

Keeping It COOL: GNSS–SLR Combination at the Observation Level

F. Dilssner², T. Springer², Ivan Sermanoukian³, Michiel Otten², F. Gini¹, E. Schönemann¹

¹Navigation Support Office, ESA/ESOC, Darmstadt, Germany

²PosiTim @ ESA/ESOC, Darmstadt, Germany

³VisionSpace @ ESA/ESOC, Darmstadt, Germany

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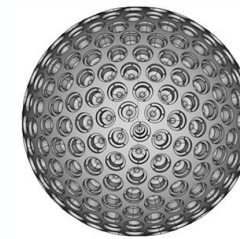
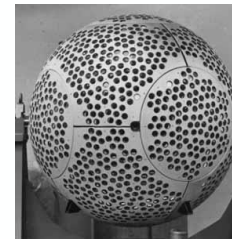
- COmbination at the Observation Level (COOL)
 - Concept and objectives
- SLR range biases
 - Relevance and analysis strategy
- Galileo LRA design and CoM calibration
- Range biases from five-year SLR tracking of GNSS and ILRS targets
 - Galileo satellite-to-satellite comparison
 - BeiDou-Galileo comparison
 - GNSS-ILRS comparison
 - Bias discontinuity at SLR “super-site” Yarragadee
- One-year “COOL” combination of GNSS and SLR
- Summary and conclusions

SLR Range Biases – Relevance and Analysis Strategy

- Careful treatment of SLR range biases is key for multi-technique TRF combination
 - As with GNSS transmit antenna z-offsets, SLR range biases directly impact TRF scale

- ILRS range bias estimation:

- LAGEOS-1/2, ETALON-1/2, LARES-2
- One bias per station-satellite link
- Seven-day ILRS ESA AC-style processing setup
- Target signature model applied (Rodriguez et al. 2019)



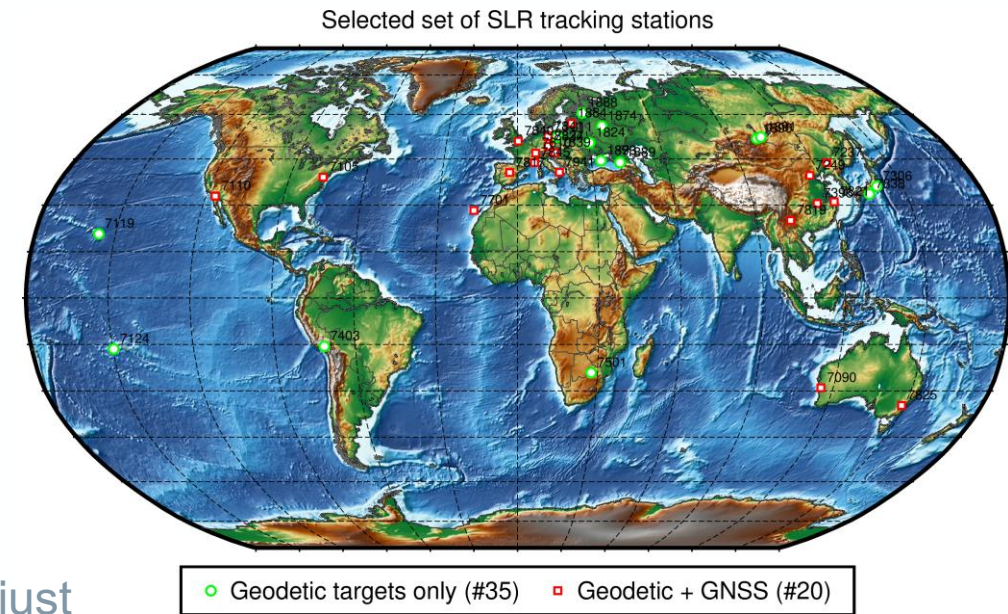
Source: NASA/ASI

- GNSS range bias estimation:

- Split into station and zero-mean constrained satellite bias part
- Independently per constellation (BeiDou, Galileo)
- Twenty higher-quality SLR sites with solid coverage selected

- Two types of analyses we will look at:

- Independent five-year ILRS and GNSS bias estimation; GNSS orbits from internal ESA/IGS reprocessing kept fixed, SLR station positions & velocities fixed to SLRF2020
- One-year “COOL” combinations with all parameters free to adjust



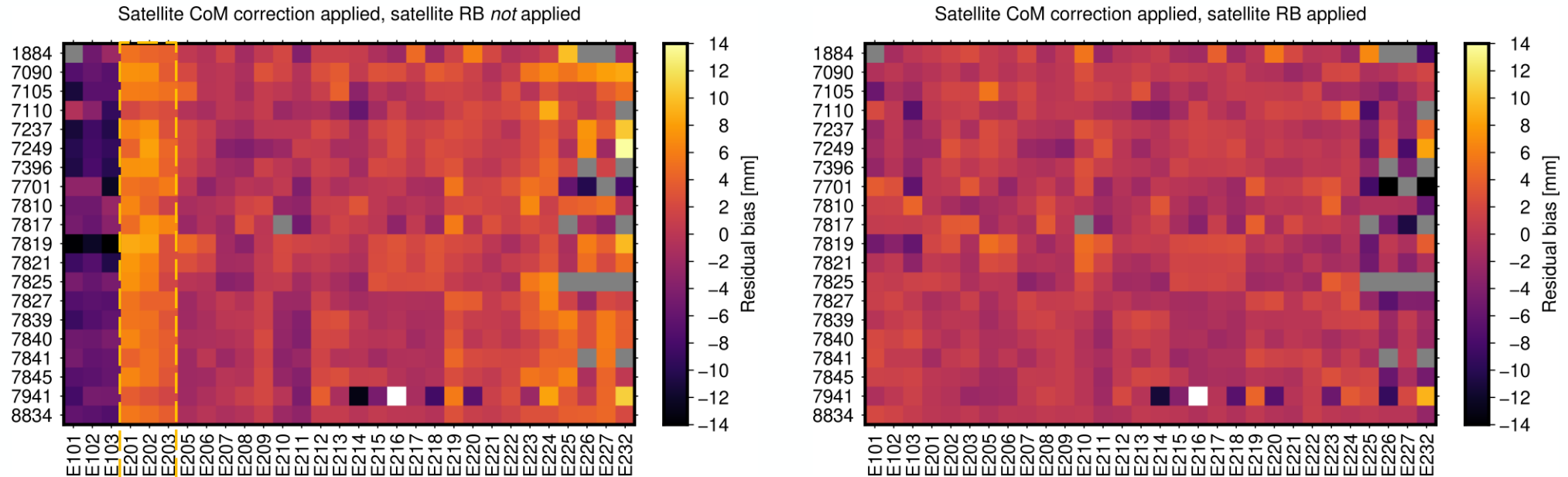
Satellite-Specific Galileo SLR Range Bias Estimates



- Nearly identical bias estimates of -12 mm for all three IOV satellites
- FOC satellite biases more variable, ranging from -6 to $+5$ mm
 - Notably higher values for GSAT201–203, matching differences in CoM ground calibration (Gonzalez 2026)

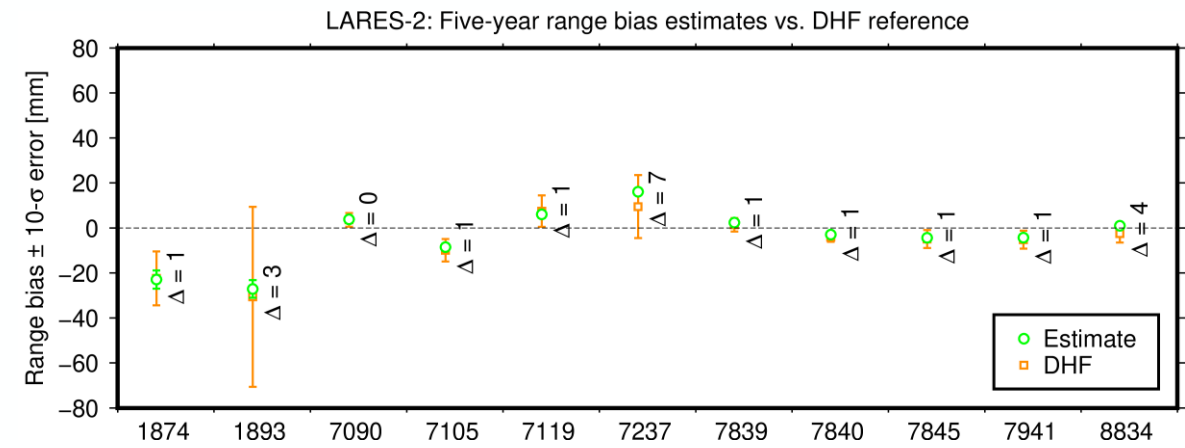
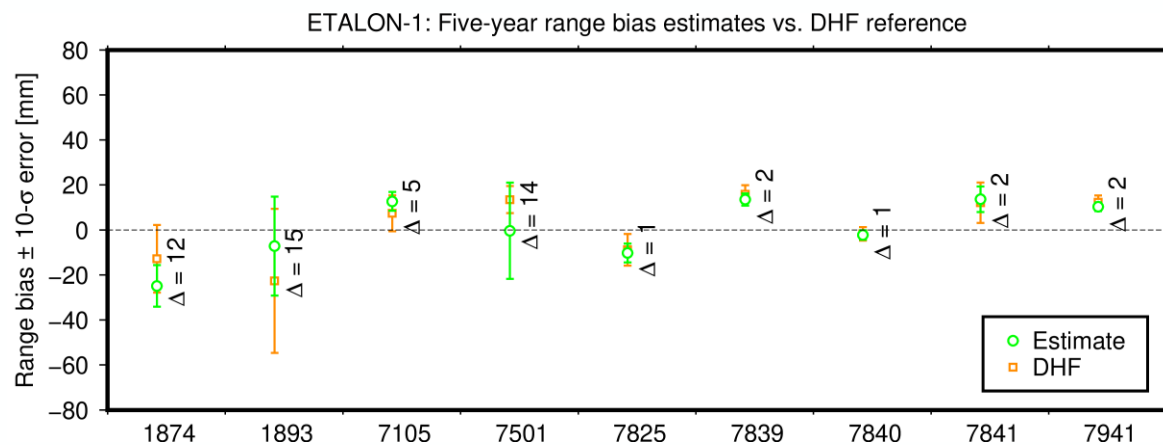
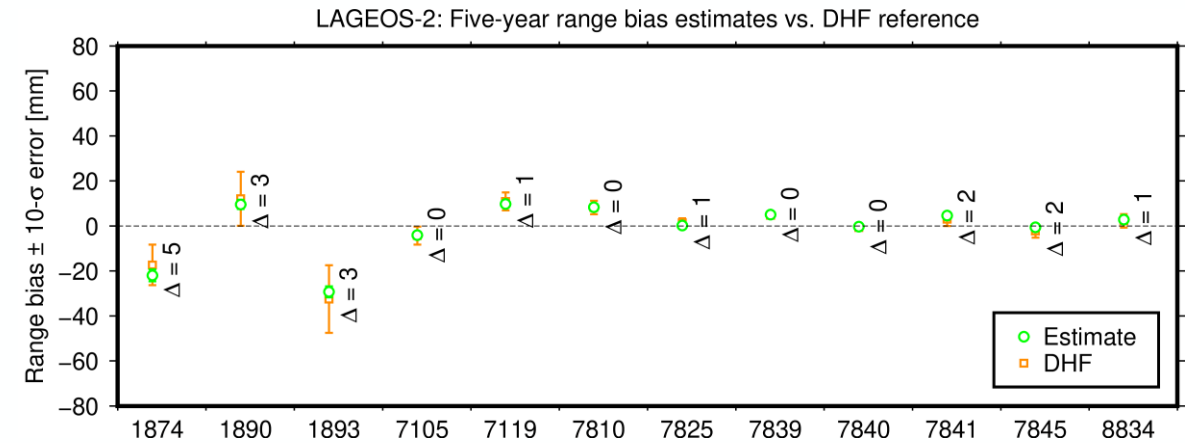
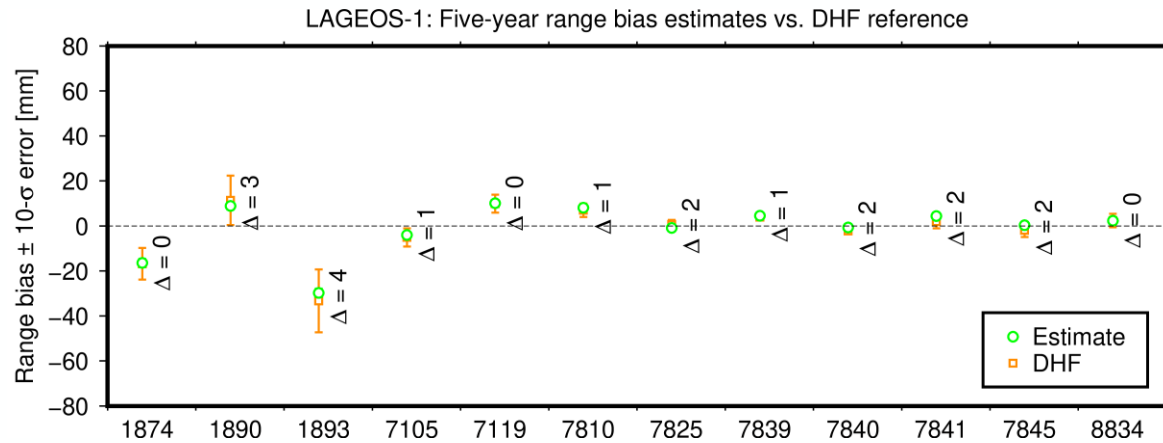
	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	232
Range bias [mm]	5	4	1	-	-3	-3	-3	-3	-2	-6	-4	-1	-3	-3	-2	-1	-2	-2	0	0	-1	-2	1	1	3	4	4	5
+Z – 565 [mm]	-7	-4	-3	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

- Consistent satellite-to-satellite differences across all stations



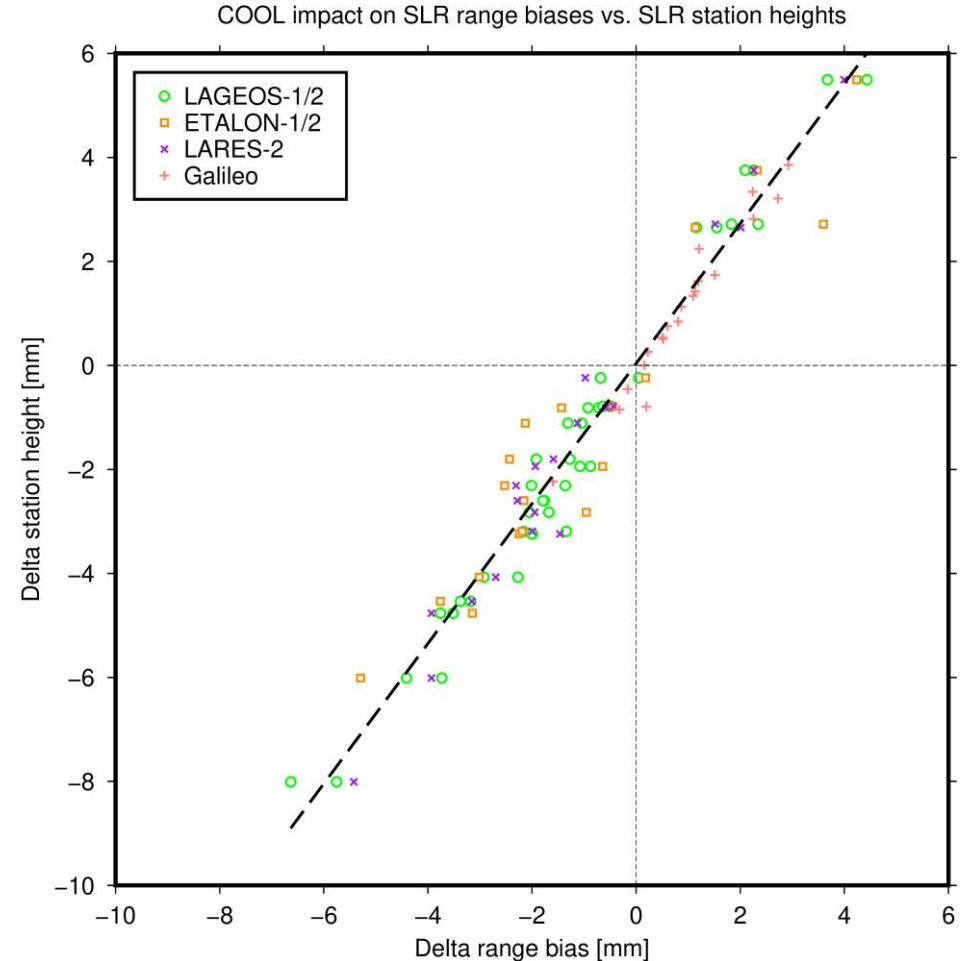
Five-Year ILRS Bias Estimates vs. Data Handling File

- Good agreement, with 1-2 mm differences (Δ) for the “better-observed” station biases
 - Sanity check confirming consistency between SLRF2020 coordinates and range biases



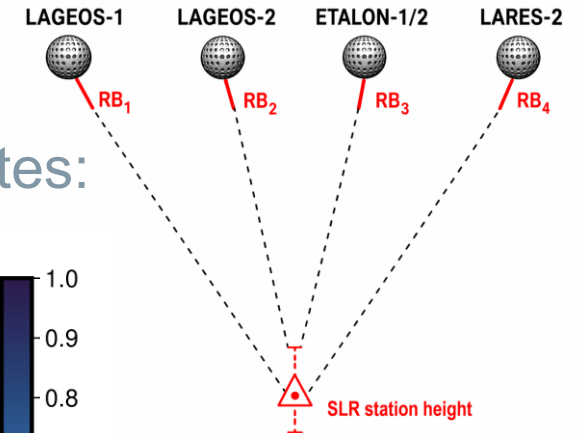
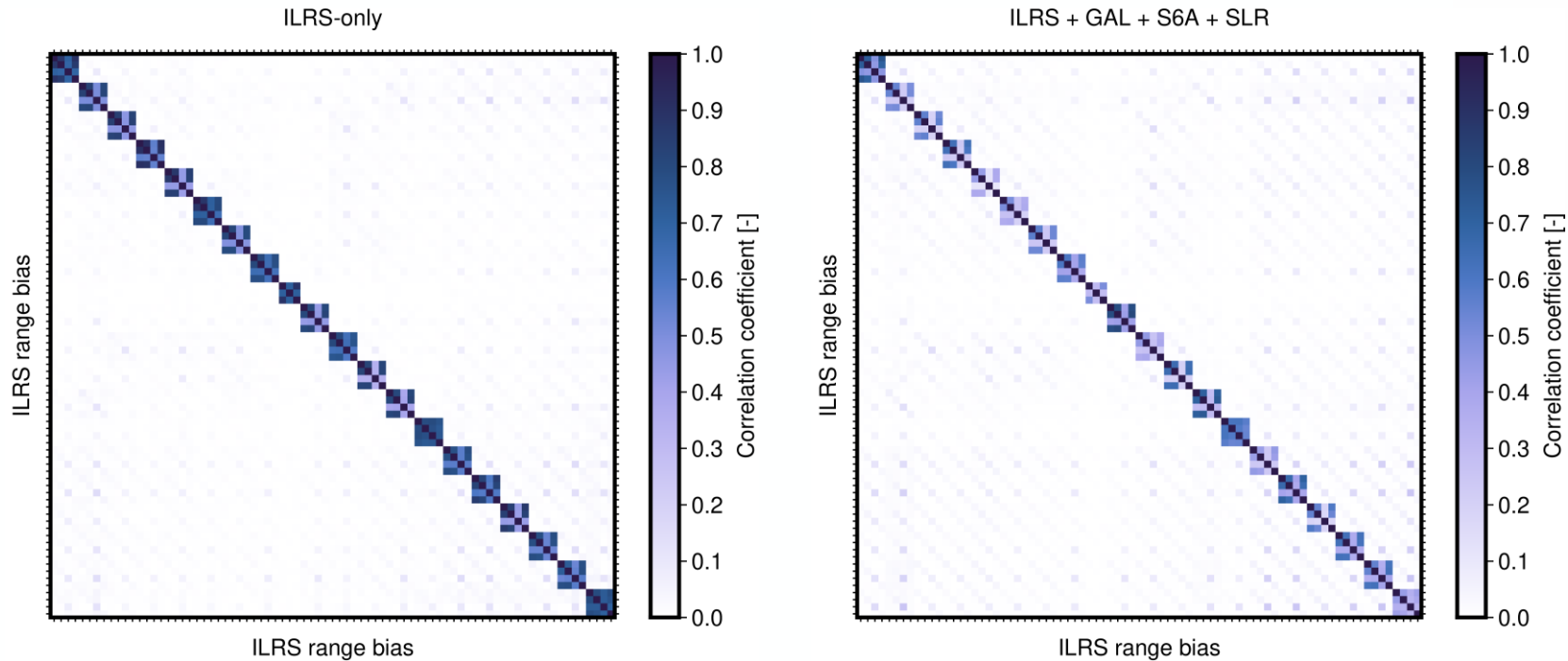
'COOL' Evaluation of Range Biases

- One-year solution spanning DOY 001-366 (2024)
 - Biases, coordinates, orbits, and other parameters estimated
 - NNR constraint applied to IGS and ILRS core stations
 - Equal weighting of SLR range data ($\sigma = 20$ mm, two-way)
- Comparison ILRS-only vs. ILRS+GAL+S6A+SLR:
 - Range bias differences at “collocated” sites of -7...5 mm
 - Compensated one-to-one by station height change (see plot)
- Comparison GAL+S6A+SLR with and without ILRS:
 - Station height and Galileo range bias change by only ± 3 mm
 - Indicates that Galileo/Sentinel SLR has stronger impact on ILRS solution than vice versa



'COOL' Decorrelation of ILRS Range Biases

- ILRS range biases highly correlated through common station height
 - Makes the (four) parameters difficult to separate from one another
- One-year correlation matrices for biases of Galileo/Sentinel-tracking sites:



- Result: Up to 75% less correlation among biases when Galileo and Sentinel are included
 - Even stronger decorrelation expected with inclusion of BeiDou and additional LEOs

- Range biases in SLR tracking of GNSS and ILRS targets investigated
 - BeiDou, Galileo, LAGEOS-1/2, ETALON-1/2, LARES-2
- GNSS biases decomposed into station and satellite components
 - Efficient parameterization, with a risk of misinterpreting the true physical origin of inter-satellite differences
- Range bias stability is critical for long-term bias stacking (cf. Yarragadee)
- Reasonable agreement between BeiDou and Galileo station range biases
 - Mean difference from five-year analysis at the ~2 mm level
 - No need for separate BeiDou and Galileo station biases; one common parameter is sufficient
- Recommended future handling of SLR range biases:
 - Strong correlations with station heights → fixing range biases, as for ITRF2020, is not justified
 - Treat biases like GNSS antenna offsets: include them in the NEQ for consistent adjustment with TRF scale
 - Systematic ~1cm offset between GNSS and ILRS range biases requires further investigation

AND DON'T FORGET—WHEN THE FRAME STARTS SHAKING, STAY COOL



THANKS FOR YOUR ATTENTION!