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## OVERFLOW SESSION SUMMARY

Chair: Mike Pearlman

Andrew Dmytrotsa gave a paper on the recent upgrading of the Simiez SLR Station. Software and optics upgrades have improved data yield. The laser power supply was replaced with a loaner from the Katzively station after the on-site system failed. Upgrades continue with new servo drivers for the stepper motors.

Julie Horvath reported that the TLRS-4 system has been refurbished, upgraded, and transferred to a new site at Haleakala in Maui. The collocation with Moblas-7 at GSFC achieved closure to 1 - 2 mm and demonstrated full capability on both low satellites and LAGEOS. Operations are anticipated by the end of the year.

Nobuo Kudo gave a paper on "Using SLR, the GPS accuracy verification experiment of ALOS". Twelve selected stations from the ILRS network supported the GPS-SLR validation campaign from August 14 to 31, 2006. The satellite had a payload vulnerable to laser light and this campaign used the new restricted tracking procedures implemented by the ILRS network last year. The campaign showed that the offset between the GPS and the SLR orbits was within a few centimeters RMS, well within the mission requirement.

Hyung Chul Lim presented the "Korean Plan for SLR system development". He described the structure and activities of the Korea Astronomy and Space Science Institute (KASSI). KASSI is building two satellites STSAT-2 and KOMPSAT-5 to be launched in 2007 and 2009 respectively. Both will carry retroreflector arrays for POD. Korea now has about 80 GPS stations and three VLBI stations and plans to build a mobile SLR station and a Fundamental Station that would include a permanent SLR. The development period for these systems will be about 2 years for the mobile system and 5 years for the Fundamental Station. In the meantime, the Chinese will provide a mobile system for use at a site in Korea for some period starting in 2007 to support the STSAT-2 satellites and ILRS requirements.

You Zhao reported on the "Fulfillment of the SLR daylight tracking of Changchun Station". The main thrust of the program is to improve orbit predictions, provide better filtering of sky noise, increase the alignment of the transmitting and receiving beams, and reduce stray light. The plan includes improved spatial, timing, and spectral filtering. The hardware and software improvements are nearly ready for testing. Work had been delayed because the Changchun Station was selected as the main Chinese tracking support for GIOVE-A, and tracking on this satellite took highest priority, but system testing is anticipated by early 2007.

Vladimir Glotov presented "GLONASS status updates; MCC activity in GLONASS Program". The paper reviewed the background and mission of the GLONASS Program which is building toward a 24 satellite complex in the 2009 timeframe. The International GLONASS - Pilot Project (IGLOS-PP) is a pilot service of the IGS to track and analyze data from the satellite constellation. The ILRS provides very important support for GLONASS by tracking three of the constellation satellites as designated by IGLOS. The need will continue and hopefully the tracking will increase. GLONASS provides a "collocation in space", a key tool to strengthening the reference frame. IGLOS-PP demonstrates the ability of IGS to accommodate other microwave satellite systems.

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## Current Status of "Simeiz-1873" Station

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### Abstract

*The SLR station "Simeiz-1873" was founded in 1989. After modernization in 2000 we have increased the amount of ranging data by approximately three times. With this modernization we have probably reached a limit of the equipment, due mainly to the shortcomings of the laser transmitter. Independent analysis groups have shown stability problems in of our data.*

*A permanent GPS receiver was installed at the site in 2000. "Simeiz-1873" became a permanent IGS station (GPS-CRAO) in 2004. Recently in our station began processing GPS data using the GLOBK/GAMIT software. We have obtained and analyzed data for the period 2002-2005.*

### Introduction

Regular satellite laser ranging started in our observatory in 1976 as an INTERKOSMOS Station with a laser system installed by K. Hamal on a KRIPTON telescope. In 1988 the Crimean Astrophysical Observatory installed a new station (near the old station). Colocations with the IFAG MLTRS system were conducted in 1991.

A modernization program was undertaken in 2000 under a CRDF grant (thanks for M. Pearlman and D. Nugent). New angular encoders and a new time interval counter were installed. After modernization we increased the amount of ranging data by approximately three times (Fig.2).

A permanent GPS receiver has been operating near "Simeiz-1873" since 2000. In 2004 it became an IGS site "GPS-CRAO" (Fig.3, right). The "Simeiz-1873" is a one of four Ukrainian SLR stations. (GLSV-1824, Lviv-1831, KTZL-1893)

### Current status

Modernization of station proceeds. It is necessary to carry out the following items:

- Implementation of the new CPF prediction format into the software;
- installation of a new modern control system of engines;
- updating of optical system of a telescope for a new calibration target and replacement of a prism with a mirror;
- ground calibration tests with the new target at 77m east;
- continue processing GPS data with GAMIT/GLOBK.

### Ranging and GPS proceeding

In 2006 we suffered appreciable downtime due to two failures of the laser power unit. The Katzively station (1893) has installed a new laser systems and loaned their old power unit to us. The loaned unit also failed and required considerable, time-consuming repair.

As you can see in Fig.2, data has increased with the modernization activities, but we have probably reached the limit with our equipment; the laser transmitter is 18 years

old! The second problem is in tracking. In 2006 we purchased new servo-drivers for the stepper motors and we hope that this will help improve our tracking capability.

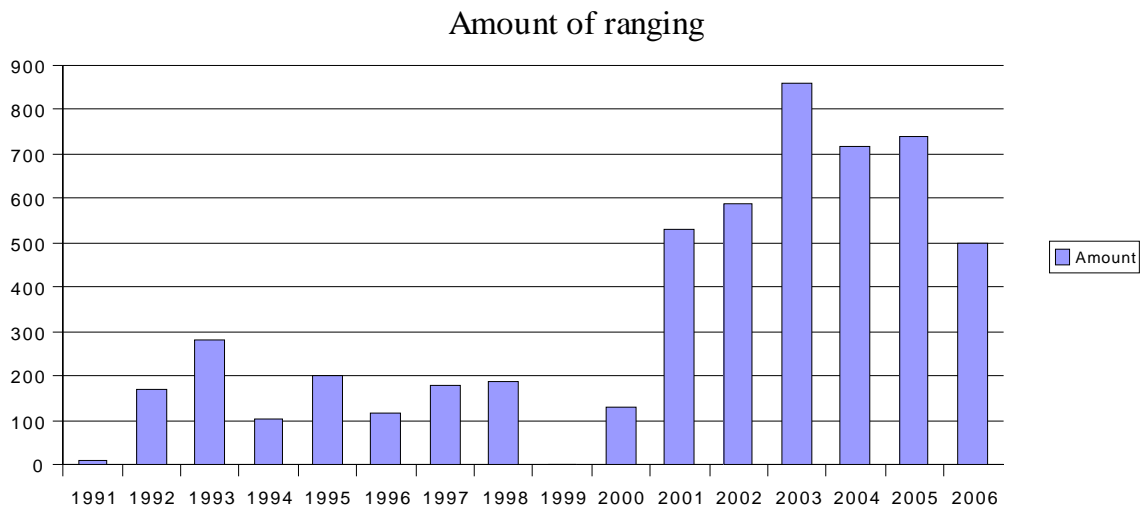


*Figure 1. SLR-1873. General view.*

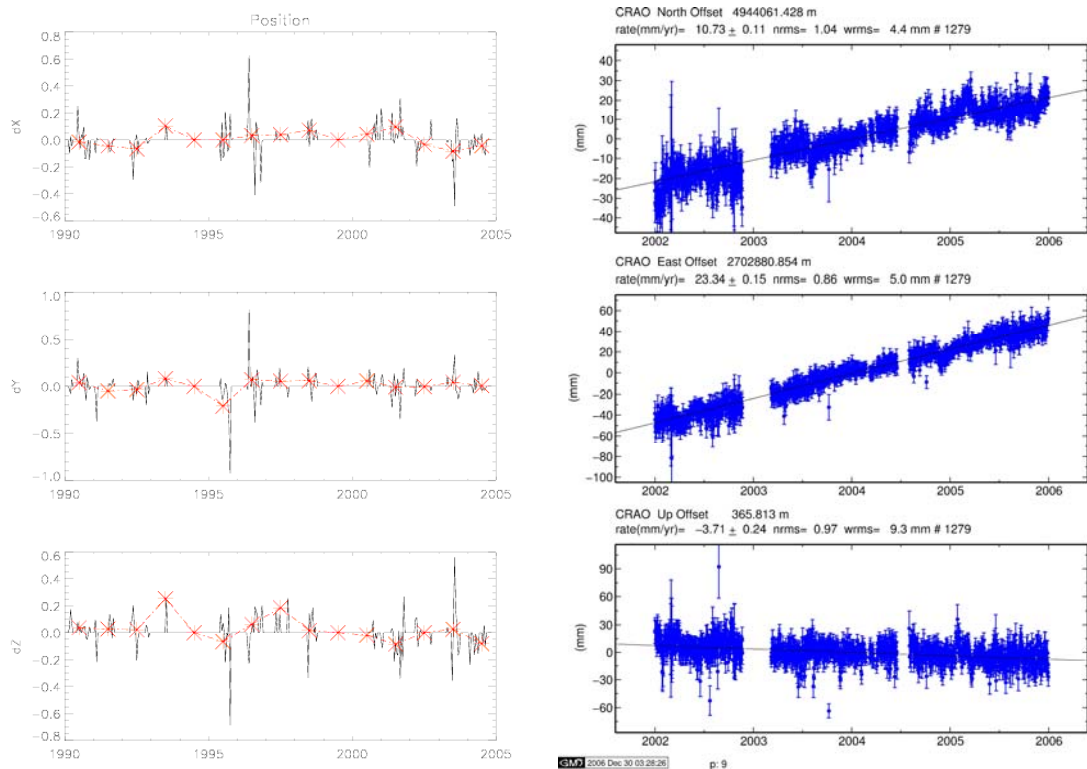
*Table 1. Main elements.*

<b>Element</b>	<b>Description</b>
Mount	Alt-Az. 1m mirror.
Angular encoders	FARRAND CONTROLS, 0.4"
Time interval counter	SR620
PMT	H6533
Time & Freq standard	TC-74, sec. from GPS.
Laser	350 ps, 5Hz. (18 years old)
Software	GUI on a JAVA, server on a C++, low level modules on a C. LINUX.
Ephemerides	CPF, (on a F77).

Analysis by two independent groups shows that the stability of the station SLR data still needs considerable work. Results from the Ukrainian Center of Determination of the Earth Orientation Parameters (Bolotina, 2006) are shown in fig.3 (left). Similar results were found by S. Schillak by processing our LAGEOS ranging data for period 1999-2003. (See Schillak, 2004).



*Figure2. Amount of ranging from 1991 to 2006.*



**Figure 3.** Geocentric coordinates (delta from mean value) obtained by SLR (left) for 1991-2005 (red is a mean by year), meters; topocentric coordinates (delta from mean value) obtained by GPS (right) for 2002-2006, mm

We have also processed GPS data with the GAMIT/GLOBK software on our station (fig.3, right). As you see, results from our SLR location are not comparable with results received by GPS. Also on the GPS results a trend is evident. It not detectable in the lower precision SLR data.

### Summary

The analysis of results has shown that we still have stability problems with the Simiez ranging systems; likely causes of the problems are the old laser transmitter, inadequacies in the calibration system, and greater breaks in ranging to LAGEOS because of equipment failure and poor weather.

The basic directions of work will be: creation of a new telescope mount model; better operations procedures, and hopefully, replacement of the laser on new.

### Acknowledgments

We acknowledge and thank to Stanislaw Schillak and to Olga Bolotina for processing our SLR results. We acknowledge and thank the Local Organize Committee of the 15<sup>th</sup> Workshop for financial assistance.

### References

- [1] Bolotina, O., Medvedskij M, Investigation of the stability of the Ukrainian SLR network, preprint, 2006
- [2] Schillak, S. Determination of the station coordinates for quality control of the satellite laser ranging data. p387-394, Proc. 14<sup>th</sup> International Laser Ranging Workshop.

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## Overview and Performance of the Ukrainian SLR Station “Lviv-1831”

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### Abstract

*Satellite laser ranging station “Lviv-1831” was found in 1998. In August 2002, it was registered as an associate SLR station in the ILRS. It is also a member of the Ukrainian network of UCEOP (Ukrainian Center for Earth Orientation Parameters).*

*The station is based on the following equipment: 1 m telescope TPL-1M on alt-azimuth mounting, an SL-212 laser with 150 ps pulses at 532 nm and a repetition rate 5 Hz, a Latvian A911 timer with internal precision of 40 ps. The current fire-receiving system can only operate at ranges above 900 km [1].*

*During 2005 the station ranged to 138 passes of LAGEOS with an RMS of 50 mm. The short term stability over 2005 was about 35 mm, and the long term stability was 25 mm.*

*At present, the station team is testing a new receiver with a Hamamatsu module H6780-20 PMT, a neutral density filters wheel for return signal strength control, and a new electromechanical shutter. Implementation of these improvements in the system should increase the performance and the accuracy of ranging results by a factor of about three. The next step in station modernization is the improvement of fire-receiving system for ranging to very low satellites at altitudes about 500 – 900 km.*

### References:

- [1] A.Bilinsky, Ya.Blagodyr, A.Lohvynenko, S.Ternavska Station reports: Lviv, Ukraine // International laser Ranging Service 2003-2004 Annual Report, June 2005, pp.B-26 – B-27.

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## 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.



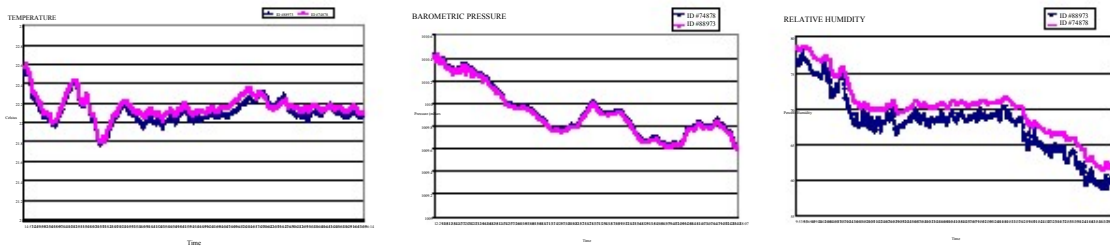
### **Repairs/Upgrades**

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 disassembly 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

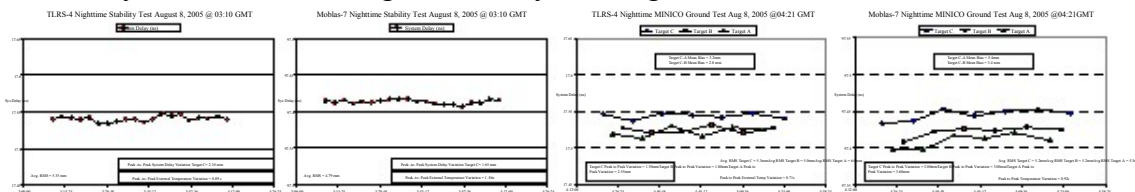
system; operations of the Continuum Laser system; safety interlock system; telescope pointing; star calibration performance; ground tracking; and controller computer operations. All SOVT Testing was successfully completed on July 15th, 2005.



### 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, simultaneous 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.

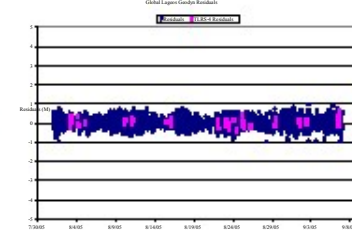
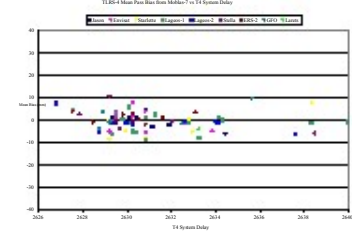
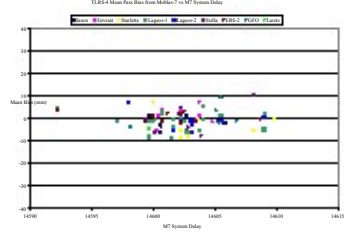
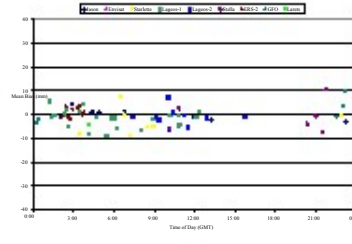
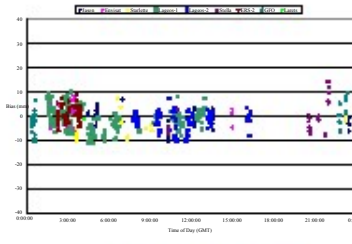
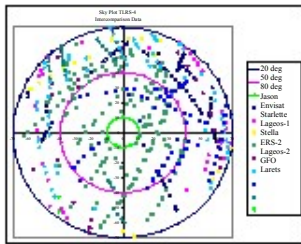
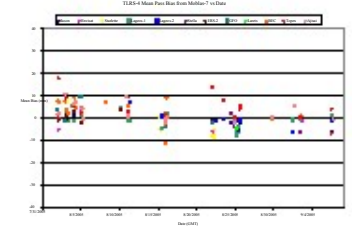
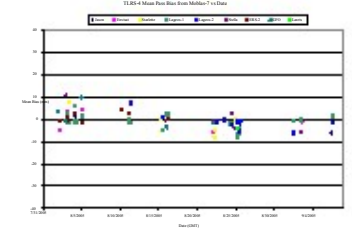
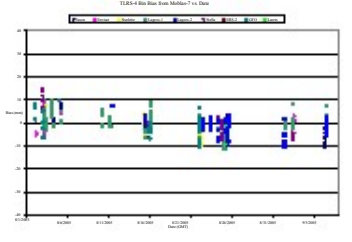
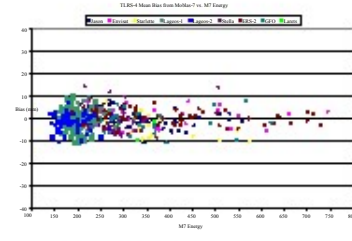
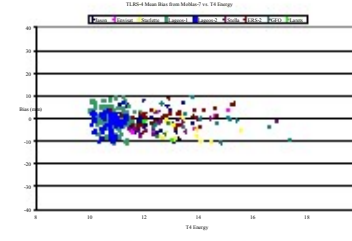
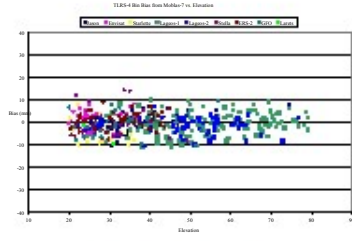
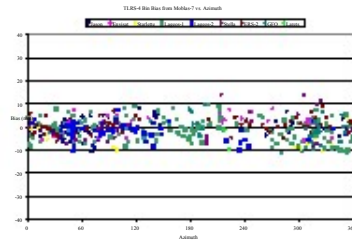
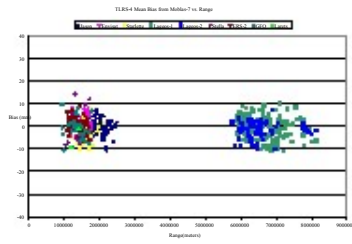
**Intercomparison Requirements:**

- 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:

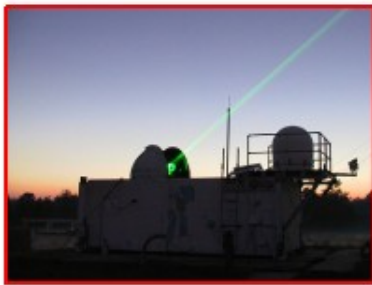
<u>System</u>	<u>Calibration RMS (mm)</u>	<u>Calibration Shift (mm)</u>	<u>Lageos RMS (mm)</u>	<u>LEO's RMS (mm)</u>
TLRS-4	< 7.0	< 10.0	< 15.0	12.0 - 30.0
Moblas-7	< 7.0	< 10.0	< 15.0	12.0 - 30.0

**Data Analysis Requirements:**

- All systematic biases between the TLRS-4 and Moblas-7, operating under normal conditions will be less than  $\pm 15$  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:



Intercomparison				
TOPIC	TLRS-4	Moblas-7	TLRS-4 Results	Moblas-7 Results
<b>Minimum Simultaneous Passes</b>				
Lageos-1 & Lageos-2	15	15	29	29
LEO's	20	20	123	123
<b>Fullrate Data RMS</b>				
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
<b>Ground Test Delay Variations</b>				
Stability Test	< 8 mm	< 8 mm	2.55 mm	1.73 mm
Extended MINICO	< 8 mm	< 8 mm	2.95 mm	2.13 mm
<b>Intercomparison Bias</b>				
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  $\pm 15$  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.



Honeywell Technology Solutions Inc  
15th International Laser Ranging Workshop, Canberra, Australia, Oct 16th – 20th, 2006

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# The Accuracy Verification for GPS Receiver of ALOS by SLR

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## Abstract

*The Advanced Land Observing Satellite (ALOS) provides precise geographical data for making global precise map. ALOS has a dual-frequency GPS receiver to determine geographic positions corresponding to points on satellite images. In order to confirm the orbit determination accuracy by GPS, we carried out a restricted laser ranging campaign with the support of the International Laser Ranging Service (ILRS). We found the GPS orbit agreed with the SLR orbit to within the resolution range of the SLR analysis.*

## Introduction

Recently, the positioning accuracy achieved by dual-frequency GPS receivers is within few dozens of cm. However we needed to verify the ALOS onboard GPS receiver because it was newly developed.

## Overview of ALOS

Advanced Land Observing Satellite (ALOS), also called “DAICHI”, was launched from Tanegashima Space Center in Japan on 24 January 2006. ALOS performs earth observations at a high resolution, which is expected to contribute to a wide range of fields such as map compilation, regional observation, notice of disaster situations and resource mapping. Detailed review of the ALOS mission and its advanced technology were reviewed in Iwata et al [1] and Hamazaki [2]. The orbit information of ALOS is described in Table 1.

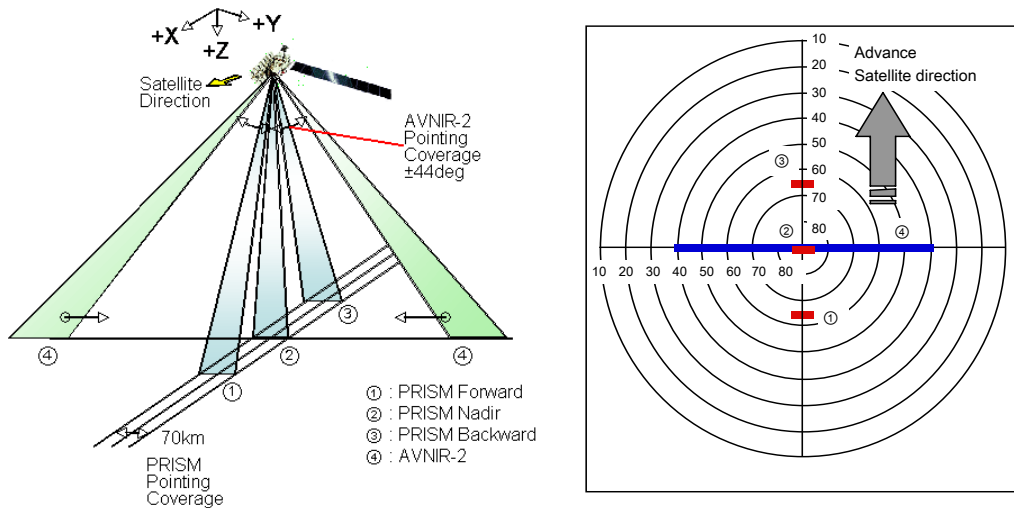
*Table 1: The value of the orbit*

Orbit Type	Solar synchronous, sub-recurrent, frozen
Height	691.65km (above the equator)
Period	98.7 min
Eccentricity	1/1000
Inclination	98.16deg
Recurrent days	46 days

ALOS is one of the largest Earth observing satellites ever developed. ALOS has a GPS receiver and a laser reflector as tools for orbit determination.

## Orbit Determination accuracy of ALOS

In order to make a precise map, it is necessary to observe the earth with high resolution and specify geographical positions corresponding to observed images. Thus, high positioning accuracy and directional precision are required for ALOS [3]. Orbit determination accuracy is required to be within 1m after processing on the ground. There are two tools for precise orbit determination for ALOS, that is, GPS receiver and laser reflector (LR) for Satellite Laser Ranging (SLR). The ALOS GPS receiver was newly developed for this mission. Detailed description of the GPS receiver is given in Toda *et al* [4]. The result of orbit determination using the GPS data is reported in



**Figure 1.** Image of the ranging restriction.

Nakamura *et al* [5]. The ALOS LR consists of nine Corner Cube Reflectors (CCR). A more detailed analytical result is described in the ALOS Tracking Standard [6].

### **Interference between ALOS's earth observation sensors and SLR laser beam**

ALOS has two earth observation sensors (PRISM, AVNIR-2) which are vulnerable to the SLR laser radiation wavelength at 532nm. The CCD of each sensor can be destroyed when the incident energy exceeds  $5 \times 10^{14} [W/m^2]$ . We checked the possibility of damage to these sensors using the specifications of some typical SLR stations. As a result, the laser of SLR could damage the CCDs of sensors if the laser beam impinges on the sensors. The results are similar for almost all stations of the world. Therefore we needed to carry out restricted laser tracking to avoid damaging sensors.

### **Restricted Laser Tracking**

The method of restricted laser tracking is standardized by the ILRS[7]. JAXA carried out restricted laser tracking to ALOS using this method. Figure 1 shows the restricted area. The pass of ALOS is sometimes divided into two, three, or four regions.

**Table 2:** List of participating station for ALOS Tracking

SLR Stations	ID	Nation
Mt. Stromlo	STL3	Australia
RIGA	RIGL	Latvia
Koganei(KOGC)	KOGC	Japan
Simosato	SISL	Japan
Monument Peak(Moblas-4)	MONL	USA
Hartebeesthoek (Moblas-6)	HARL	South Africa
Yarragadee(Moblas-5)	YARL	Australia
Tanegashima	GMSL	Japan
Zimmerwald	ZIML	Swiss land
Herstmonceux	HERL	United Kingdom
Greenbelt (MOBLAS-7)	GODL	USA

### **SLR data acquisition and ILRS campaign**

We asked ILRS to provide support for ALOS SLR. Thanks to ILRS support, eleven SLR stations (Table 2) participated in the ALOS SLR campaign. We carried out the

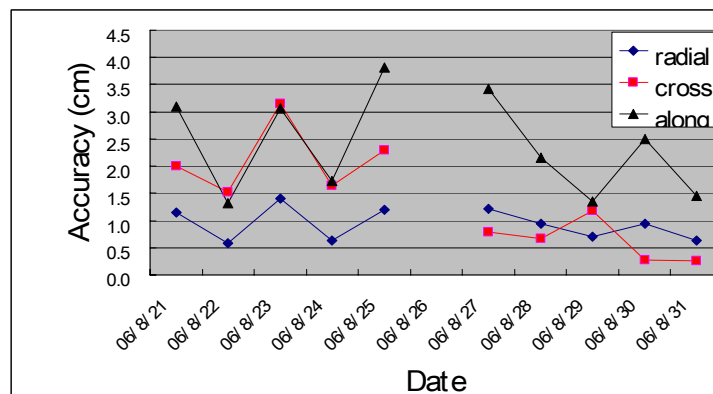
ALOS SLR campaign from UT 00:00:00 on 14 August 2006 to UT 16:00:00 on 31 August 2006. We obtained 100 passes and 2979 data points.

### The accuracy of orbit determination using GPS data

First, we review the accuracy of orbit determination using GPS data. The details of method of orbit determination using GPS are described in Nakamura *et al*[5].

#### The accuracy of orbit determination using GPS data

Figure 2 and Table 3 shows the accuracy of orbit determination using GPS data during ALOS SLR campaign. The accuracy of orbit determination is evaluated by overlap comparison and expressed in terms of the RMS value during the orbit determination period. Figure 2 and Table 3 show that the accuracy of orbit determination using GPS data is within a few cm.



**Figure 2.** Accuracy of orbit determination using GPS data (RMS)  
The horizontal axis is date and the vertical axis is the accuracy of orbit determination.

**Table 3.** Summary of GPS OD Accuracy (cm)

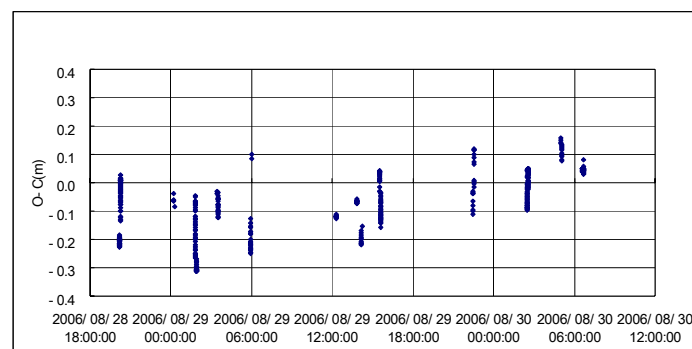
	Radial(ave)	Radial(sig)	Cross(ave)	Cross(sig)	Along(ave)	Along(sig)
GPS Overlap	-0.04	0.94	0.03	1.38	0.56	2.39

### Analysis

Our SLR analyses used both global arc and short arc methods.

#### Global arc analysis

We compared GPS data with SLR data and evaluated the residual of SLR data. Figure 3 shows a typical result and Table 4 shows the statistic result.



**Figure 3.** Difference between GPS orbit and Laser ranging data (as example)

Our analysis shows that the SLR data is within  $-4.8 \pm 12.0$  cm of the GPS orbits. What is noteworthy is that the standard deviation value is larger than the average value. This means that the difference between GPS-determined orbit and SLR data is well within the margin of error; there is no significant difference.

**Table 4.** Results of residual (cm)

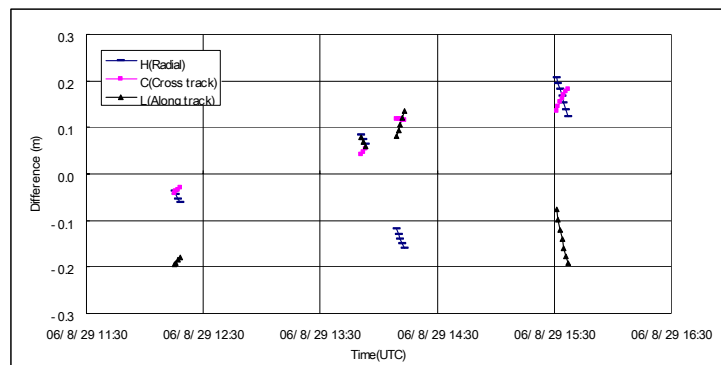
	Average	St Dev
SLR O-C Analysis	-4.78	12.03

### Short arc analysis

The above analysis cannot separate the radial, cross, and along components of GPS-determined orbit. Next we performed the orbit determination using only SLR data and compared it with the orbit determination using GPS data in each direction. Because SLR is an independent method from GPS, this analysis provides an objective evaluation of the ALOS onboard GPS receiver specifications.

Several passes are needed to perform orbit determination using SLR data. If we used daily data sets, the accuracy of orbit determination would be degraded because of the irregularity in data density. Therefore we performed the orbit determination using SLR data acquired during periods when more than three stations carried out SLR within a few orbital cycles. This means that our analysis is not the short arc analysis in a strict sense.

We calculated only the six orbital elements for the orbit determination using SLR data. We used a polyhedral model to represent the satellite and also considered the attitude model of ALOS. We didn't estimate the range bias for each station data. (We used the calibration data of each station.) And the analysis was performed for the periods where SLR data existed.



**Figure 4.** The difference between the orbit determinations using SLR and GPS

We compared the two orbit determinations of SLR and GPS approaches, and verified each direction (Cross, Along, Radial) result. The summary of result is shown in Table 5.

**Table 5.** Summary of Difference between SLR and GPS (cm)

	R(ave)	R(sig)	C(ave)	C(sig)	A(ave)	A(sig)
SLR-GPS	-2.98	20.54	-4.69	38.32	-5.44	28.76

These results show that the position estimated by GPS overlap method, and the position estimated by comparison of GPS orbit determination and SLR orbit determination fell within the margin of error (1sigma).

## **Conclusion**

The analysis using the overlap method is a relative evaluation of GPS-based orbit determination and the analysis using SLR data is an absolute evaluation of GPS-based orbit determination. In other words, the overlap method is the evaluation of random error and the analysis using SLR data is the evaluation of bias error.

From this analysis, the error estimated by GPS overlap method was small compared to the error estimated by the analysis using SLR data. This means that the error estimated by GPS overlap method is negligible. The result of global arc analysis shows that there is no significant difference between the SLR and GPS data. Next we checked the difference in each direction between SLR determined-orbit and GPS determined-orbit by short arc-like analysis. As a result, the position estimated by GPS overlap method, and the position estimated by comparison of GPS orbit determination and SLR orbit determination agreed to within the margin of error (1sigma). Because the ALOS onboard GPS receiver was newly developed, we needed to verify the specifications. The result of this analysis showed that ALOS GPS receiver provides correct positioning information, to at least within the accuracy confirmed by our SLR-based analysis. In this analysis, 1 sigma was about 30 cm. This means that the accuracy of the ALOS onboard GPS receiver satisfies the requirement from ALOS mission, which is within 1m (peak to peak).

## **Acknowledgements**

ALOS tracking campaign was performed successfully with the cooperation of ILRS and participating SLR stations, to all of whom we would like to express our deep appreciation. And we also would like to express our deep appreciation to Mr. Iwata, Mr. Toda and Mr. Matsumoto of ALOS project team, who explained the structure of ALOS in detail.

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# Fulfilment of SLR Daylight Tracking In Changchun Station

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## Abstract

*The paper introduces the performance and progress for Satellite Laser Ranging (SLR) system daylight tracking in Changchun station. This paper first introduces the problems and difficulties facing this system for daylight tracking—mount model, the separation of emitting and receiving parts of the telescope, control range gate, installing narrower filter. Third it presents some work which was done in the system for daylight tracking: system stability improvement, laser stability improvement, mount model adoption, control system, etc. From these analysis and work which have been done, the system performance has been greatly improved. A routine operation system in daylight tracking has been set up.*

**Keywords:** SLR, daylight tracking

## Introduction

### *Some main technical problems for daylight tracking*

The daylight tracking is necessary and the tendency of SLR in the future. Many stations in the world can take the daylight observations. According to the experience at the most successful station, recent years, Changchun station has been working on the daylight tracking technique. Some things to consider:

- Precise orbit prediction

Predictions of position and range of satellites and pointing of tracking mount with high accuracy. No problem for current CPF predictions.

- Reduce the effect of daylight sky background noise on photoelectric detector

Day background noise level is higher in SLR daylight tracking. Pointing of the telescope; Mount model problem for the telescope; Generating control range gate narrower; the application narrow Spectrum filter; the receiver filed of view want to be small, above all will efficiency reduces amount of background light.

- Parallelism of transmitting and receiving paths

For our station using telescopes with separated transmit and receive, it is sometimes difficult to maintain correct laser beam pointing due to Coude path mirror drifts. It required good collimation.

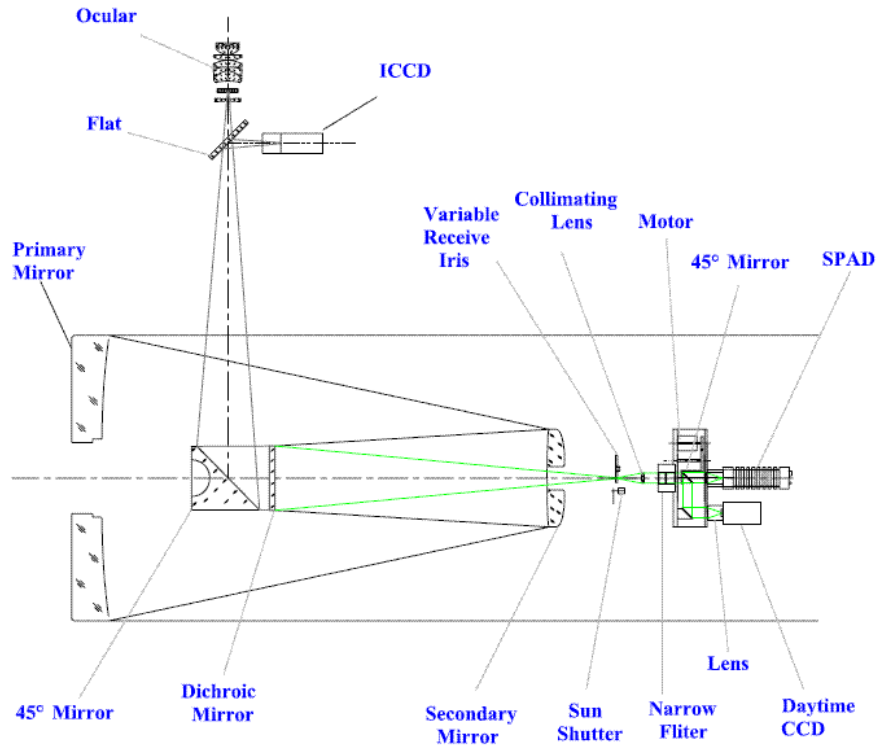
- Intensive light protective methods

To avoid the damage of the detector by focused Intensive light.

### **Progress for Daylight Tracking in Changchun SLR System**

Even there are so many difficulties, we still have done some work to try to fulfill daylight tracking, such as system stability improvement, laser stability improvement, mount model adoption, control system, etc. In order to improve the system stability, a new control system has been adopted, including an industrial control computer, data collecting board and counter card for timing and range gate. Control and data preprocessing software are also updated so that all work can be done automatically. For

laser stability, the room is air-conditioned. The cooling system is also improved for its liable working, including some system protections. In order to improve the pointing accuracy, mount model correction is also adopted in the satellite prediction. A spherical harmonics pointing model was built by using astronomical observation at our telescope system. It is proved that the pointing model is an effective correction to the system error. This makes the pointing bias become very small in most directions. The design of tracking optical scheme on Changchun SLR system is shown in Figure 1.

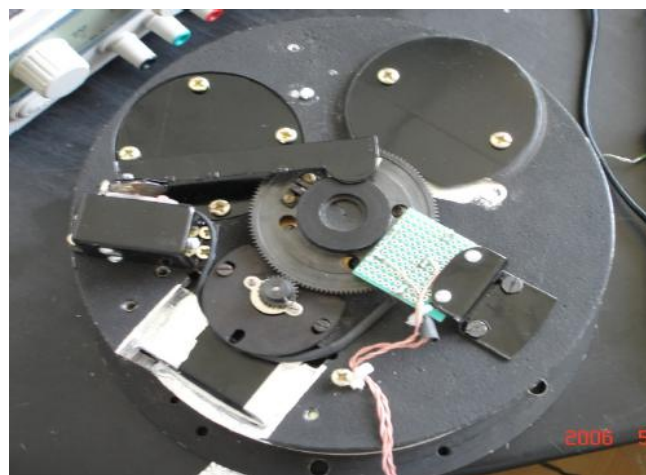


*Figure 1. Optical scheme of Changchun SLR system*

### Ways to reduce effect of daylight background noise

#### *Space filter*

The electric-powered adjustable iris is used for field of view. Receiving Field of view: 45"-12'. Figure 2 shows receiving iris diaphragm.



*Figure 2. Variable Receiving Iris diaphragm*

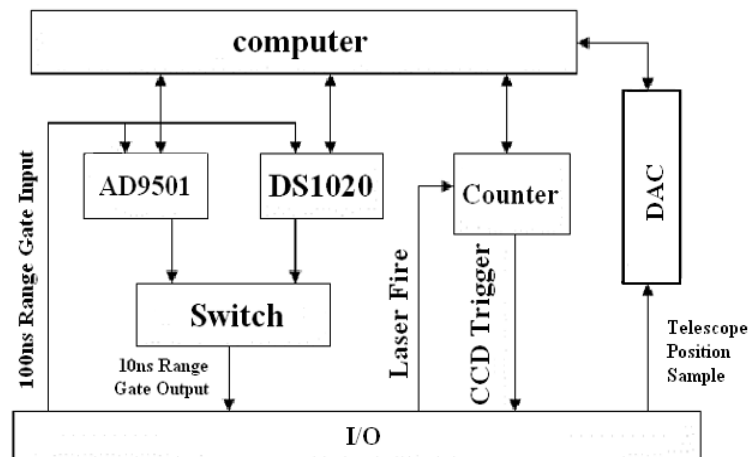
### ***Timing filter***

We designed and developed the precise range gate generator.

It can produce 1ns range gate to make the time closer to the arrival echo. We provide two devices to generate range gate:

AD9501: Programmable digital delay generator.10ps precision time delay, delay: 2.5ns—10us (capacitance and resistor);

DS1020: 8 bit programmable delay device, serial parallel mode. Max. Delay time: 48.25ns (fast mode), 520ns (slow mode). Figure 3 is the control precise range gate Generate Circuit Chart.



***Figure 3. Control precise range gate Generate Circuit Chart***

### ***Spectrum filter***

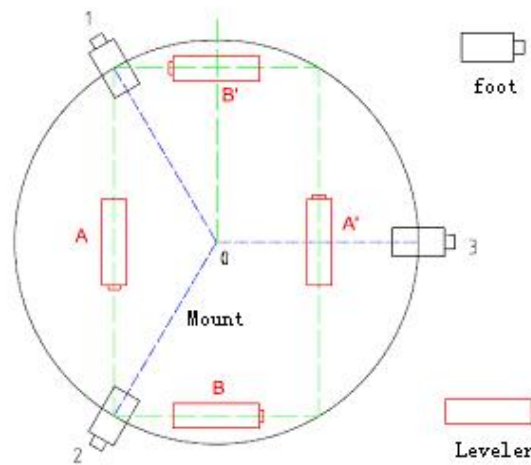
The application of 0.3nm narrow band pass interference filter form Andover Corp. and the constant temperature box to cut more background noise and to make the filter working in a constant temperature environment. The temperature controller provides protection against the influences of ambient temperature fluctuation. The specs of Andover Narrow Band Interference Filter are: Center Wavelength: 531.9 nm; Bandwidth: 0.3±0.1 nm; Peak transmission: 41.30 %; Ambient temperature: 23°C; Size:Φ25.00 ± 0.25 mm. Figure 4 is the photograph.



***Figure 4. Spectrum filter and constant temperature box***

## Pointing of the telescope

- Mount leveling Collimation measurement



**Figure 5.** Mount leveling Collimation measurement

The first step is mount leveling. The data of mount leveler is recorded each 30 degree.

After leveling

$$i = \sqrt{a_1^2 + b_1^2}$$

$$A = \arctan\left(\frac{a_1}{b_1}\right)$$

where

$$a_1 = \frac{1}{6} \sum_{j=0}^{11} f(\alpha_j) \cos(30^\circ \cdot j); b_1 = \frac{1}{6} \sum_{j=0}^{11} f(\alpha_j) \sin(30^\circ \cdot j)$$

After calculation: the azimuth angle perpendicular to the slant direction is  $A=1.2''$

- Collimation measurement

$$C = (A_R - A_L \pm 180^\circ) / 2$$

$$\text{RMS} = 3'02''$$

- Zero error measurement of encoder

Polestar observation the error of encoder zero position:

$$\Delta A_0 = 180.682431^\circ$$

$$\Delta E_0 = 0.01684^\circ$$

- Star Calibration

Observe positions of known stars (calculation from FK5) using night camera. Mark reference position on screen of night camera. Our system can to gather data from 48--60 stars in 1 hour. Compare observed (encoder readings) with calibration position (O-C). The Least Squares to fit the mount model parameters (13 parameters each axis). Application of current mount model provides a good fit for elevations from 15 degrees to 80 degrees. System pointing is at the few arc second level.

RMS of fit: Azimuth: 5.5"

Altitude: 4.8"

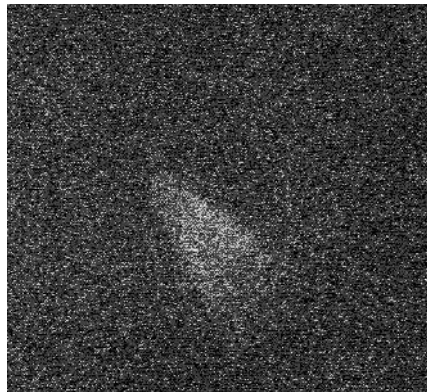
### ***Parallelism of transmitting and receiving paths***

- 1) Adjustment of sensitive area of detector.
- 2) Coude path fine adjustment.
- 3) Monitor laser beam during daylight.

We have installed a CCD camera in the receiver path; a switched mirror can direct this green light into the CCD or into the SPAD. This CCD is triggered by the laser start pulse that is delay 153us; an exposure time of down to 1/20000 s. Using software image / contrast enhancement techniques to display the backscatter of laser beam in real time.

- 4) Directional adjustment of output laser beam.

To adjust the laser beam direction with remote control of the last Coude mirror to fit the parallelism of transmitting and receiving path. Figure 6 is the image of daylight laser beam.



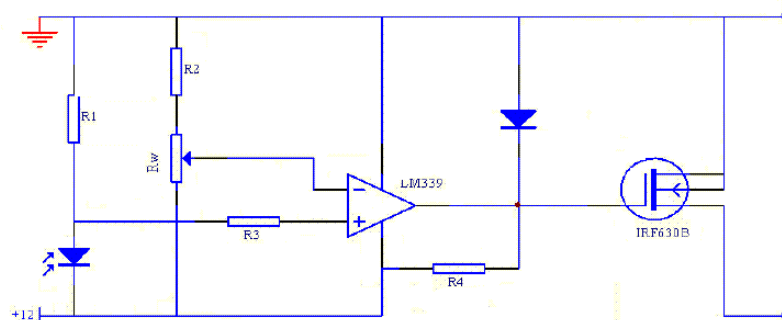
***Figure 6. Image of Daylight Laser Beam***

### **Intensive light protective methods**

In order to avoid the damage of the C-SPAD detector by focusing sunlight, we must prevent the mount from pointing to the Sun. The double methods were used:

#### ***Hardware protection***

Four strong light detectors were adopted on the top of mount, when the telescope moves to the place with strong light (such as to the sun or moon), the detectors will trigger a circuit to shut off the emergency shutter of the field of view. Figure 7 shows the electronic circuit diagram.



***Figure 7. Electronic diagram of light protective circuit***

#### ***Software protection***

The software will control the telescope to avoid the sun when the satellite path travels across the sun area (less than 15° distance to sun) and stop the laser. It can choose a tracking path automatically when multi-satellite alternative tracking.

## **Conclusion**

Almost everything, including hardware and software, is ready since the end of last year. Because of the cold weather we decided to do the test at the beginning of this year. In March of 2006, Galileo project was launched. Changchun station was selected to track Galileo satellite by Chinese government and ESA. So we have to change our plan and daylight tracking test has to be delayed. The Galileo project of first phase was finished, but the acceptance is not done. We have to wait for until it is over. But we are sure the condition is suitable for daylight tracking. And we will try the daylight tracking in the near future.

## **Acknowledgement**

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## **GLONASS status update. MCC activity in GLONASS program.**

V.D. Glotov, S.G. Revnivykh, V.V. Mitrikas

### 1. Russian Mission Control Center

#### **Introduction**

The Global Navigation Satellite System (GLONASS) is a government satellite navigation system which is designed for providing a continuous all-weather support of an unlimited number of aeronautical, maritime, terrestrial and space-born users with high-precision position-fixing and timing information at any point of the Earth and in the near-Earth outer-space. The Russian Federation Presidential Directive No. 38-RP of February 18, 1999 designated the GLONASS system as a dual-purpose space facility applied for solving the scientific, industrial, economical, social, defense, security and other relevant problems. It was also specified that the Federal Space Agency (Roscosmos) is a co-customer of the GLONASS system on equal footing with the Russian Ministry of Defence.

#### **GLONASS Status**

The first GLONASS satellite was launched into orbit on October 12, 1982. The GLONASS system formally attained the initial operation capability with a reduced-scale orbital configuration on September 24, 1993. The fact was approved with Presidential Directive No. 658 RP. Russian Federation Government Directions No. 237 of March 07, 1995 assigned a mission to implement a full-scale deployment of the GLONASS orbital constellation (24 satellites), to provide for mass-production of user equipment and to introduce the GLONASS system as an integral element of the international satellite navigation system for civil users.

The Russian Federation Government approved a long-term program of the GLONASS system modernization on August 20, 2001. It is designated as the Global Navigation System (GNS) federal objective program. The GNS Program covers improvement of space, ground-based and user equipment segments of the GLONASS system. Government commitments are associated with appropriation of funds to the Program for ten years by the State Budget Act.

There are new main tasks with the Presidential Directives issued at January 18, 2006 and at April 19, 2006:

- To ensure GLONASS minimum operational capability (constellation of 18 NSV) by the end of 2007
- To ensure GLONASS full operational capability (constellation of 24 NSV) by the end of 2009
- To ensure GLONASS performance comparable with that of GPS and GALILEO by 2010
- To ensure the navigation equipment mass production: encourage the industry in the manufacture renovation
- Mass market development

The Federal GLONASS Program update was approved by the Government Resolution at July 14 2006, No423.

## **Main reasons for SLR data application to GLONASS**

There are a lot of the civil and scientific applications where navigation data from GPS are not enough for the complete analysis. The GLONASS navigation data are useful and helpful in these situations. Thus it's very important to use the same geodetic base with GPS by the GLONASS data generation. From this point of view it is necessary to calibrate geodetic base, the navigation signals accuracy for GLONASS system as good as possible. On the other hand the Russian Ground-Based Control Facility (GBCF) provides for management of the GLONASS orbital constellation and consists of the GLONASS Control Center and a network of tracking/control stations deployed in different areas of the Russian Federation only. SLR data from world wide stations net is the source of calibration data for ephemeris determination, international geodetic base providing and accuracy factor improving for GNSS etc.

So SLR data from ILRS network provide:

- Improving of the geodetic base for GLONASS on the way to ITRF
- Studying and improving of the SC motion model etc.
- Calibration and validation of the microwave means
- Testing and validation of the software and analysis results
- Monitoring of the real on-board ephemeris and clock

## **IAC activity in GLONASS Program**

Informational Analytical Center (IAC - the department of the Russian Mission Control Center) since August, 15, 2006 has been formally assigned by the Federal Space Agency as the GLONASS official information portal for users with the next issues:

- Daily brief bulletins for GLONASS and GPS status based on the global data available (IGS network)
- GLONASS Control Center (Space Force) information
- NAGU generation
- Monthly bulletins with deep analysis of GLONASS performance
- GLONASS news
- GLONASS ICD, etc.

So, IAC is now acting as positive feed-back in the GLONASS control segment.

The IAC has been making contributions to the International GPS Service (IGS) by providing precise orbits based on SLR observations for those GLONASS satellites that are observed by the ILRS network. These independent orbits help to validate and evaluate precise orbits computed by Analysis Centers from the IGS tracking network observations. Since 1995, the MCC has permanently supported orbit determination of GLONASS satellites based on SLR data. Orbits for GLONASS satellites (in SP3 format) are regularly sent to the CDDIS for the determination of the final orbits based mainly on the GLONASS "phase" data.



## GLONASS SLR data analysis

The global products from the International GLONASS service as part of the IGS should facilitate the use of combined GLONASS and GPS observations and analysis results for the civil scientific and engineering applications in the frame of the prototype Global Navigation Satellite System (GNSS). The ILRS supports this effort by a continuous tracking of three GLONASS satellites as part of their standard tracking protocol and by delivering precise GLONASS orbits through one of its Analyses Centers (MCC). Average number of the SLR data pro month for three GLONASS satellites is 500 – 700 passes from 15-18 stations (see the Table 1 as example of the month SLR tracking.)

Table 1.  
Time interval: 30.07.2006 – 26.08.2006

SC	Passes	Stations
GLONASS-07	133	14
GLONASS-22	154	15
GLONASS-03	220	16
<b>Total</b>	<b>507</b>	<b>18</b>

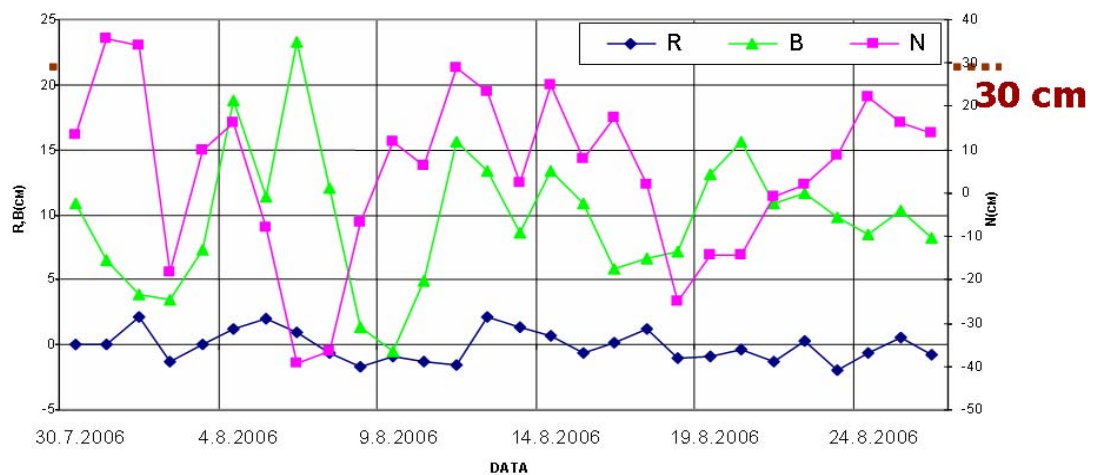
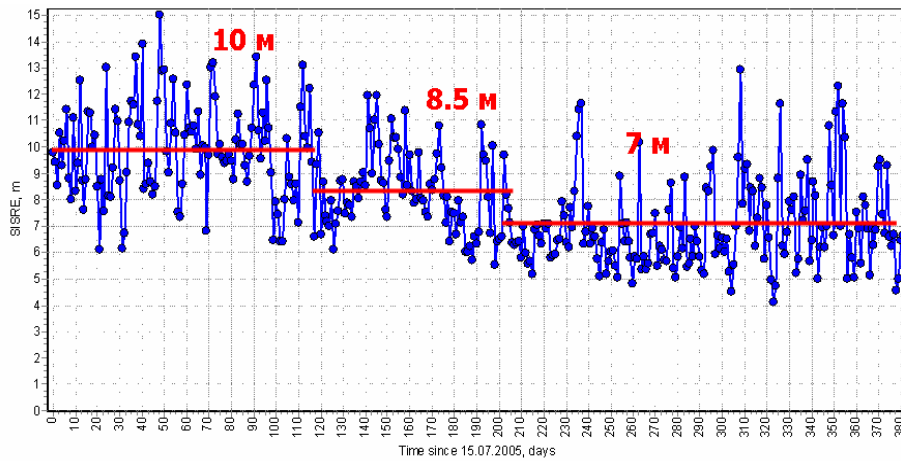


Figure 1. The average difference between SLR and navigation orbits for GLONASS-89 (August 2006)

Figure 1 shows the average difference between SLR and “microwave” orbits as potential GLONASS Performance (R-radial, B-across orbit, N- along orbit).

Figure 2 shows the improving of the on-board ephemeris & clock data for GLONASS constellation in the last years (since July 2005).



*Figure 2. Average Signal In Space Range Error (SISRE), m  
(Since July, 2005)*

## Conclusions

- ILRS support is very important for GLONASS modernization by the way to the Global Navigation Satellite System
- Need to continue/increase tracking of GLONASS satellites by ILRS for the realization of the real collocation in space (Microwave / Laser)
- The International GLONASS - Pilot Project demonstrates the extensibility of IGS to accommodate other microwave systems (GLONASS, GALILEO).