Verification and Benchmarking the NASA SGSLR System at the 1 mm Level prior to Field Deployment

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NASA SGSLR: Millimeter level Verification

Overview of this talk

1. Provide an introduction to the verification plans in preparation;
2. Highlight areas of SLR performance that need special attention and effort for delivering millimeter level performance;
3. How will we verify at the system and network levels?
4. How to establish Millimeter legitimacy - Challenges, ideas, strategies;

Verification: Introduction

1. SGSLR system is in its early stage of development for Network build;
2. Intends to leverage NGSLR prototype, wherever applicable;
3. Verification of NGSLR previously completed as a prototype at TRL 6;
4. Compelling need for "mm" level data – precision, accuracy, stability;
5. Science requirement analysis through network simulation;
6. Precision is straight forward; challenge is to establish credible 1 mm level verification for the system accuracy and stability;

Verification: Introduction (contd…)

Range data = f (x1, x2, …xn),

where x = system engineering parameters, external parameters (atmosphere, satellite, models, processing algorithms….)

Data Quality = ϕ (x1, x2,..),

where x = capability and constraints of measurement and analysis;

System Quality = φ (x1, x2,..),

where x = **$,** resources, time

∑ (Small millimeter)i = "Big millimeters"

Verification: Definition and Scope

- **Definition:** Verification is the process of ensuring that a system/ product complies with its requirement, specification, regulation, or functional condition; all rolled into requirement in the case of SGSLR;
- **Scope**: what, how, when, where, to what extent, at what level.
- **Challenge:** How can we bound the scope of verification to qualify the system without compromising the required performance?

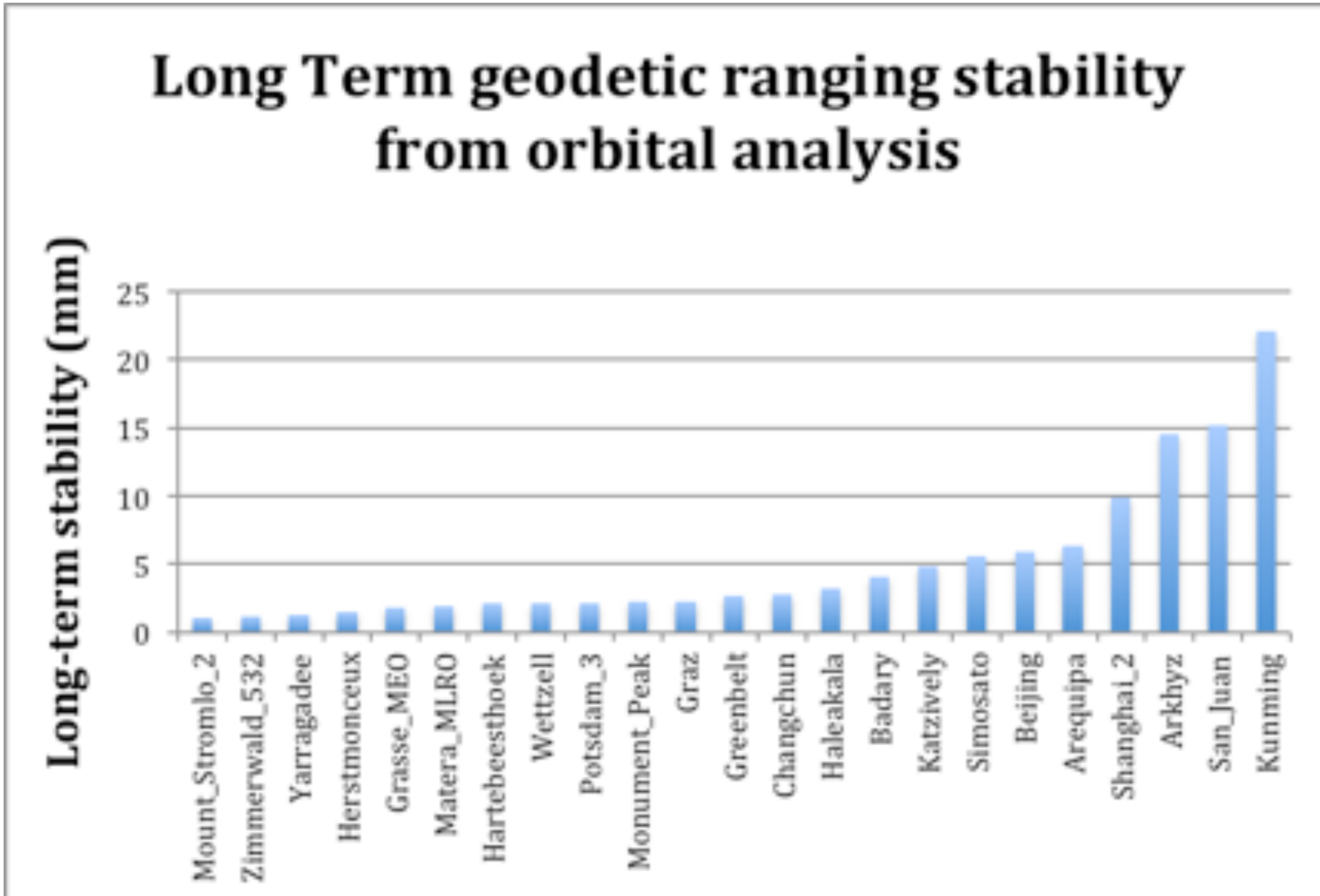
Verification: Implications

- **Data Issues:** "millimeter level geodetic inaccuracies" introduced by a SLR station can only be established over a long period;
- **"core stations"** must be accurate to allow estimation of errors in others.
- **Question:** Level of RB detectability within the current analysis techniques?
- **"Magnification Effect" of a network**:
  - Network of "n" stations vs.1 Station;
  - Verification process has a huge impact on Network evolution;
  - Positives and negatives affect the outcome in a big way;
- **Project**: Performance; Schedule; Cost;
- **Compromised technical performance**: harder and costly to change especially for remotely deployed sites;

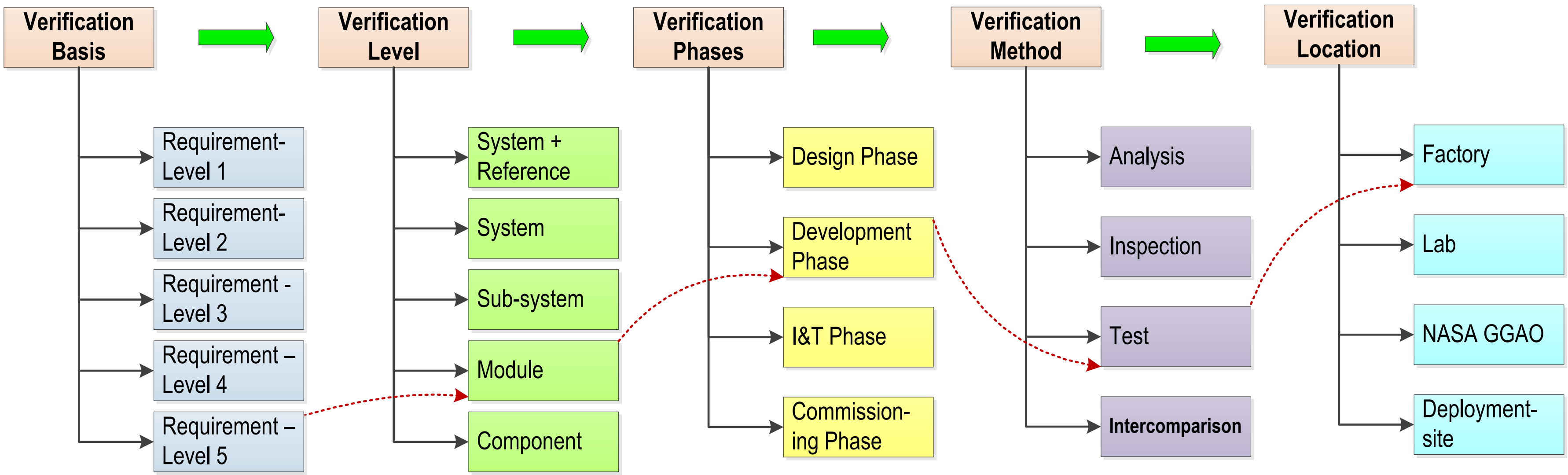
Verification: Scope

1. Verification needs to be managed through the system Life cycle phases across the various constituents;
2. System Level Verification
   a) Standalone;
   b) Comparison / Benchmarking with a reference;
3. The rigor of verification executed is a pointer to the performance quality achieved;
   1. Shorter time scale
   2. Longer time scale

Long Term geodetic ranging stability (mm) from ILRS AC QC orbital analysis 2013/14 <Graham Appleby>



Verification: Implementation Process



- **Internal process**
- **Verification Plan reviews:** MCR, SRR, PDR, and CDR;
- **Verification Planning:** Commences with the development of the system reqs;
- **NASA requirements** - Levels 1 through 5;
- **SGSLR system reqs**: Level 3 - 5;
- Prior to SRR, a verification matrix for the requirements to be created.
- Before CDR, a detailed set of verification tests will be created.

Verification: Key Performance Requirements

Under Standard Clear Atmospheric Conditions, achieve data quality and data quantity equal to or better than

1. CAL Normal Point Precision: 1mm
2. CAL Normal Point Stability: 1mm
3. CAL Normal Point Accuracy: 1mm
4. SLR Normal Point Precision: 1mm
5. SLR Normal Point Stability: 1mm

1. SLR Data quantity: LEO – 50%
2. SLR Data quantity: Lageos – 20%
3. SLR Data quantity: HEO – 10%
4. SLR Data quantity: GEO – 3%

Note: margins to be built in for the above specs

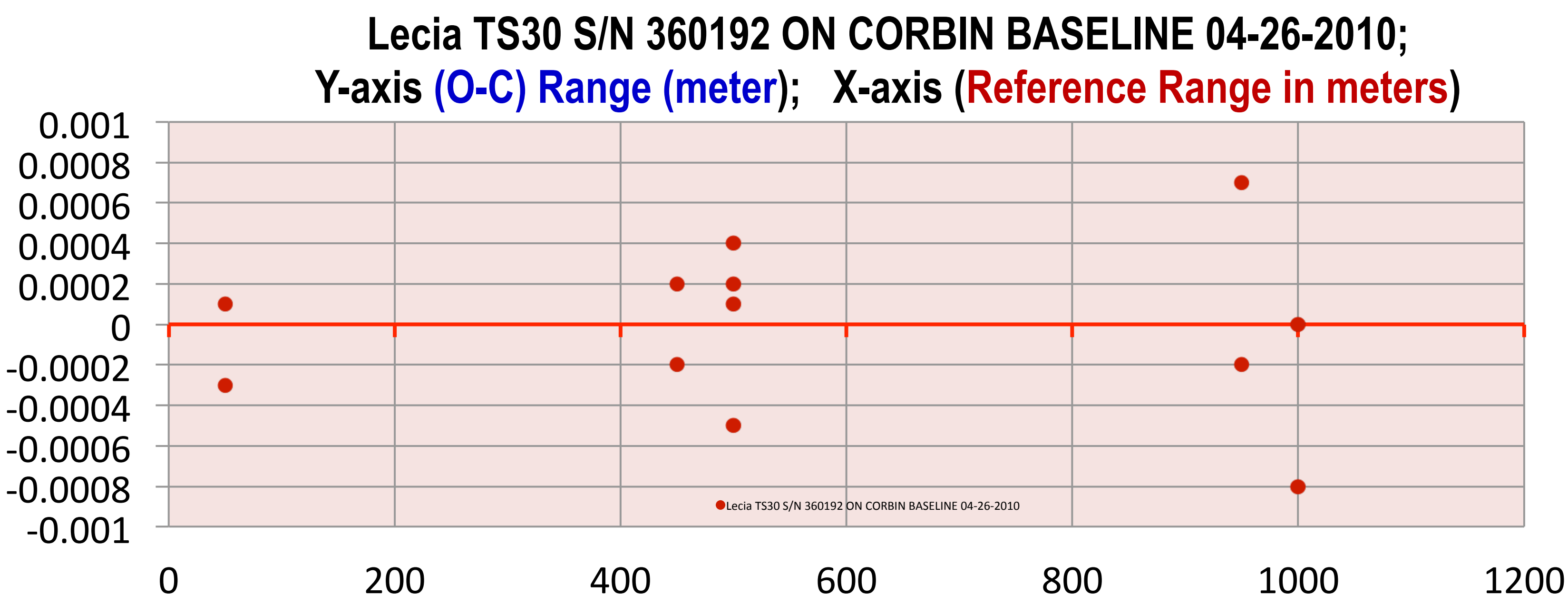
Verification: Critical Areas

- **Survey Verification**
  - Telescope Axes Intersection
  - Monuments
  - Calibration Targets
  - Processing Sofware
- **Meterological Verification**
  - Pressure
  - Temperature
  - Humidity
- **Time & Freq Verification**
  - Short-term freq stability
  - Long-term freq stability
  - UTC accuracy
- **Ranging Verification**
  - Laser
  - Detection scheme
  - Signal Processing
  - Event-timing
  - LRA Correction
  - Atmospheric Correction
  - Difference in CAL vs. Satellite
  - Range and Time Biases
  - Telescope Pointing, Imaging
  - System link Margins
  - Data pre/ post processing SW
  - Data volume
- **Safety Verification**
  - Near field limit
  - Far field limit
  - False positives
  - False Negatives
  - RFI

Ensuring precision, accuracy, and stability of SLR sensors & devices via traceability to National Standards

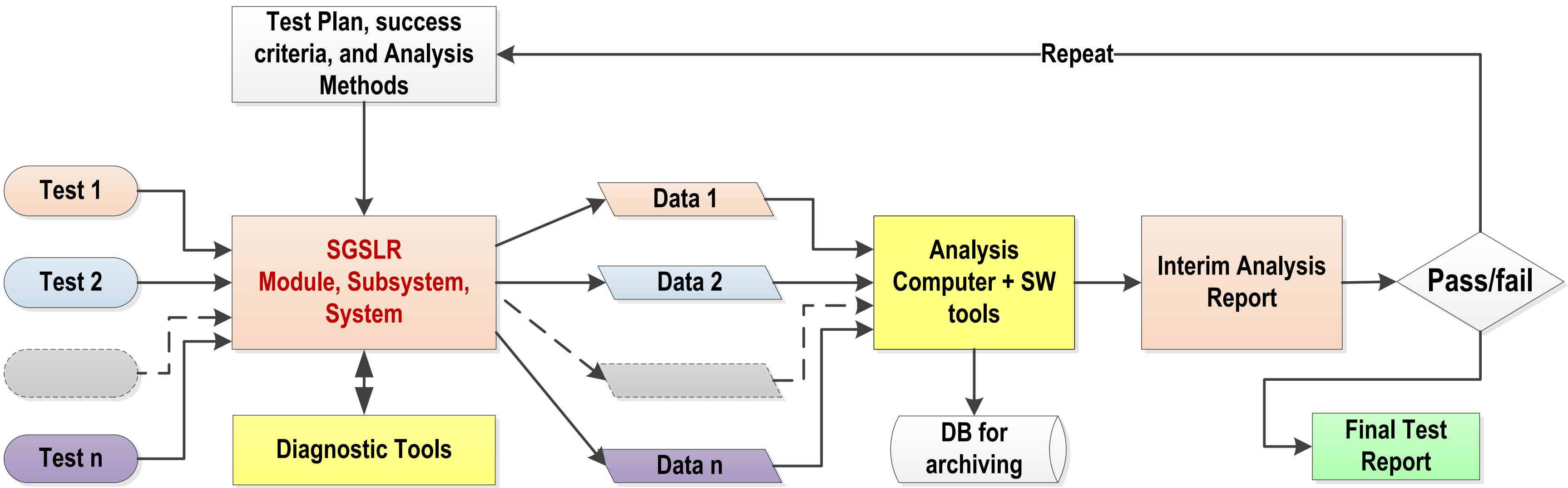
Ensuring precision, accuracy, and stability of Range Measurements via direct measurements as well as Intercomparison with a comparable or better SLR standard

Verification - Survey Instrument Capability



How well do we transfer the measurement capability in survey instruments to actual measurements?

Verification: Standalone Approach



Approach common to verification at any level (e.g., system to component)

Verification – Benchmarking Approach

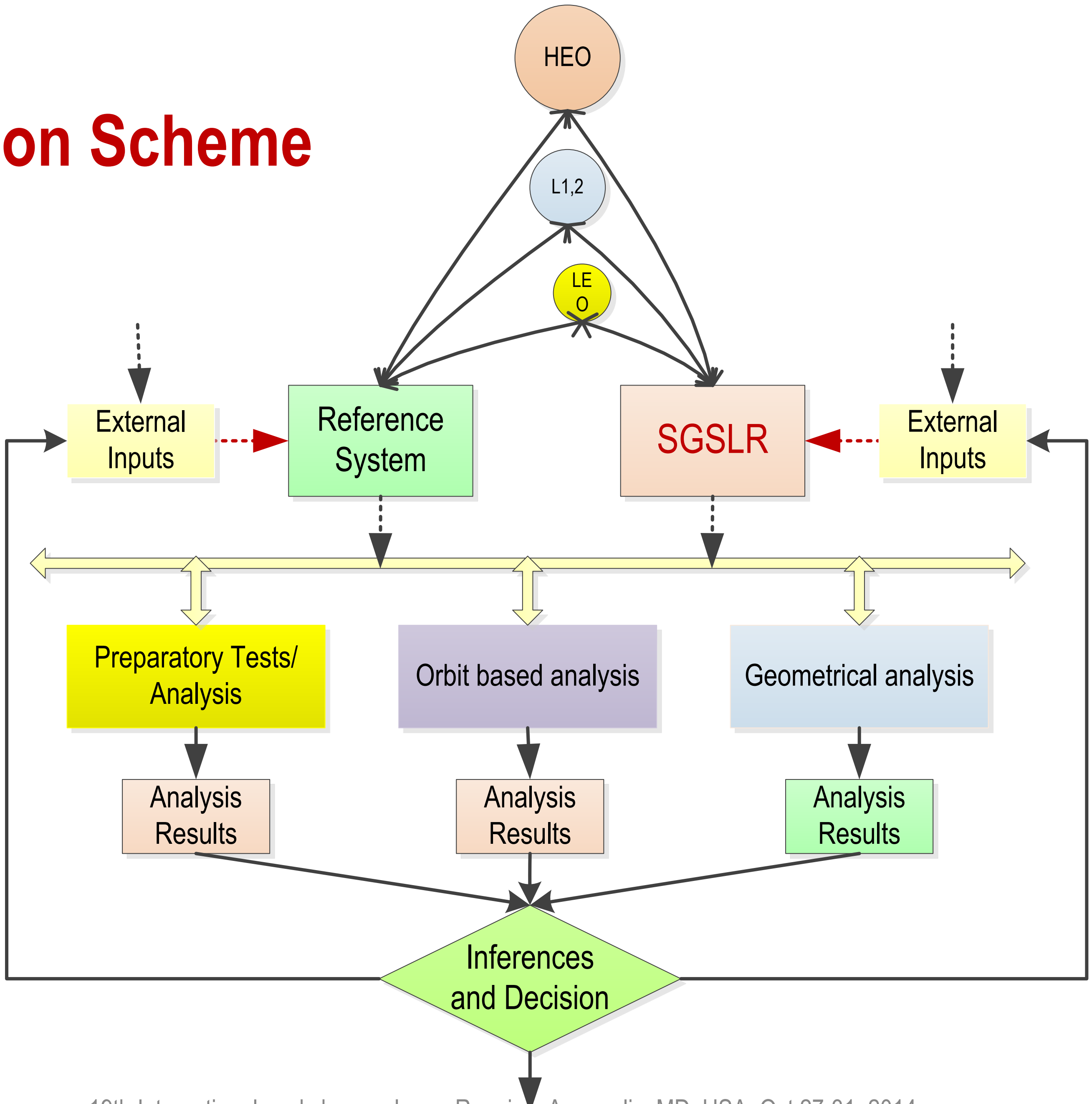
- **Benchmarking**:
  - Commercial world uses benchmarking to known references to gauge the performance of new products and technologies
  - Performance verification by comparison with a reference;

- **SLR benchmarking**:
  - Collocation for intercomparison
  - Local Reference – Geometrical & Orbit based analyses;
  - What constitutes a millimeter level "benchmarking" system?
  - System level and Network Level

Verification: Collocation Technique

1. Independent Ranging performance comparison on a pass by pass basis using
   - geometrical (2 stations, Local Geometry);
   - orbit analysis techniques.
2. Verify the short term, long term stability requirements, satellite pass geometry
3. Mature verification approach; Full Rate or NPT basis
4. helped NASA SLR network to achieve the uniformity and consistency of performance across its global SLR network;
5. Minimize the performance risk across core sites;

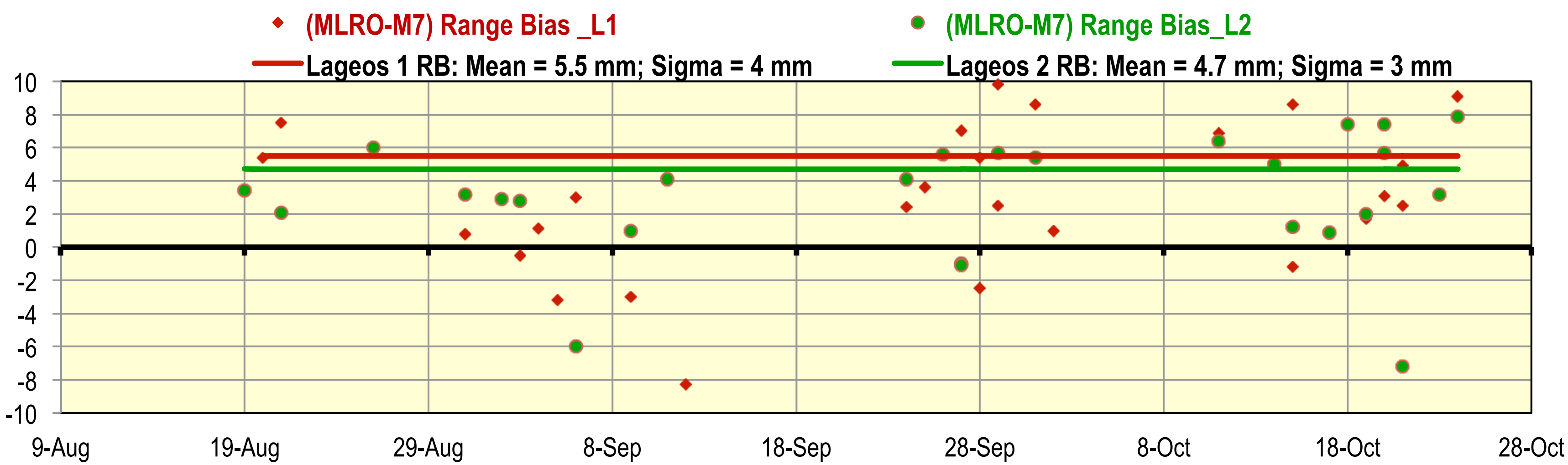
Collocation Scheme

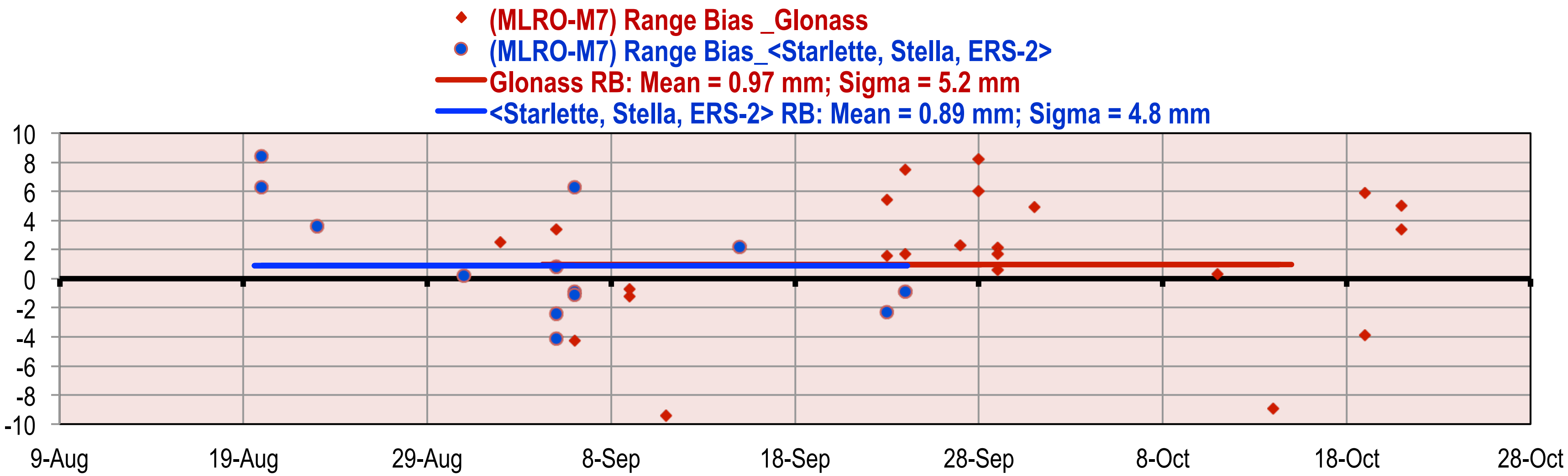


Verification: Commonality in Collocation

- **Commonality in Collocation on a macro scale**
  - Proximity placement – ties to local datum
    - ground water motion,
    - seasonal effects
  - Ground targets
    - Survey;
    - Calibration;
    - Geodetic effects
  - Atmospheric effects
  - Meteorological data;
  - Satellite view.

Collocation Example – M7 vs MLRO



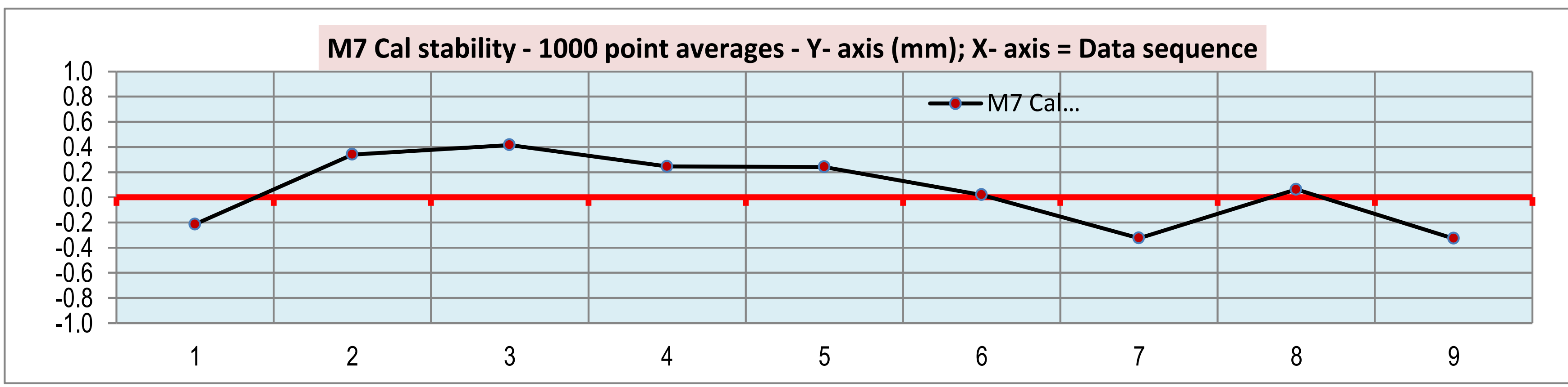


Verification – Strengthening Collocation

1. Improving and establishing a reference system with high level of confidence over a sufficiently long period of time;
2. Adding auxiliary measurement capability;
3. Applying a rigorous approach to measurement and analysis
4. Improving the analysis techniques;

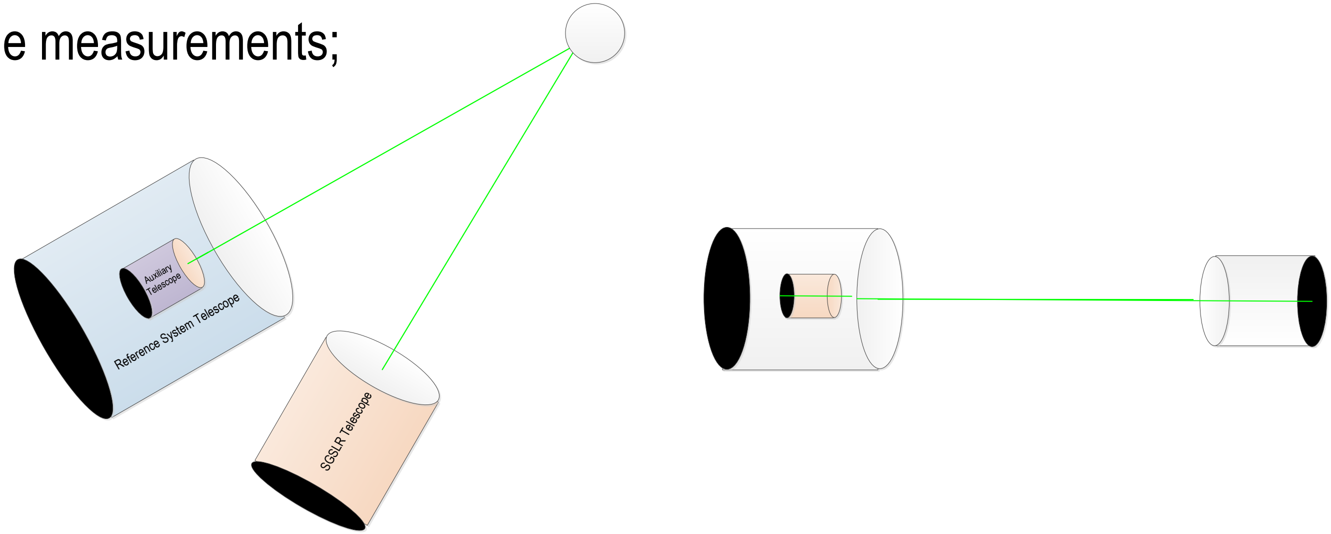
M7 – Recent Test data on Cal and Lageos

Bin #	# Points in 120 secs	Edits	Epoch (Sec of Day)	Normal Point (m)	O-C (m)	Fit Res (m)	Bin Mean (m)	Bin RMS (m)	Bin Skew	Bin Kurt	Wt Mean	Wt RMS	Wt Skew	Wt Kurt	Receive Energy	NPT RMS (mm)
1	38	1	9688.200517	8061648.3	0.0014	0.0034	0.0014	0.0076	0.17	2.29	0.0008	0.0067	0.29	2.69	298.2	**1.25**
2	57	0	9786.800521	7889052	0.0041	0.0037	-0.0013	0.0065	0.5	3.34	-0.001	0.0055	0.33	3.85	300.5	**0.86**
3	23	0	9911.000516	7690931.5	-0.0009	-0.0022	-0.0022	0.0054	-0.15	1.81	-0.0015	0.0048	-0.41	2.27	315.6	**1.13**
4	120	3	10006.60052	7554660.2	0.007	0.0059	0.0016	0.0065	0.33	2.72	0.0011	0.0055	0.42	3.33	357.7	**0.60**
5	112	0	10140.80052	7389708.8	-0.0015	-0.0018	0.0006	0.0062	-0.01	2.55	0.0004	0.0053	0.12	3.01	281.2	**0.59**
6	264	5	10261.20052	7270244.9	0.0029	0.0032	-0.0011	0.0066	0.2	2.68	-0.0009	0.0057	0.16	3.06	400.1	**0.41**
7	266	1	10384.80052	7177900.6	-0.0032	-0.0026	0.0001	0.0062	0.18	3.02	0	0.0053	0.16	3.55	367.3	**0.38**
8	169	0	10483.80052	7127308.1	0.0046	0.005	0	0.0069	0.07	2.29	0	0.006	0.05	2.76	354.8	**0.53**
9	205	0	10619.80052	7093099.2	-0.0051	-0.0054	0.0011	0.0064	0.32	3.19	0.0007	0.0054	0.39	3.84	385.6	**0.45**
10	93	0	10717.40052	7094296.6	-0.0012	-0.0021	-0.0008	0.007	0.28	2.42	-0.0007	0.0061	0.16	2.83	302.7	**0.73**
11	105	1	10875.00052	7141976.2	-0.0058	-0.0069	0.0004	0.0063	0.2	2.38	0.0002	0.0055	0.18	2.74	305.7	**0.62**
12	115	2	10975.00052	7201209.2	-0.0046	-0.0048	-0.0008	0.0058	0.14	2.83	-0.0006	0.005	0.07	3.29	316.5	**0.55**
13	49	2	11057.40052	7266504.5	0.0025	0.0044	-0.0001	0.0065	-0.25	3.31	0	0.0055	-0.17	3.79	370.8	**0.95**
	1616	**15**													**Mean (mm)**	**0.69**



Auto-correlated & Cross correlated Range Measurements

- May need to augment verification capability of the reference system; piggy-backed with a small aperture auxiliary telescope;
- Receive in common view with different ranging electronics for auto-correlated measurements;
- Simultaneously receive the satellite returns from the test system for cross-correlated range measurements;



Verification: Success Determinants

1. Human Resources;
2. Schedule availability;
3. HW and SW Analysis tools, test equipments, test facilities

4. Clearly defined
    a) success criteria for verification;
    b) Repeat criteria for verification, in case of non-compliance;
5. Repeatability/ Consistency of results;
6. Well-qualified bench marking system;

7. Cost effective and Time efficient strategies;
8. Verification of “n-1/n-2” stations;
9. Lessons learned in the ILRS community;

Summary

- Plans underway for creating a robust verification framework for NASA SGSLR stations and the future NASA SGSLR network;
- Millimeter challenges for verification are plentiful across the system;
- Needs to push the performance, verification, and analysis frontiers to realize millimeter objectives;
- Embracing the best practices within the ILRS community to achieve millimeter performance;
- Extending SGSLR lessons and practices to the ILRS community;