SECTION 3
ILRS NETWORK

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SATELLITE LASER RANGING (SLR)

Michael Pearlman/CfA, Graham Appleby/NSGF, Scott Wettzell/HTSI

The satellite laser ranging network as of December 31, 2010 as shown in Figure 3-1, includes 42 stations in 23 countries. Stations designated as operational meet the minimum ILRS qualification for data quantity and quality as specified by the ILRS (*http://ilrs.gsfc.nasa.gov/network/system_performance/global_report_cards/index.html*). A dozen stations dominated the network output, with the Yarragadee, Mt. Stromlo, Changchun, Zimmerwald, Matera, Graz, Herstmonceux, and Monument Peak were the strongest overall performers for this period. However the improved performance in the stations at San Fernando, the new Grasse (MEO), Potsdam, and Shanghai are also noted. A number of stations including Wettzell, Haleakala, Greenbelt, Hartebeesthoek and Arequipa were down or had subdued operations due to system repairs and upgrades.

Figure 3-1. ILRS tracking network in 2009-2010.

The ILRS welcomes the new station (ALTL 1879) at Altay Optic-Laser Center (AOLC) administered by the Institute for Precision Instrument Engineering (IPIE). This station fills a very large gap in central Asia. Other stations that have resumed operations include Simosato, which resumed operations in January 2009 after replacement of the telescope and laser control unit, and Komsomolsk after a telescope replacement. The new MEO station replaced the legacy station at Grasse for both SLR and LLR as the 3 year refurbishment was completed and the station qualified as an operational station.

Several stations implemented kilohertz ranging during this period. The Beijing (7249) station returned to operation in August 2010 after telescope servo repairs and kHz laser upgrades. In October 2010, the Shanghai system was again in operation with a kHz laser and new event timer, and meets the qualification for an operational station.

The TIGO system in Concepcion, Chile resumed two-color ranging with its Ti:Sapphire laser system after operations being limited to the near-infra-red for almost two years. Since August 2009, the station has been sending both optical 847 nm and infrared wavelengths 423.5 nm up to LAGEOS altitudes; the “primary product” is still the data in the near-infra-red. The magnitude 8.8 Chilean earthquake on February 27, 2010 disrupted operation, but the stations resumed operations on April 28. We congratulate the station crew on a remarkable recovery.

The NASA stations were configured for additional 10 Hz operation for low orbit satellites to increase data yield and improve satellite interleaving capability. The Yarragadee station added a hydrogen maser frequency reference source from the new VLBI station to be co-located at the site. The NASA Next Generation SLR (NGSLR) at GGAO is now routinely supporting one-way LRO-LR ranging at GSFC.

This period also saw a number of stations with prolonged downtime and quarantine after a repair. The Greenbelt station was down from April to November 2010 to check safety systems and revise engineering procedures. Hartebeesthoek and Tahiti were also down for periods of time with system repair issues.

In July 2009, the Wettzell SLR station WLRS was back on the air after a long repair period involving the system detectors, laser and calibration stability issues.

The Japanese stations at Tanegashima (GMSL 7358) and Koganei CRL (KOGC 7308) had problems with the their Telescope and mount systems.

The Borowiec station has been off-line since March 2010 with several laser problems. The station in Lviv has also been off the air since December 2009 with laser problems.

The station in Riyadh remains down while KACST develops a plan for refurbishment. Johan Bernhardt has moved from Hartebeesthoek to Riyadh to help lead the station.

Increased emphasis has been given to station change reporting, with a new status table available online at http://ilrs.gsfc.nasa.gov/stations/station_upgrades.html.

This is important to the data analysts, as subtle data anomalies have to be tracked to their origin. It is preferred to account for such events before the data is incorporated into operational products.

LUNAR LASER RANGING (LLR)

Jürgen Müller/IfE

During three U.S. American Apollo missions (11, 14, and 15) and two unmanned Soviet missions (Luna 17 and Luna 21), retro-reflectors were deployed near the landing sites between 1969 and 1973 (Figure 3-2). The LLR experiment has continuously provided range data for about 41 years, generating about 17000 normal points (Figure 3-3, left). The main benefit of this space geodetic technique is the determination of a host of parameters describing lunar ephemeris, lunar physics, the Moon's interior, various reference frames, Earth orientation parameters and the Earth-Moon dynamics [3, 5]. LLR has also become one of the strongest tools for testing Einstein's theory of general relativity in the solar system; no violations of general relativity have been found so far [1, 2, 4, 5]. However, the basis for all scientific analyses is more high quality data from a well-distributed global LLR network.

From all of the ILRS observatories (nearly 40), there are only a few sites that are technically equipped to carry out Lunar Laser Ranging (LLR) to retro-reflector arrays on the surface of the Moon (Figure 3-4). The McDonald Observatory in Texas, USA, the Apache Point Observatory, New Mexico, USA, and the Observatoire de la Côte d' Azur, France are the only currently operational LLR sites. The latter has undergone renovation since late 2004, and returned to action in September 2009. The McDonald observatory has major problems to get further LLR tracking funded. Although no system upgrade could be made in the past years, lunar tracking could be continued at a certain level. The most recent site with lunar capability at the Apache Point Observatory, New Mexico, USA, is equipped with a 3.5 m telescope. This station, called APOLLO, is designed for mm accuracy ranging. A new set of data from APOLLO was released in 2011 with a total of ~940 normal points. The data are now available in the newly adopted ILRS CRD data format through a reformatting effort at the McDonald Observatory. The measurement statistics of the major lunar observatories between 1970 and early 2011 is shown in Figure 3-3 (right).

Also other modern stations have demonstrated lunar capability, e.g., the Matera Laser Ranging Station, Italy in 2010, but all of them suffer from technical problems or funding restrictions. The Wettzell observatory, Germany, plans to resume lunar tracking by end of 2011. The Australian station at Mt. Stromlo is expected to join this group in the future, and there are plans for establishing lunar capability at the South African site of Hartebeesthoek.

Current LLR data is collected, archived and distributed under the auspices of ILRS. All former and current LLR data is electronically accessible through the EDC in Munich (*http://ilrs.gsfc.nasa.gov/network/site_procedures/station_upgrade_status.html*), Germany and the CDDIS in Greenbelt, Maryland (*ftp://cddis.gsfc.nasa.gov/*).

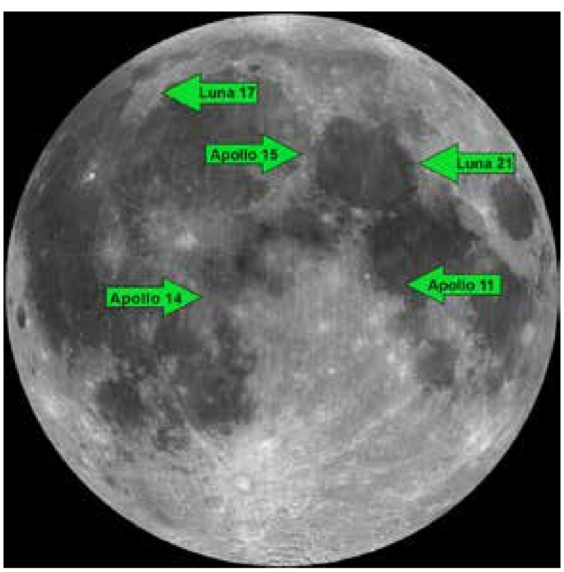

Figure 3-2. Retro-reflector sites on the Moon

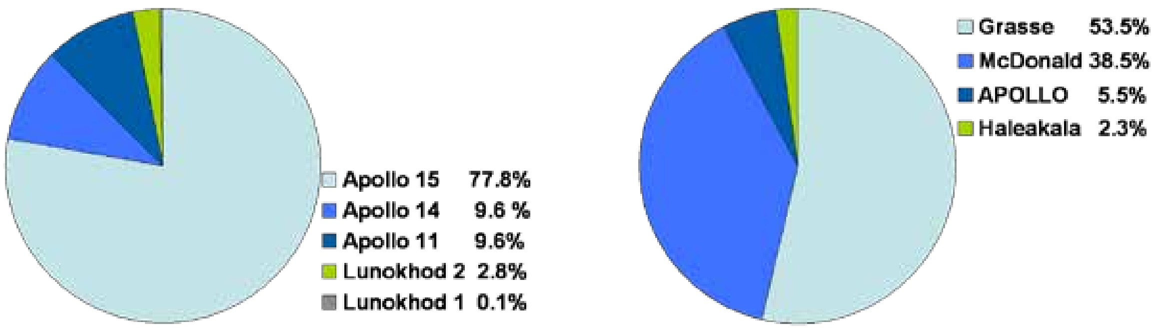

Figure 3-3. Measurement statistics of the retro-reflector arrays on the lunar surface (left), and of the major lunar observatories (right)

Figure 3-4. ILRS sites with potential lunar capability demonstrated in the past or planned for the near future. The green arrows indicate active stations, the green-grey arrows the possible future stations and the grey arrows the former stations

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NETWORK PERFORMANCE

Network Performance Report Cards are issued quarterly by the ILRS Central Bureau. These reports tabulate the previous 12 months of data quality, quantity, and operational compliance by station and can be found along with established guidelines for station performance on the ILRS website at:

http://ilrs.gsfc.nasa.gov/network/system_performance/global_report_cards/index.html

The ILRS Central Bureau uses these report cards to review stations performance and to maintain lists of the best performing stations which are tabulated at:

http://ilrs.gsfc.nasa.gov/network/system_performance/station_classification/index.html

As shown in Figures 3-5 through 3-8, network data yield has been fairly constant over the last few years, attributed mainly to the large number of systems that have spent time under maintenance and upgrade. We anticipate strong increase over the next several years as the stations come back into operation and additional satellites are added to the roster. In particular, with the planned increase in the number of GNSS satellites with arrays meeting the ILRS Standard, there should be considerable improvement in GNSS tracking performance.

As can be seen in Figures 3-6, -7, and -8, station data yield performance falls into three categories. About a quarter of the stations are very prolific, far exceeding the ILRS criteria for an operational station. Another quarter of the stations are performing satisfactorily with some caveats on LAGEOS tracking. These two categories of stations are having a major impact on the development of the reference frame and POD. Some of the stations on the lower half are recovering from engineering activities and will hopefully experience improved operations in 2011.

A fair number of the stations are starting to take data on GNSS satellites. More effort is need to refine individual stations procedures to improve performance.

Figure 3-8 tabulates the number of minutes of tracking during this 2-year reporting period. Out of a total of about a million minutes possible, Yarragadee and Zimmerwald are doing remarkably well. With the advent of more automated systems that should expand operating hours, the network has tremendous potential that is yet to be realized.

Almost all of the stations are meeting the 2 cm normal point RMS threshold, with about 80% operating below the cm level (see Figure 3-9). Several of the stations are working down at the 2-3 mm precision level which approaches the GGOS requirements. The implementation of the KHz lasers with shorter pulse widths and improved detectors should increase the number of stations with such performance.

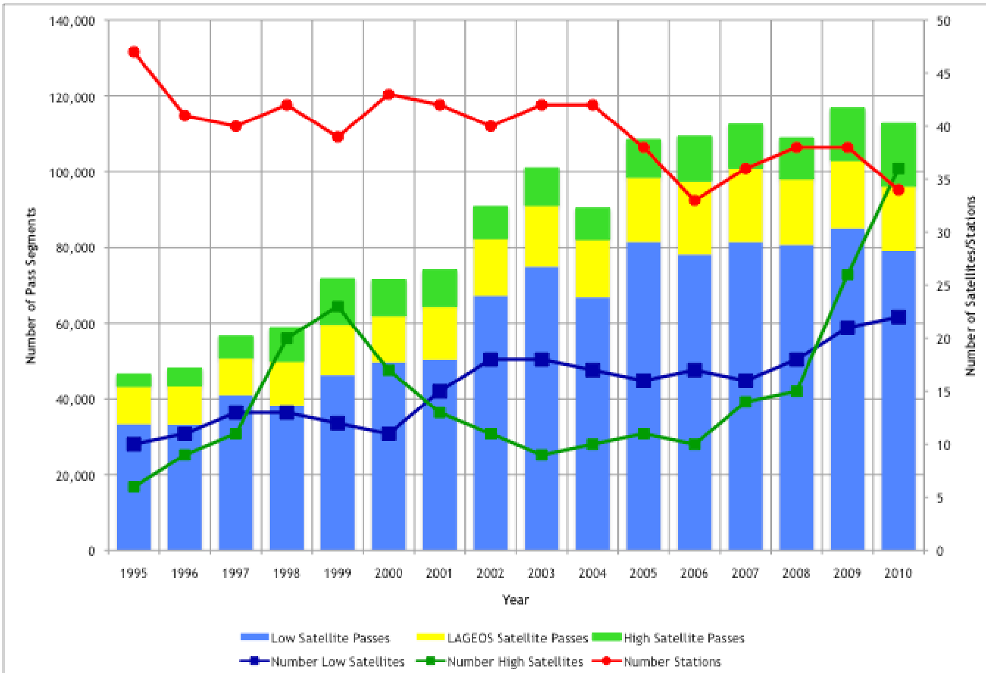

Figure 3-5. Network data yield continues to increase with the reopening of stations after repair and upgrading, improved network proficiency, and additional satellites mainly at GNSS altitude.

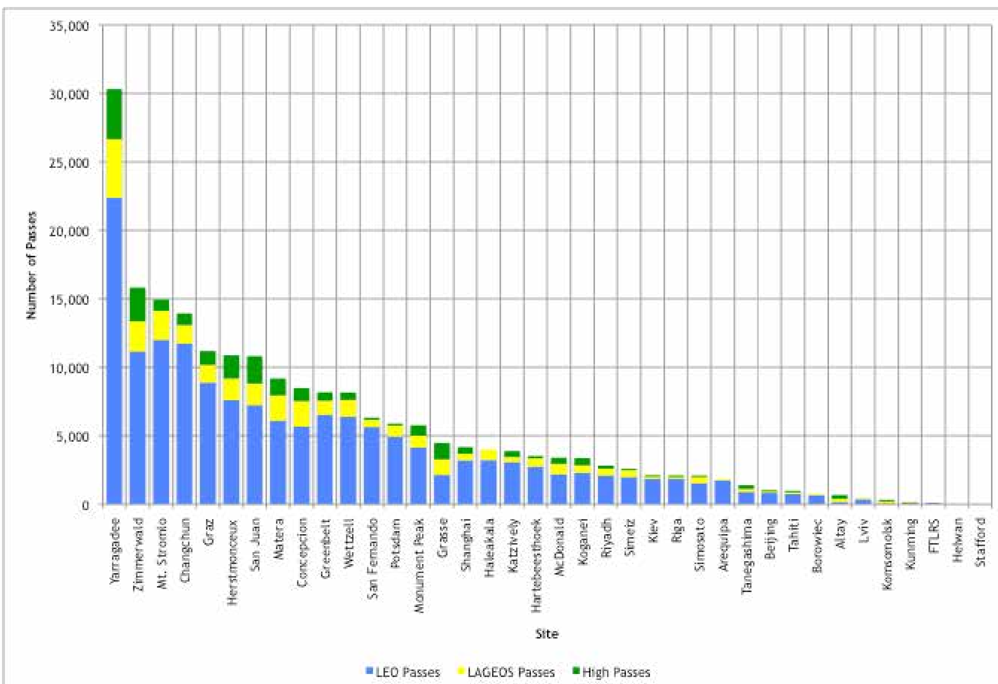

Figure 3-6. Number of passes tracked from January 2009 through December 2010

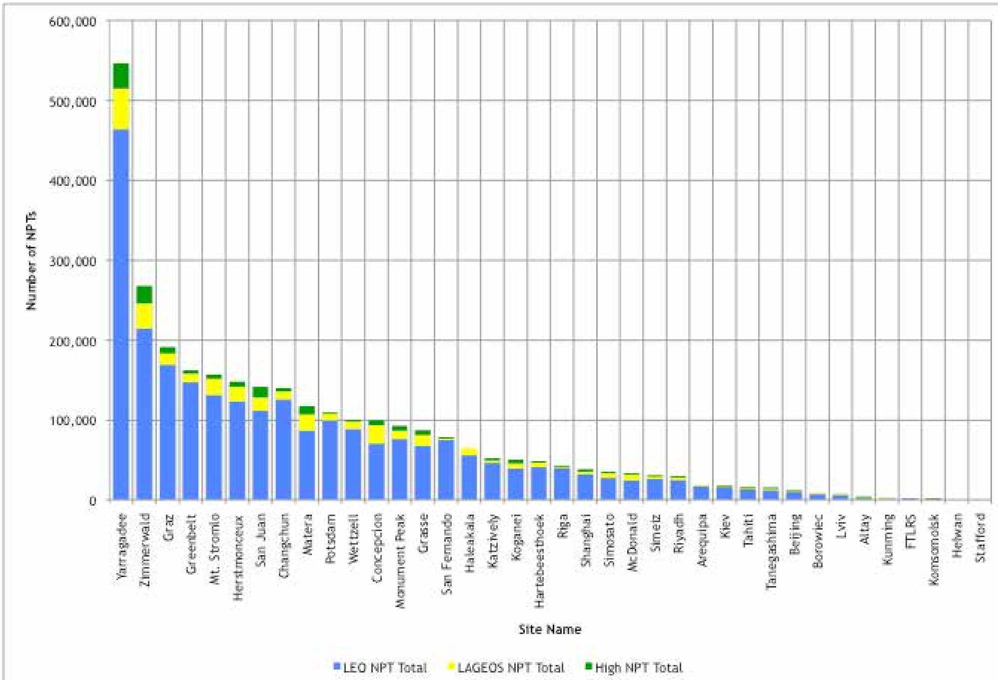

Figure 3-7. Number of normal points from January 2009 through December 2010.

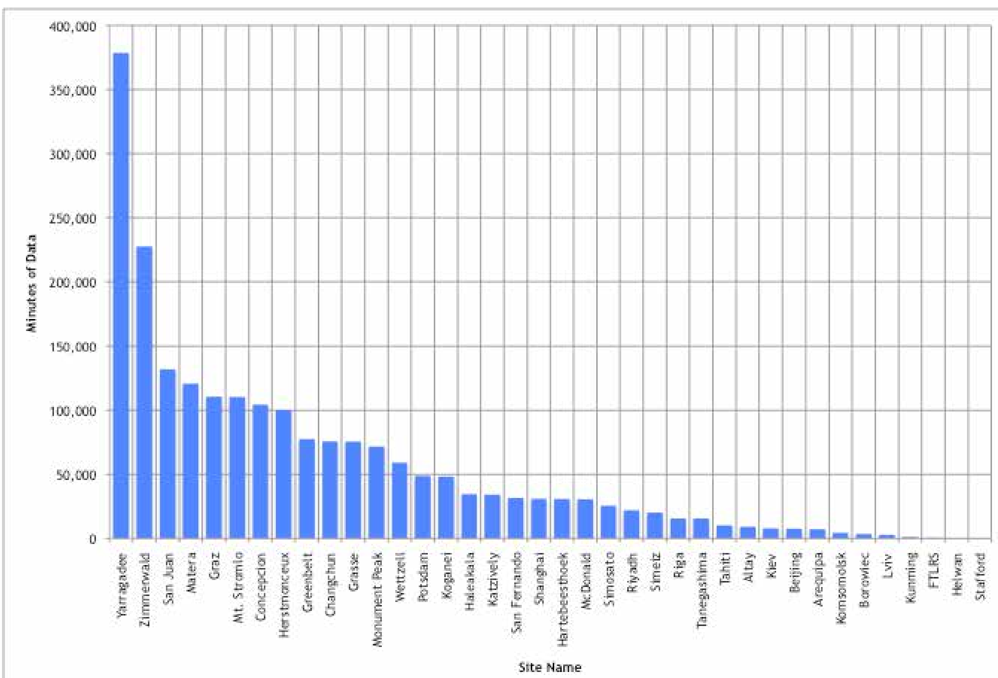

Figure 3-8. Number of minutes of data from January 2009 through December 2010.

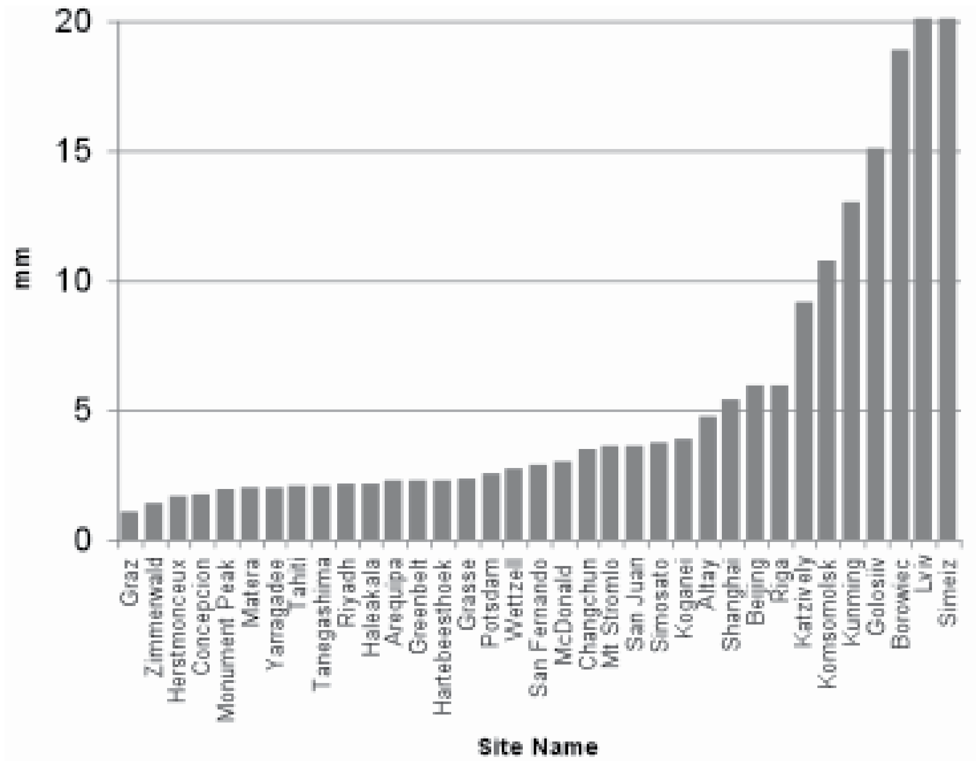

Figure 3-9. Average normal point precision in mm from January 2007 through December 2008 as calculated by Hitotsubatshi University, Japan

SITE SURVEYS AND CO-LOCATION SITES

Zuheir Altamimi/IGN and Michael Pearlman/CfA

The Terrestrial Reference Frame (ITRF) is the means by which we connect measurements over space, time and evolving technologies. Space may be ten thousand kilometers. Time will be decades and probably generations. Evolving technologies are the changes in the ground systems and the satellites that will happen as measurement capabilities improve. If we are going to see change in the Earth and its environment, we need the long-term stability of the reference frame. The reference frame should have and accuracy of 1 mm and a stability of 0.1 mm/year to satisfy the GGOS requirements.

Satellite Laser Ranging (SLR) is one of the fundamental geodetic techniques (along with GNSS, VLBI, and DORIS) that define and maintain the ITRF. Each technique is fundamentally different; each has its own unique strengths and its own systematic errors. We can exploit the strengths and mitigate the systematic errors through the co-location of space techniques (SLR, GNSS, VLBI, and DORIS) at common sites. This is an essential part in our achievement of the high–accuracy Terrestrial Reference Frame.

The very existence of the ITRF relies on the availability and quality of local ties among instruments at co-location sites as well as the number and distribution of these sites over the globe. A co-location site is defined by the fact that two or more space geodesy instruments are occupying simultaneously or subsequently very close locations, for which intersystem vectors have been accurately determined.

Intersystem-vectors or “site ties” among instruments at co-location sites are an essential, but often unappreciated component in the development of the reference frame. These vectors are a combination of (1) ground surveys between accessible points on or near each instrument and (2) an extrapolation to the reference points that maybe imbedded inside an instrument or at a point outside an instrument.

Ground surveys are very precisely surveyed in three dimensions using classical surveys and/or the GNSS technique. Classical surveys are usually direction angles, distances, and spirit leveling measurements between instrument reference points or geodetic markers. Adjustments of local surveys are performed by national geodetic agencies operating space geodesy instruments to provide differential coordinates (local ties) connecting the co-located instruments.

Extrapolations to the reference points are estimated through iterative ground-based survey procedures, engineering modeling, and vendor specifications. This component is obviously the most susceptible to error and the most in need of innovative approaches.

The value of mm level measurements across intercontinental distances can be lost through missing or inaccurate local ties, inconsistencies in ground survey techniques, poor survey control network geometry and monumentation, improper analysis of survey data, and lack of proper documentation.

Current Status of the Co-location Sites

The VLBI and SLR networks each include sites. The DORIS network is more homogeneous and includes 56 sites. The IGS GNSS network contains more than 440 permanent sites. In the worldwide currently operating Space Geodesy Network, 59 sites host two observing techniques (SLR, GNSS, VLBI, and/or DORIS); 17 sites have three, and only two sites have four, as illustrated by Figure 3-10.

The status of site co-locations with SLR is shown in Table 3-1 and Figure 3-10. There are currently only three SLR sites operating with SLR, GNSS, VLBI, and DORIS (one fully operational in 2010), and ten SLR sites operating with GNSS and VLBI. Seven are co-located with DORIS. All of the SLR sites in the ILRS operational network are co-located with GNSS; six of the other participating SLR stations do not have GNSS. The distribution of these co-located sites is not well placed and in some cases operations of one or more of the techniques is marginal. Local surveys are also an issue at nine of the SLR co-located sites.

Co-location of techniques and measurement and monitoring of local inter-technique vectors to the mm level must continue to be a high priority with the SLR network. Figure 3-10 shows all SLR and VLBI stations operated in 2010 where most of them are co-located with GPS. It also shows the current GPS and DORIS co-locations.

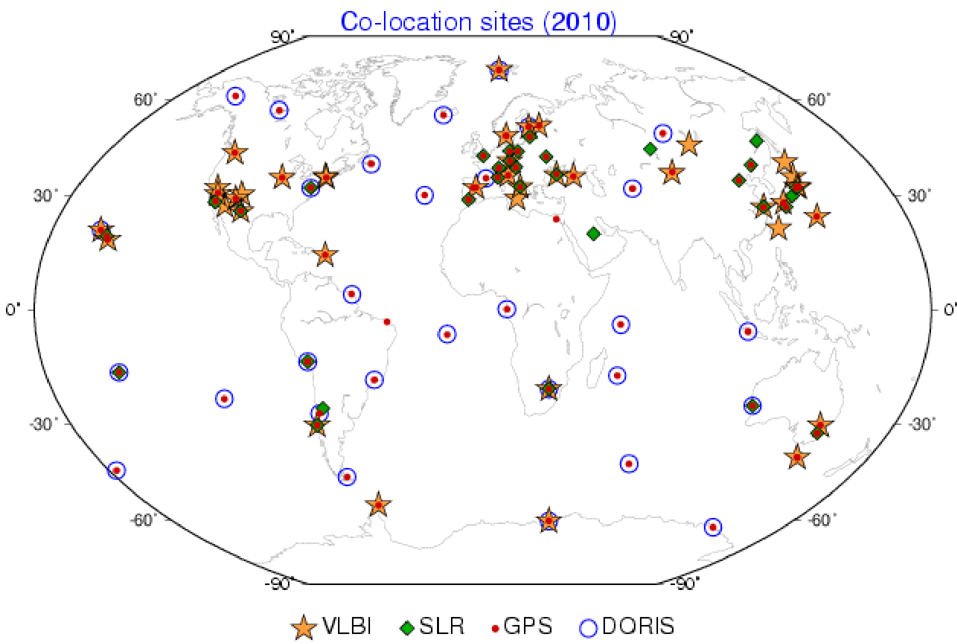

Figure 3-10. Current status of SLR, VLBI, DORIS, and GNSS co-locations (2010).

New Surveys

During this period, The Institut Géographique National (IGN), France conducted a complete survey of the Herstmonceux site, comprising two techniques: SLR and GNSS.

The adjustment of this survey is accomplished, including final report and SINEX file, which are available at the ITRF website *http://itrf.ensg.ign.fr/.*

Table 3.1. Space Techniques Co-Located with SLR (2009-2010)

Site Name	Country	GNSS	VLBI	DORIS	Gravimeter
Altay	Russia				
Arequipa	Peru	X		X	
Beijing	China	X			X
Borowiec	Poland	X			X
Changchun*	China	X			
Concepción	Chile	X	X		X
Grasse	France	X			X
Graz	Austria	X			X
Greenbelt, MD	USA	X	X	X	
Haleakala, HI	USA	X			
Hartebeesthoek	South Africa	X	X	X	
Helwan*	Egypt	X2			
Herstmonceux	UK	X			X
Katzively	Ukraine				
Kiev	Ukraine	X			
Koganei	Japan	X	X		
Komsomolsk	Russia				
Kunming*	China	X			X
Lviv*	Ukraine	X			
Maidanak	Russia				
Matera	Italy	X	X		X
McDonald, TX	USA	X	X		
Mendeleevo	Russia	X			
Metsahovi	Finland	X	X	X	X
Monument Peak, CA	USA	X		X	
Mount Stromlo	Australia	X		X	X
Potsdam	Germany	X			X
Riga	Latvia	X			X
Riyadh*	Saudi Arabia	X			
San Fernando	Spain	X			
San Juan	Chile				
Shanghai	China	X	X		
Simeiz*	Ukraine	X	X		
Simosato	Japan	X			
Stafford, VA	USA				
Tahiti	F. Polynesia	X		X	
Tanegashima*	Japan	X			
Wettzell	Germany	X	X		X
Wuhan	China	X		X	X
Yarragadee	Australia	X		X	
Zimmerwald	Switzerland	X			X
Totals:	41	35	10	9	15

Notes: * indicates missing tie