SECTION 2
ILRS TRACKING NETWORK

Section 2

Satellite Laser Ranging (SLR) Network

Michael Pearlman/CfA

The present ILRS network, as shown in Figure 2-1, includes forty stations in 23 countries. Stations designated as operational have the minimum ILRS qualification for data quantity and quality. A dozen stations dominated the network with the Yarragadee, Mt Stromlo, and San Juan stations being the strongest performers. Since operations began about two years ago, the San Juan station performance has been dramatic; in 2008 station performance has risen to second only to Yarragadee. Congratulations to the San Juan team. There has also been noticeable improvement at Greenbelt, San Fernando, Concepción, Mount Haleakala, Arequipa and Katzively. The improved orbital coverage over the Pacific region should have a very fundamental impact on our ILRS data products. Problems that have caused reduction of data at Monument Peak and Hartebeesthoek are being addressed and should be remedied shortly.

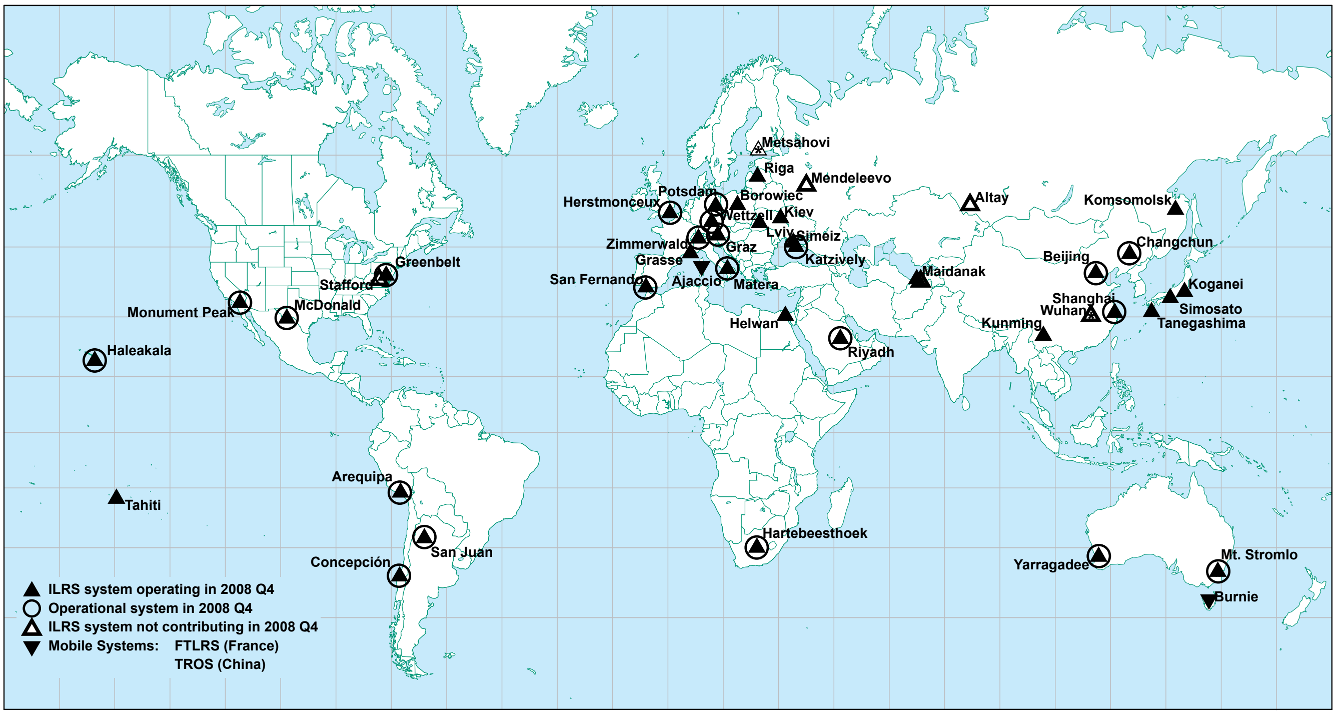

Figure 2-1. ILRS tracking network in 2007-2008.

A NASA/CNES/UPF team visited the Papeete site in late 2008 and formulated a report with a set of recommendation to improve site performance. The Arequipa stations and Mt Haleakala stations were both rededicated in early 2007 with TLRS-3 and -4 respectively; both are back in operation. A second shift was been added to the Greenbelt station, substantially increasing data yield.

In addition to San Juan, the rest of the Chinese SLR network continues its outstanding support of the ILRS network. The Changchun station maintained its very strong performance; activities continue to help strengthen daylight ranging. Data yield continues to improve at the new Shanghai station. The Chinese Mobile TROS system had its first session at the Korea Astronomy and Space Science Institute (KASI), Daejeon, Korea from August to October 2008; the next session is scheduled for mid-April through early July, 2009.

The Riyadh station continues to do well; playing a vital role in the network as the only SLR station on the Arabian Peninsula.

A number of other stations have started or completed system upgrades during the last two years. The TIGO system in Concepción, Chile underwent substantial repairs in the 2005-6 time frame and is now performing very well, having reached full operational status in the network. Congratulations to the team.

System upgrades are nearly complete at the MEO station at Grasse; the station should be on the air in early 2009 with both SLR and LLR. The French Transportable Laser System (FTLRS) conducted campaigns in Ajaccio, France and in Burnie, Tasmania to support altimeter calibration and validation for Jason. While located at these sites, the system also supported general ILRS requirements.

The Graz system continues its impressive performance with 2 kHz operation, a technology that will most likely become more prevalent in the network as time goes on. A 2 kHz laser has been added to the Herstmonceux station; several other stations have this upgrade underway. Several stations have replaced their Stanford Counter with epoch timers and replaced their detectors with SPADs.

In 2007, the Zimmerwald station using its two-wavelength system collected the second largest number of passes in the network, second only to Yarragadee. Zimmerwald introduced a new 100 Hz Nd:YAG laser into their operation in the spring of 2008, and rapidly became again one of the major data producing stations in the network in 2008.

The GUTS facility in Tanegashima, Japan was brought back into operation after suffering severe storm damage, but data yield is still sparse.

We also expect that the Russian stations will again submit their data in early 2009. The CB is working with the sponsoring organizations to complete the required site log forms. In particular, the Altay station will begin participating in the ILRS in early 2009.

The Next Generation SLR (NGSLR) is now routinely collecting data at GSFC. Many of the subsystems including the Risley prism point-ahead are working and co-location with MOBLAS-7 will start at the beginning of 2009. There are still many things to clean up, but congratulations go to the NGSLR team; it has been a long hard road.

Lunar Laser Ranging (LLR) Network

Jürgen Müller/IfE

The 40 anniversary of the first manned landing on the Moon in 2009 is also the 40 anniversary of laser tracking the Moon. During three US Apollo missions (11, 14, and 15) and two un-manned Soviet missions (Luna 17 and Luna 21) retro-reflectors were deployed near the landing sites between 1969 and 1973 (see Figure 2-2). The lunar laser ranging (LLR) experiment has continuously provided range data for about 40 years, generating about 16000 normal points. 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. LLR has also become the strongest tool for testing Einstein's theory of general relativity in the solar system (e.g., tests of the equivalence principle, time-variable gravitational constant, metric parameters); no violations of general relativity have been found so far (e.g., Müller et al., 2007). Even further predictions of general relativity (secondary effects), which were

not fit for in the past, can be investigated, e.g., those parametrizing effects of modifications of Einstein's theory (Will, 1993). In addition, quantum physical predictions, assuming Lorentz violation, which will manifest itself as oscillatory perturbation of the lunar orbit (Battat et al., 2007) can be determined. However, the basis is more high quality data from a well-distributed global LLR network.
Despite steadily improving tracking technology, lunar ranging is extremely challenging. Because of the large lunar distance, energy loss in the atmosphere, the small reflector sizes on the Moon, and the limited telescope apertures, the laser link budget is extremely poor. Therefore, from all of the ILRS observatories (>30), there are only a few sites that are technically equipped to carry out Lunar Laser Ranging to the Moon (Figure 2-3). The McDonald Observatory in Texas, USA and Observatoire de la Côte d' Azur (OCA), France were the only currently operational LLR sites achieving a typical range precision of a few cm. The latter has been undergoing renovation since 2006, which left only one site operational over the past years. But in April 2009, the new OCA laser ranging system was inaugurated and it is planned to track the Moon again starting in summer 2009.

A new site with lunar capability has been built at the Apache Point Observatory, New Mexico, USA, equipped with a 3.5 m telescope. This station, called APOLLO, is designed for mm accuracy ranging. A few releases of data from APOLLO were added to the set of normal points used for the global LLR based parameter determination. The data look promising, but are still not provided on an operational basis.

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, and at Wettzell observatory, Germany, once there are new telescopes installed. Also other modern stations have demonstrated lunar capability, e.g., the Matera Laser Ranging Station, Italy in 2005, but all of them suffer from funding restrictions or technical problems when upgrading their systems. Hopefully, further sites may provide lunar data on a routine basis in the near future.

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, Germany and the CDDIS in Greenbelt, Maryland.

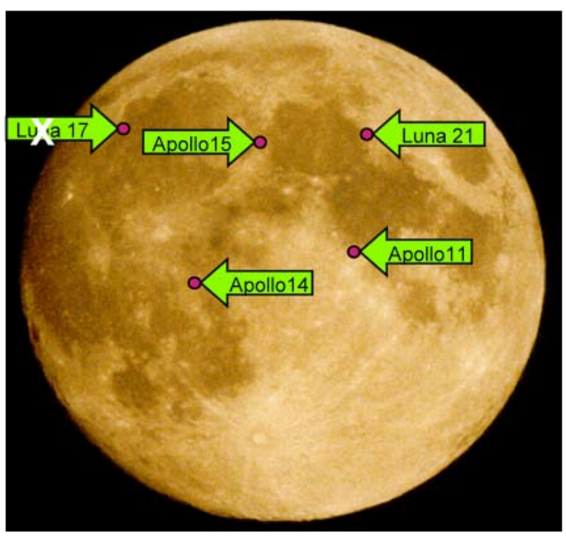

Figure 2-2. Retro-reflector sites on the Moon, Luna 17 has never been successfully tracked

Figure 2-3. ILRS sites with potential lunar capability demonstrated in the past or planned for the near future

References

Battat, James B. R.; Chandler, John F. ; Stubbs, Christopher W.: Testing for Lorentz Violation: Constraints on Standard-Model-Extension Parameters via Lunar Laser Ranging. In: Physical Review Letters 99, No. 24, p. 241103, 2007

Müller, J., Williams, J., Turyshev, S., Shelus, P.: Potential Capabilities of Lunar Laser Ranging for Geodesy and Relativity. In: Dynamic Planet. P.Tregoning, C.Rizos (eds.), IAG Symposia 130, pP. 903-909, Springer, 2007, gr-qc/0509019.

Will, C. M.: Theory and Experiment in Gravitational Physics, Cambridge University Press, England, 1993

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 Web site at: *http://ilrs.gsfc.nasa.gov/stations/site_info/global_report_cards/index.html.* The ILRS Central Bureau uses these report cards to maintain lists of the best performing stations which are tabulated at: *http://ilrs.gsfc.nasa.gov/stations/station_classification.html.*

As shown in Figures 2-4 through 2-7, network data yield dropped in 2004 due mainly to reductions in NASA network support and the Mt Stromlo outage, but data yield is recovering as these stations have come back into operation and as the rest of the network has become more proficient. Most notable is the pickup in LAGEOS and high satellites passes.

The network is still experiencing a wide dichotomy in performance. As can be seen in Figures 2-5 and -6, 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 stations. 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 reference frame and POD. Some of the stations on the lower half are recovering from engineering activities and will hopefully experience improved operations in 2009. All of the stations are meeting the 2 cm normal point RMS threshold, with about 75% operating below the cm level (see Figure 2-7).

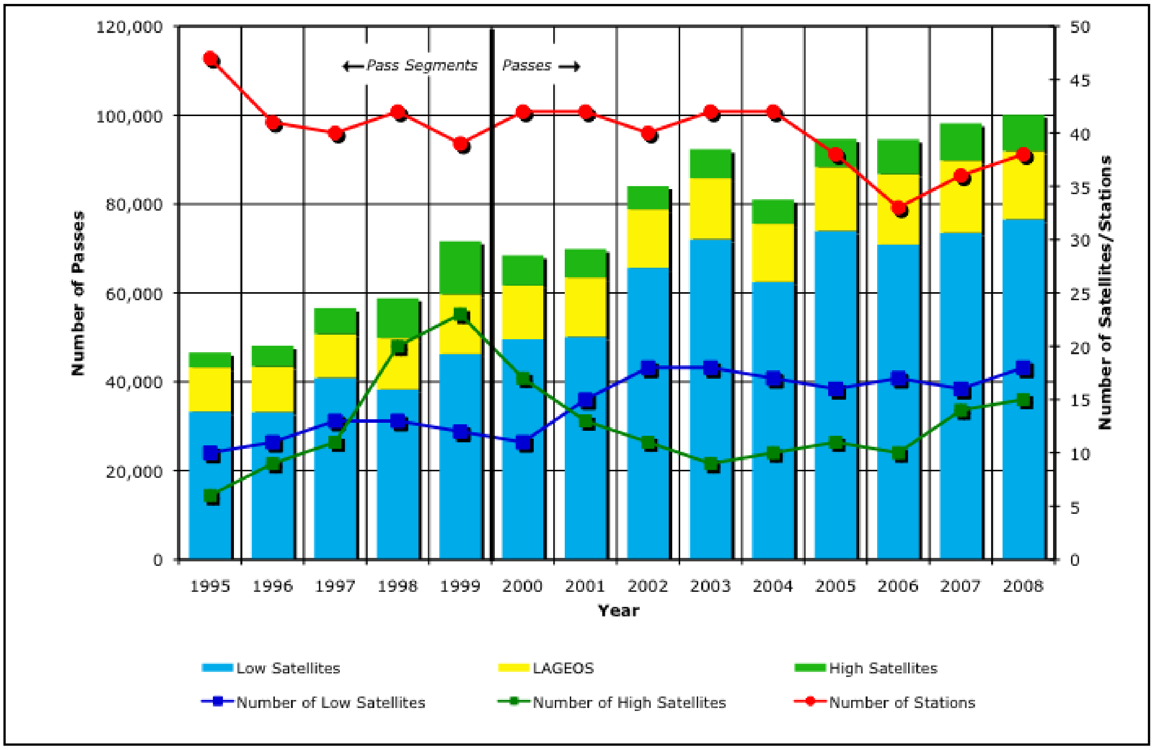

Figure 2-4. After the reductions in 2004, network data yield increased with the reopening of stations, improved network proficiency, and additional satellites.

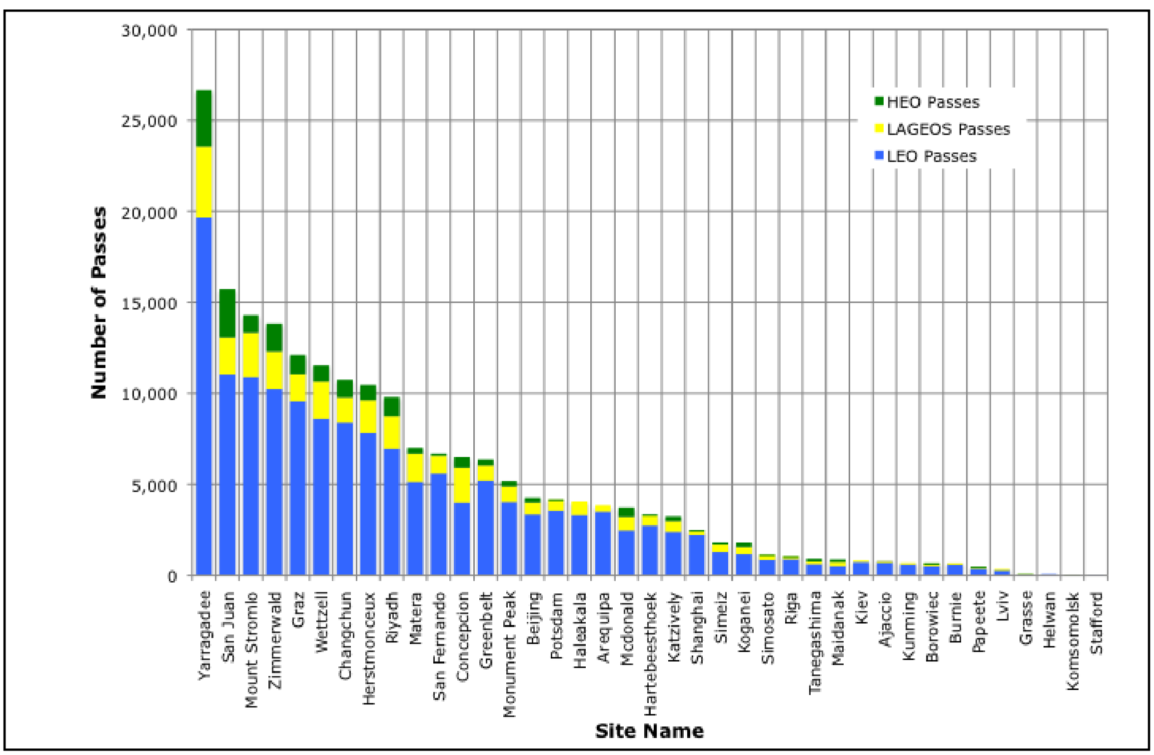

Figure 2-5. Number of passes tracked from January 2007 through December 2008.

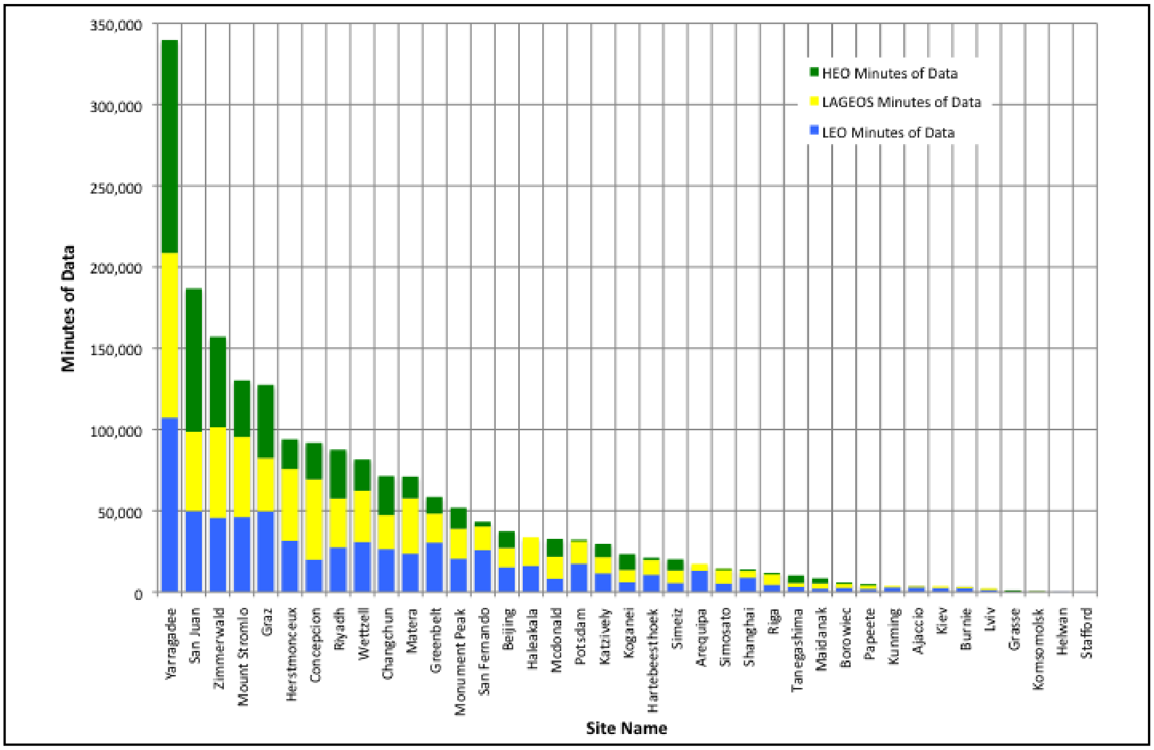

Figure 2-6. Number of minutes of data from January 2007 through December 2008.

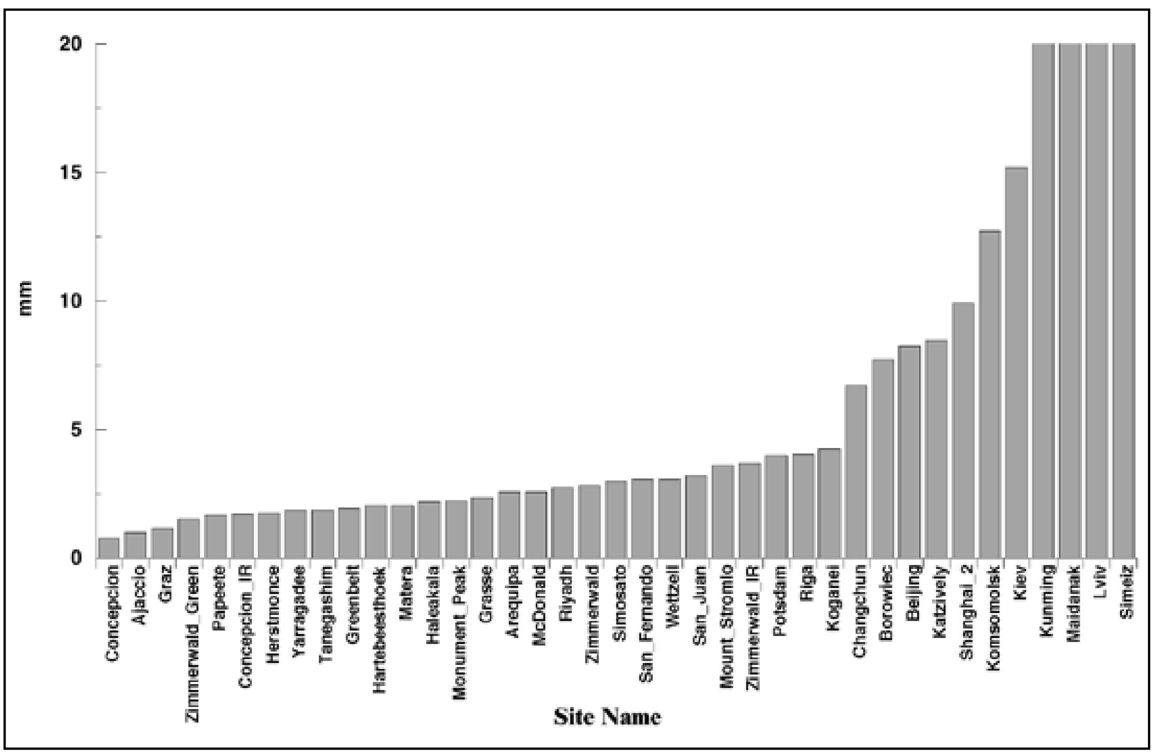

Figure 2-7. Average normal point precision in mm for data from January 2007 through December 2008 as calculated by Hitotsubatshi University, Japan.

Site Surveys and Co-Location Sites

Zuheir Altamimi/IGN and Michael Pearlman/CfA

The Terrestrial Reference Frame 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.

Satellite Laser Ranging (SLR) is one of the fundamental geodetic techniques (along with GNSS, VLBI, and DORIS) that define and maintain the Terrestrial Reference System. 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.

Site surveys between co-located instruments are a basic, but often unappreciated aspect in the development of the reference frame. The value of sub-centimeter 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.

The very existence of the ITRF relies on the availability and quality of local ties in 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 simultaneous (or subsequently very close) locations, which are very precisely surveyed in three dimensions using classical surveys or/and 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.

Current Status of the Co-location Sites

The VLBI and SLR networks each include less than fifty sites. The DORIS network is more homogeneous and includes 56 sites. The IGS GNSS network contains more than 350 permanent sites. In the worldwide currently operating Space Geodesy Network, 59 sites host two observing techniques (SLR, GNSS, VLBI, and/or DORIS); only 17 sites have three, and only two sites have four, as illustrated by Figure 2-8. The figure shows also seven sites where local ties are missing: (four VLBI-GNSS, one SLR-VLBI, one SLR-GNSS and one DORIS-GNSS).

The status of site co-locations with SLR is show in Table 2-1 and Figure 2-8. There are currently only three SLR sites operating with SLR, GNSS, VLBI, and DORIS, 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.

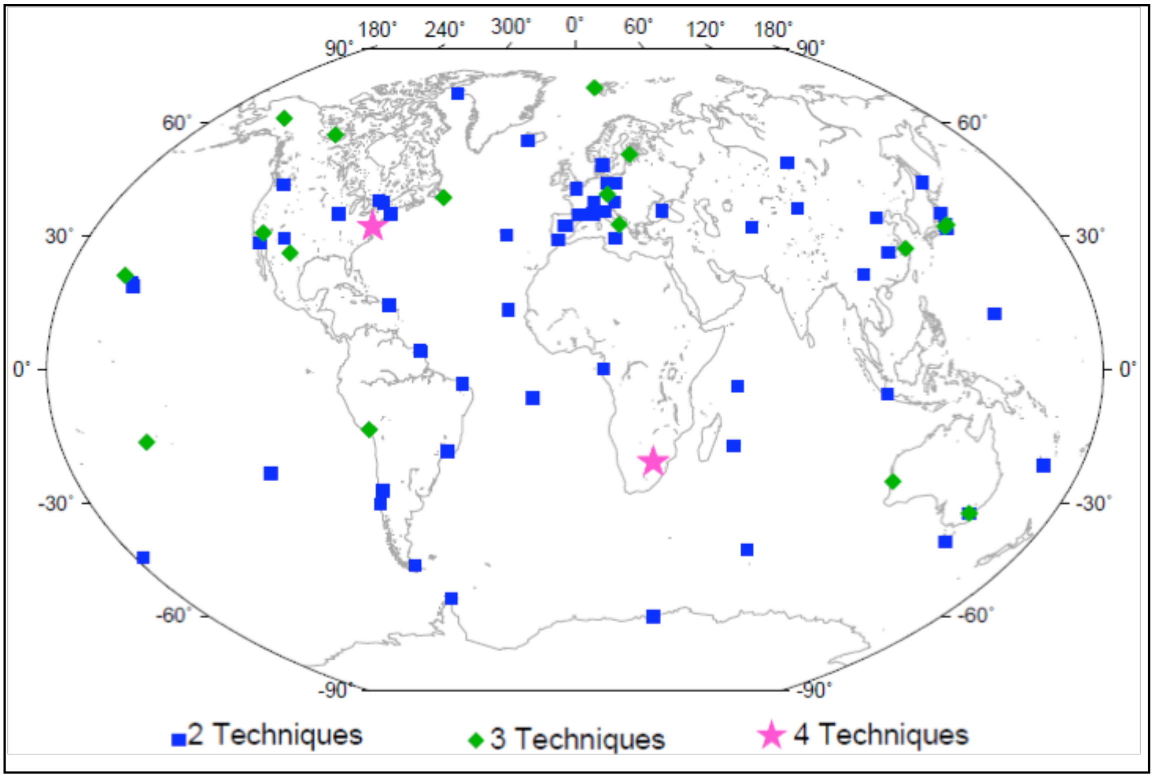

Figure 2-8. Current status of SLR, VLBI, DORIS, and GNSS co-locations.

New Surveys

During this period, The Institut Géographique National (IGN), France conducted complete surveys of the following two co-location sites:

- Tahiti, comprising three techniques: SLR, GNSS and DORIS
- Herstmonceux, comprising two techniques: SLR and GNSS

The adjustment of these three surveys is accomplished, including final report and SINEX files, which are available at the ITRF web site *http://itrf.ensg.ign.fr/*.

Table 2.1. Space Techniques Co-Located with SLR (2007-2008)

Site Name	Country	GNSS	VLBI	DORIS	Gravimeter
Ajaccio [1]	France	X			
Arequipa	Peru	X		X	
Beijing	China	X			X
Borowiec	Poland	X			X
Burnie[1]	Tasmania				
Changchun [2]	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 [2]	Egypt	X[3]			
Herstmonceux	UK	X			X
Katzively	Ukraine				
Kiev	Ukraine	X			
Koganei	Japan	X	X		
Komsomolsk	Russia				
Kunming [2]	China	X			X
Lviv [2]	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 [2]	Saudi Arabia	X			
San Fernando	Spain	X			
San Juan	Chile				
Shanghai	China	X	X		
Simeiz [2]	Ukraine	X	X		
Simosato	Japan	X[3]			
Stafford, VA	USA				
Tahiti	F. Polynesia	X		X	
Tanegashima [2]	Japan	X			
Wettzell	Germany	X	X		X
Wuhan	China	X		X	X
Yarragadee	Australia	X		X	
Zimmerwald	Switzerland	X			X
Totals:	40	35	10	9	15

Notes: [1] *indicates mobile occupation in 2007-2008*
[2] *indicates missing tie*
[3] *indicates non-IGS site (Simosato pending approval)*