SECTION 2 - CENTRAL BUREAU REPORT

2.0 INTRODUCTION

Michael Pearlman, *Harvard-Smithsonian Center for Astrophysics*

The Central Bureau (CB) is responsible for the daily coordination and management of ILRS activities to ensure ILRS objectives are achieved consistently and continuously. It facilitates communications and information transfer and promotes ILRS standards. The CB monitors network data quality and quantity to ensure mission requirements are being achieved. It maintains the ILRS Web site and ILRS documentation (e.g. bibliography, meeting minutes, administrative and technology databases). The CB organizes meetings and workshops and also the completion of the ILRS Annual Report. The Science Coordinator and Analyst Specialists, within the CB, strengthen the ILRS interface with the scientific community to promote Satellite and Lunar Laser Ranging goals, capabilities, and accomplishments, and to lead efforts to ensure that ILRS data products meet the needs of the user community.

2.1 STATUS AND ACTIVITIES

Van Husson, *Honeywell Technology Solutions, Inc.*

ORGANIZATION

The Central Bureau (cb@ilrs.gsfc.nasa.gov), funded by NASA, provides the necessary skill mix to support the technical and administrative services required by the ILRS. The Central Bureau staff includes personnel from NASA GSFC, the Harvard-Smithsonian Center for Astrophysics (CFA), Honeywell Technology Solutions Inc (HTSI), Raytheon Information and Technology and Scientific Services (RITSS), and the three regional networks (i.e. NASA, EUROLAS, WPLTN):

Table 2.1-1. Central Bureau staff

Name	Title	Institution
Michael Pearlman	Director	CFA
Carey Noll	Secretary	NASA GSFC
Steve Klosko	Science Coordinator	Raytheon ITSS
Van Husson	SLR Systems Specialist	HTSI
Peter Dunn	Analysis Specialist	Raytheon ITSS
Mark Torrence	Analysis Specialist	Raytheon ITSS
Scott Wetzel	Operations Specialist	HTSI
Julie Horvath	Operations Specialist	HTSI
Hoai Vo	Web Master	HTSI
Erricos Pavlis	Analysis Specialist	JCET
Georg Kirchner	EUROLAS Network Coordinator	Austrian Academy of Sciences
Hiroo Kunimori	WPLTN Network Coordinator	CRL
David Carter	NASA Network Coordinator	NASA GSFC

ACTIVITIES

During the last year, the CB has worked with ILRS entities and their members to add or enhance services that were deemed necessary. Many of these services were formulated as joint action items between one or more Working Groups and the Central Bureau. Some of the key accomplishments for the last year include:

- monthly on-line campaign reports including graphics;
- proposal for Qualification for ILRS Station s by performance;
- the ILRS 2000 Annual Report;
- enhanced global performance report card;
- ILRS site tie analysis;
- coordinated new mission support requirements;
- updated predictions survey; and
- ILRS Web site by adding the services mentioned above.

Others still in process include implementation of:

- an automated quality control (i.e. format and data integrity) of site log information and development of a automatic master site description data base;
- additional enhancements to the Web site through a better search engine, and standardized navigation bars, and breadcrumbs;
- an enhanced search capability of the ILRS Bibliography using keywords; and
- an SLR Bias File of historical recoverable biases and known problem data.

Since the inception of the Central Bureaus, a core group of its members has met monthly to monitor progress on its action items, to assess station performance and interactions with other entities, and to monitor the status of Working Group activities.

MEETINGS

The Central Bureau organized the ILRS General Assemblies in Nice, France in March 2001 and Toulouse, France in September 2001, which was cancelled. A presentation on the ILRS was given at the IAG Scientific Assembly in Budapest, Hungary in September 2001.

CHALLENGES

Although many tasks were accomplished by the end of 2001, near and long term challenges for the Central Bureau include:

- strengthening the promotion of SLR and LLR goals, capabilities and accomplishments;
- encouraging and assisting stations and analyst centers to meet minimum performance criteria;
- continuing the maturation of the ILRS Web site and supporting data bases;
- encouraging and assisting stations in their timely maintenance of their site information logs and local survey ties;
- encouraging advancements in SLR technology to achieve millimeter accuracy; and
- incorporating GPS data into the regular prediction cycle.

2.2 NETWORK PERFORMANCE EVALUATION

Van Husson, *Honeywell Technology Solutions, Inc.*

ACTIVITIES

The CB is responsible for network performance evaluation and coordination of data problem resolution. The CB analysis team maintains and develops diagnostics tools using data processing parameters provided in the normal point data along with orbital analysis results from the Analysis Centers (ACs).

When the diagnostics indicate a problem, an investigation is initiated. The investigation involves the coordination with the ACs, station operations and station engineering. The data problem is documented and communicated to the user community. If the data is recoverable, the data will either be re-supplied or a data correction algorithm will be provided and will appear in the master SLR Bias File.

The CB generates the quarterly Network Performance Report Card posted on-line at:

http://ilrs.gsfc.nasa.gov/stations/performance_statistics/index.html

The report card contains site metrics, which are assessed versus established ILRS performance goals in data quantity, data quality, and operational compliance. These goals have evolved from guidelines presented at the Shanghai 10th International Workshop on Laser Ranging in November 1996. The last report card in 2001 appears in Section 8.4.

CHALLENGES

The CB will continue to enhance its systematic bias detection capability to the sub-cm level. This will greatly assist the ILRS as it pursues mm accuracy. These improvements include:

- automated comparison of analysis center results;
- automated comparison of biases from sites in close proximity;
- automated meteorological data integrity checks at finer resolutions; and
- an SLR Bias file (knowledge base of bias corrections and *bad* data)

The CB will continue to push the responsibility of data quality control from the analyst centers to the stations. To accomplish this objective, the CB will continue to provide technical assistance and ongoing training via workshops and the ILRS Web site.

2.3 MISSION PRIORITIES

The ILRS satellite priorities as of December 31, 2001 are given in Tables 1.2-1 and 1.2-2.

ILRS tracking priorites decrease with increasing orbital altitude and orbital inclination (at a given altitude). Priority of some satellites may then be increased to intensify support for active missions (such as altimetry), special campaigns, or post-launch intensive tracking phases. Priorites may also be slightly reordered to accommodate increased importance to the analysis community.

During 2001, at the request of IGLOS GLONASS 72 and 79 were replace with GLONASS 78 and 84 on the ILRS tracking roster.

Tracking priorities are formally reviewed semiannually at the ILRS General Assembly Meetings. Updates are made as necessary at the discretion of the Governing Board.

2.4 NETWORK CAMPAIGNS

INTRODUCTION

The ILRS is responsible for the tasking and coordinating of special SLR tracking campaigns that are requested by users, supported by the Missions Working Group, and approved by the ILRS Governing Board. A user can request a tracking campaign through the ILRS Central Bureau by first completing the on-line SLR Mission Support Request Form accessible through the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/ilrssup.html

The form provides the ILRS with a description of the mission objectives; mission requirements; responsible individuals, organizations, and contact information; timeline; satellite subsystems (including details of the retroreflector array and its placement on the satellite).

NEW MISSIONS IN 2001

METEOR-3M

The Meteor-3M spacecraft, launched on December 10th, 2001, is an advanced model of the Meteor spacecraft that was developed over 30 years ago. The payload includes SAGE III (Strategic Aerosol and Gas Experiment) and other instruments designed to measure temperature and humidity profiles, clouds, surface properties, and high energy particles in the upper atmosphere. The SAGE III/Meteor-3M satellite mission is a joint partnership between NASA and the Russian Aviation and Space Agency (RASA). SAGE III is a gyrating spectrometer that uses ultraviolet/visible observations to measure the vertical structure of aerosols, ozone, water vapor, and other important trace gases in the upper troposphere and stratosphere. Meteor-3M was also designed for flight testing of the novel-type spherical retroreflector for precise laser ranging.

SLR will be used for precise orbit determination and retroreflector research. Two NASA systems and one Russian system are currently tracking Meteor-3M for a short retroreflector experiment prior to the SAGE III activation. A request for full ILRS support will be made in early 2002.

Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/meteor3m/

CAMPAIGNS COMPLETED IN 2001

Two campaigns were completed in 2001

Table 2.4-1 ILRS Campaigns Completed in 2001

Campaign	Initiated by	Start Date	End Date	Purpose	No. Passes
BE-C*	Univ. of Texas Minkang Cheng	July 15, 1999	Dec. 31, 2001	Gravity field modeling	6214
GFO-1*	NASA Frank Lemoine	Apr. 22, 1998	Apr. 6, 2001	POD for ocean surface studies	4017

converted to mission status

BEACON EXPLORER-C

Beacon-C (BE-C) was launched in 1965 as part of the US National Geodetic Satellite Program. SLR tracking on BE-C was reactivated after many years to augment the current complex of satellites used to study the secular and long period tidal variations in the Earth's gravity field. Since all of the current geodetic satellites are orbiting at inclinations ranging from 50 to 110 degrees, BE-C satellite is the only useful target with a relatively low inclination (41 degrees).

A six-month campaign was initiated in July 1999. An extension was authorized through December 2001, and based on the success of this campaign, was voted by the ILRS Governing Board to be upgraded to an ILRS mission effective January 1st, 2002. Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/beaconC.html

GFO-1

The GEOSAT Follow-On 1 (GFO-1) program is the U.S. Navy's initiative to develop an operational family of radar altimeter satellites to maintain continuous ocean observation, including precise measurement of both mesoscale and basin-scale oceanography. GFO-1 was launched on February 10th, 1998 and ILRS tracking support commenced on April 22nd, 1998. With the failure of the on-board GPS units, SLR and Doppler are the only source of precise orbit data

GFO-1 was accepted by the U.S. Navy and was declared operational on November 29th, 2000. On April 5th, 2001, the ILRS Governing Board upgraded the GFO-1 satellite to ILRS mission status. Additional information for GFO-1 can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/gfo/index.html

NEW CAMPAIGNS

Three new tracking new campaigns were adopted by the ILRS 2001 (see Table 2.4-2).

Table 2.4-2. New ILRS Campaigns in 2001

Campaign	Initiated by	Start Date	Planned End Date	Purpose	No. Passes
Etalon 1 and 2	ILRS Analysis Working Group Ron Noomen	Apr. 1, 2001	Apr. 1, 2002	POD/ Improvement of the Earth Orientation Parameters (EOP)	3001
H2A/LRE	NASDA/Japan Hiroo Kunimori	Aug. 29, 2001	Sept. 29, 2001 Continued for interested stations	Test new launch vehicle for placing satellites in geosynchronous transfer orbit	18
Reflector	ROSAVIA-COSMOS Victor Shargorodsky	Dec. 10, 2001	Sept. 10, 2002	POD research for space debris detection	11

ETALON

Etalon are a Russian family (Etalon-1, Etalon-2) of passive geodetic satellites dedicated to satellite laser ranging. Etalon-1 was the first geodynamic satellite launched by the former Soviet Union. The Etalon spacecraft were launched in 1989 in conjunction with a pair of GLObal'naya Navigatisionnay Sputnikovaya Sistema (GLONASS) satellites. The mission objectives were to determine a high accuracy terrestrial reference frame and Earth rotation parameters, to improve the gravity field, and to improve the gravitational constant.

At the request of the ILRS Analysis Working Group, the ILRS Governing Board approved a six-month Etalon intensive tracking campaign from April 1st, 2001 to September 30th, 2001. The mission was subsequently through April 2002. The objectives of the campaign are to enhance Precision Orbit Determination (POD), station positions, EOP and EOP derivative determination, GM computation, and assessment of station biases (range and frequency bias).

Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/etalon/index.html

H2A/LRE

Laser Ranging Equipment (LRE) was a test of a SLR to help evaluate a new launch vehicle, H2A, in a transfer orbit for geosynchronous satellites. SLR tracking on LRE could also provide a means of calibrating SLR systems over a broad range of distances, help monitor vehicle spin rates, and support tests on the degradation of low-cost BK-7 cubes on the array. This mission, with its highly eccentric orbit, could also be used to refine current air drag and gravity field models.

The ILRS Governing Board approved a one-month campaign beginning at launch, August 29th, 2001. Due to a three-hour launch delay, good tracking conditions were lost for the first few months of the mission and no SLR data was achieved. Interested ILRS stations were encouraged to continue SLR efforts after the completion of the formal campaign and the Grasse LLR station acquired returns from the LRE satellite on December 17th, 2001. LRE support has continued on a limited basis.

Additional information can be found on the NASDA Web site at:

http://god.tksc.nasda.go.jp/lr/lre.html

And at the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lre/index.html

REFLECTOR

The Reflector microsatellite (Figure 2.4-1) is a passive satellite with retroreflectors placed at reference points (nodes) about the spacecraft. The satellite was designed to use the SLR return signal structure for studies of spatial (angular) resolution, of spacecraft attitude, and identification of space debris.

The ROSAVIACOSMOS, Science Research Institute for Precision Instrument Engineering (IPIE) requested a nine-month campaign for the Reflector satellite, beginning immediately after separation from the METEOR-3M satellite. The ILRS Governing Board granted emergency approval of this campaign request shortly after launch in December of 2001. A formal request will be acted upon in early 2002.

Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/reflector/index.html

Figure 2.4-1. Reflector satellite.

UPCOMING MISSIONS AND CAMPAIGNS

Request for tracking support for new missions must be submitted to the Central Bureau, reviewed by the Missions Working Group and approved by the Governing Board. New missions request tracking support by first completing an on-line SLR Missions Support Request Form accessible through the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/ilrssup.html

2.5 NEW MISSIONS AND CAMPAIGNS PLANNED FOR 2002 — 2003

A number of new missions and campaigns are anticipated during 2002 — 2003 (See Table 1.3-1)

JASON-1

Jason-1 is an oceanography mission to monitor global ocean circulation, study the tie between the oceans and atmosphere, improve global climate predictions, and monitor events such as El Ni o conditions and ocean eddies. The Jason-1 satellite, a joint France/USA mission, is a follow-on to the TOPEX/Poseidon altimeter mission.

Although the Jason-1 satellite has onboard GPS receivers, the SLR data will provide a crucial centering of the orbit relative to the Earth's center of mass. SLR also provides the only absolute calibration of the radial orbit error through the analysis of high elevation SLR passes. Jason-1 was launched on December 7th, 2001 and will be maneuvered into a tandem orbit with TOPEX/Poseidon. The satellites will be separated by approximately one minute in time. SLR will commence on Jason-1 on January 14th, 2002 after the satellite is maneuvered into its final orbit. Several test passes have been taken by ILRS stations during this maneuvering period to ensure the retroreflector array performance.

Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/jason/index.html

ENVISAT-1

ENVIronmental SATellite (ENVISAT) -1 is the successor to the European Space Agency (ESA) Remote Sensing Satellites ERS-1 and ERS-2. It will provide continuity with most of the ERS-1, 2 altimeter and SAR measurements and adds significant new capabilities. The mission will: (1) provide long term data sets for both climatological and environmental research; (2) monitor and support studies of the Earth's environment and climate changes; (3) support management and monitoring of the Earth's resources, both renewable and non-renewable; (4) help the development of a better understanding of the structure and dynamics of the Earth's crust and interior.

SLR will be combined with DORIS for POD to calibrate the on-board altimeter. The altimeter data will be used to determine ocean surface heights to monitor global ocean circulation, regional ocean current systems, and study the marine gravity field.

ENVISAT-1 will be launched on March 1, 2002 and maneuvered into a tandem orbit with ERS-2. The satellites will be separated by approximately 30 minutes in time.

Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/envisat/index.html

GRACE

The Gravity Recovery And Climate Experiment (GRACE) is a joint US/German satellite mission, which will provide global high resolution estimates of the Earth's gravity field and its variability in time. The GRACE mission will have two identical spacecraft flying about 220 kilometers apart in a polar orbit 500 kilometers above the Earth.

GRACE will map the Earth's gravity fields by making accurate measurements of the distance and relative velocity between the two satellites, using GPS and a microwave ranging system. It will provide an efficient and cost-effective way to map the Earth's gravity fields with unprecedented accuracy. The results from this mission will yield crucial information about the distribution and flow of mass within the Earth and it's surroundings.

The SLR data will be used for precise orbit determination in combination with GPS tracking data for gravity field recovery, calibration of the on-board GPS Space Receiver, and technological experiments such as two-color ranging. The GRACE satellites will be launched on March 17, 2002 and will be separated by approximately 30 seconds in time.

Additional information can be found on the ILRS Web site at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/grace/index.html

ICESAT (GLAS)

The Ice Cloud and land Elevation Satellite (ICESat) is scheduled for launch in December 2002, into a near polar Low Earth Orbit (LEO) at an altitude of 600 km with an inclination of 94 degrees.

ICESAT primary objectives are to study the mass balance between the polar ice sheets and global sea level change. Secondary objectives are to measure cloud heights and the vertical structure of clouds and aerosols in the atmosphere; to map the topography of land surfaces; and to measure roughness, reflectivity, vegetation heights, snow-cover, and sea-ice surface characteristics. The primary instrument onboard ICESAT is the Geoscience Laser Altimeter System (GLAS), an integral part of the NASA Earth Science Enterprise (ESE). GLAS will operate over ice, ocean and land.

SLR will be used for validation of GPS POD, back-up POD, and orbit maintenance.

For more information on ICESat refer to:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/icesat/index.html

GRAVITY PROBE B (GP-B)

Gravity Probe B will carry the Relativity Gyroscope Experiment being developed by NASA and Stanford University to test two extraordinary, unverified predictions of Einstein's general theory of relativity. The experiment will check, very precisely, tiny changes in the direction of spin of four gyroscopes contained in an Earth satellite orbiting at 400-mile altitude directly over the poles. The gyroscopes provide an almost perfect space-time reference system to measure how space and time are warped by the presence of the Earth, and how the Earth's rotation drags space-time around with it. These effects, though small for the Earth, have far-reaching implications for the nature of matter and the structure of the Universe.

SLR and GPS will be used for precision orbit determination. Launch is scheduled for 2003.

Additional information on Gravity Probe-B can be found at:

http://ilrs.gsfc.nasa.gov/gravity_probe_b.html

ADEOS-II

The ADvanced Earth Observing Satellite 2 (ADEOS-II) will support the monitoring of global environmental changes while continuing and furthering the broad-ranging observation technology created by ADEOS-1.

SLR data will be used to determine a precise orbit during the first 39 days of the mission. Once the Global Imager (GLI) instrument is turned on, SLR will cease operations due to the sensitivity of the sensor to 532 nm laser illumination. The ILRS will provide small tracking campaigns during the ADEOS-II lifetime as NASDA requires. SLR will provide limited amounts of data for the strengthening of the GPS solutions and validation/comparison of independently determined orbits.

Additional information on ADEOS-II can be found at:

http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/adeos2/index.html

2.6 SCIENCE COORDINATOR REPORT

This coming decade has been referred to as the Decade of the Geopotential given the wealth of satellite missions ongoing and planned from year 2000 onward which are designed to improve our understanding of the Earth s geogravity and geomagnetic fields. For gravity field modeling, the CHAMP, GRACE, and GOCE missions are expected to yield many orders of magnitude improvement in field recovery. For geomagnetic studies, we again find CHAMP, along with _RSTED, SAC-C, DMSP-F15 and other mission planned for later in the decade. We see a wealth of radar altimeter missions including ENVISAT, JASON, TOPEX/Poseidon, ERS-2, and GFO that are currently on-orbit. Space-based laser altimetry will reach new levels of sophistication and science yield with the December 2002 launch of ICESat, and the eventual launch of VCL. Never before have we seen such an abundance of missions, with each being underpinned by space geodetic requirements to provide precise orbit determination, data validation, and model development and testing. For the geogravity and altimeter missions especially, cm-level orbit determination is the goal.

Geophysical change detection is a major area of scientific interest. Important signals, both in the geogravity and geomagnetic fields, and also in continental, ocean, and ice sheet topography will allow a direct assessment and monitoring of some of the most important dynamical processes ongoing within the Earth s environmental system.

At the same time it is important to recognize the ubiquity of the GPS Constellation for a wide range of space geodetic applications, and in support of most of these missions. And clearly SLR must be recognized and evaluated in light of the increasingly important role that GPS is playing in precision orbit determination and model recovery. Nevertheless, it is no accident that every altimeter and geogravity mission mentioned deploys a laser retroreflector array as part of its spaceborne complement. With regard to the importance of SLR, the designers of these missions have already spoken.

There are three major roles for SLR-based science support:

- Providing independent information, both as unambiguously accurate tracking data, and for model verification, to ascertain model performance and improvement when using GPS. This includes studying how SLR data matches orbits determined by GPS systems, evaluation of new geophysical models like static and time varying/tidal gravity models, and providing end-to-end system calibration support for altimeters.
- Supporting science investigations for which SLR is clearly the preferred data resource to achieve science goals.
- Providing a low cost, low risk, fail-safe source of back-up to other orbit tracking and monitoring systems. Herein, SLR has already salvaged two altimeter missions: ERS-1 and GFO

Science support deserves elucidation, for it is important not to loose sight of the critical role that SLR will play for the foreseeable future in supporting many pressing science objectives. Examples of these are discussed briefly below:

TIME VARYING GRAVITY FIELDS:

Monitoring the changes in the gravity field is a remote sensing of global changes in mass transport, complementary to other means of remote sensing. Temporal variations of the Earth s gravitational field can provide important global constraints to better understand models of mass movement and exchange ongoing within the solid Earth-hydrosphere-atmosphere system. These variations occur on a variety of time scales, and there is considerable variation in their character and amplitude since they are caused by variable, simultaneously occurring geophysical phenomena. Very accurate data acquired on highly stable orbits are required to resolve these effects. To date, SLR has uniquely supported recovery of the long wavelength components of the non-tidal, temporal variations in the gravity field and has provided unique insight into global scale mass-transport.

From the changes in secular orbital perturbations they induce, temporal changes in the zonal harmonics provide the largest and most readily observable effects. An evaluation of the SLR data acquired principally from Lagoes-1, Starlette, Ajisai and Lageos-2, has produced reliable estimates of the secular change in the J_2, J_3, J_4, J_5 and J_6 harmonics and quite remarkably, have shown sudden changes in the J_2 rate in recent years. It is the strength one sees from more than 25 years worth of tracking on the most stable orbits that gives SLR a unique advantage in revealing long term global-scale mass transport.

Aperiodic and seasonal changes in the complete low degree and order gravity harmonics have also been observed using SLR orbital analyses. Monthly (and for recent time periods, 10-day) time series have been produced and compared with predictions obtained from Atmospheric Circulation Model/General Circulation Model (ACM/GCM) have been shown considerable strength for the complete long wavelength gravity field.

LONG WAVELENGTH TIDAL MODELS:

The mechanical/elastic properties and internal structure of the Earth can be better understood by observing its response to external forcing over a wide range of frequencies. The rich tidal spectrum provides a range of forcing (from $2x10^{-5}$ to $1x10^{-9}$ Hz) which is highly complementary to that acquired from seismic sources (1 to $2x10^{-4}$ Hz). Tidal analyses have the capability of revealing a five-decade addition in frequency range of the observed Earth's response.

The small phase lag in the solid Earth's tidal response arises from anelasticity in its body. Isolating and observing this phase lag over a wide range of tidal frequencies is the goal. The most successful experimental approach is to orbitally analyze very precise SLR data, and from perturbed orbital motion, derive accurate tidal parameters representing the integrated mass redistribution in the Earth/ocean/atmospheric system. To date, SLR is the only technique which has produced accurate estimates of the "whole Earth" tidal response, with solutions available for the longest wavelength components of the main tidal frequencies. Forward models are then used to remove ocean and atmospheric contributions. Modeling the ocean tides, given their large rate of energy dissipation and complexity, has caused significant uncertainties for accurate forward modeling. However radar altimeter derived ocean tide models have made enormous advances recently and with these advances, recent efforts have produced reliable detection of the solid Earth's lagged response at several semi-diurnal and diurnal tidal frequencies. An important benefit of SLR over other methods is that, by observing long-period orbital perturbations, SLR allows the important degree-2 terms that describe the Earth's body-tide response to be isolated. No numerical quadrature of poorly spaced surface measurements is required; since a satellite's orbit naturally provides the best numerical quadrature algorithm.

Again, it is the length of SLR data time series on a multitude of satellites which has led to the effective separation and recovery of these tidal effects. Since the most important of these effects are in resonance with orbital motion, the semi-diurnal, diurnal and long period tides all manifest themselves with long period orbital perturbations. Therefore, many satellite inclinations, and many years of accurate data are required to achieve a decorrelated tidal series. Again, SLR has proven itself unique for this application.

With the long SLR tracking history on LAGEOS and Starlette, important results are starting to be seen for the solid Earth's response to the 18.6 and 9.3 year lunar tides. Problems arise in separating secular zonal geopotential effects from these very long period tides, and a very long data record is therefore required. Again, SLR uniquely provides this data resource. Studies of these long period tides are aimed at understanding the transition from the high-Q seismic regime to the low-Q glacial-rebound regime and to determine whether the transition is sharp or smooth. For example, it is important to verify that the Earth's response (Q) is significantly different for the 18.6 year tide from that observed at diurnal/semidiurnal frequencies.

From the analysis of tides, the energy dissipation in the solid Earth can constrain the anelastic properties of the Earth at frequencies much lower than those accessible with seismology. With the goal being the determination of Q as a function of frequency across the entire tidal spectrum, a significant challenge remains.

GEOCENTER AND STATION VERTICAL MOTIONS:

It is convenient to consider the motion of stations with respect to the Earth's center-of-mass as being composed of two parts: the translation of the polyhedron of crust-fixed stations with respect to the center-of-mass, and the deformation of the polyhedron. We refer to the translation of the polyhedron origin (ITRF origin) with respect to the center-of-mass as the geocenter motion. Accurate measurement of the geocenter motion is needed to supplement measurements of polar motion, Earth rotation, precession and nutation, which connect the terrestrial and inertial frames, and to complete the realization of the ITRF. The geocenter signal provides information about hemispherical mass redistribution in the atmosphere, oceans and surface water (ice-sheets, snow, soil moisture and groundwater) and is normally less than 10 mm at seasonal frequencies. Measurements of the geocenter motion with a few mm accuracy quantify the hemispherical mass transport in the Earth system and are useful constraints for understanding the processes that lead to the redistribution of mass on the planet. The tidally driven geocenter can be monitored to improve ocean tidal models. Herein, SLR continues to provide the most accurate system for the recovery of geocenter motion on a daily basis.

The radial component of the deformation of the station polyhedron is caused by the solid Earth's response to tidal and rotational potentials, to past and present loading of the crust by ice, water, and air, and by tectonic processes. Measurements of the vertical component of the deformation with few mm accuracy are useful in studying these effects, and are an essential part of the job of maintaining the accuracy of the terrestrial reference frame needed for full use of tide gauge and altimeter measurements of the ocean surface. While SLR continues to be important for determining the absolute vertical motion of sites located throughout the world, GPS is providing an increased capability to provide comparable measurements.

SUMMARY:

SLR tracking data will continue to make important contributions to the scientific results which will come from this decade of geopotential investigations. With the recent deployment of several new stations in the Southern Hemisphere and the implementation of more automation and systems improvements, global coverage has improved and the cost of SLR tracking has decreased, in some cases very significantly. The major challenge to further strengthen the SLR role is still largely a matter of cost and coverage. New highly automated systems under development offer promise of significantly improving both the economic and geographic limitiations with the current SLR network. With the effective development, testing, and deployment of these systems, a more geographically dense network, with lower operational costs, will yield SLR tracking coverage which far surpasses that available today.