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## SCIENCE PRODUCTS SESSION SUMMARY

Chairs: Steven Klosko and Gerhard Beutler

The 15th International Laser Ranging Workshop held in Canberra, Australia in October 2006 provided an overview of the state of SLR technologies, campaign activities, and science products. The Science Products Sessions began the meeting and consisted of 16 papers. These presentations demonstrated that satellite laser ranging continues to provide an important resource for satellite orbit determination, verification and validation of active remote sensing systems, and for producing science products that are needed to support a wide range of space geodesy and geodynamic investigations.

A theme of the meeting was the continued contribution of SLR to the progress being made in studying the Earth's system in four dimensions. At the same time, the SLR techniques are being used to both directly provide precision orbits and calibrate precise orbit positioning provided by other tracking systems. And by being a dynamic as opposed to reduced dynamic technique, SLR investigators have contributed significant insight into the intricate force modeling needed to produce cm-level orbit accuracy. All of these topics were discussed during the Science Products Session of the Workshop.

The first set of presentations of the session focused on the orbit determination capabilities of SLR. While GPS analyses benefit from continuous 3-D tracking, which allows "reduced" dynamic orbital techniques, SLR satellites are only observed and directly tracked for a small percentage of the time. Thereby precision orbit determination for SLR requires a high level of sophisticated conservative and non-conservative force modeling.

R. Noomen (1) gave a presentation demonstrating the state of the art in modeling the thermal imbalance and radiative forces acting on the LAGEOS 1 and 2 satellites. These satellites, given their specific design and highly stable orbits, provide an excellent laboratory to study very subtle thermal and drag-like effects acting on these orbits. The thermal perturbations acting on these satellites evolve over time as the satellite spin rate slows and the satellite experiences larger levels of thermal imbalance. R. Noomen presented results obtained at the Delft Technical University of the detailed modeling they have undertaken for the pair of LAGEOS satellites to determine the spin orientation and spin rates for the LAGEOS satellites. In the analysis they account for the complete regime of the spin behavior of the LAGEOS satellites as well as a complete description of the satellites' material composition. This has allowed them to greatly improve the orbit accuracy and fit to the SLR data while reducing the need for empirical correction parameters. SLR provides important and in many cases key independent validation capabilities for a variety of orbit applications. Herein, SLR is complementing GPS and measurements being acquired by these missions to validate orbit accuracy, detect manoeuvres, and provide a back up, fail safe orbit determination capability. Papers given by Urschl (2,5), Govind (4), and Deleflie (3) focused on SLR orbit determination applications that are being applied to study the orbits of GPS-35 and GIOVE-A.

Dedicated SLR satellite missions continue to provide unique long wavelength gravity and decadal time histories of site motions to help establish the geophysical context for many phenomena, a robust reference frame to report these changes within, and place constraints on the geophysical models themselves. Kurt Lambeck (6) gave a paper on the status and future plans for the geodetic network and geospatial modeling framework

within Australia. Australia is moving towards a highly integrated GPS, VLBI, and SLR geodetic reference and geophysical monitoring system. Currently there are two widely e-w separated SLR stations (Yarragadee and Mt Stromlo). Kurt discussed the possibility of deploying a third station in the north central part of the country co-located with VLBI near Katherine.

Contributions are coming from SLR to monitor and better understand long wavelength changes in the Earth's gravity field. Mass flux within the Earth's system over large spatial scales can be observed through the orbit changes they induce on well tracked SLR satellites. The return of the Earth to isostatic equilibrium since the time of the most recent Ice Age is a major source of nearly secular long wavelength gravity field changes. To understand the glacial mass flux apart from the total mass flux dominant over high latitude regions, detailed understanding of the Glacial Isostatic Adjustment (GIA) processes are needed. Dick Peltier of the University of Toronto gave a paper on recent refinements he has instituted to improve GIA modeling (7). Frank Lemoine (8) gave a talk on the long time history of gravity changes obtained from SLR for the longest wavelengths in the field and how they relate to GRACE. To understand contemporary ice sheet mass balance and its contribution to sea level rise, both the high latitude gravity changes and their decoupling from GIA processes are needed.

As knowledge of the long wavelength gravity field has improved, especially with advances coming from the GRACE Mission, further improvements have been made in deriving a constraint on the Lens Thirring effect. Erricos Pavlis (9) of the University of Maryland gave a paper on an improved estimate of the Lens Thirring term. This team has measured the value of this term to approximately 1% of its expected value as predicted by General Relativity. The experiment reported by Ciufolini and Pavlis was based on the long term behavior of the argument of the ascending node of the LAGEOS 1 and 2 satellites. The Lens Thirring predicted "frame-dragging" is seen as an unmodeled node signal for the LAGEOS pair. By evaluating more than eleven years of these data, these authors were able to isolate Lens Thirring from zonal gravity field error sources.

There were a set of papers focused on the reference frame, SLR contributions to the International Terrestrial Reference Frame (ITRF) and www-based tools for comparing time series from different experiments and technologies. D. Delefilie (10) of GRGS gave a presentation on a www-based tool for comparing geodetic times series. D. Coulot (11) of IGN presented a paper on different approaches to accommodate the "least squares mean effect", that is, the effect in a least squares environment of the variation of solved for parameters when a model is imposed on their behavior. H. Mueller of GFZ gave two papers (12 and 16). In the first, he discussed various experiments ongoing to compare SLR solutions using different processes and these results to VLBI and GPS. In the 2nd paper, the authors evaluated the contribution of SLR to the ITRF and presented a comparison of SLR solutions being produced at GFZ with those of IGN. Of high interest in this paper, in contrast to results described below, the GFZ Group is not seeing a scale difference from 2001 onward with their SLR solution and VLBI.

A contrasting paper was given by Z. Altamimi (15) of IGN on the construction and results he derived in computing the ITRF 2005 solution. Therein, this author found a greater than 1 ppb scale difference between SLR and VLBI, and this scale difference seemingly got progressively larger from 2001 onward. Zuheir went into considerable

detail about the use of local survey ties to bring SLR, GPS, and VLBI into a common frame.

The contrast between the IGN and GFZ results with regard to SLR scale, and the decision to use the scale provided by VLBI in the final ITRF 2005 realization caused a great deal of discussion, splinter groups, and involvement of the Analysis Centers in an attempt to better understand, resolve, and develop a strategy for utilizing the ITRF in future SLR analyses.

Also given during this portion of the session were papers by R. Govind (13) who discussed geocenter solutions he has obtained from SLR. This was followed by a paper by D. Gambis (14) of GRGS who presented results for the determination of EOP and Earth rotation using both SLR and LLR and the changing balance of contributions from all technologies over time in the combination solutions produced by IERS.

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