Results of the TLRS-4 / moblas-7 Intercomparison test

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Abstract

In March 2005, Honeywell Technology Solutions Inc. (HTSI) was tasked to restore the Transportable Laser Ranging System 4 (TLRS-4) to operational capability. This was in preparation for replacement of the Hollas SLR system, located on Mt. Haleakala that had ceased operations in 2004.

Introduction

The TLRS-4 had ended routine operations following a successful tracking campaign in Richmond, Florida on May 22, 1995 and was held at the Goddard Geophysical and Astronomical Observatory (GGAO) at the NASA Goddard Space Flight Center in a semi- operational status until 1999. Less than six months after beginning the restoration of the TLRS-4, the system was providing quality ground and satellite tracking. This culminated in the validation of the TLRS-4 by a direct intercomparison of TLRS-4 with the Network Standard, Moblas-7. The TLRS-4 / Moblas-7 Intercomparison occurred from August 1st – September 6th, 2005. Results of this test were presented at a NASA Operational Readiness Review on September 15th, 2005 to a panel of ILRS members and other NASA management.

This paper provides a description of the work performed to restore the TLRS-4 to operational status, a description of the intercomparison test, the analysis of simultaneous satellite tracking data along with ground target tests and the results of the test.

History

The TLRS-4 system has a history that dates back to the early 1980's when two identical TLRS systems (Transportable Laser Ranging Systems) -3 and -4, were originally designed and built by NASA. These systems were designed as compact and transportable,

and were deployed to many diverse locations for short (2-6 months) SLR tracking campaigns. HTSI, as NASA's mission contractor, was tasked to maintain, operate, and deploy each system for these tracking campaigns. TLRS-4 was assigned to North American locations.

In 1995, after a major decrease in the NASA SLR budget, TLRS-4 returned to GSFC. Since 1995, HTSI maintained the system in caretaker status at the GGAO under NASA SLR Mission contract. HTSI maintained TLRS-4 while supporting all other NASA SLR systems, as well as operating two systems at the GGAO and Monument Peak, CA (Moblas-7 and Moblas-4). TLRS-4 was frequently used as a test-bed to support SLR engineering projects, and was used for spare parts to support operational stations. In March of 2005, NASA tasked SLR to return the TLRS-4 to operational status. The system required a major engineering effort to return the system to regular operations.

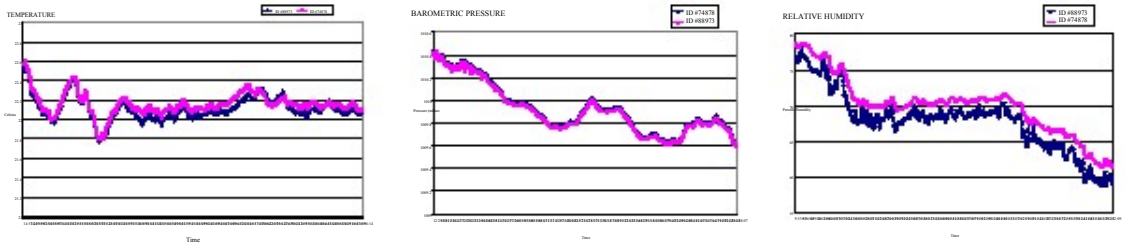
Repairs/Upgrades

The TLRS-4 system's pre-upgrade status was that of an inoperable system missing both hardware and software upgrades that had been installed into all other systems in the NASA Network. Major repairs and upgrades were required for every major subsystem of the TLRS-4. The Laser subsystem required new oscillator and amplifier heads, a solid state pulse slicer, a laser interlock system, a laser collimation lens, dye pump power supply, calibration transmit filter, laser bracket, and a laser warning light. The telescope/optics subsystem required a new 10Å Daylight Filter, a complete upper deck upgrade, and a diassembly and cleaning of the telescope. The transmit/receive subsystem required a T/R Switch motor and synch board, installation of the Photek MCP upgrade, and installation of a low-loss receive cable. The computer subsystem required a fully upgraded processing computer, a new administration computer, modifications to software for the controller computer, and upgraded Internet communications. The console subsystem required a new trackball board and microprocessor, a new tracking scope, and a new HP5370B Time Interval counter. The timing subsystem required a modification to the Time Code Generator for 4pps, the modification for 4/5 pps Auto switch, and updated CNS Clock Software. The facility subsystem was upgraded with dome control sensors, dome weather protection, a new remote operated dome shutter, and a complete refurbishment of the Instrumentation van and Support trailer. The safety subsystem was completely overhauled and coordinated through GSFC Code 250 for laser safety compliance.

System Operations Verification Tests (SOVT)

In July 2005, after all system upgrades and repairs were completed, HTSI began SOVT testing of the TLRS-4 system. SOVT Tests are performed subsequent to each relocation and prior to any laser system beginning operational support. SOVT's are comprehensive testing that ensures that the system is ready for operations by addressing every major and minor subsystem. These include tests for verifying station communications; station timing; mount level and dome control; interface of the tracking computer, mount, and data interface system; processing computer; performance of the data measurement

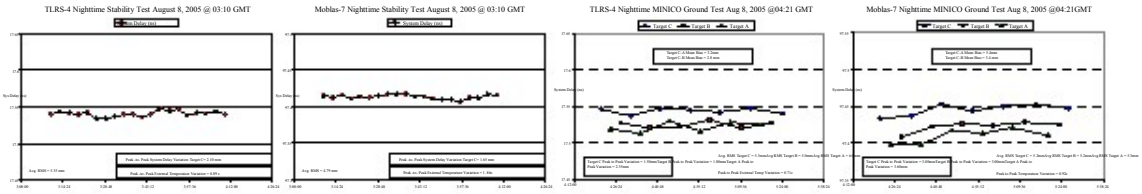
system; operations of the Continuum Laser system; safety interlock system; telescope pointing; star calibration performance; ground tracking; and controller computer operations. All SOVT Testing was successfully completed on July 15th, 2005.



System Validation

The NASA SLR program validates newly built, or newly upgraded SLR systems with an Intercomparison or Collocation Technique developed at NASA and HTSI in the 1980's. Designed to directly compare an upgraded SLR system to an established SLR tracking system (Moblas-7 at GGAO currently operates as the NASA Global Standard SLR system), this technique characterizes and verifies the operational performance and laser ranging capabilities of the upgraded system prior to establishing routine operations. During this project, system performance of the TLRS-4 system was compared, relative to that of Moblas-7 with an Intercomparison between the two systems. Both datasets were also compared against known orbits. The Intercomparison was achieved by using NASA SLR- developed Intercomparison software packaged called Polyquick and orbit comparisons were achieved by using the NASA-developed GEODYN software package. Polyquick was developed to identify laser system ranging anomalies by utilizing intercomparison geometry to isolate station dependent, systematic ranging errors from other external sources of systematic errors such as refraction and orbital errors. Directly comparing these two stations will provide a reliable technique to accurately calibrate the TLRS-4's SLR performance at the centimeter and sub-centimeter accuracy level.

A pre-intercomparison phase was established to ensure that all prerequisites for the Intercomparison were completed. Prerequisites included a first order system survey to establish the DX, DY, DZ components between the two systems, simultaneous ground tests to establish stability and dependency issues, simultananeous satellite tracking to establish performance, comparison of the two systems MET systems, comparison of the two systems station timing, and finally a configuration freeze.



STATION	LATITUDE	LONGITUDE	HEIGHT(m)
7105	39° 01′ 14.17743″ N	76° 49′ 39.69784″ W	19.194
7130	39° 01′ 15.27139″ N	76° 49′ 38.82201″ W	18.632

On August 1st, 2005, the configuration of both the Moblas-7 and TLRS-4 systems were frozen for the formal Intercomparison phase of the TLRS-4 Return to Operations Project. An Intercomparison test consists of simultaneous satellite and ground tracking where an evaluation is done for data quantity and data quality, as well as simultaneous data analysis to establish any biases or dependencies between the two systems. The Moblas-7, the NASA Network standard, was established as the base system because of its known performance, and was to be tested against the unknown TLRS-4 system.

Intercomparison Requirements:

– Data Quantity and Quality:

– Minimum of 15 simultaneous Lageos-1 or Lageos-2 passes must be tracked during the Intercomparison period.

– Minimum of 20 low orbital satellite passes will be tracked during the Intercomparison period.

– Both systems must achieve the specified data quality standards for any pass to be qualified for the test pass total. The quality criteria are as follows:

System Calibration RMS (mm) Calibration Shift (mm)	Lageos RMS (mm)	LEO's RMS (mm)
TLRS-4< 7.0< 10.0	< 15.0	12.0 - 30.0
Moblas-7< 7.0< 10.0	< 15.0	12.0 - 30.0

Data Analysis Requirements:

– All systematic biases between the TLRS-4 and Moblas-7, operating under normal conditions will be less than ±15 millimeters

– Only passes with 30 full-rate observations for Moblas-7 are qualified for Intercomparison data analysis

– Minimum of 10 simultaneous points per Polyquick bin per station.

– Analyses by Polyquick will be performed for each simultaneous pass taken during the Intercomparison test period.

• Range Difference Computation

• Bias Tests

– Range-dependent Range Bias Test

– Range-rate dependent Bias Test

– Elevation Dependent Range Bias Test

– Azimuth Dependent Range Bias Test

– Energy Dependent Range Bias Test

– Test for Long Term Mean Range Bias Stability

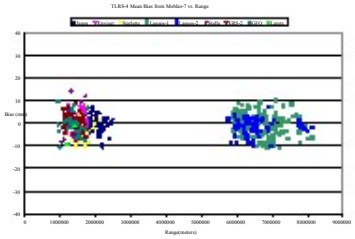
– Test for Diurnal Effects

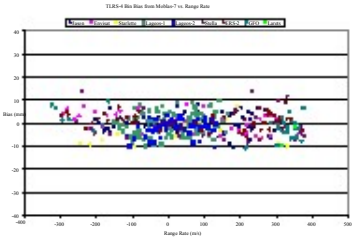
– System Delay Range Bias Test

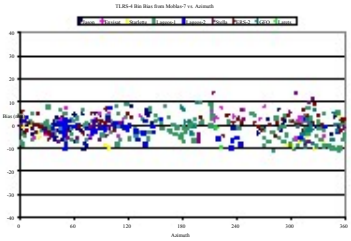
– Sky Coverage Test

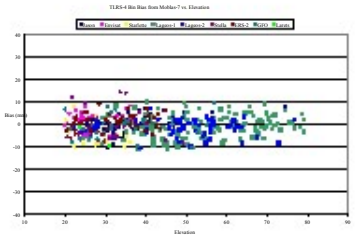
– Orbital comparison Test

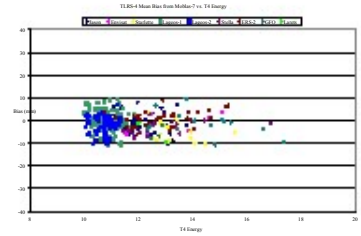
• Data Analysis:

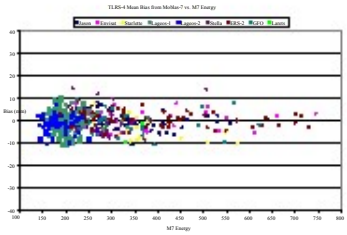

TLRS-4 Mean Bias from MoNav-7 vs. Range
Range(meters)

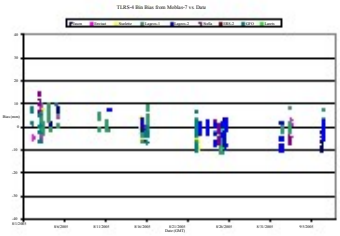

TLRS-4 Bin Bias from MoNav-7 vs. Range Rate
Range Rate (m/s)

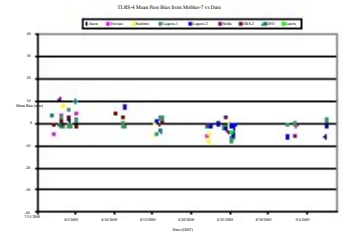

TLRS-4 Bin Bias from MoNav-7 vs. Azimuth
Azimuth

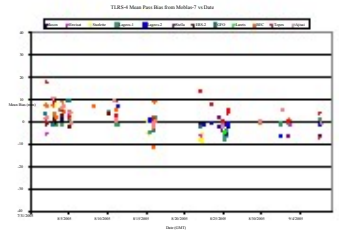

TLRS-4 Bin Bias from MoNav-7 vs. Elevation
Elevation

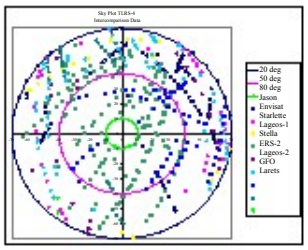

TLRS-4 Mean Bias from MoNav-7 vs. T4 Energy
T4 Energy

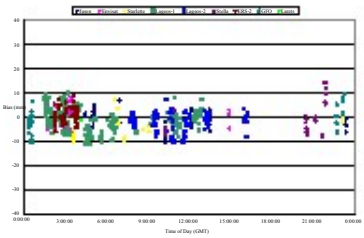

TLRS-4 Mean Bias from MoNav-7 vs. M7 Energy
M7 Energy

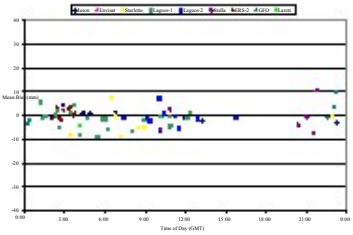

TLRS-4 Bin Bias from MoNav-7 vs. Date
Date (GMT)

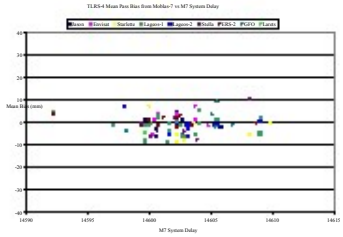

TLRS-4 Mean Pass Bias from MoNav-7 vs Date
Date (GMT)

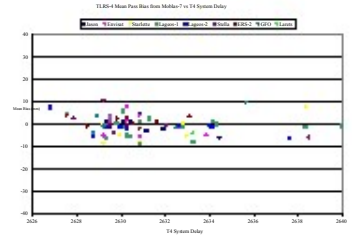

TLRS-4 Mean Pass Bias from MoNav-7 vs Date
Date (GMT)

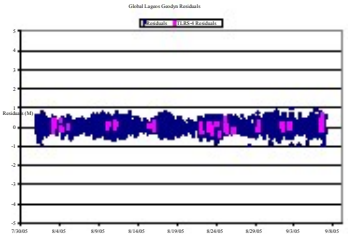

Sky Plot TLRS-4
Intercomparison Data
20 deg
50 deg
80 deg
Jason
Envisat
Starlette
Lageos-1
Stella
ERS-2
Lageos-2
GFO
Larets


TLRS-4 Bin Bias from MoNav-7 vs. Time of Day
Time of Day (GMT)


TLRS-4 Mean Pass Bias from MoNav-7 vs Time of Day
Time of Day (GMT)


TLRS-4 Mean Pass Bias from MoNav-7 vs M7 System Delay
M7 System Delay


TLRS-4 Mean Pass Bias from MoNav-7 vs T4 System Delay
T4 System Delay


Global Lageos Geodyn Residuals
Residuals
TLRS-4 Residuals

Intercomparison				
TOPIC	TLRS-4	Moblas-7	TLRS-4 Results	Moblas-7 Results
Minimum Simultaneous Passes				
Lageos-1 & Lageos-2	15	15	29	29
LEO's	20	20	123	123
Fullrate Data RMS				
Calibration	≤ 7 mm	≤ 7 mm	5.44 mm	5.49 mm
Calibration Shift	≤ 10 mm	≤ 10 mm	0.31 mm	0.71 mm
Lageos-1 & Lageos-2	≤ 15 mm	≤ 15 mm	11.25 mm	9.17 mm
LEO's	≤ 12 - 30 mm	≤ 12 - 30 mm	16.11 mm	11.21 mm
Ground Test Delay Variations				
Stability Test	≤ 8 mm	≤ 8 mm	2.55 mm	1.73 mm
Extended MINICO	≤ 8 mm	≤ 8 mm	2.95 mm	2.13 mm
Intercomparison Bias				
TLRS-4 Mean Pass Bias from Moblas-7	± 15 mm		1.07 mm	
Lageos-1 & Lageos-2	± 15 mm		0.91 mm	
LEO's	± 15 mm		1.67 mm	

Results

The TLRS-4 / Moblas-7 Intercomparison produced some of the best intercomparison results ever achieved by a NASA system. The TLRS-4 system bias from Moblas-7 was 1.07 mm, far exceeding the ±15 mm requirement. The system exceeded every other intercomparison requirement and was declared an operational system after the NASA Operational Readiness Review on September 15, 2005. TLRS-4 was deployed to Maui, Hawaii on April 19th, 2006. It was then moved to the summit of Haleakala on September 7, 2006, and will return laser ranging to a critical global geographical position in the very near future.