SECTION 3

WORKING GROUP REPORTS

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SECTION 3 - WORKING GROUP REPORTS

The Governing Board, at its discretion, can create or disband Working Groups. A Working Group (WG) may be either permanent (Standing) or temporary (Ad-Hoc) in nature. Standing Working Groups are created by the GB to carry out continuously evolving business of the ILRS. Occasionally, Ad-Hoc Working Groups are appointed to carry out special investigations or tasks of a temporary or interdisciplinary nature.

The Coordinator of each Standing WG is selected by the GB from amongst its members to ensure close coupling of the WG with the GB and its goals. The WG Coordinator can independently appoint additional members to the WG from among the other GB members, ILRS Associate Members or ILRS Correspondents (see below). The WG Coordinator may also designate a Deputy to act on his/her behalf in his/her absence. All GB members, with the exception of ex-officio members, Chairperson and IERS representative to the ILRS are required to serve on at least one of the Standing Work Groups.

The coordinator for Ad-Hoc Working Groups may be chosen, at the discretion of the Board, from outside its membership in order to best fulfill the goals of that WG.

Currently the Governing Board has established Standing Working Groups for:

- Missions
- Data formats and procedures
- Networks and Engineering
- Analysis

The Governing Board has also established an Ad-Hoc Working Group for Signal Processing.

3.1 MISSIONS WORKING GROUP

Scott Wetzel, *Honeywell Technology Solutions, Inc.*
Hiroo Kunimori, *Communications Research Laboratories*

INTRODUCTION

The Missions Working Group (MWG) was formed at the first ILRS meeting in Deggendorf, Germany in September 1998. Since then, the MWG has had two formal meetings, at the ILRS meeting in The Hague, the Netherlands in April 1999, and at the ILRS meeting in Florence, Italy in September 1999. Additionally, the MWG has had a number of ad hoc discussions via e-mail or telephone, to discuss current issues such as the approvals of request for support for new satellite missions and for intensive tracking campaigns.

The following sections describe the charter of the MWG, the membership, past activities, and continuing projects that the MWG addressed in the past year.

CHARTER

An SLR system can only track one satellite at a time. There has been a steadily growing number of new satellites with many different tracking requirements requesting SLR support of the past 5 years. As this number has increased, the need has increased for an organized mechanism to review all requests for SLR support of future missions and campaigns and to ensure that the currently supported missions still require SLR tracking. This ILRS Missions Working Group is tasked to review the needs of current and future SLR missions and to make SLR tracking support and priority recommendations to the ILRS Central Bureau and Governing Board.

The Central Bureau refers Mission Support Request Forms submitted for new satellites to the MWG. The MWG reviews them for adequate scientific or engineering relevance and sufficient justification for laser tracking support. Additional requirements such as SLR temporal and spatial coverage, prediction services, data processing and community interest are reviewed. Special mission requirements such as time biases, drag functions, liberating functions, modes of calibration, accelerated data submissions, and organization of the data flow from the data centers to the mission analysis centers are reviewed for relevance and compliance with ILRS capabilities.

Whenever the normal procedures and formats are inadequate for proper support of a new mission, the MWG will try to work out possible solutions in cooperation with the Mission sponsor and the other Working Groups.

The MWG proposes to the ILRS Governing Board the acceptance or refusal of a new or modified mission, based on the documents submitted by the mission sponsor (including a mission plan and the current workload of the network). Prior to making a recommendation to the

Board, the MWG consults with the Network and Engineering, Data Format, and Analysis Working Groups as necessary.

The MWG recommendation to the ILRS Governing Board includes any changes in the current priority list required to accommodate the new missions

The full charter for the Missions working Group can be found at:

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

MISSIONS WORKING GROUP MEMBERSHIP

Name	E-Mail	GB Member	Position
Hiroo Kunimori	kuni@crl.go.jp	Yes	Coordinator
Francois Barlier	francois.barlier@obs-azur.fr	Yes	Deputy Coordinator
Peter Shelus	pjs@astro.as.utexas.edu	Yes	GB Appointee
John Degnan	jjd@ltpmail.gsfc.nasa.gov	Yes	GB Appointee
Scott Wetzel	scott.wetzel@honeywell-tsi.com	No	
Pippo Bianco	bianco@asi.it	No	
Vladimir Vassilvev	lavaser@orc.ru	No	
Ulrich Schreiber	schreiber@wettzell.ifag.de	No	

ACTIVITIES

Meetings

Two MWG splinter group meetings were held during the past year: one at the Hague during the EGS meetings in April 1999 and the second at the SPIE meetings in Florence, Italy in September 1999.

The Hague Meeting

At the Hague meeting the following issues were discussed: The charter and the membership of the MWG were presented. The Mission Support Request Form was renewed and approved for installation on the ILRS web site in interactive form. The Mission Request Form can be found at:

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

The first use for the new form was completed by the SUNSAT mission. The form was also sent to the IRS-P5 (India) and VCL (NASA) missions to be completed for submission. A description of the mission approval process is found in Figure 3.1-1

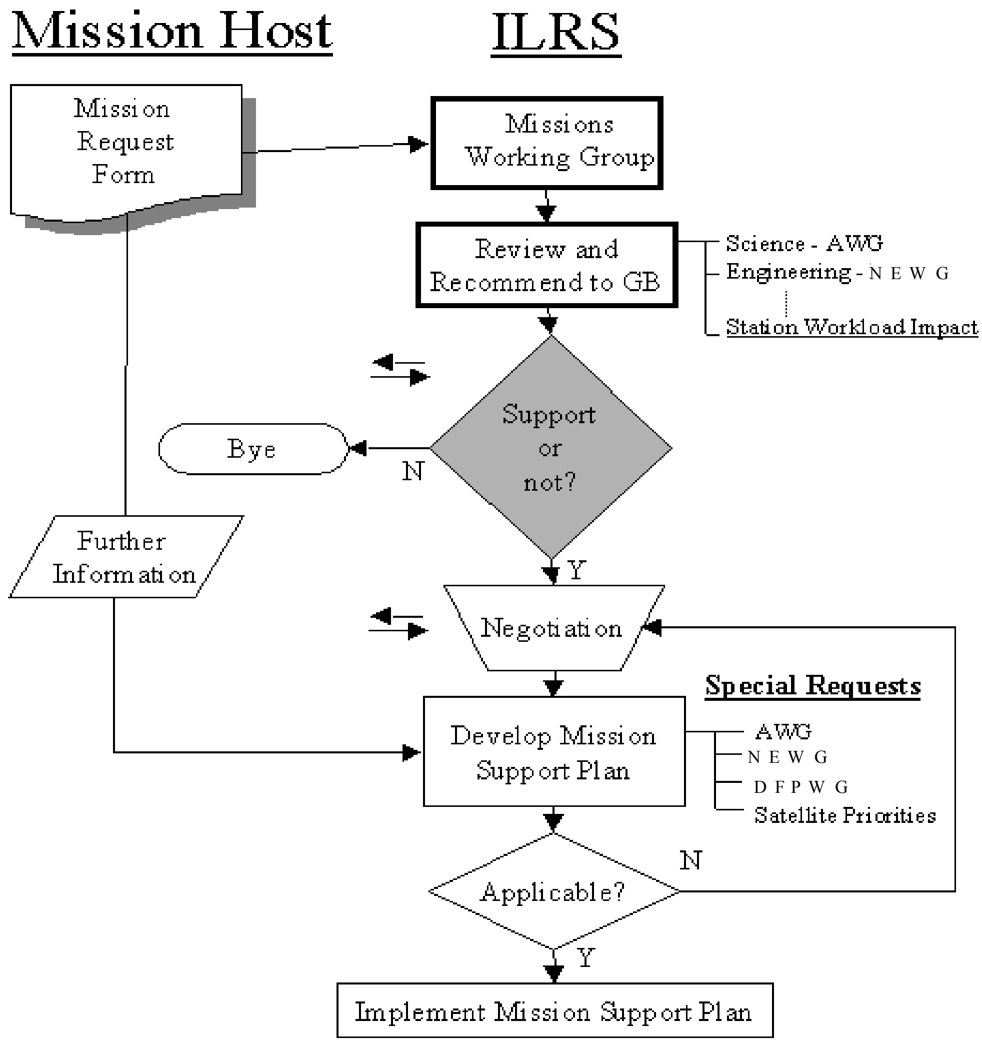

Figure 3.1-1 Procedures for New Campaigns/Missions

Following approval by the Governing Board, the next step is the development of a tracking support plan. It was agreed that new missions should submit a preliminary form early so that the MWG and the Governing Board can provide early feedback and suggestions. A final version of the form can be submitted closer to launch. It was suggested that requestors of new campaigns using satellites already in orbit should also submit a Missions Support Request Form using the relevant fields. Several of the working groups pointed out the need for standardization and documentation of the center-of-mass corrections.

Other issues discussed included some unresolved issues on the GLONASS numbering system, but it wasn't clear if this adversely affected SLR tracking. Further investigation on the topic would continue.

The Florence Meeting

At the Florence meeting the topics of discussion included: (1) provisions for handling special requests as part of mission support, (2) criteria for ILRS acceptance of new missions, (3) determination of future tracking priorities, and (4) development of a flow diagram of procedures for new missions.

The approval procedures for campaigns conducted over the previous 6 months were reviewed with an eye toward the large number of new missions in the near future (twelve new missions were anticipated over the next three years). Mission support requests for CHAMP and VCL were under MWG review. Discrepancies in the several GLONASS numbering systems continue to cause confusion. The Missions Working Group and the Central Bureau agreed to work through a standard numbering system for the SLR community to use for its operational activities. Spacecraft center-of-mass changes during mission lifetime (due to expenditure of fuel) will be investigated and worked with the Signal Processing (Ad Hoc) Working Group.

Campaigns

Requests for special campaigns have been approved for the following satellites: GEOS-3, ERS-1, Etalon, BEC, Sunsat, and GFO-1. Brief summaries follow.

The new ILRS Board approved a campaign on GEOS-3 for gravity field modeling in September 1998. The campaign began in October 1998 and concluded in April 1999 with over 2200 passes tracked. The ERS-1 campaign was requested for the period beginning from July 1998 through the end of 1999 to support the tandem SAR Mission with ERS-2. The failure of the radio tracking system early in the ERS-1 mission had left SLR as the only method of POD for the satellite. As with all campaigns, ESA was required to reapply for SLR support on an annual basis and to provide periodic updates on the status and usefulness of the SLR data.

An Etalon campaign was requested by the WPLTN for continuing geodetic modeling in the Western Pacific region. The campaign covered the month of November 1999. A total of 297 Etalon segments were received from the global SLR community in support of the brief campaign. Due to the success of the campaign, the WPLTN is anticipating future monthly campaigns on an annual basis.

An 18-month BEC campaign was proposed by the University of Texas at the ILRS meeting at the Hague in April. A mission request form was received and approved with the requirement of 6 month data reviews to ensure adequate SLR coverage was being provided to support the science objectives of the mission. The campaign began in July 1999 and is expected to conclude in December 2000.

An ongoing Sunsat campaign was extended through March 2000 by the Governing Board in support of the GPS/SLR intercomparison experiment. The Sunsat mission was not recommended for full mission status as it had no long term goals that required SLR support. The Board is open to extensions of the campaign to meet program needs.

GFO-1 - (NASA)

The GFO-1 altimeter satellite, launched by the US Navy in April 1998 continued its shakedown and diagnostic phase. The MWG recommended campaign status at high priority while the Navy and their contractors worked to resolve a number of on-board problems. The tracking campaign and the status of the satellite are being reviewed every six months.

WORK IN PROGRESS

Continued efforts are required bu the MWG to develop:

- A more automated and user friendly Mission Support Request Form
- A Mission Support Plan Template to help satellite hosts in mission planning
- A procedure to periodically (1) review mission requirements and applicability of SLR to meeting these requirements and (2) require satellite owners or key science and technical contacts to justify continued SLR support

Issues such as SLR coverage and data volume will be reviewed, whole arc or pass segmentation may be planned to support a rapidly growing number of missions. Also to be considered would be periodic intensive tracking campaigns to relieve the high number of #1 priority missions.

Mission Name	Support Requester	Application	Planned Launch Date	Mission Duration	Received Mission Request Form
CHAMP	GFZ	Gravity and magnetic field mapping	July 2000	5 years	Yes
JASON-1	CNES/NASA	Earth sensing	November 2000	5 years	No
ADEOS-II	NASDA	Earth sensing	December 2000	3 years	No
Grace	NASA/GFZ	Gravity	Fall 2001	5 years	No
IceSat (GLAS)	NASA	Earth sensing	July 2001	3-5 years	No
Envisat-1	ESA	Earth sensing	June 2001	5 years	No
VCL	NASA	Earth sensing	September 2001	18 Months	Yes
Gravity Probe B	NASA	Relativity	May 2002	1-2 years	No
ALOS	NASDA	Earth sensing	February 2003	3 years	No
ETS-VIII	NASDA	Experimental	July 2003	3 years	No

Table 3.1-1 Planned Future Missions

3.2 NETWORKS AND ENGINEERING WORKING GROUP

Werner Gurtner, *Astronomical Institute of Berne*

MEMBER LIST

Name	E-Mail	GB Member	
Werner Gurtner	werner.gurtner@aiub.unibe.ch	yes	Coordinator
Graham Appleby	gapp@ite.ac.uk		
David Carter	dcarter@eib1.gsfc.nasa.gov	yes	
John Degnan	jjd@ltpmail.gsfc.nasa.gov	yes	
Howard Donovan	howard.donovan@honeywell-tsi.com		
Van Husson	van.husson@honeywell-tsi.com		
Georg Kirchner	kirchner@flubpc04.tu-graz.ac.at		
Rolf König	koenigr@dfd.dlr.de		
Hiroo Kunimori	kuni@crl.go.jp	yes	
Mike Pearlman	mpearlman@cfa.harvard.edu	yes	
Ulrich Schreiber	schreiber@wettzell.ifag.de		
Wolfgang Schlüter	schlueter@wettzell.ifag.de	yes	Deputy coord.
Fumin Yang	yangfm@center.shao.ac.cn	yes	
Tom Zagwodzki	thomas.w.zagwodzki@gsfc.nasa.gov		

PRIMARY TOPICS

The following major topics for the Working Group activities have been defined based on the Terms of Reference. In order to distribute the workload, each working group member has been assigned one or more fields of activities and chairpersons have been assigned for each activity.

The six primary topics of activity (as defined in the Terms of Reference) are distributed among the Working Group members as follows.

1. Provide a communications link between the analysis community and the global network (*Yang, Koenig, Appleby*)
   - Find out what feedback is desired by the stations, what feedback or information already exists and who works on or initiates improvements of this feedback
2. Facilitate ranging data problem and/or anomaly resolution (*Koenig, Husson, Donovan*)
   - Generation of a catalogue of quality checks performed by the various analysis centers. Specification of the feedback needed by the tracking sites.
   - What is already available and who actually can “routinely provide” such feedback?
   - Development of a consistency and format check program for ILRS normal point files (to be run on-site)

3. Review and maintain the system configuration database (*Husson, Gurtner*)
   - Development of a new site/system log form
4. Maintain a "knowledge base" (*Pearlman, Kunimori, Degnan*)
   - Knowledge data base: Online collection of papers, reports, descriptions, manuals, whatever
   - Generation of a catalog of satellite-specific tracking properties
5. Perform engineering analyses in support of new missions and network scheduling (*Schreiber, Carter, Husson*)
   - Example: Spacecraft link calculation
6. Coordinate and catalyze engineering improvements within the global network (*Kirchner, Degnan, Zagwodzki, Donovan*)
   - Monitor reported developments, tests of new equipment, etc.
   - Encourage the respective specialists to help prepare well formulated, summarized and to a certain extent educational proposals for improvements to be distributed to the network

POSSIBLE ADDITIONAL TOPICS:

- Initiate prediction flow chart (Special working group)
- Define a procedure to quickly request highest priority tracking of specified passes
- Define a procedure to prevent the network from ranging to a satellite during a specified period
- Define a procedure to quickly contact the operators with urgent messages.

WORK IN PROGRESS

ILRS Site and System Information Form

W. Gurtner has developed a proposal for a site log form similar to the well-established site log form routinely used by the International GPS Service for the permanent GPS tracking stations. The proposal was review by several working group members and presented at the Florence General Assembly in September 1999. After the Assembly four stations were asked to fill out the form as a final check and as basis for an explanatory supplement.

In early 2000 the Central Bureau should request all stations to fill out the form.

The form collects information about the following items:

- Form
- Identification of the Ranging System Reference Point (SRP)

- Site Location Information
- General System Information
- Telescope Information
- Laser System Information
- Ranging Electronics
- Tracking Capabilities
- Calibration
- Time and Frequency Standards
- Preprocessing Information
- Aircraft Detection
- Meteorological Instrumentation
- Local Ties and Eccentricities
- Local Events Possibly Affecting Computed Position
- On-Site, Point of Contact Agency Information
- Responsible Agency
- Additional Information

Four-Character Site Code

A list of new SINEX compatible four-character acronyms for the SLR sites is in preparation. These acronyms would replace the four-digit CDP code in file names, tables and lists, etc., to improve the readability.

Knowledge Data Base

The Central Bureau has established an on-line bibliography of SLR related papers and articles including all of the Laser Workshop articles (except Workshop #1). Many of the most recent articles are on line and links may be added if deemed appropriate. Search categories will be established for the bibliography to facilitate access to the large amount of scientific, technical and operational information.

Many of the ILRS responsible entities, rules, regulations, constraints, algorithms, forms etc, are being collected and put on line.

Databases will be developed for all of the station information that will be forthcoming from the completed site survey forms and other queries that are underway.

Real-time Status Exchange

A description of the procedures used by the EUROLAS subnetwork to exchange current SLR system status information and satellite tracking activity (including actual time bias) has been distributed within ILRS by SLRMail 372 (see also EUROLAS contribution in Section 4.1).

Link Budget

A web-based program for satellite link budget calculations has been prepared by Stefan Riepl at:

http://www.wettzell.ifag.de/publ/linkbudget/linkbudget.html

which computes the number of return photons expected as afunction of SLR system parameters and the satellites. The web pages also show a standardized link budget relative to the Lageos satellite for a selection of satellites.

Calibration Workshop

Ulrich Schreiber, Wettzell, organized a joint EUROLAS/ILRS two-day workshop on “System Calibration” in Florence, Italy (September 23/24, 1999).

Other activities

Since there is considerable overlap between the areas of interest of our working group and those of other groups (Data Formats and Procedures, Prediction Subgroup), close contacts have been maintained with those groups.

3.3 DATA FORMATS AND PROCEDURES WORKING GROUP

John Luck, *Australian Surveying and Land Information Group*

CHARTER

The following charter was ratified in January 1999 and updated on 7 May 1999 as a result of The Hague Data Formats and Procedures WG Meeting.

Objective

The objectives of the Data Formats and Procedures Working Group (DFP WG) are to:

- Standardize procedures affecting data up to generation of full-rate and normal point data.
- Maximize the efficiency of the process of generating the laser data, by ensuring that accurate predictions are available and that standardized software procedures are available to produce a uniform quality data product.
- Ensure that the data product contains all the information needed by the analyst, and that the data and related information are available for the analyst in a convenient form.

Role

Predictions

Document and maintain standards for:

- Force model and reference frame of IRV integrator.
- Format of IRV state vectors.
- Standard methods to correct IRVs for unmodeled forces.
- Standard format for time bias functions, drag functions, satellite maneuvers, etc..
- Standard software packages for generating predictions from IRVs.

The Working Group will endeavor to ensure that there are several groups within the network with the capability of generating IRVs and time bias corrections, and that there are efficient and rapid means of distribution.

Data Processing

Document and maintain the standard algorithm for:

- Formation of normal points.

The Working Group will endeavor to maintain standard software packages for fitting a trend function to pass residuals, or analyzing the distribution of pass residuals, and calculating various reference points (mean, peak, etc).

Station Information

Document and maintain formats for recording station information, such as:

- Eccentricity vectors
- Site occupancy details
- Changes to systems (e.g., SCH log files)
- Alternative operational configurations of stations (e.g., SCI log files)

Final Data Product Formats and Transmission Standards

- Maintain documentation of formats for the final data products, full-rate data (FR) and normal points (NP).
- Coordinate continuing review of formats, and if necessary revise.
- Document standards for transmission, including file naming conventions.

MEMBERSHIP

Name	**E-mail (ilrsdfpwg@ilrs.gsfc.nasa.gov)**
John Luck, Coordinator	johnluck@auslig.gov.au
Wolfgang Seemueller, Deputy Coordinator	Seemueller@dgfi.badw-muenchen.de
Ron Noomen, GB Appointee	ron.noomen@lr.tudelft.nl
Van Husson, CB Representative	dsgvsh@slral2.atsc.allied.com
Randy Ricklefs, LLR Representative	rlr@astro.as.utexas.edu
Graham Appleby	gapp@ite.ac.uk
Reinhart Neubert	neub@gfz-potsdam.de
Andrew Sinclair	Atsinclair@aol.com
Roger Wood	rw@gxvf.rgo.ac.uk
Vladimir Glotov	vd.g@g23.relcom.ru
Roland Schmidt	Rschmidt@gfz-potsdam.de
Brion Conklin resigned, October 1999	

STUDY GROUPS

Signal Processing Working Group ("Tiger Team")

This team led by Graham Appleby was initially formed by the Data Formats and Procedures WG at its first meeting at the Second General Assembly at The Hague, the Netherlands to develop unimproved satellite center-of-mass corrections. It was subsequently established as an ad hoc Working Group in its own right by the Governing Board.

Predictions Study Group ("Lion Team")

The Predictions Stusy Group was also established under the leadership of Roger Wood at The Hague.

Objective

To review the way in which predictions are currently produced and distributed in order to improve the quality of predictions at the telescope and to provide them at a frequency appropriate to each satellite.

Tasks

(1) Investigate the immediate benefits of building on the present IRV system by way of:

- Computing fresh predictions daily;
- Producing multiple IRVs per day;
- Arranging for orbit-by-orbit re-prediction for difficult satellites.

(2) For the longer term, examine the merits of supplying stations with fully-modelled predictions (by-passing IRVs) for every pass.

Report to ILRS making recommendations on how to proceed together with standards for procedures and formats, as required.

Membership

Roger Wood (leader), Brion Conklin (resigned), Werner Gurtner, Rolf Koenig, Jan McGarry, Chris Moore, Randy Ricklefs, Wolfgang Seemueller.

Progress to Date

With the broad aim of looking at the whole prediction cycle, it was agreed that it would be useful for the Central Bureau of ILRS to conduct a survey of observing stations, prediction centers and data centers to find out what is current practice for all aspects of predictions, and to hear from all component parts of the network what they regard as strengths and weaknesses. It is recognized that it would be advantageous to speed up the data flow in all the links: observing station ➔ data center ➔ prediction center ➔ data center ➔ observing station and so on. A questionnaire will be distributed in early 2000.

The well-established system of prediction distribution by IRVs has much to recommend it: it is compact, robust and well-proven. However, it is now perfectly possible, utilizing the speed and efficiency of data traffic on the Internet, to make worthwhile improvements with only minimal changes to the IRV system. For example, it would be useful to amend Line 1 of the standard IRV format to give more uniform identification for the prediction centers which produce them (and to be identical with those used in Time Bias Functions). There are other data which might be included here, like information about the multiplicity (i.e. number of IRV sets per day) for cases where the time span is less than 24 hours.

By far the most dramatic improvement would be the wider production of IRVs daily, or even sub-daily for "difficult" satellites. The main questions are then the ability of the network as a whole to handle the increased traffic. Further automation of processing should make such increases transparent. For some stations where it is not easy to change quickly, it would be necessary to run the existing system in parallel with any new ideas.

In the more distant future (again especially for some of the planned low-flying missions) it may be necessary for stations to be able to accept geocentric XYZ files generated directly from the precise orbits computed at prediction centers. The benefits for the prediction centers are that they then do not need to compute IRVs from their precise orbits, a process which does inevitably cause some degradation in the precision inherent in those orbits. Observing stations will only have to make some minor adjustments to their software to allow direct use of these files by bypassing the IRV integrator. HTSI (for SLR 2000) and NERC (for GFZ-1 and other low satellites) have already been experimenting with this approach with promising results.

One other aspect of some of these new missions which may lead to better tracking by the SLR network is the fact that several of them have other position measuring systems (GPS, DORIS) on board, and the rapid utilization of data from these devices (having the great advantage of weather independence) could significantly improve data yield from SLR.

For data centers, the main issue will be handling the increased traffic. Some careful thought needs to be paid to the question of archiving predictions: are they to be regarded as truly ephemeral ephemerides and discarded as soon as the relevant date has passed, or should they be retained for later use? Now that prediction data are available in several FTP sites it would seem sensible to agree to a common directory structure (below some entry point) for all files; and further to standardize the naming conventions for prediction and other files.

All observing stations should be encouraged to move to using daily IRVs, especially for the GPS and GLONASS satellites and LAGEOS, where the results are excellent.

One very valuable addition to the ILRS Website has been the expansion of the information on prediction centers and the detail of what IRVs are available from whom at what frequency, together with hyperlinks to all sources. See:

http://ilrs.gsfc.nasa.gov/prediction_centers.html and

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

Normal Point Study Group ("Jaguar Team")

This team led by John Luck was established at the meeting in The Hague. Having reached a conclusion, it was disbanded at the Working Group meeting in Florence, September 1999.

Objective

To test whether a significant proportion of normal points rejected by Analysis Centers contained low numbers of returns, and to make the appropriate recommendation to the Governing Board.

Membership

John Luck (leader), Graham Appleby, Richard Eanes, Gerd Gendt, Peter Dunn, Vladimir Glotov, Tim Springer, Jean-Claude Raimondo, Ron Noomen.

Conclusion and Recommendation

Data on normal point rejection rates for normal points constructed from 1, 2, 3, 4 and many individual returns were presented for ERS-1, ERS-2, WESTPAC, STARLETTE, STELLA, LAGEOS-1 and LAGEOS-2, by several Analysis Centers. The study found the following:

a) the percentage rejected depends roughly on the inverse of the square root of the number of returns in the normal point

b) only 30% of 1-return normal points are rejected;

c) the Analysis Centers are detecting adequately the outliers among these sparse normal points.

Accordingly, the Study Group made the following recommendation was presented to the ILRS Governing Board: "The ILRS should make no restriction on the minimum number of returns used to generate Normal Points."

Refraction Formula Study Group

The Working Group was charged at the Florence meeting of the Governing Board with the task of setting up a study of the adequacy of the Marini-Murray formula for atmospheric propagation delay, and to promote the development of a new formula and methodology if necessary. This task is in hand at the time of writing.

BUSINESS ARRANGEMENTS

Meetings

Two meetings were held for the DFP WG and friends, immediately prior to ILRS GB meetings:

(1) The Hague, Holland, 20 April 1999, 8:15-10:30 pm. This meeting discussed 23 agenda items, and produced decisions or positive action plans on all of them.

(2) Florence, Italy, 21 September 1999, 6:30-10:00 pm. This meeting received reports from the Central Bureau and Study Group leaders, and discussed 10 agenda items.

These meetings were very useful, and enabled recommendations to be finalized for approval by the GB. It is proposed to continue this procedure.

ACTIVITIES OF THE DFP WG

A summary of the activities of the WG can be found on the ILRS Web Site at:

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

The initial activities dealt largely with tightening up existing formats and procedures, rectifying anomalies, providing standardized documentation via the Web site, and setting up study groups for the more serious questions.

All Web references below are preceded by http://ilrs.gsfc.nasa.gov.

Decisions Implemented

Official Names of Station Data Products:

To emphasize the official status of the ILRS in determining formats, the nomenclature for station products was changed as follows:

- ILRS NP for Normal Point format and data (formerly “CSTG ONP”).
- ILRS FR for Full-Rate format and data (formerly “MERIT-II Full-Rate”).

ILRS Normal Point Format and Algorithm:

The April meeting in The Hague ratified the existing CSTG ONP format adopted in March 1997. Conversion of all historical LLR Normal Point data to this format was accomplished by University of Texas by July 1999 - LLR files have their own interpretations in bytes 49-52.

The ILRS NP format is described in detail in /np_format.html, and its history dating back to Herstmonceux 1984 has been placed at /np_format_intro.html. The NP algorithm has remained essentially unchanged since the Herstmonceux Agreement. Details are at /np_algo.html.

The Central Bureau has developed "sanity checks" on NP data files submitted by stations, and has implemented them with the authority of the ILRS by notifying stations immediately of anomalies and format non-compliances. Examples of non-compliance include:

- Incorrect bin sizes per satellite.
- Single-shot precisions divided by √n.
- Bin boundaries not starting at 00:00:00 UTC + k*(binwidth).

ILRS Full-Rate Format Changes:

The official ILRS FR format at /fr_format_v3.html contains changes to the contents of several fields adopted as a result of the meeting in The Hague, April 1999.

- Data prepared with these new conventions must contain '3' in the Format Revision Number (byte 129).
- The Wavelength field (bytes 65-68) conforms to the definition adopted for ILRS NP Header bytes 21-24.
- Normal Point Bin Size Indicator (byte 115) conforms to the definition adopted for ILRS NP Header byte 43.
- Epoch Time Scale Indicator (byte 121) includes '4' to mean UTC determined by GPS time transfer or GPS timing receiver, where UTC for practical ILRS purposes is realized by USNO, BIPM or cognizant national authority.
- The Calibration and Configuration flags (bytes 126-128) are rearranged and slightly reinterpreted, to conform to ILRS NP Header bytes 45-47.

The WG suggested July 1, 1999 as an implementation date.

Format and Procedure for Notification of Satellite Maneuvers:

The adopted format is based on the D-PAF maneuver message, and is available at /manoeuver.html. The appropriate Prediction Center will advise the ILRS stations of upcoming maneuvers. The CB and Missions Working Group are to prevail upon all concerned mission operators to comply with the format and procedure. There is no consensus on how to spell it.

Drag Function Format and Procedure:

Since it is conceivable that drag functions such as those used for GFZ-1 will be required for some of the upcoming very low altitude missions, the format and algorithm developed for GFZ-1 have been adopted. The format is shown at /drag_function.html and the algorithm is described by Fortran subroutines available at /drag_function_subroutines.html.

System Configuration (SCI) and System Change (SCH) Files:

The formats and procedures adopted in March 1997 are documented at /sys_cong_proc.html. Stations were reminded that changes/updates to existing files require transmission of ONLY the new information (i.e. they should not re-send the whole file).

Prediction Centers and their Acronyms:

A list of Prediction Centers producing Tuned IRVs, together with their adopted 3-character acronyms and statements on how to access prediction files, has been placed at /prediction_centers.html. A list of the satellites for which predictions are made by each Prediction Center, and the frequency of updating, can be found at /prediction_types.html. These lists are prepared as a service to the stations, and to record the standard naming conventions to be adopted for Time Bias Functions, Drag Functions, Maneuver Notifications, and IRVs themselves.

Site Occupancy Designators and DOMES Numbers:

The Central Bureau has developed the process for the assignment and communication of Site Occupancy Designators (SOD) in a manner consistent with the IERS Directory Of MErit Sites (DOMES) Designators' requirements. The SOD numbering system and procedure for allocation of new SOD numbers are found at /sod.html.

It was clarified during the Florence meeting that the last two digits of the CDP occupancy sequence number will be incremented when there is a new system occupation or when the system's eccentricities for a given monument have changed significantly (i.e. the change is greater than the uncertainty in the measurements in any of its components. A change in occupation number indicates there is new eccentricity information, which must be forwarded immediately to the CDDIS.

The DOMES numbering system and procedure are explained at /domes_and_domex.html. Van Husson has compiled a cross-reference table of SOD and DOMES numbers for ILRS stations active at October 1999, at /sod_domes.html. Ron Noomen has provided the complete historical cross-reference table, at /sod_domes.xls.

System Status Monitoring:

Some stations seem to "disappear" for extended periods. The ILRS wishes to know if they need help, or whether the Data Centers can expect to receive a backlog of files at some future time. The Florence at the recommendation of the Working Group a weekly one-line "Station Status Report" was adopted. A station not submitting this report will be flagged as "non-operational" by the Central Bureau, which will investigate the cause if it persists. The procedure was inaugurated in February 2000 - see e-mail from Mike Pearlman to all stations, 10 February 2000: "Station Status Reporting - Required for All Stations." The CB will include the station status flags in its weekly tracking statistics reports.

Y2K:

The membership and components of ILRS were strongly advised to perform Y2K compliance testing well before the date rollover to January 1 2000. The ILRS published a NASA/HTSI Y2K Benchmark Report and allied documents. Nevertheless, there were a number of minor Y2K problems throughout the ILRS, which were quickly fixed.

Decisions Awaiting Implementation

Data Transmission Procedures:

The Data Center representatives at the Florence meeting agreed to codify the procedures for transmission of data from the stations, and retrieval from the Data Centers by the stations. Data access and file naming conventions are now available on the ILRS Quick Reference Card (see /ilrs_qrcard.doc). A summary of the data flows is presented in Section 6. The Predictions Study Group (Lion Team) is closely involved in specifying, codifying and advertising the requirements and procedures, with the aim of making all data transmissions as automatic and unambiguous as possible.

Standard Software Packages:

At the time of writing, the NASA/HTSI Operations Center is doing final testing and debugging on its new NP data format and data integrity checking routines. The algorithms for these checks were agreed at the Working Group meeting in Florence in September 1999. As well as checking such things as correct NP bin sizes per satellite, typical checks include sensible meteorological readings per station.

The WG has agreed in principle that it is responsible for having standard subroutines/packages prepared for such things as the computation of skewness and kurtosis, and the filtering and compression of raw data into ILRS NPs, when and if they become practicable or necessary. The routines would be written in standard, common computer languages for the popular platforms.

Future Actions Considered

SLR Data Product Holdings:

It has been proposed to debate the feasibility of having identical data (tree) structures below the entry point, for SLR information at both CDDIS and EDC. This would involve major restructuring of data product holdings.

Full-Rate Calibration Data:

The Signal Processing Working Group requested an examination of the need for ground-target calibration data to be made available on a return-by-return basis, and foreshadowed a request to incorporate the data in ILRS FR format.

ILRS FR and NP Format Conformance:

Is there merit in having both forms of data in the same format? Is it feasible? Should improved methods of data compression (e.g. Hatanaka) be adopted?

3.4 ANALYSIS WORKING GROUP

Ron Noomen, *Delft University of Technology*

INTRODUCTION

The International Laser Ranging Service (ILRS) was established in 1998. Its main tasks are to:

- coordinate the use of Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) instruments;
- coordinate the analyses of the observations obtained by these instruments, and provide for consistency and unambiguity of the results;
- provide a so-called Standard Solution, an official ILRS combined product; and
- stimulate the use and interpretation of SLR/LLR analysis products and promote the laser ranging community as a whole. Section 1 of this report has addressed these issues in more detail already.

The AWG focuses on analysis aspects of the laser range measurements in particular.

CHARTER

The charter of the Analysis Working Group (AWG) can be found on the ILRS web page at:

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

and in summary they are:

- provide internal quality control on data analysis results;
- ensure analysis results compatibility with results obtained using other techniques;
- develop an official and combined ILRS data analysis strategy and analysis product(s);
- provide feedback to the network on performance;
- support ILRS in mission planning; and
- establish and maintain a knowledge base for the analysis community.

One of the most prominent scientific contributions of the laser ranging technique to the global geodetic and geophysical community is a time-series of solutions of Earth Orientation Parameters (EOPs; submitted to the International Earth Rotation Service IERS), and individual station coordinates and velocities (included in the models of the International Terrestrial Reference Frame ITRF).

During the last decade, new geodetic observation techniques (GPS, DORIS, GLONASS, etc.) have come to fruition and have significantly increased the number of individual contributions to

IERS/ITRF. This has necessitated a better coordination and definition of the products, and has encouraged quality improvements for all contributions. Very importantly, the combination of individual contributions is being done, more and more, individually for each technique. As a consequence, each technique is ultimately responsible for its own combination, quality control of the individual contributions and of the end product, and consistency with the results obtained by others techniques.

It is recognized that the great strength of the laser ranging technique is in the definition of scale and the determination of origin of the ITRF. It is thus likely that rapid monthly solutions for station coordinates will be of practical use as contributions to timely multi-technique reference frame determination which will support many geodetic research programs. In addition the computation of high-quality orbits for altimetry and SAR satellites will continue to be important. For all these products, high quality observations and analyses are crucial.

MEMBERS

The AWG currently consists of 16 members (status December 31, 1999) representing a wide variety of laser targets and satellite missions (Moon, LEO and MEO satellites), the large number of geophysical subjects that are being studied, and the worldwide distribution of institutions involved in the analysis of laser ranging data. The full list of members is given in Table 3.4-1.

Name	Institute/Country
Graham Appleby	NERC/United Kingdom
Richard Biancale	GRGS/France
Richard Eanes	CSR/USA
Ramesh Govind	AUSLIG/Australia
Rolf Koenig	GFZ/Germany
Hiroo Kunimori	CRL/Japan
Cinzia Luceri	ASI/Italy
Vladimir Mitrikas	MCC/Russia
Juergen Mueller	IAPG/Germany
Ron Noomen (coord.)	DEOS/Netherlands
Toshi Otsubo	CRL/Japan
Bernd Richter	BKG/Germany
Remko Scharroo	DEOS/Netherlands
Pete Shelus (dept. coord.)	CSR/USA
Tim Springer	AIUB/Switzerland
Mark Torrence	NASA/USA

Table 3.4-1. ILRS AWG members (status December 31, 1999).

ACTIVITIES IN 1999

The year 1999 has been very important for the AWG, since it saw the beginning of the efforts to coordinate the analyses and to come to a set of unified data analysis products. First of all, the membership of the working group was finalized. In the course of the year, e-mail discussions on various issues that face the ILRS in general and the AWG in particular were held, which led to a dedicated Working Group meeting during the Conference on Laser Radar Ranging and

Atmospheric Lidar Techniques in Florence, Italy, in September 1999. About half of the members of the AWG attended this meeting.

Here, a number of topics were discussed, such as analysis standards, products, formats and quality control. As for the use of analysis standards, it was decided to not so much prescribe but rather recommend a certain standard (typically, the IERS 1996 Conventions are most appropriate). In this way, analysts are encouraged to continuously improve their technique, strategy and models, stimulating a certain competition between contributors to see who is best in describing the physical reality of satellite and earth dynamics, whereas the strict prescription of a single standard would not encourage such progress. Analysis products that can be generated with the laser ranging technique are abundant, but it was decided to initiate the coordination and combination efforts with the fundamental products “station positions” (including site motions, observations allowing) and Earth orientation. In the future, other parameters (e.g. geocenter, temporal variations in the gravity field, ephemerides, lunar precession and nutation, etc.) may also be included. The group members present also decided to adopt the internationally well-established SINEX format for exchange of analysis results; in principle this format has all the elements that are necessary for providing full information on positioning and earth orientation solutions, and it is in principle open for new parameters. Finally, the problem of fast-turnaround quality control, in particular at various levels (on-site, analysis center, etc.) was discussed.

Most important, three pilot projects were initiated, each of them with the overall goal to improve the quality of SLR/LLR analysis results. They are:

- a project to unify the results of semi real-time quality control analyses of SLR observations on several satellites;
- a project aimed at the computation of station coordinates; and
- a project aimed at the computation of earth orientation parameters.

Each of these will be described in more detail below.

Pilot project 1: unification of fast-turnaround analysis results

At this moment, six different analysis institutionss analyze SLR measurements on different targets on a routine basis. They are summarized in Table 3.4-2. The frequency of these analyses ranges from daily to weekly. The results are distributed in a rather uncoordinated way, i.e. each analysis center produces in some way or another an analysis report, which is made available to customers (stations, satellite managers) typically without comparison or checking with results obtained by others. This pilot project aims at two things: first, it intends to improve the interpretation of the “quality verdict” in the various analysis results. This can be achieved by interpreting time-series of range and/or time biases, instead of looking at absolute values. Ultimately, all individual analysis results should be merged into a single report, with a unique interpretation of the data problem(s) and the uncertainty of such an assessment. To make a first step, it was agreed that all groups should have their analysis results ready by Wednesday morning of each week.

Institute	Satellite						
	ERS-1	ERS-2	AJISAI	LAGEOS-1	LAGEOS-2	GPS-35	GPS-36
AIUB						+	+
CRL			+	+	+		
CSR				+	+		
DEOS	+	+		+	+		
MCC				+	+		
NERC				+	+		

Table 3.4-2. Overview of fast-turnaround SLR quality control analyses.

Pilot project 2: computation of station positions

The ILRS is tasked to coordinate the SLR/LLR analysis activities, stimulate a high quality of analysis results and develop an official ILRS product. The latter may pertain to various subjects: positioning/reference systems, earth orientation, geocenter, gravity field, tides, ephemerides, lunar precession and nutation, fundamental constants, etc. (cf. ILRS Terms Of Reference at:

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

To make a start with this, two additional pilot projects were defined in Florence (September 1999): one on positioning and another one on Earth orientation, respectively. These pilot projects have a number of goals:

- to test the communication between the various analysis centers and data centers (aspects are transfer of solutions, use of and adherence to a data exchange format, meeting deadlines and adherence to the product definition);
- to stimulate and encourage individual analysis centers to improve the quality of analysis;
- to explain and minimize the discrepancies between different analysis results obtained by individual analysis centers;
- to develop an operational analysis procedure, including official ILRS products with maximum quality and meeting time constraints; and
- to promote the laser technique in general.

Since the initial goal was not so much absolute quality but more communication, formats and relative consistency, it was decided to limit the pilot project to a relatively small dataset of SLR observations: LAGEOS-1 data for a period of 28 days (i.e. September 5 until October 2, 1999, inclusive). To stimulate intellectual freedom of the analysts and prevent a mere repetition of each other's computations, no analysis standard was prescribed; people were encouraged to use the well-known IERS 1996 Conventions as a starting point. For a proper definition of parameters, it was decided to model the station motions according to the ITRF97 solution (and keep them fixed), and use the ITRF97 positions as *a priori* positions for the (solved-for) station coordinates. Finally, it was recognized that the LLR component could contribute to this pilot project only marginally, at least at this stage, so it was decided to focus on SLR first.

Pilot project 3: computation of earth orientation parameters

The third pilot project which was defined in Florence is on the computation of Earth orientation parameters, one of the traditional products of the laser ranging community. This project is very similar to the previous one on station positioning, in the sense that the goals, the proposed procedure and the test dataset are all more or less the same. This project, in particular, aimed at providing a (short) time-series of solutions for

1. the position of the pole as expressed in x and y coordinates,
2. the rotation of the earth as expressed by the UT1-UTC time difference. These parameters were to be provided at 3-day intervals. For more information, the reader is referred to the description of the project on station positioning.

Pilot projects "positioning" and "earth orientation:" results

The projects officially started directly after the Third General Assembly in Florence. The first activity was the preparation of a clear dataset of SLR observations to be used by all analysis centers. This dataset was available as of October 12 and was not screened for single outliers or bad passes, to reflect a semi real-time, operational situation as well as possible.

During the remainder of October and November, the Analysis Centers processed the measurements and submitted network solutions to the central archiving facility at NASA's Crustal Dynamics Data Information System (CDDIS). These first results highlighted quite a number of mainly format-related problems with the individual solutions, necessitating a second round of analysis for almost all contributions. During the final weeks of December and the first weeks of January 2000, the results were compared and/or combined by several institutes.

The results have been presented and discussed at an AWG workshop which was held in Frankfurt, on January 17-19, 2000. Although strictly beyond the time-span of this annual report, the results will be described here briefly.

Twelve analysis groups submitted solutions for the overall network of SLR stations, whereas 6 groups contributed to the comparison/combination. The specific contributors are listed in Table 3.4-3. NCL was not directly involved in the analysis of the pilot-study SLR measurements, but did make a significant contribution to the testing and comparison/combination of the solutions provided by others. As an example, Figure 3.4-1 shows the differences of a number of the submissions w.r.t. the ITRF97 solution, and also w.r.t. a weighted average. The results shown here have been computed by GRGS [*Altamimi,* 2000]; other analyses revealed similar results.

Institute	Station Positioning		Earth Orientation	
	Solution	*Comparison*	*Solution*	*Comparison*
ASI	Yes	Yes	Yes	Yes
AUSLIG	Yes	No	Yes	No
BKG	Yes	No	Yes	No
CRL	Yes	No	Yes	No
DGFI	Yes	Yes	Yes	No
GRGS	Yes	Yes	Yes	Yes
GSFC	Yes	Yes	Yes	No
IAA	Yes	Yes	Yes	No
IMVP	Yes	No	Yes	No
JCET	Yes	No	Yes	No
MCC	Yes	No	Yes	No
NCL	No	Yes	No	No
NERC	Yes	No	Yes	No

Table 3.4-3. Contributors to the ILRS pilot projects.

During the workshop, a number of problems were identified and discussed intensively. First of all, the definition and adherence to the SINEX format appeared not 100% clear to all groups involved. The discussion ended with a consensus on which elements to use and which not; the result is almost fully equivalent with the official description, but is more stringent on a small number of blocks: the FILE/COMMENT block is recommended (originally: optional), and the FILE/REFERENCE, SITE/ECCENTRICITY and SOLUTION/STATISTICS blocks are mandatory (original: mandatory for IGS only [2x] and optional).

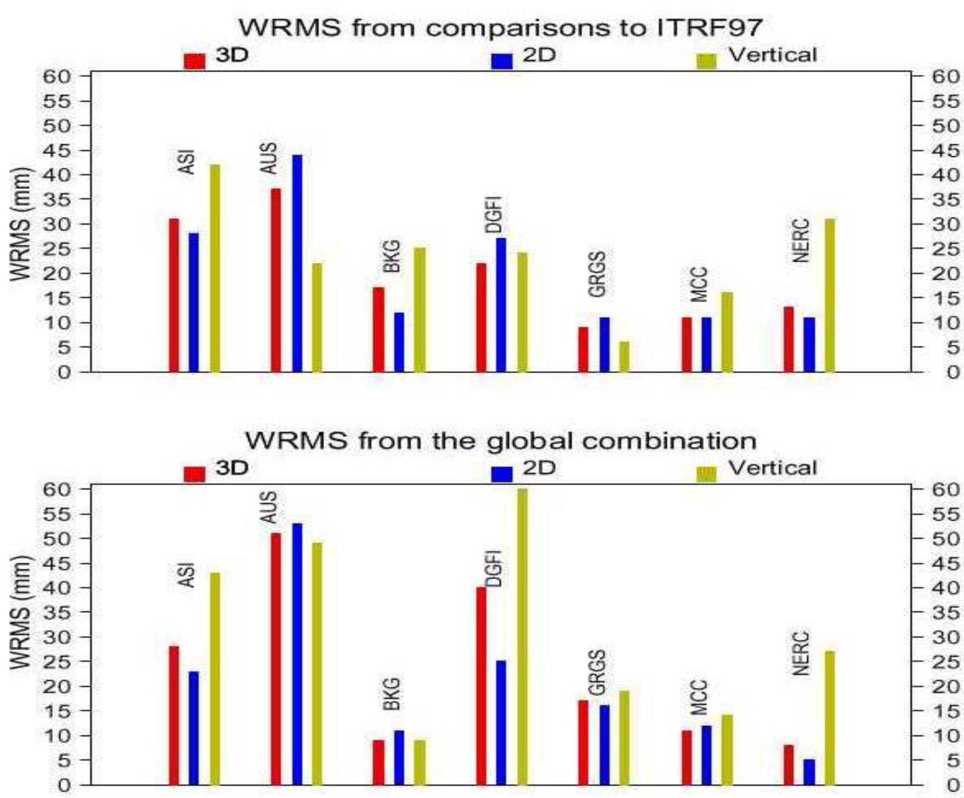

Figure 3.4-1. Comparison of initial results of the pilot projects on station positioning (Altamimi, 2000).

Another problem appeared to be the constraining of the individual network solutions: some of the solutions were overconstrained, providing various problems in the comparisons and combinations. It was decided to provide as little constraints as possible in future solutions, i.e. at least 1 m (10 m) for good (bad) stations and the equivalent of at least 1 m for polar motion and earth rotation.

Also, the definition of solve-for parameters turned out to cause some problems. Here the conclusion already achieved in Florence was emphasized once again: position solutions should refer to the official SLR reference point (i.e. the SLR marker) wherever possible, i.e. in situations for which an eccentricity vector is available the latter should be subtracted. In other cases the optical center of the telescope is the reference point for the solution. All solutions must be accompanied by the DOMES number to uniquely specify the location. In addition, it was decided to refer position solutions for both Zimmerwald and San Fernando (2 stations that have received new instrumentation recently) to the new telescope, at least when computed with observations from these new instruments.

In addition, the parameter to represent Earth rotation was discussed. In Florence, it was decided to use the UT1-UTC time difference for this purpose (in line with the demands for SLR submissions to IERS), although the length of day (LOD) may serve as an alternative. After lengthy debate, it was agreed to continue to use the UT1-UTC parameter, but on the understanding that satellite-based techniques cannot of course determine the true inertial UT1-UTC.

Finally, a proposal for the submission procedure (including testing and a naming convention) was discussed; this will be further developed during the coming months.

Most importantly, it was decided to continue the pilot project on harmonizing the quality control issues, and to combine the projects on station positioning and Earth orientation. To better define and assess the quality of the Earth orientation products, it was decided to repeat the analyses and solve for two time-series of EOPs, at 2-day and 3-day intervals respectively. As a consequence, the data period was extended from 28 days to 30 days.

In addition, 2 new pilot projects were proposed: one on satellite orbits (LAGEOS-1 initially), and another one on software benchmarking. These extensions are further discussed in the next section.

OUTLOOK FOR 2000 AND BEYOND

During the year 2000, the AWG will further develop the pilot project on station positioning and Earth orientation. In particular, it will first of all execute the conclusions and agreements from the workshop in Frankfurt and verify that these are implemented properly. This is expected to be finished in the middle of the year. In all likelihood, this will be followed up by the computation, using at least both LAGEOS satellites, of a relatively short (1 year) time-series of station positions and Earth orientation parameters, the consistency and quality of which will be assessed thoroughly. This will probably take place during the 2nd half of 2000, and is expected to result in an official ILRS product set. The AWG hopes to be in an operational scheme for product delivery as of January 1, 2001.

In addition, two new activities were initiated in Frankfurt:

1. A pilot project on the comparison/combination of satellite orbit solutions. This will be instrumental in improving and understanding the quality of the individual orbit solutions, where each analysis institute (again) is free to adopt its own preferred computation model, and also will stimulate improvement in the quality of solutions. Also, it will clearly show the capabilities and limitations of the most important element of this type of space geodetic work: the description of the orbit of the satellite. This project is likely to start in February, and results are expected in the middle of the year.
2. Benchmarking the software packages that are in use at the various analysis centers to try to reproduce results (orbits, parameters) that are obtained at different institutes, and strive for 100% agreement. Clearly, the participants will be obliged to adhere to a well-defined analysis standard. The overall intention of this project is to make sure that the various software packages that are in use at different analysis groups are free of errors; in addition, it will stimulate a better understanding of these programs. This pilot project is not expected to start until May of this year.

The results of these analyses and comparison/combination activities are likely to be reported and discussed during a number of informal meetings which will take place during 2000.

Finally, and very important for the community, the AWG strives for a better inclusion of the LLR component. This application of the laser technique is also capable of delivering solutions of the fundamental products, and it is the intention that these results will also be included in the ILRS comparison and combination efforts.

REFERENCES:

Altamimi, Z., “Analysis of station positions of the individual contributions within the ILRS pilot projects”, paper presented at the ILRS AWG workshop, Frankfurt, Germany, January 17-19, 2000.

3.5 SIGNAL PROCESSING WORKING GROUP

Graham Appleby, *NERC Space Geodesy Facility*

CHARTER

The following Charter was created for the Signal Process Working Group (SPWG) by the ILRS Governing Board at The Hague ILRS Meeting of April 1999.

To determine accurate laser range Center-of-Mass corrections for a variety of satellites, appropriate to the major observing configurations.

In particular, to examine the corrections necessary to transform from raw range measurements to the center-of-mass of each satellite target, having regard to:

- array transfer function
- pulse-width and signal strength
- receiver characteristics (single photon, multi-photon, etc.)

To determine optimum processing strategies for each case.

- location measure in forming normal points (mean, mode, LEHM, something else)
- role of skewness and kurtosis measures
- filtering and trend-removal procedures

To propose procedures for recording and reporting the data required and used in determining and applying the corrections.

- data base used by Operational, Data and Analysis Centers
- station Information data base
- explicit data needed in ILRS NP and FR files
- format changes as appropriate

MEMBERSHIP

The following ILRS members are formally serving on the Working Group, but other members have contributed to the work being carried out:

Andrew Sinclair	Christopher Moore	Georg Kirchner
John Luck	Leigh Dahl	Mike Selden
Peter Dunn	Reinhart Neubert	Stefan Riepl
Thomas Zagwodski	Toshimichi Otsubo	Ulrich Schreiber

INTRODUCTION

The ILRS tracking network consists principally of three types of observing systems:

1. Systems employing multi-channel plate detectors (MCPs) and large numbers of return photons,
2. Systems employing single photon detectors (principally SPADs) and working close-to single-photon levels of return, and
3. Systems using SPADs but working at greater than single photon return levels. Modern SPADs employ a compensation circuit which can be tuned to the laser pulse-length [*Kirchner et al.,* 1996], and thus minimize energy-dependent time-walk effects.

Most of the systems in the network continue to produce high-precision laser range measurements, but this very diversity amongst the systems means that to realize the full potential accuracy in the measurements they have to be processed in a way commensurate with the differing observing characteristics. In particular it has been known for some time that the center of mass correction (CoM) to be applied to range measurements varies according to the type of system making the measurement [*Otsubo et al.,* 1999; *Sinclair et al.,* 1995]. For example, results to date suggest that measurements to the principal geodetic satellite LAGEOS made by a system working at single-photon return levels are on average some 10mm *long* on the same measurements made by an MCP system working at high return levels. If this effect is not taken into account when the data are analyzed, such a 'range bias' will be absorbed partly into station height determination, the quality of which will thus be degraded. For determination of scale, for which the SLR technique is particularly suited, such system-dependent differences will necessarily impact on the accuracy of a solution for GM for example. Advances in understanding these phenomena have been made over a number of years, most notably under the guidance of Andrew Sinclair within the EUROLAS network. This ILRS Working Group will build on that understanding.

During this first year, the strategy has been to understand the observing practices of some of the major systems in order to model those processes and derive appropriate CoM corrections. This has been carried out by involving them in the procedure and by analyzing full-rate satellite and calibration range data and statistical measures of system stability. At an early stage the Group agreed that the aim is not necessarily to recommend changes to current processing practices, as this could potentially create a discontinuity relative to older data sets from a given system.

SUMMARY OF WORK CARRIED OUT TO DATE

The Group has built on previous work in order to develop and test models to derive CoM corrections appropriate to various observing systems for a number of satellite arrays. In particular, the following have been considered:

- CoM corrections for LAGEOS and AJISAI for single-photon detector systems;
- Return energy effects for single-photon detectors;
- Data clipping effects;
- Statistics to monitor system stability;

- Planar array effects (e.g. GLONASS);
- TOPEX/POSEIDON array model.

Full details of these studies and results to date are presented by the originators on a web-site at:

http://nercslr.nmt.ac.uk/sig/signature.html

which is also linked-to in the Working Groups section of the official ILRS web-site. As an example of some of this work we present here in more detail some results of determinations of system-dependent center-of-mass (CoM) corrections for LAGEOS.

PRINCIPLES

To outline the principles of the ongoing work to derive tracking-system-dependent CoM corrections for the current constellation of laser-tracked satellites, we discuss the work being carried out for the primary geodetic satellite LAGEOS, and specifically for systems employing single-photon detectors. Our baseline assumption is that the pre-launch ground tests carried out for NASA on LAGEOS-2 are applicable only to systems using multi-photon detectors such as MCPs. The CoM correction determined from these tests was 251mm, the value currently in use by the analysis community to process range observations from the entire network.

We can begin to model the laser ranging process by convolving a (Gaussian) representation of the energy distribution of the laser pulse with an impulse function for the satellite reflector array (LRA). Previously both Degnan and Neubert have derived analytical impulse functions applicable to the spherical laser satellites and which give relative reflectivity as a function of distance from the surface of LAGEOS. We use here the impulse function of *Neubert* [1996]. The resulting distribution represents the probability density function (pdf) of the returning pulse from the satellite. We can then statistically sample from this pdf, modelling both the efficiency of the detector and the return energy (single or multi-photon), and further convolve with a model of the detector and timing system response. In practice, we use the range-distribution of measurements to a system's calibration target to represent the whole-system response to a flat target. The mean value of this response, computed according to the station's standard practice, is the system's origin. About this origin we then convolve the system response with the satellite impulse, obtaining a model of the expected distribution of range measurements obtained at single-photon return levels, as a function of distance from the surface of LAGEOS. If we now process this model to obtain the mean value, using the same rejection criteria as employed at the station when forming normal points, we obtain an estimate of the mean value of the CoM correction appropriate to that system.

This analysis has been carried out for two systems employing compensated SPADS, namely Herstmonceux, UK, and Koganei, Japan which use similar observing strategies. Herstmonceux works strictly at a single-photon level of return for all satellites, while Koganei attempts to keep the return rate reasonably low. The results of the analysis suggest that for the Herstmonceux system a CoM correction of 240 mm is appropriate, while for Koganei a value of 246 mm is indicated. Uncertainties in these values are estimated to be at a level of about ± 2 mm.

The distributions of range residuals in histogram form and our empirical models are shown in Figure 3.5-1. The long 'tail' in the model distributions is characteristic of the SPAD response.

Apparent in the distributions of range residuals are the different clipping levels employed by the systems which cause the truncation in the data with respect to the models.

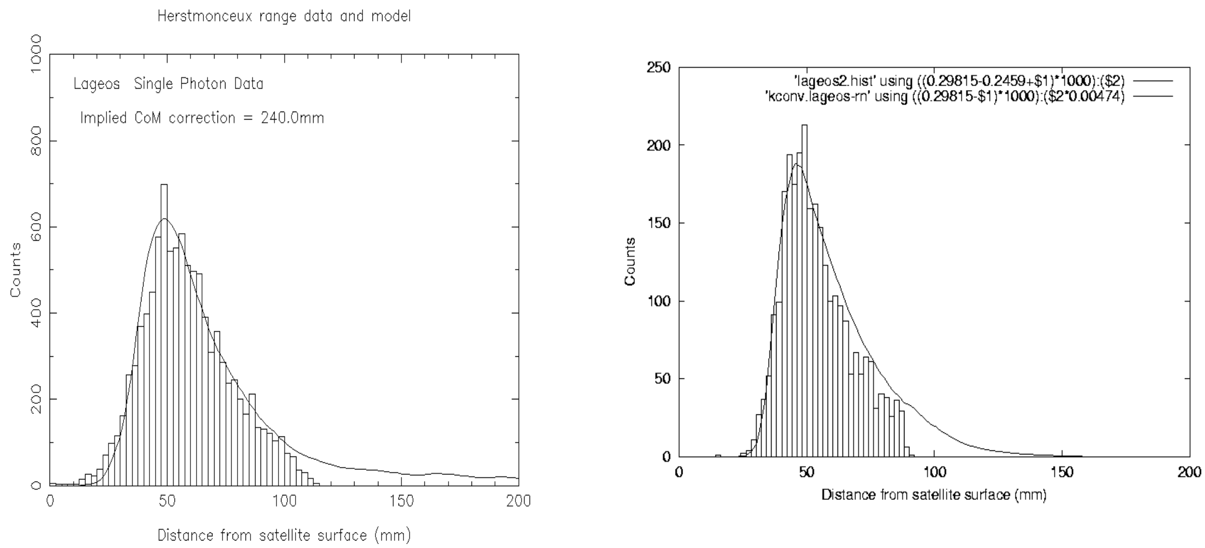

Figure 3.5-1. Comparison of data distribution with single-photon empirical model.

The same analysis has been carried out using calibration and LAGEOS range data from Graz, Austria. The system employs a compensated SPAD detector working at a multi-photon level of return, and employs a tighter clipping level than the other two stations. The result, as shown in Figure 3.5-2, is a more symmetrical distribution of range residuals, and as expected a poorer agreement of the single-photon model. More work is required to model properly this scenario, which suggests that a higher CoM value is appropriate.

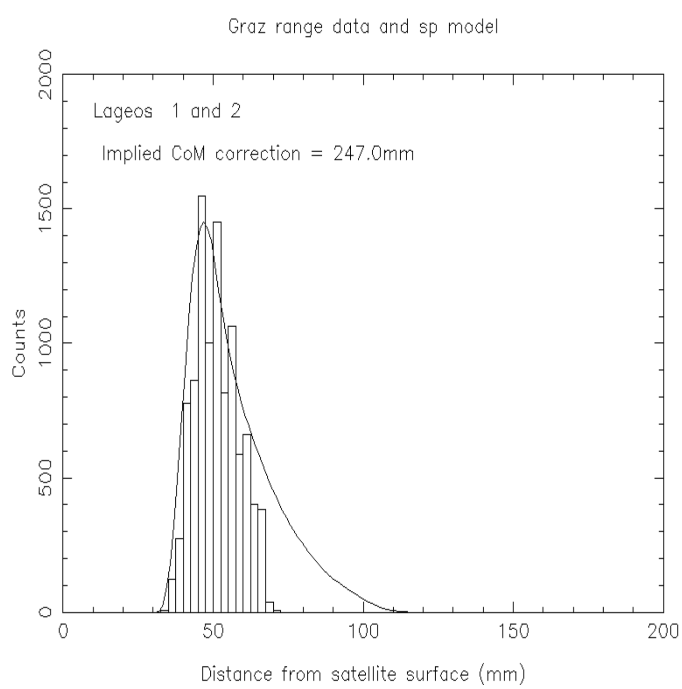

Figure 3.5-2. Comparison of Graz data distribution with single-photon empirical model.

PRESENTATION OF RESULTS.

Much of the work carried out by members of the Working Group was presented during the Colloquium on SLR-System Calibration Issues held in conjunction with the EOS/SPIE Symposium on Remote Sensing in Florence on September 20-24 1999. The following presentations were made:

- *Mark Torrence:* GM determination from multi-satellite analysis, and subsequent CoM deductions;
- *Graham Appleby:* Single photon model for LAGEOS;
- *Reinhart Neubert:* Data clipping and return energy effects + a model for the T/P array;
- *Toshimichi Otsubo:* AJISAI and GLONASS array functions and systematic effects;
- *Van Husson:* Signatures in GLONASS range data;
- *Francois Barlier:* Signatures in GLONASS range data;
- *Andrew Sinclair: (written report)* Statistics to measure systems' stability;
- *Pippo Bianco:* Probable observational evidence of LAGEOS rotation by MLRO observations;
- *Stefan Riepl:* Turbulence effects in SLR data.

Several of the presentations related to the signature effects of the large, planar arrays on the GLONASS spacecraft. Both Husson and Barlier presented observational evidence of systematic 'bias-type' effects in range residuals which increase as a function of satellite elevation. Otsubo presented a novel explanation for the observed effects, pointing out that SLR systems that work at high return levels will tend to measure from the edge of the array, whilst those working at low return levels will obtain reflections from all parts of the visible array. The systematic difference in the range measurements from these two types of system can amount to a relative 'bias' of up to 15cm, this mechanism possibly explaining the reported radial offset between laser range measurements and microwave-based orbits for the GLONASS satellites.

The last two presentations related to interesting spin-off applications from studies of satellite signature effects. The results presented by Bianco on work carried out with R. Devoti, V. Luceri and M. Seldon were obtained from analyses of range residuals from LAGEOS-2. The detection of signature-induced modulation of the residuals was used to infer a rotation rate of the satellite of about 11 seconds. This technique has been successfully employed by *Otsubo et al.* [2000] in the determination of a time-series of rotation rate values for the Japanese geodetic satellite AJISAI.

Riepl investigated the presence of range residuals 'ahead' of the modelled leading edge, which are evident in Figure 3.5-1 and more clearly seen in the corresponding results from AJISAI investigations. This slight misfit can be explained by scintillations in the received signal strength induced by atmospheric turbulence. Due to signal-strength statistics we cannot exclude the possibility that a SPAD-detector, operated on average at say 10% return rate, is detecting a few returns up to the level of 100 photons. Modelling this effect in conjunction with a time walk model for the SPAD we find that the maximum peak shift of the resulting signature for AJISAI is about 1cm.

RECOMMENDATIONS

From discussions during the colloquium we make the following recommendations to other ILRS Working Groups:

- For some current satellites (including GLONASS, ETALON, Starlette), this Working Group needs better information on array characteristics and configuration (to Missions W/G);
- For all future missions, this Working Group must have access to pre-launch detailed information on composition and 3-D configuration of elements of the LRA. (to Missions W/G);
- That each Site/System Log File include 'standard practice' information (detector, return energy, data clipping) (to Networks and Engineering W/G)

FUTURE WORK

Detailed information on the location and characteristics of the elements of the GLONASS and ETALON LRA has been provided by the Russian Space Agency, thanks to the efforts of H. Kunimori on behalf of the Missions Working Group. This will enable more precise modelling work for these two classes of satellites.

Impulse functions for most of the spherical satellites will be computed by Neubert and Otsubo.

Models will be developed for multi-photon systems (MCP and SPAD).

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