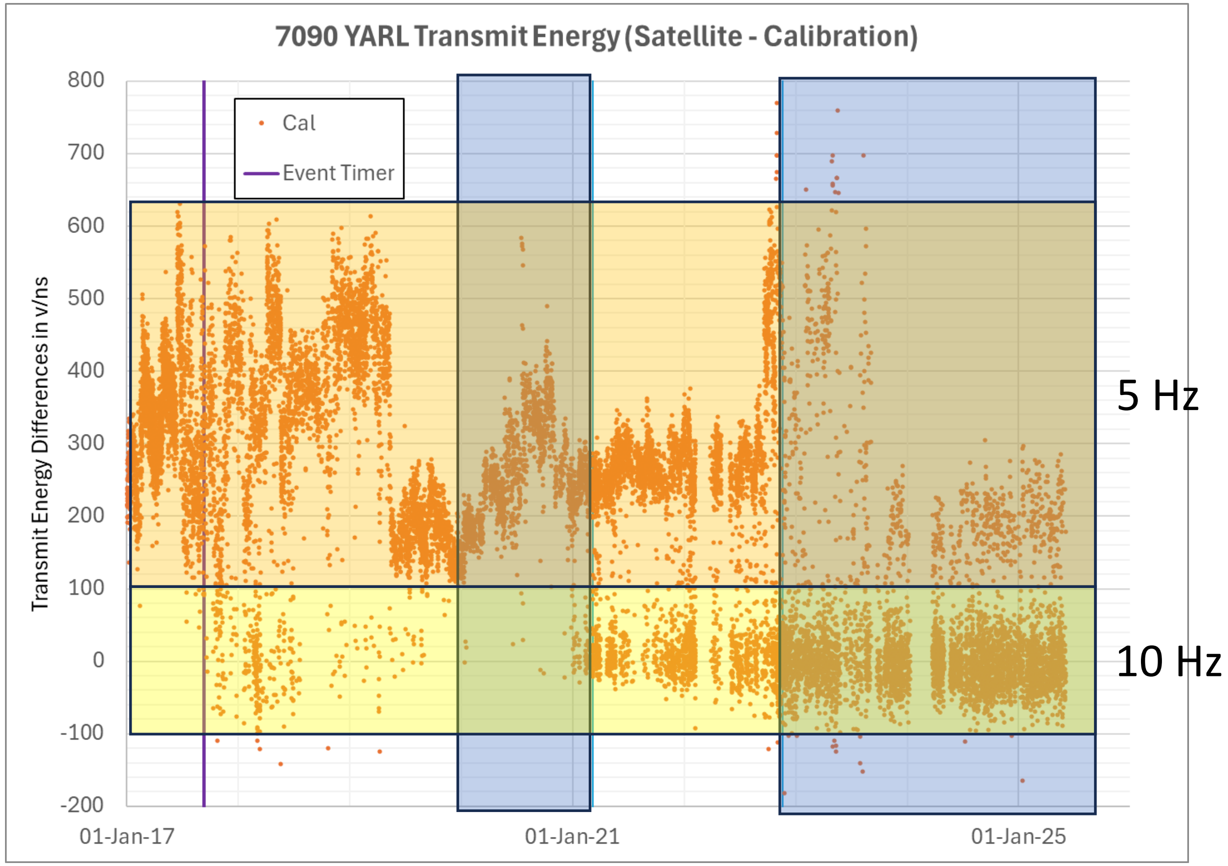


Legend	
Transmit Energy	PMT Voltage
Receive Energy	Calibration RMS

- ❑ Based on the DHF, the 7090 Etalon data is bias free since 27-Jul-2014, but not according to the SSEM results for 2023

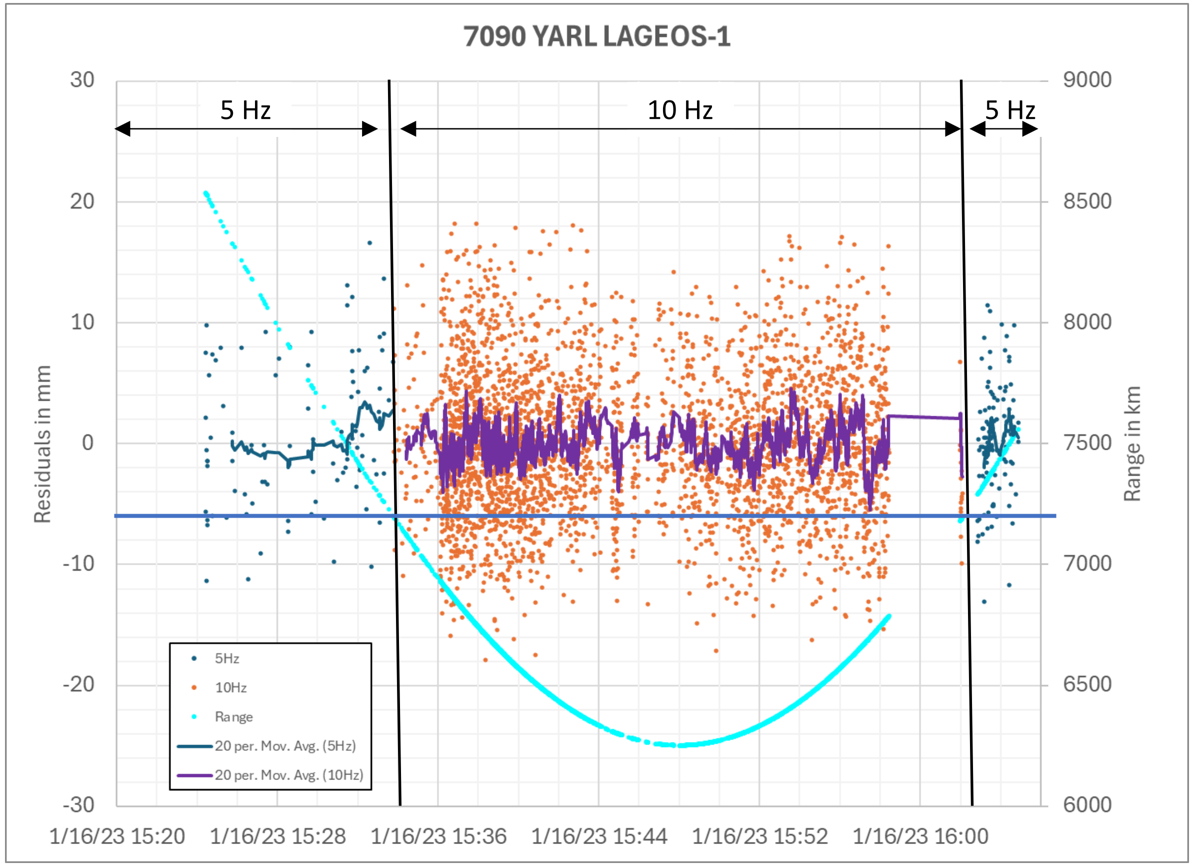
7090 YARL Laser Transmit Energy Analysis (LAGEOS and LARES-2 Pass Segments)

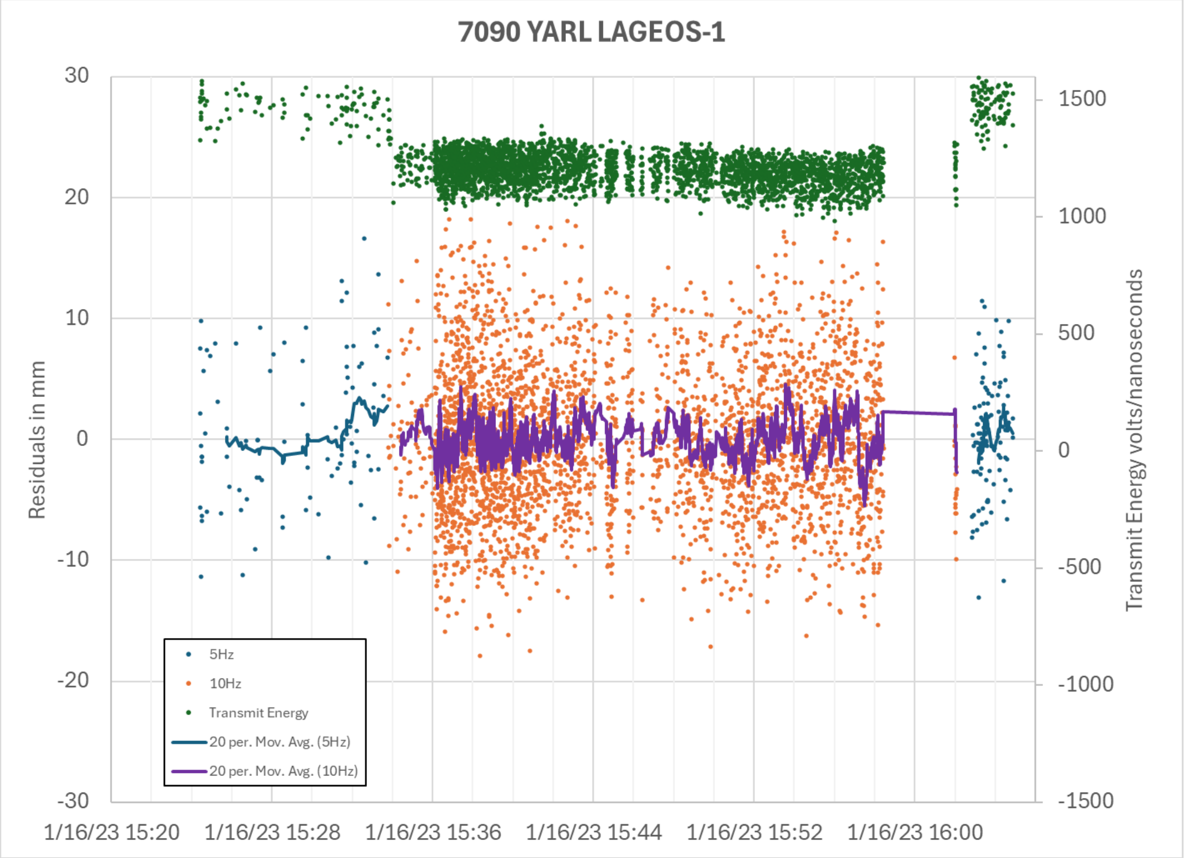




- The laser was upgraded in 2009; maximum firerate increased from 5 to 10 Hz. Since 2009 and pre–Event Timer, calibration and LEOs taken at 10 Hz, while LAGEOS and Etalon taken at 5 and 4 Hz; respectively. Post Event timer; LAGEOS could be tracked at 5 or 10 Hz depending upon the range, but the laser can only be optimized at one firerate. At least two characteristics of the laser change between 5 and 10 Hz, beam divergence and transmit power.

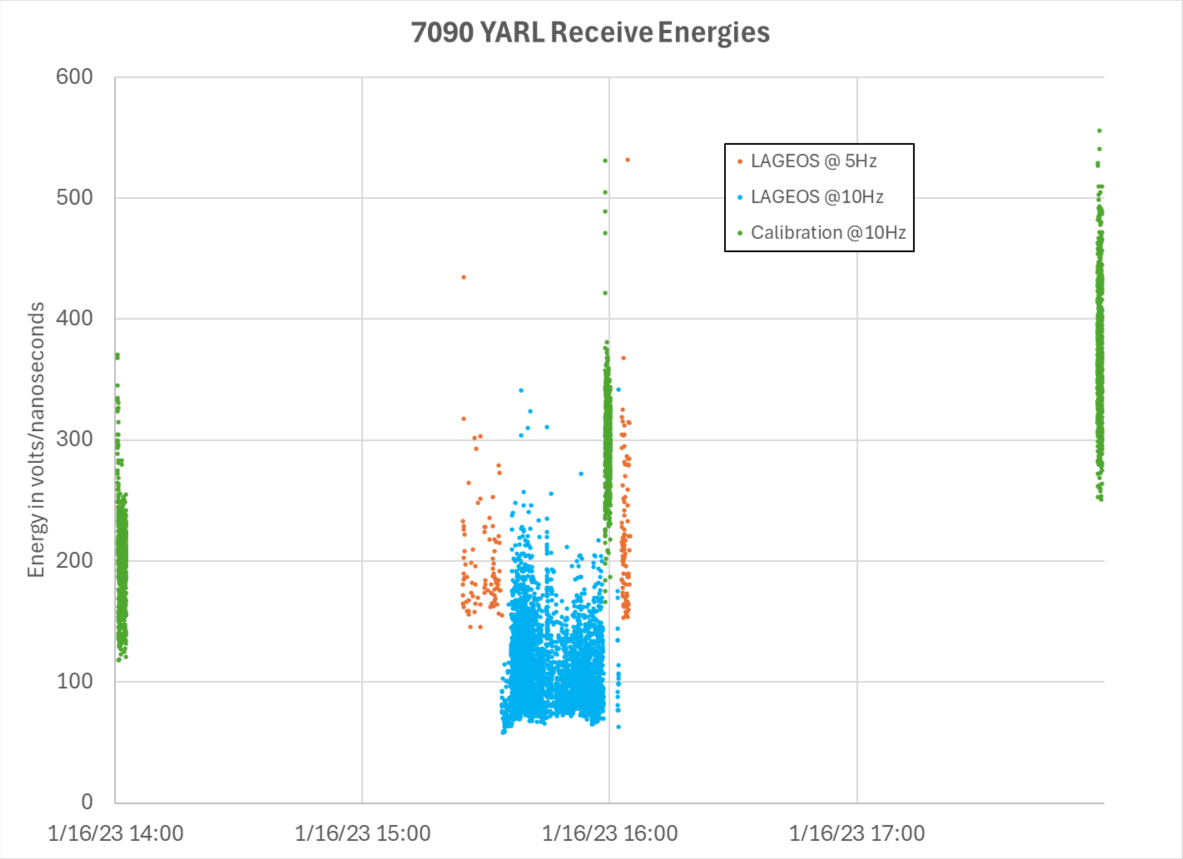
7090 YARL LAGEOS-1 on 16-Jan-2023

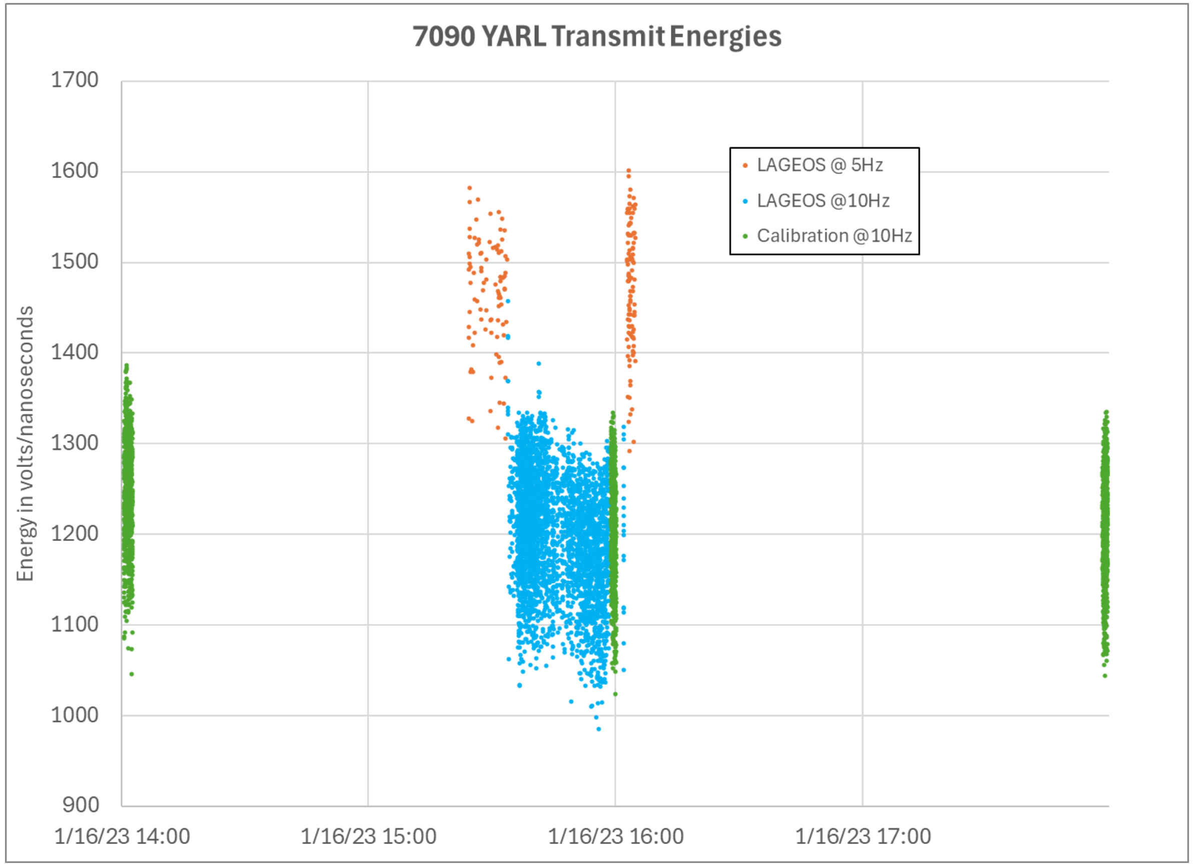




- ❑ **OrbitNP 7090 fullrate residuals. Station switches between 5 and 10 Hz ranging based on a satellite range of ~7200 km (left chart). The laser is optimized at 5 Hz, see laser transmit energy on right chart. The beam divergence also changes when switching from 5 to 10 Hz. Data yield and residual scatter increases at 10 Hz**

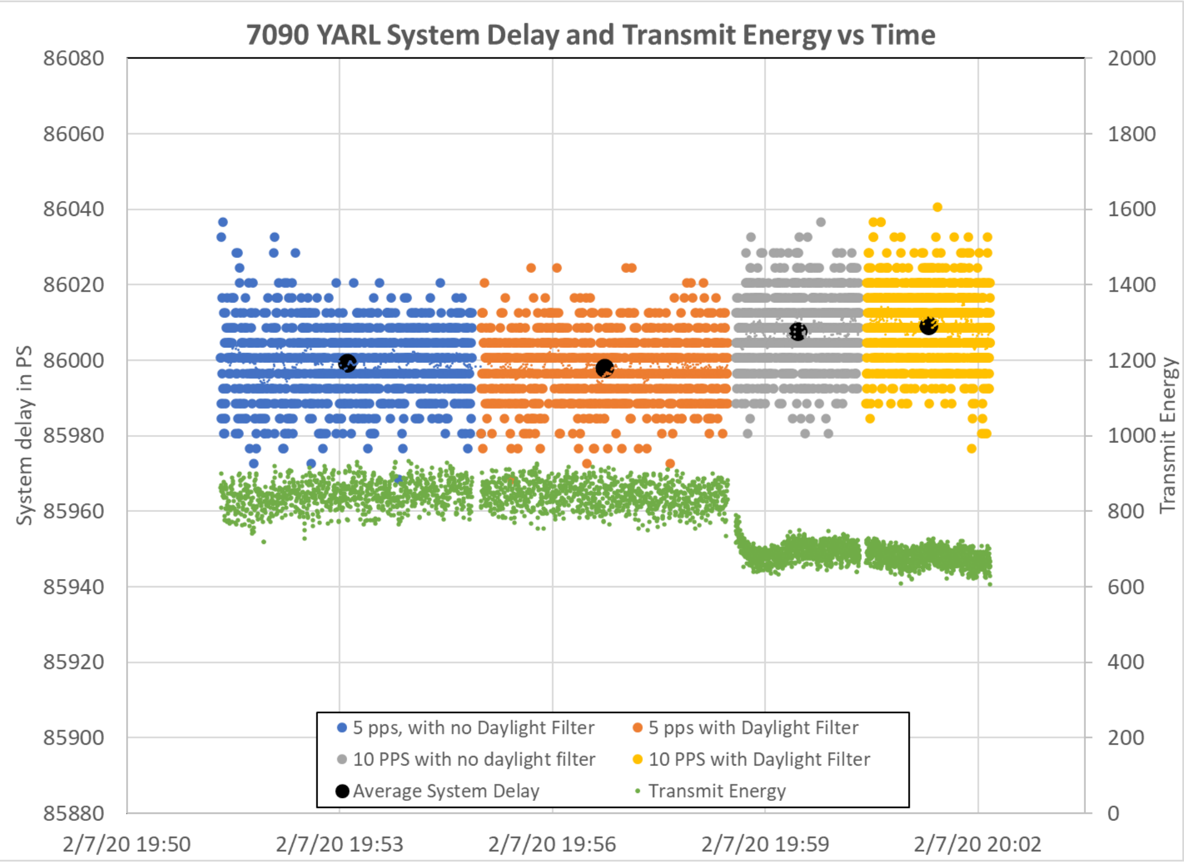
7090 YARL LAGEOS-1 on 16-Jan-2023

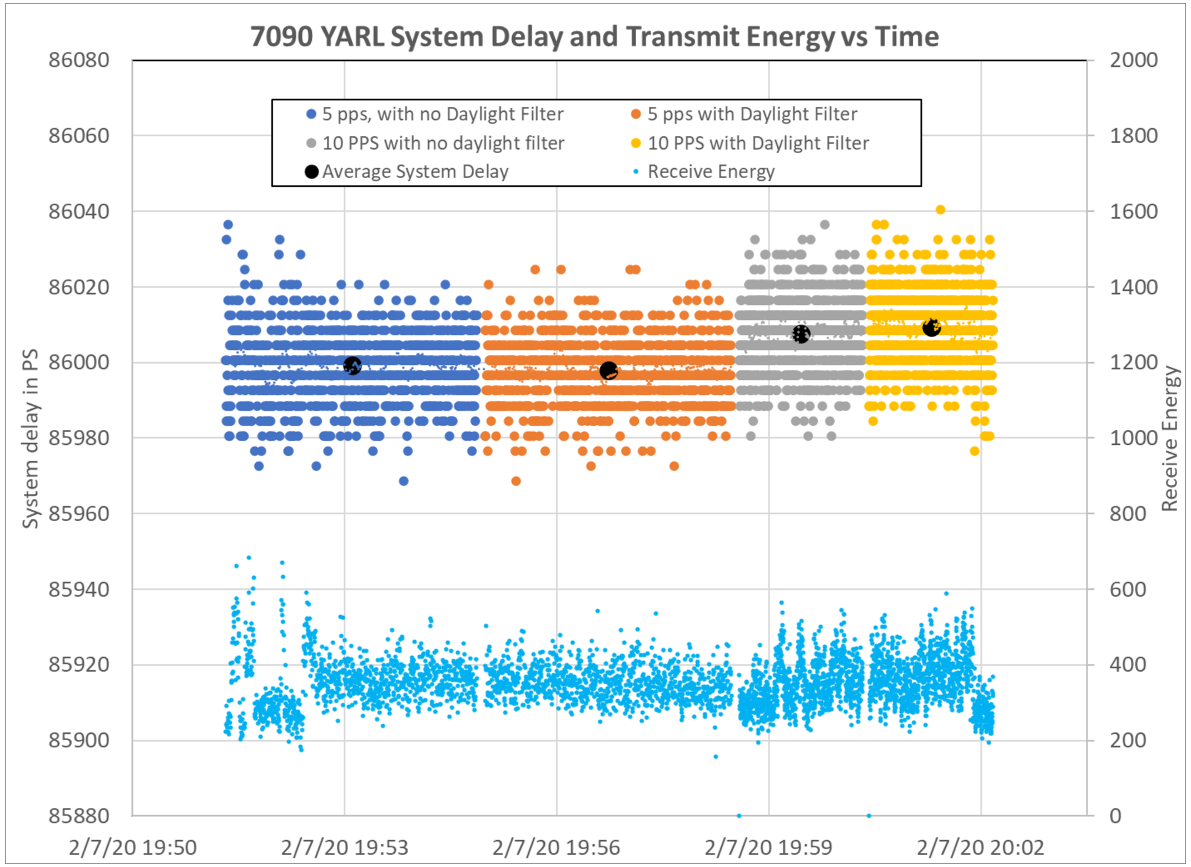




- **Here is a time series of receive and transmit energies including calibration data. A calibration was interleaved towards the end of the LAGEOS pass**
- **Calibration data is taken at 10 Hz and at least once every 2 hours. LAGEOS data is taken at 5 or 10 Hz dependent upon the satellite range due to gating constraints**
- **Different parts of the LAGEOS pass had different calibrations applied which is a potential source of systematic error. The 5 Hz data is better calibrated in terms of receive signal strength, but the 10 Hz data is better calibrated in terms of laser transmit energy.**

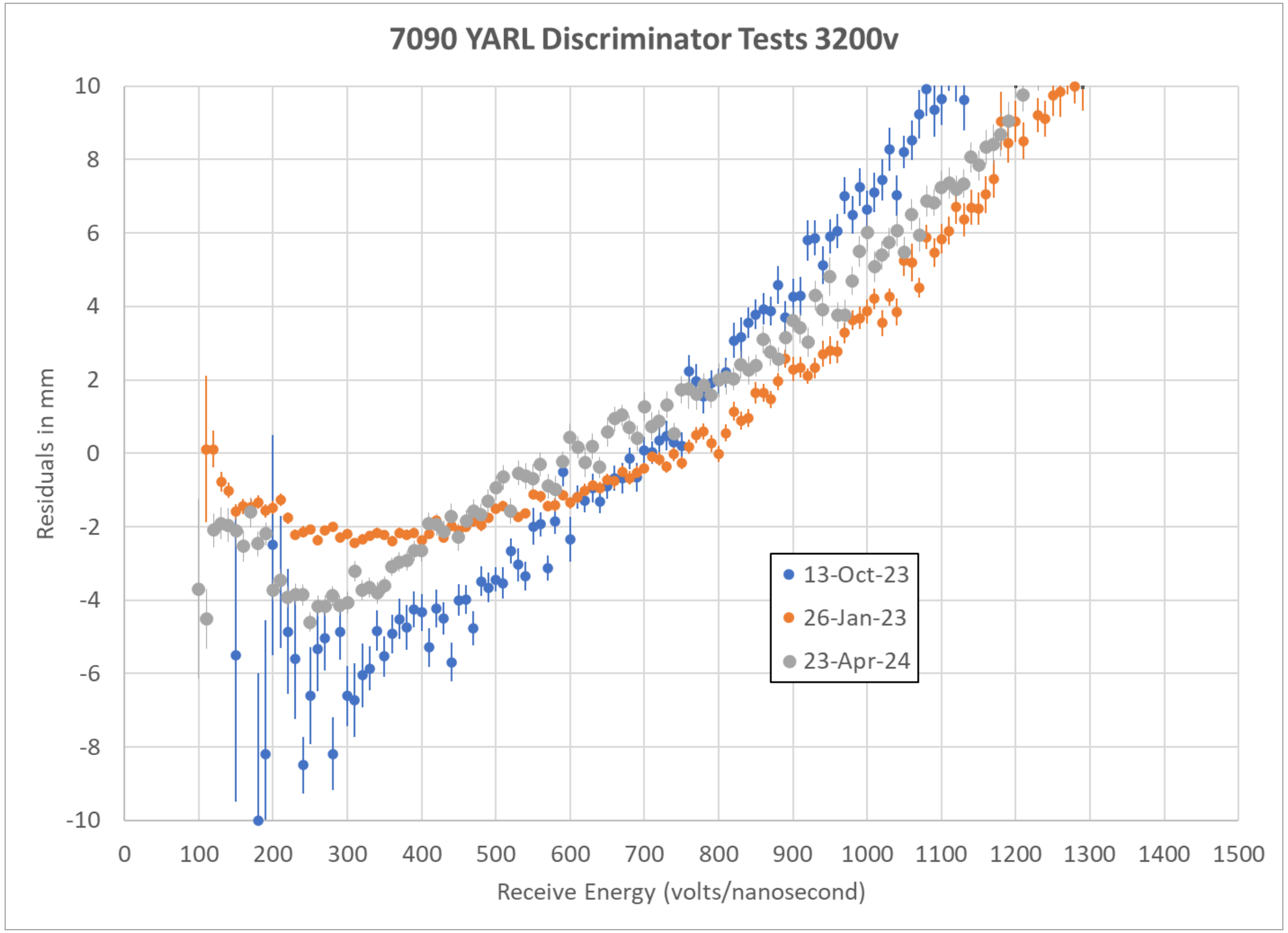
7090 YARL Laser Fire Rate Characterization Test





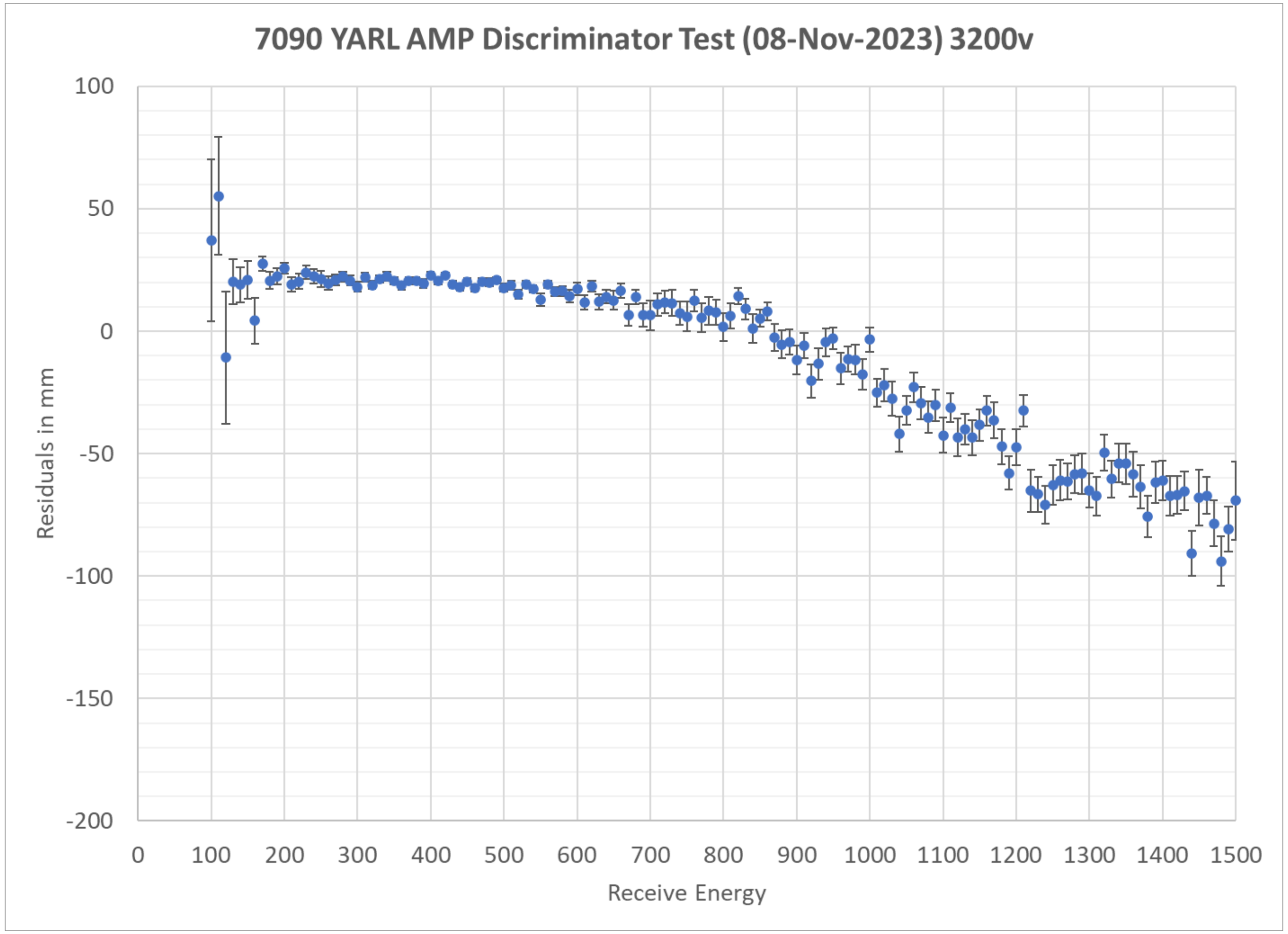
- **This was a laser fire rate characterization test from early 2020, indicating a 10 ps (1.5 mm) bias between ranging at 5 versus 10 Hz on a ground target. The NASA SLR systems have dual cascading constant fraction discriminators on both the transmit and receive side. Since 28-Sep-2009, all calibration data were taken at 10 Hz, but LAGEOS data was always at 5 Hz until the Event Timer Installation on 11-Sep-2017**

7090 YARL Receive Discriminator Characterization Test (Primary)



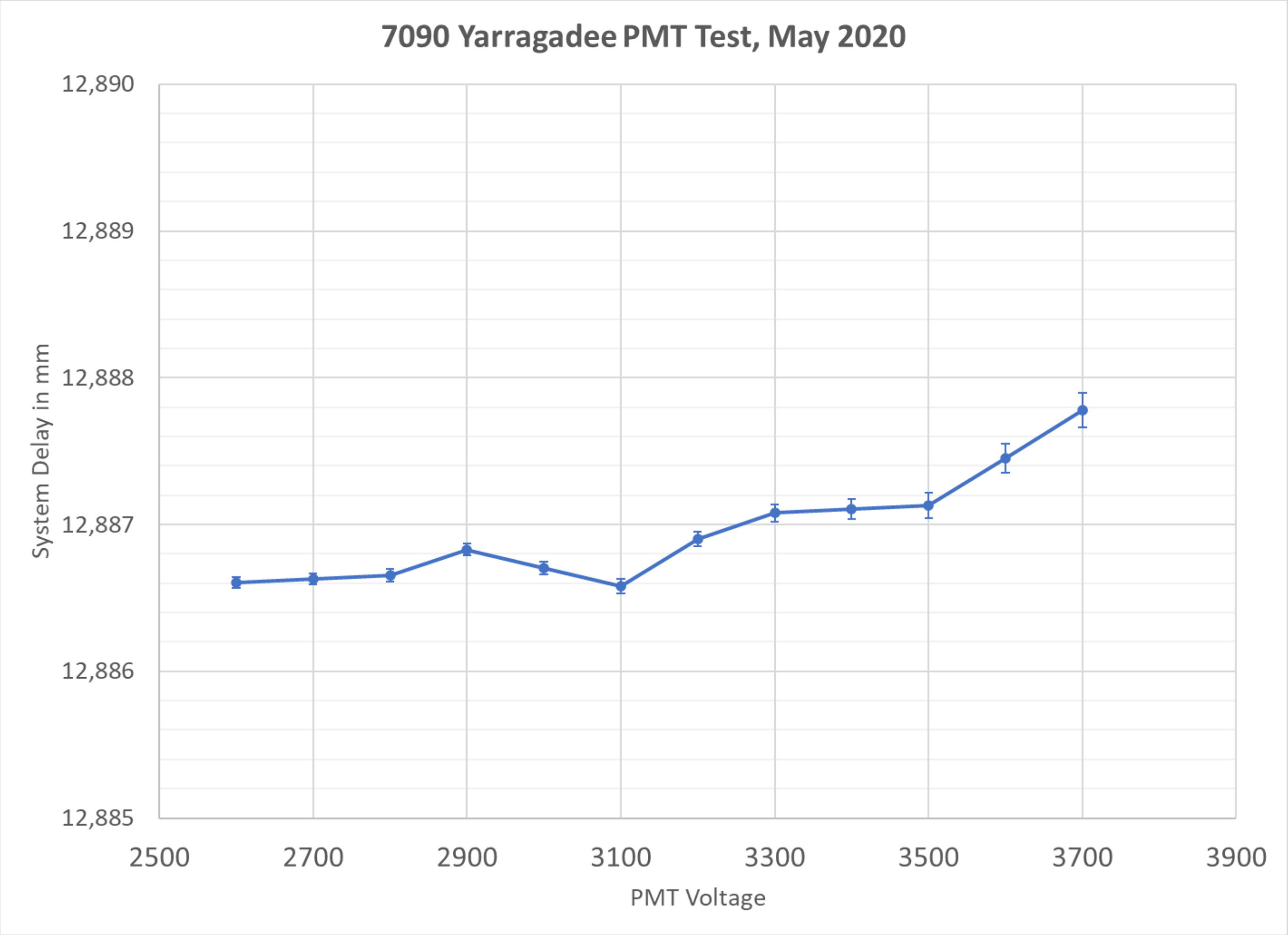
- ❑ Near the threshold of the receive discriminator, the scatter and system delay increase
- ❑ Calibration data are typically taken in the 200 to 500 volts/nanosecond range
- ❑ LAGEOS and LARES data is more concentrated below 200 volts/ns
- ❑ The October 2023 results, which are near the November 2023 single shot RMS peak, show more timewalk than the January 2023 test

7090 YARL Receive Discriminator Characterization Test (Secondary)



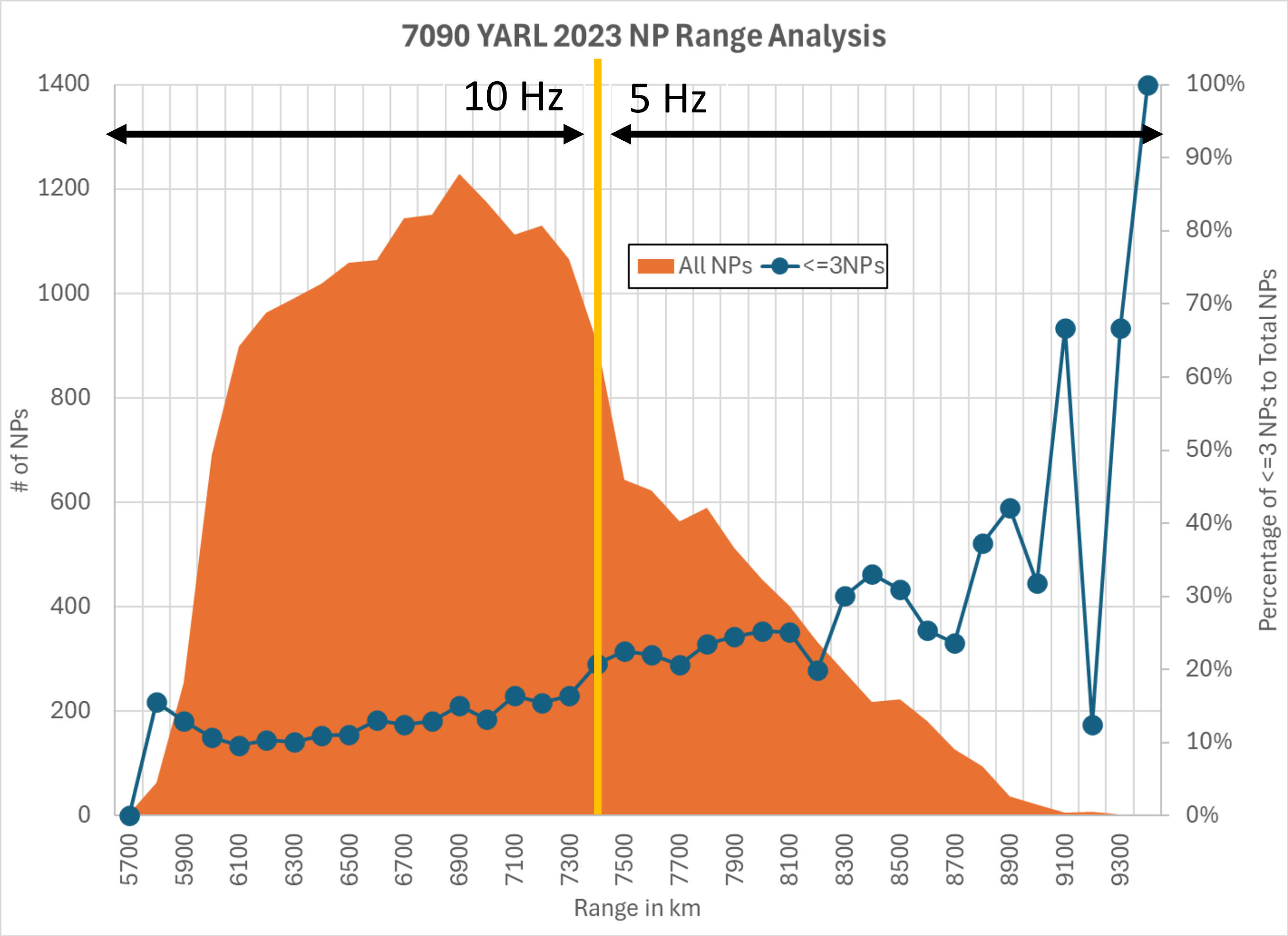
- ❑ Here is discriminator test from the secondary receiver chain, the Amplified Return Signal Unit (ARSU)/High Sensitivity Laser Receiver (HSLR)
- ❑ The primary and secondary receiver chains have separate cascading receive discriminators

7090 YARL PMT Voltage Characterization Test



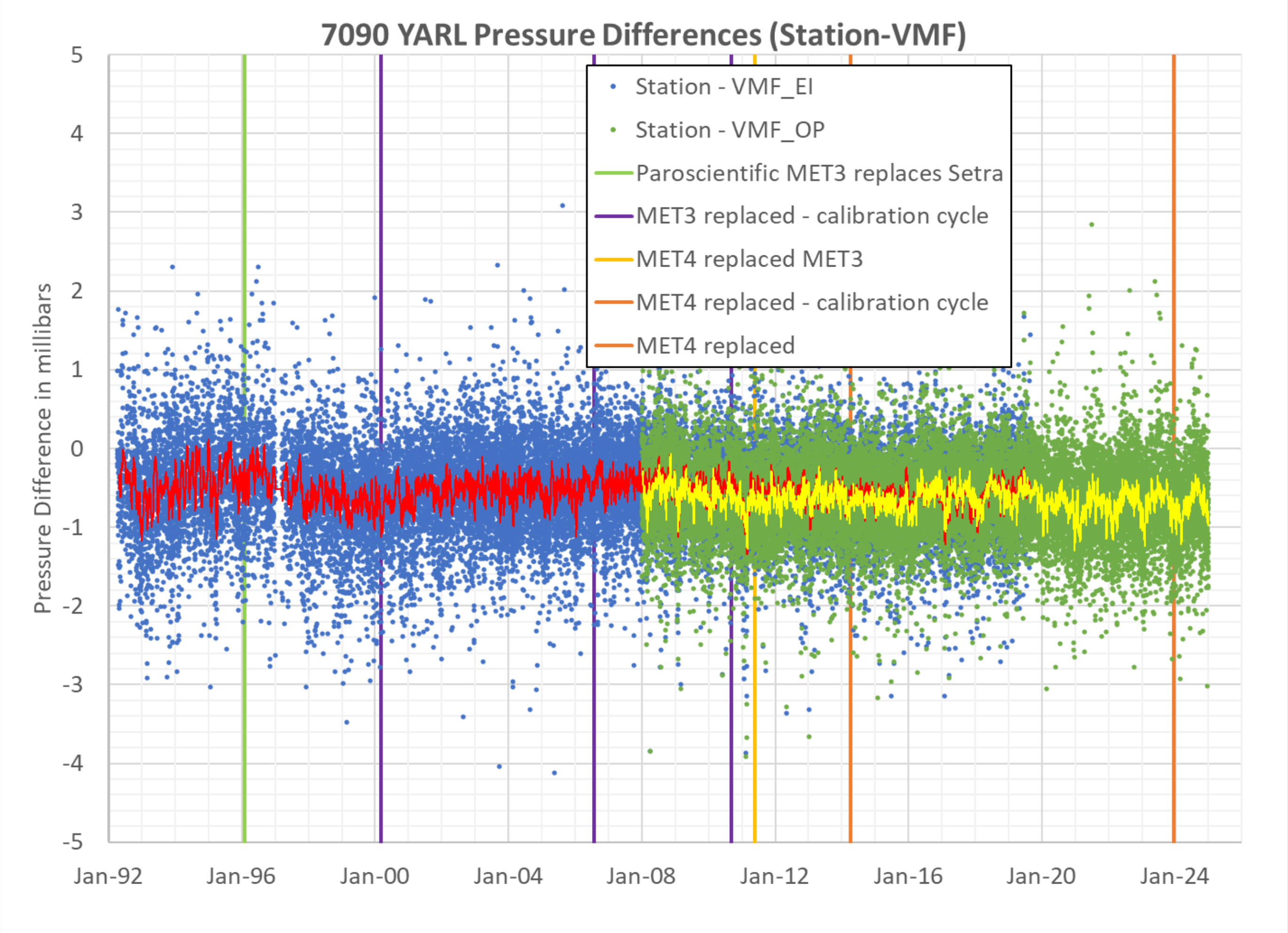
- **This test was taken in May 2020**
- **As the PMT Voltage increases, the system delay and RMS increase. The peak-to-peak variation was 1 mm**

7090 YARL 2023 NP Range Analysis (LAGEOS and LARES-2 Combined)



- ❑ **An area chart indicating the distribution of NPs per range**
- ❑ **Most NPs in 2023 were taken at 10 Hz**

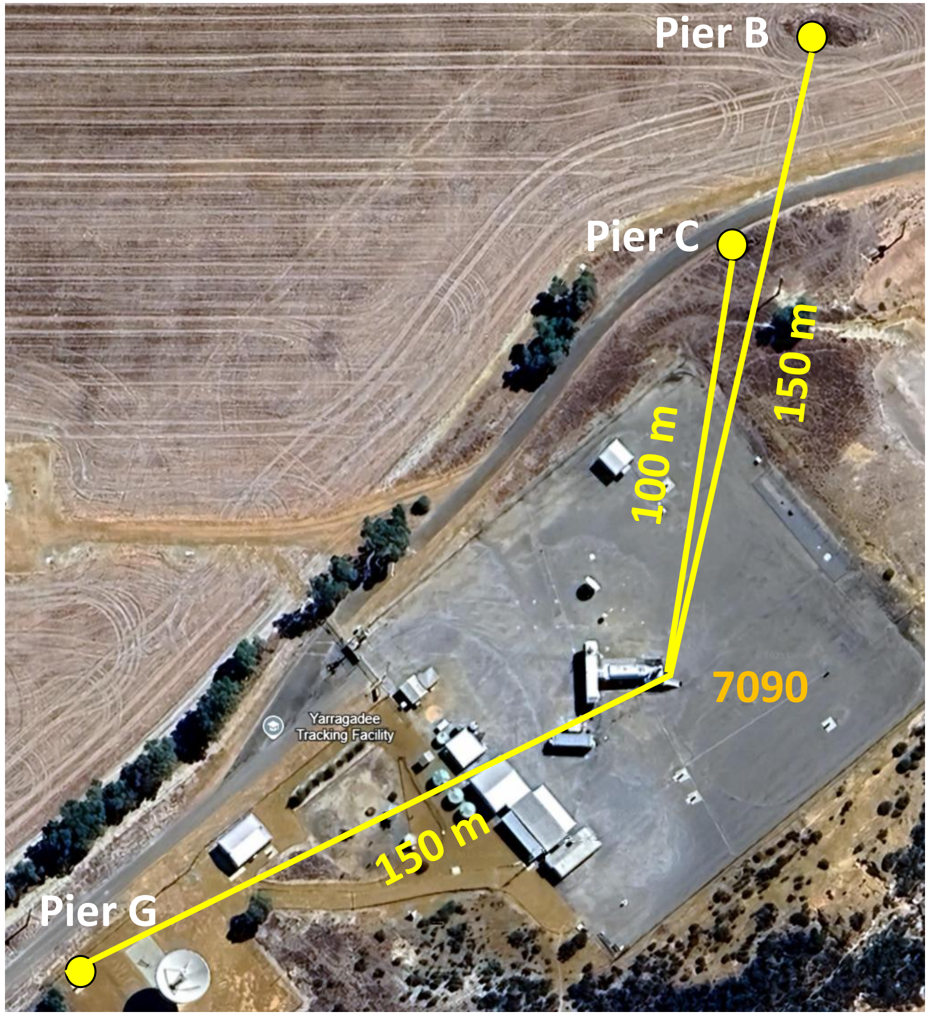
7090 YARL Barometric Analysis



- ❑ **7090 barometric pressure differences every six hours (Station minus VMF_EI and VMF_OP)**
- ❑ **The vertical bars on the chart is when the sensor was replaced with a freshly calibrated sensor**

MOBLAS-5 at 7090 YARL (Yarragadee)

- ❑ MOBLAS-5 has three calibration targets B, C, & G. Target B is prime
- ❑ The last four Geoscience Yarragadee surveys were 2007, 2010, 2014 and 2024. No final reports for 2007, 2010, and 2014 were published, but 7090 eccentricities were provided. A preliminary report exists for the June 2024 survey



7090 YARL System Eccentricities

Data Start	Data End	UNE	Up (m)	North (m)	East (m)	Delta Up (mm)	Delta North (mm)	Delta East (mm)	SOD	Comments
79:182:00000	83:207:86399	UNE	3.1850	0.0030	0.0110				70900501	
87:225:00000	87:237:86399	UNE	3.1770	0.0030	0.0100	(8.0)	0.0	(1.0)	70900506	
92:021:00000	92:083:86399	UNE	3.1813	-0.0096	0.0192	4.3	(12.6)	9.2	70900511	Post Mount Replacement
98:234:00000	03:330:86399	UNE	3.1809	-0.0083	0.0178	(0.4)	1.3	(1.4)	70900513	
03:331:00000	07:150:86399	UNE	3.1821	-0.0083	0.0184	1.2	0.0	0.6	70900513	
07:151:00000	10:195:86399	UNE	3.1823	-0.0062	0.0190	0.2	2.1	0.6	70900513	
10:196:00000	14:079:86399	UNE	3.1820	-0.0068	0.0164	(0.3)	(0.6)	(2.6)	70900513	
14:080:00000	24:154:86399	UNE	3.1827	-0.0064	0.0194	0.7	0.4	3.0	70900513	
24:155:00000	00:000:00000	UNE	3.1838	-0.0069	0.0201	1.1	(0.5)	0.7	70900513	Preliminary

- **Once the 2024 report is published, these eccentricity changes will be retroactive causing some rework by the end users and will result in small change in the RB estimates. Unfortunately, no one knows exactly when this change occurred since 2014**

7090 YARL Calibration Target Distance Changes

- Using the preliminary Geoscience Local Survey data from the 2024 report and using the NASA/NGS measured prism constants versus the Geoscience prism constants, the range to both the prime calibration Target B and the backup calibration target C have changed by the following amounts:
- If these 2024 values are correct, these distance changes alone would account for a +6.4 mm RB.

Target	onsite range (m)	2024 Survey Prel (m)	Delta in mm
B	150.4245	150.4181	6.4
C	100.4185	100.4127	5.8

Randall's Comments

❑ Randall's initial comments about high single shot RMSs in 2023

- Our main problems in 2023 were the laser induced instability caused by the non-optimal setting of the AML frequency synthesizer – as noted. Since correcting that, I believe we are now close to historic cal/pass RMS values for same MCP voltage settings. In 2022 we were running 3400V for non-amp calibrations as we are now – then we had an avg RMS of 2.7mm now we are running at 3.00mm(avg June/July). I suspect we could narrow the laser pulse slightly with tweaks of the bragg angle or cavity length and get back to a 2.5mm avg.
- We just tested 3200 and 3000V and they are giving us Calibration RMS of 1.9mm so I think that roughly puts us back to where we were pre laser troubles.
- Will run some lageos passes at 3200V tonight and see how that looks.

❑ Randall's initial comments about weak NPs

- I stopped most of my tracking duties around 2018/19 and unfortunately, I think I have induced some poor tracking practices in the observing team in my attempt to "keep the numbers up".
- I tried to emphasize the capability of tracking everything by interleaving as much as possible. In theory this can be done without sacrificing LAGEOS NP's but I think in the attempts to maximise segments, some NPs became sub-standard (too many low count NPs were produced). I am soon to implement a flag on our Daily Ops report that will alert the ops to low count NPs. Hopefully along with re-education this corrects that issue.
- Our system is also slowly degrading optically and obtaining optimal returns per NP is a harder task than it once was – especially in daylight.

Conclusions

- **The increase in scatter of the 7090 YARL ITRF2020_U2023 height residuals have several contributing factors**
  - In mid-November 2022, there was a noticeable change in calibration procedures in terms of PMT Voltage and Laser Fire Rates inducing some mm level systematic errors
    - Laser fire rate systematics are elevation dependence
  - In 2023, there were documented laser performance issues evidenced by the increase in single shot RMSs and an increase in receive discriminator timewalk; a decrease in total LAGEOS passes; a noticeable increase in ‘weak’ LAGEOS NPs at the longer ranges
  - Based on the ILRS Data Handling File starting on 20-Nov-2022, 7090 LAGEOS (-1,-2) range biases were to be estimated, but a constant RB was assumed for LARES-2 and no RBs were to estimated for Etalon since 27-Jul-2014
  - When there are systematic errors that are elevation dependent coupled with weak NPs at the longer ranges makes it more difficult to separate range biases from station height

Conclusions (con't)

- **The sources of the positive RBs in 2023 and 2024 have a few contributing factors**
  - The single biggest contributor is a ~+6 mm change in the distance to the primary calibration target
  - Receive Discriminator timewalk of a ~+2 mm at the weakest LAGEOS signal strengths
  - There was a change in the secondary receiver chain on 21-Oct-2023, which seems to correlate to a large change (+25mm) in the Etalon RB
  - Did a change in the secondary receiver result in a change in the Etalon Center of Mass (CoM) correction? (This change was documented in the station change history but was not documented in the site log)
  - A 1.1 mm change in the 'Up' eccentricity

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SLR RANGE BIASES ASSESSMENT AND OUTLOOK

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07/21/2025

SUMMARY

01
OVERVIEW

CONTEXT

- SLR data are crucial for mean sea level applications to :
  - provide strong tracking information to potentially complement GNSS or DORIS based orbits
  - derive a state-of-the-art independent validation of the orbit accuracy of altimetry-dedicated satellites, especially in the radial direction
- How to better use SLR observations and eventually reduce their systematic errors?
  - SLR validations of the orbit would need 1 mm RMS short-term accuracy, with long-term stability within 0.1 mm/yr per decade to monitor the evolution of climate-driven regional sea-level patterns (Meyssignac et al., 2023)

Clearing systematic range biases from SLR observations is also an essential step to meeting stringent future requirements such as for ESA's GENESIS mission or enabling the calibration of altimeter range biases for the next generation of altimetry missions

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 CN of SLR stations once their range biases are taken into account

METHOD

In this contribution, we use:

- Altimetry satellites to determine SLR station range biases: 1 bias per station per year
- Geodetic sphere (e.g., LAGEOS-1/2) measurement SLR residuals to assess the quality of the previously derived range biases

Systematic differences between the two independent approaches are analyzed, especially for well-performing laser stations with diverse detector types (e.g., single/multi-photon)

	Saquet et al. (2023)	CNES/CLS ILRS AC
Softwares	ZOOM (Carrou, 1986)	GINS combined with DYNAMO (Marty, 2011)
Orbits	Fixed (GNSS/DORIS CNES POE-G)	Simultaneously estimated (CNES/CLS ILRS AC)
Constellations	CryoSat-2, Saral/AltiKa, Sentinel-3A, Sentinel-6A	Lageos-1, Lageos-2, Lares-2
Station position	ENU adjusted	ENU adjusted
Elevation cut-off	10°	12°

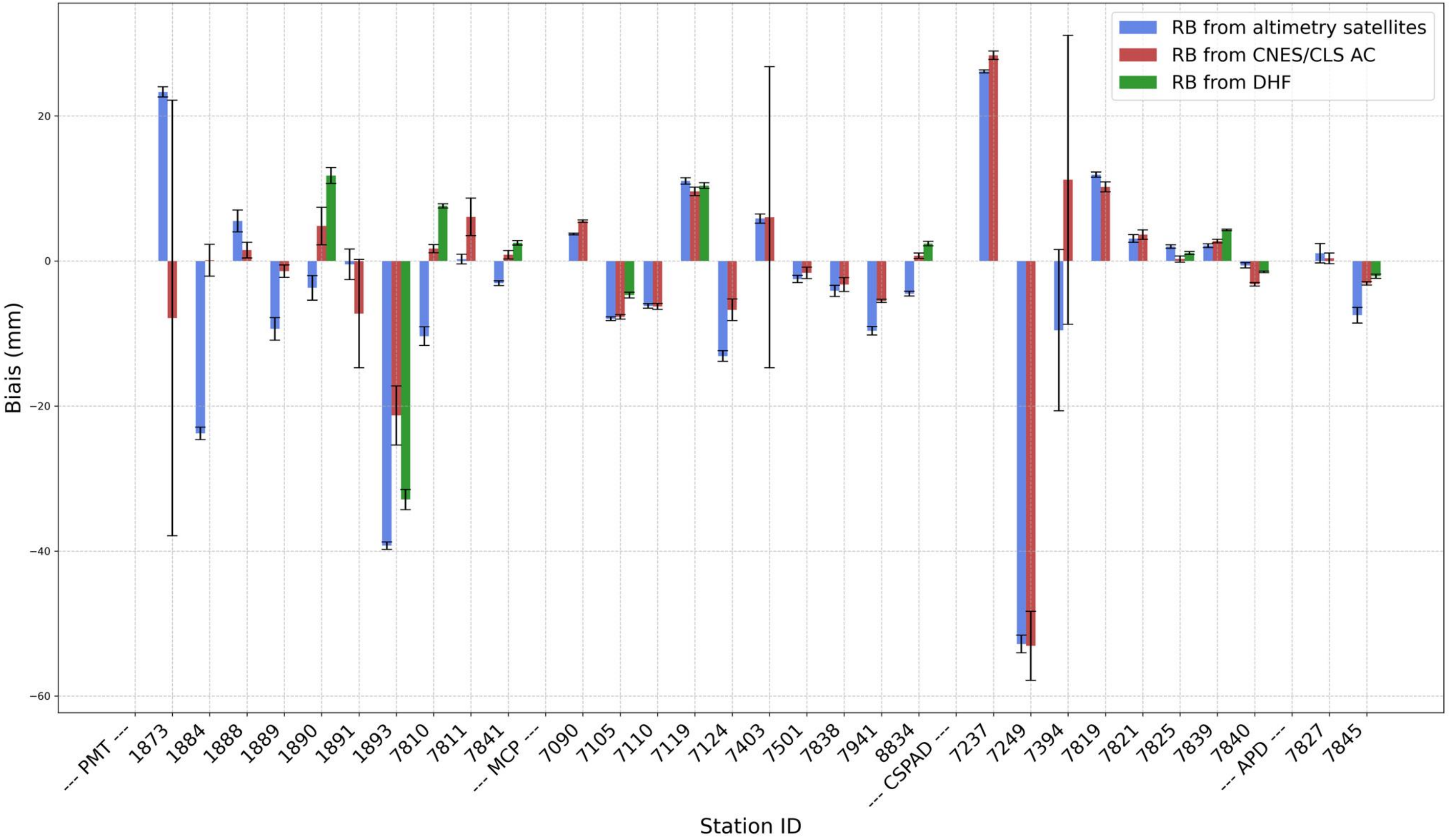
02

RB COMPARISON WITH CNES/CLS ILRS AC

COMPARISON OF THE SLR STATION RANGE BIAS SOLUTIONS (2023)

Some stations show significant discrepancies between measurement sources (like station 1890 where satellite altimetry shows a negative bias while CNES/CLS AC shows a positive bias). From the AC side, these stations show a big formal error due to poorly tracking and low number of observations

Other stations show good agreement between our method and CNES/CLS CA results (7090, 7105, 7110, 7119, 7249, 7403, 7501, 7819, 7821, 7825, 7827, 7838, 7839).The measurement uncertainties (error bars) vary considerably between stations and systems



COMPARISON OF THE SLR STATION RANGE BIAS SOLUTIONS (2023)

Station ID	RB from alti. Sat.	RB from AC	Bias diff. (abs)	Station type
1873	23.3	-7.9	31.2	PMT
1884	-23.8	0.1	23.9	PMT
1888	5.5	1.5	4.0	PMT
1889	-9.4	-1.4	8.0	PMT
1890	-3.7	4.8	8.5	PMT
1891	-0.5	-7.3	6.8	PMT
1893	-39.3	-21.3	18.0	PMT
7090	3.7	5.5	1.8	MCP
7105	-8.0	-7.7	0.3	MCP
7110	-6.2	-6.3	0.0	MCP
7119	11.0	9.6	1.4	MCP
7124	-13.1	-6.7	6.4	MCP
7237	26.2	28.4	2.2	CSPAD
7249	-52.8	-53.1	0.2	CSPAD
7394	-9.5	11.2	20.7	CSPAD

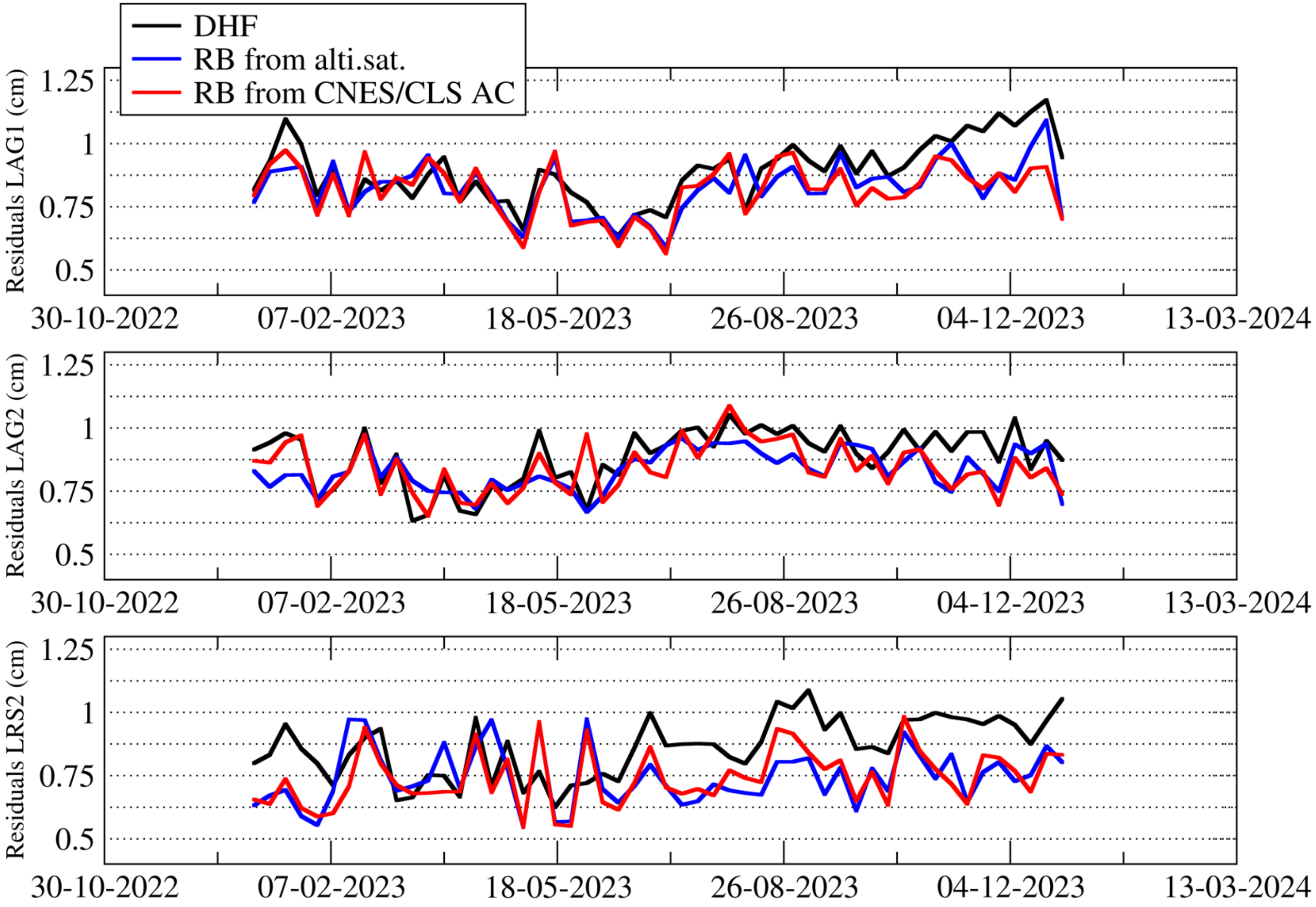
Station ID	RB from alti. Sat.	RB from AC	Bias diff. (abs)	Station type
7403	5.9	6.0	0.2	MCP
7501	-2.5	-1.6	0.8	MCP
7810	-10.4	1.7	12.1	PMT
7811	0.3	6.1	5.8	PMT
7819	11.9	10.2	1.7	CSPAD
7821	3.1	3.6	0.5	CSPAD
7825	2.0	0.3	1.7	CSPAD
7827	1.1	0.4	0.7	APD
7838	-4.1	-3.2	0.9	MCP
7839	2.1	2.7	0.6	CSPAD
7840	-0.6	-3.2	2.6	CSPAD
7841	-3.1	0.9	3.9	PMT
7845	-7.5	-3.1	4.4	APD
7941	-9.6	-5.5	4.1	MCP
8834	-4.5	0.7	5.2	MCP

03

SLR RESIDUALS COMPARISON

SATELLITE RESIDUALS USING DIFFERENT RANGE BIAS SOLUTIONS

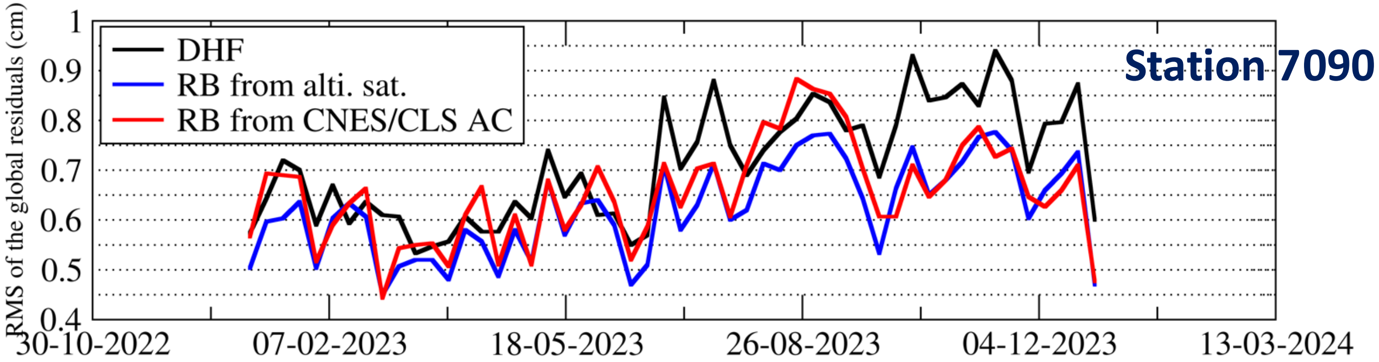
- Range bias solutions (from altimetry satellites or from AC) improve the SLR residuals of spherical satellites when comparing to the solution with DHF from ILRS
- Same number of RBs has not been applied in all three solutions. In the black solution, there are fewer because the DHF contains fewer stations with an associated bias



STATIONS RESIDUALS USING DIFFERENT RANGE BIAS SOLUTIONS

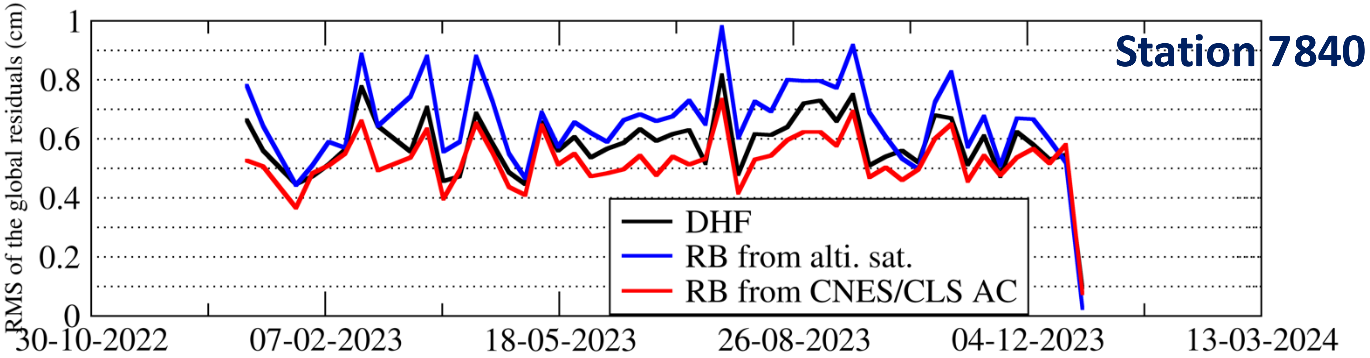
- For Yarragadee: the bias estimated by the two solutions is very close (< 2 mm). The blue solution has smaller RMS than the other two solutions

- For Herstmonceux, the bias estimated by the two solutions is larger (between 2 and 5 mm) and we notice that the RMS with the CNES/CLS AC solution are smaller



LEO altimetry satellites can be used for the precise determination of laser station biases

The biases we have determined with altimetry satellites are very consistent and well tracked, with notable differences primarily emerging when formal variances are high



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04

MEAN SEA LEVEL APPLICATIONS

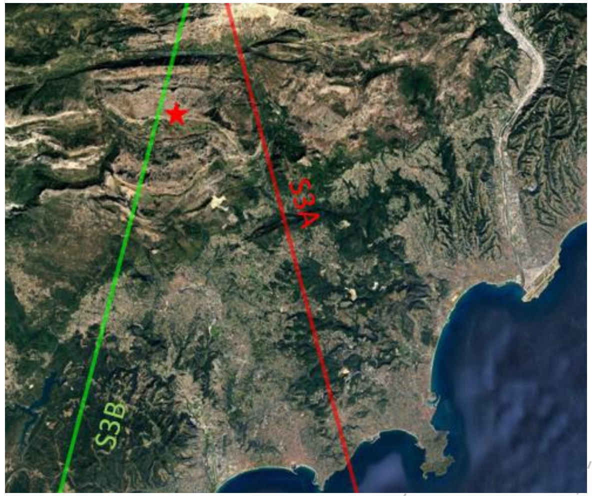
CONCEPT

Corner reflector observations can help deriving an error budget of satellite altimeters

- <u>Objective:</u> Determining the altimeter bias with 1 mm average accuracy over 1 year
- Knowing the position of the corner reflector, the altimeter residuals reflect the combination of the altimeter bias and the radial orbit error
- With a collocated SLR station, the laser residuals reflect the combination of the station bias and the radial orbit error (assuming a sufficiently small distance to the ground-track), allowing the removal of the radial orbit error contribution in the *altimeter-laser residuals* (provided the range bias of the laser system is resolved beforehand)

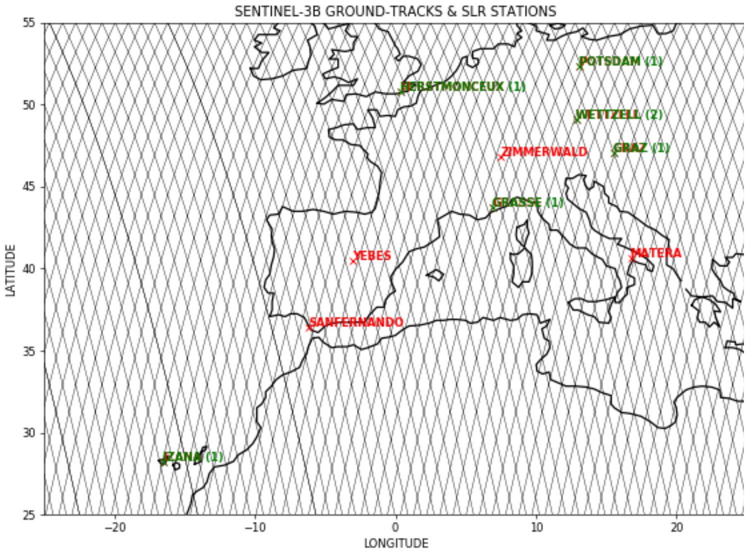
Example with the Calern site:

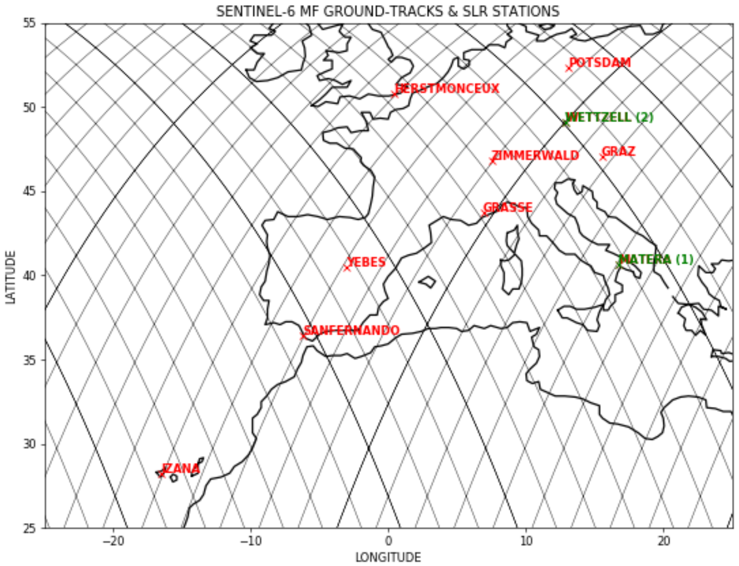
- Sentinel-3A & B altimeter errors can be evaluated from the Grasse Observatory
  - Across-track distances are of 1 km and 5 km, for Sentinel-3B and Sentinel-3A, respectively → *Almost zenithal observations*
  - The corner reflector is currently being manufactured
- For the SLR station, care should be paid to:
  - Singular tracking points at zenith
  - Long term acquisitions of altimeter/geodetic satellites needed for a ~2 mm accuracy yearly recovery of laser range biases



INTEREST FOR POD AND ILRS

- Refinement of orbit-related sea level errors owing to a *passive network of stations*
  - Regional orbit errors could then be evaluated over remote corner reflector locations
  - A well distributed ground network of such corner reflectors could eventually be deployed globally to better constrain the orbit accuracy in the radial direction
- The stability and knowledge of SLR station range biases is the main limitation
  - Long-term regional satellite altimetry orbit errors can be quantified today relying on SLR residuals and applying our yearly determined range biases
  - New objective: reduce this time scale to the length of a few weeks
    → *Regular laser tracking needed of a few well identified altimeter/geodetic satellites to calibrate more frequently these range biases?*
- Current developments
  - 1 CR in the French Pyrenees (1 Sentinel-3A and 2 Sentinel-6 MF tracks), 1 CR in Spain, 2 CRs in Crete
  - Definition of additional calibration sites collocated with SLR stations in preparation for Sentinel-6 NG





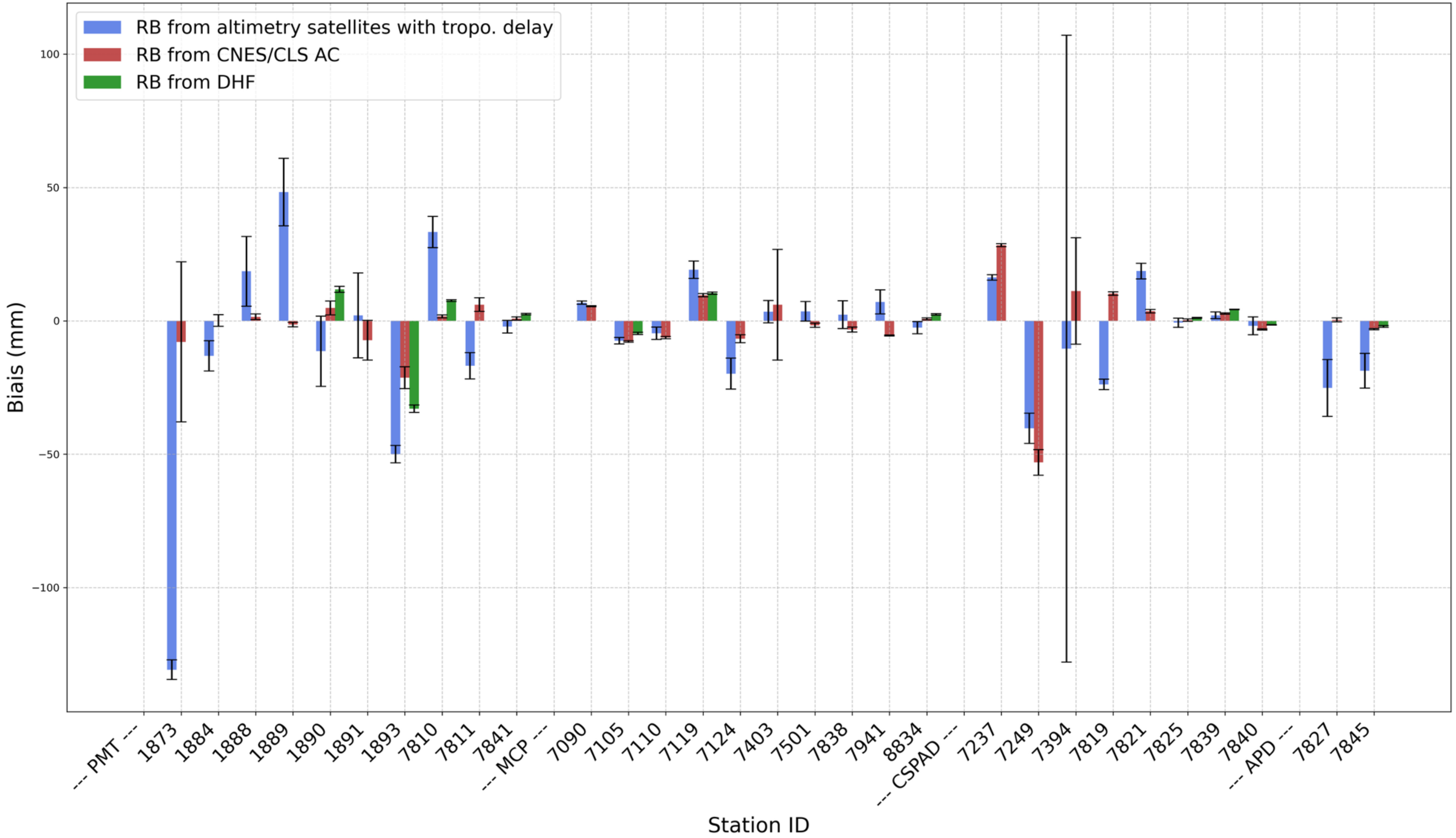
BACKUP

05

ERROR SENSITIVITY

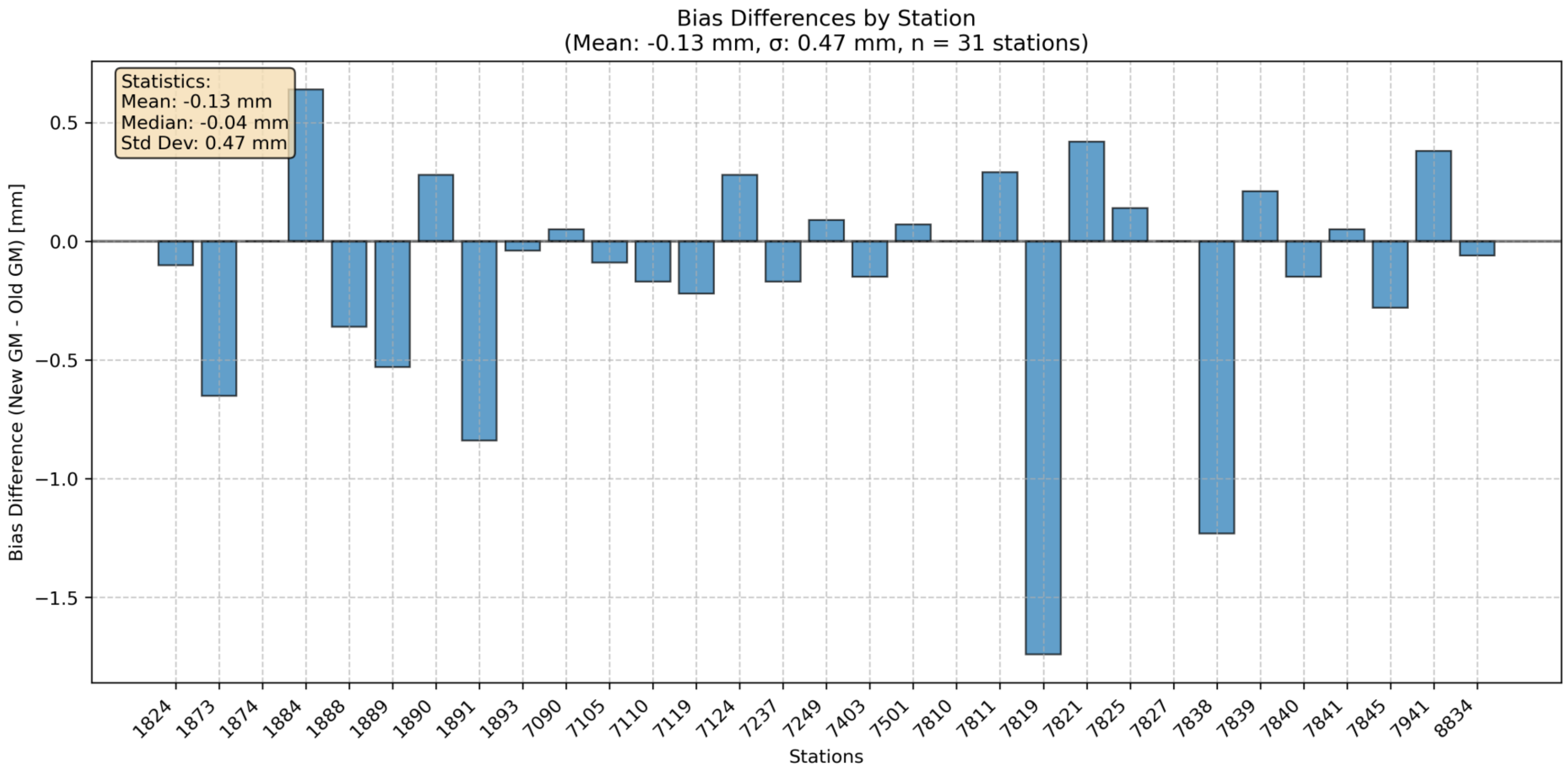
CONTRIBUTION OF TROPOSPHERIC DELAY MODELING ERRORS

- Adjustment of the tropospheric parameter per station per month (no yearly accumulation and constraint)
- For some stations (7090, 7105, 7110, 7403, 7825, 7839, 7840, 7841 , 8834) the RB difference is less than 5 mm
- For several stations there is clearly a concern for observability in estimating all these terms simultaneously based on the formal variances



IMPACT OF THE GM MISMODELING

- Analysis for 2024.
- New GM value: 4419 (from Cherrier, M., Couhert, A., Exertier, P., Mercier, F., and Saquet, E.: Reducing uncertainties in the determination of the Earth's GM, EGU General Assembly 2025)



ILRS QCB Meeting

07/21/2025

Claudia Carabajal & Mike Pearlman

Agenda

Van:
7090 Yarragadee Analysis

Eleonore Saquet and Alexandre Couhert (CNES)
Clearing systematic range biases from SLR observations: assessment and outlook, Eléonore Saquet, Alexandre Couhert, Franck Reinquin, and Adrian Banos Garcia.

Claudia/Mike:

- Updates from the ILRS CB

Others?

Station News

- Tsukuba and Zimmerwald returned Restricted Tracking agreements for Sentinel 3A/3B.
- Data from Xian (new station) started to flow.
- No update/application from new SLR/LLR temporary prototype station developed at the facility in Stafford, VA, ~150 meters from the Stafford ILRS Station in Virginia (Jake G.).
- Pawel Lejba informed us that due to a failure of the old detector at Borowiec (BORL) SLR station. They are temporarily suspending tracking activities for the next 2–3 months. A new detector is planned to be installed during this period. They will keep the ILRS updated on the progress.

Mission Updates/New Missions

- Tracking for the Nano-FF A/B satellites has been postponed to the beginning of September. The mission is still upgrading a few things on their end and remain in touch with the colleagues from CDDIS regarding the upload of the CPF files.

Mission Updates/New Missions

- **QZS-6** (JAXA) Tracking Campaign ended.
- No news from IRNSS mission colleagues.
- Agreements to track QPS-SAR received from Beijing, Shanghai, Hetsmonceux, Tsukuba. Graz pending, trying to work on divergence.
- Launch date of the Sentinel-6B/Jason-CSB will take place on 17th November 2025. They are beginning to coordinate tests this summer with the CDDIS.
- Ex-Alta 3 mission, the University of Alberta's (Edmonton, Canada) contribution to the Canadian Space Agency CUBICS initiative, submitted a MSRF. Expected to launch in June 2026 (at the earliest). CUBICS is a Canadian Space Agency (CSA) initiative that provides professors in post-secondary institutions with an opportunity to engage their students in an end-to-end space mission adapted to their needs and their level of comfort, expertise and readiness. Selected teams will have the unique opportunity to design, build, test, launch and operate their own miniature satellite called a CubeSat. Project managers: Joanne Cai, Priya Manavalan, Tom Cundict. The Ex-Alta 3 Principal Investigator is Dr. Carlos Lange. They have worked with the MSC to fill out the MSRF for the Ex-Alta 3, and sent it for evaluation. They aim for the Ex-Alta 3 operations team to act as the primary prediction center. Given that the Ex-Alta 3 project is volunteer-run, we have also sought out a secondary (back-up) prediction center (Lumi Space). The ILRS will seek the recommendation from the MSC, and forward to the ILRS GB for their approval.

Reports to IAG

- Submitted IAG Travaux 2023-2025 inputs by June 10th, 2025. Thank you to all that contributed.

GGOS C-DIS

- DF&P standing committee and others met to go over the GNSS and SLR site log comparison to determine what keywords we may want to have added to GeodesyML, and if changes may be needed. Will meet again in late August. So far, Justine, Randy, José, Van, Kalvis, Evan, Claudia involved.

SDWG updates

The Space Debris Study Group has been tracking Topex at the request of Daniel Kucharski. The plot shows nearly 4,000 spin period data points collected over the past 11 years. This plot shows the spin periods as observed by the stations – which includes the effect of an "apparent rotation" caused by the changing telescope view angle during a pass. The data is currently going through a cleaning process that will remove the apparent rotation and leave only the true, inertial spin period minimizing the spread of the trend.
Subsequent analysis will involve fitting a physics-based model to estimate parameters related to long-term spin evolution, with the dominant torques expected from solar radiation pressure and the Earth's gravitational field. Ultimately, this process will enable the determination of absolute attitude parameters: spin axis orientation, spin period, and rotational phase angle about the spin axis. They hope this can be determined (and predicted) at sub-degree accuracy level. The satellite attitude state forecast will be formatted and delivered in CPF files.

Interestingly, the Topex spin period has stabilized at ~9.5 s, which may indicate an equilibrium state where the major forces and torques acting on the satellite are balanced.
They will continue tracking Topex at the rate of 1-2 passes/week, uploading to the Graz space debris FTP server.