Combination of High Precision Space Geodetic Techniques

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Abstract

Global and Regional GPS, SLR and DORIS computations are routinely being undertaken at AUSLIG. Current activity is to develop a computation and analysis system that combines all space geodetic techniques (including VLBI) to produce single consistent solutions as part of routine operations; contributing to the ITRF. The current analysis of GPS, SLR and DORIS data and their subsequent combination (with VLBI as well) is discussed; and results from processed/combined data sets are presented.

1. Introduction

The importance of individual space geodetic observing systems has traditionally been based on the determination of some unique product. The emerging importance of the co-location and combination of space geodetic techniques for geodesy and geodynamics is a consequence of the capability of the individual techniques to also provide high quality common products. The benefits of co-location and combination are:

- High precision geodetic products are determined in a single consistent solution.
- The opportunity to calibrate space geodetic observing systems with respect to each other; deciphering between technique specific observation errors and geodynamic signals.

Global and Regional GPS, SLR and DORIS computations are routinely being undertaken at AUSLIG. Current activity is to develop a computation and analysis system that combines all space geodetic techniques (including VLBI) to produce single consistent solutions as part of routine operations; contributing to the ITRF. The implementation of the combination of space geodetic techniques (SLR, GPS, DORIS and VLBI) was initiated as part of the computations of the Asia Pacific Regional Geodetic Network and is reported in (AUSLIG, 1998 and Govind et. al. 1998).

GPS and SLR (Lageos-1 and Lageos-2) data spanning a period of four months was processed using the appropriate models for the observables, orbit determination, station position modelling and parameterisation in the estimation process for satellite orbits, station coordinates, earth orientation parameters and measurement biases. Subsequently, the normal equations generated from the individual daily GPS solutions and the individual monthly solutions for Lageos-1 and Lageos-2 were combined using local terrestrial tie information at ten co-located sites. It is recognised that, in the combination process, a relative weighting scheme has to be developed for the various space geodetic techniques.

The quality of the individual GPS and SLR solutions are presented in terms of the data fit, differences between the estimated satellite orbits and those of the IGS combined product (for GPS), the daily and weekly repeatability of the estimated station coordinates (monthly for SLR), a comparison with the ITRF96 set of station coordinates (SSC) and the set of transformation parameters between the estimated station coordinates and the ITRF96 SSC.

Future work is aimed at continuing to add the DORIS data for this period and all future combination/co-location solutions. The capability to include VLBI solutions into the combination process by reading the SINEX files and transforming them into normal equation files for input into SOLVE (Ullman, 1992) has already been developed and will be incorporated at the next opportunity. A weighting regime is currently being investigated and developed.

2. SLR and GPS Data

Four months of data for July to October 1998 for Lageos-1 and Lageos-2 was processed. The global distribution of the SLR stations used in the computations is shown in figure 2.1. Over the same period, one week of GPS data per month was processed. The global distribution of the GPS stations used in the computations is shown in figure 2.2. The distribution of the co-located GPS and SLR stations used in the computations are shown in figure 2.3. Table 2.1 shows the number of days of GPS data processed.

Table 2.1 Number of GPS solutions computed

Month	# 24 hour arcs processed in a GPS week.
July 1998	7
August 1998	4
September 1998	5
October 1998	6

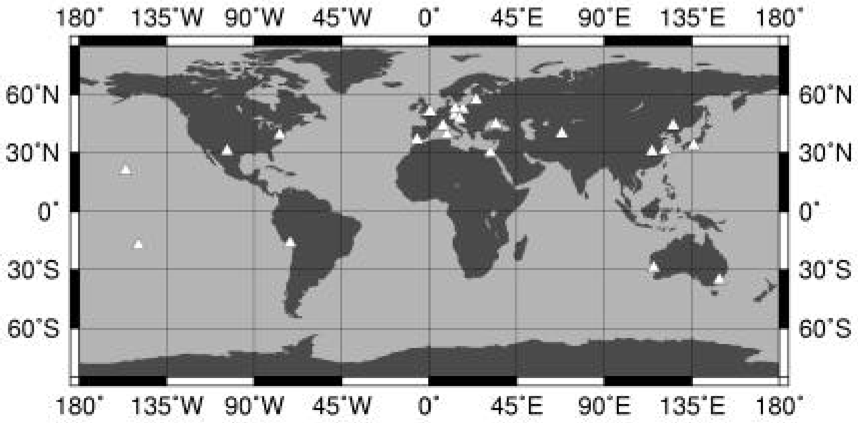

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Fig. 2.1 SLR stations used in AUSLIG processing; Maidanak, Simeiz, Riga, Katsively, McDonald, Yaragadee, Greenbelt, Tahiti, Maui, Wuhan, Changchun, Arequipa, Cagliari, Tigo, Borowiec, Sanf, Helwan, Grasse, Potsdam, Shanghai, Simosato, Graz, RGO, Orroral and Stromlo.

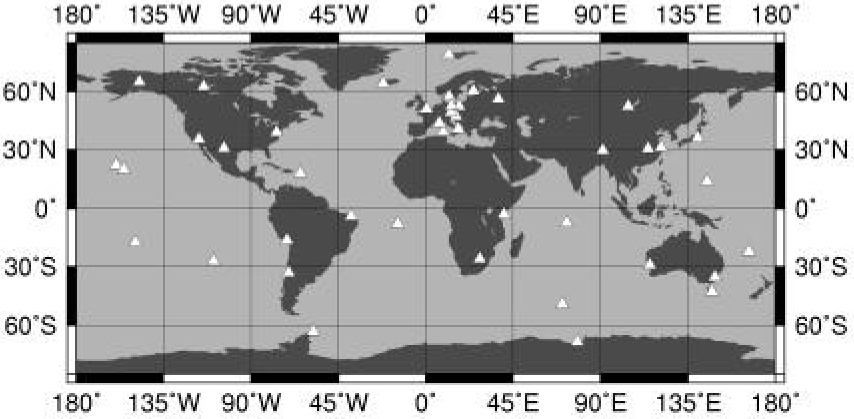

Fig. 2.2 GPS (IGS) stations used in AUSLIG processing; gold, yell, fair, kokb, guam, mkea, gode, mdo1, cro1, tidb, hob2, yar1, noum, mate, nyal, irkt, graz, hers, wtzr, onsa, sant, areq, eisl, fort, thti, asc1, hark, dgar, mali, hrao, shao, wuhn, lhas, tskb, ohig, dav1, kerg, mets, mdvo, bor1, cagl, gras, pots and reyk.

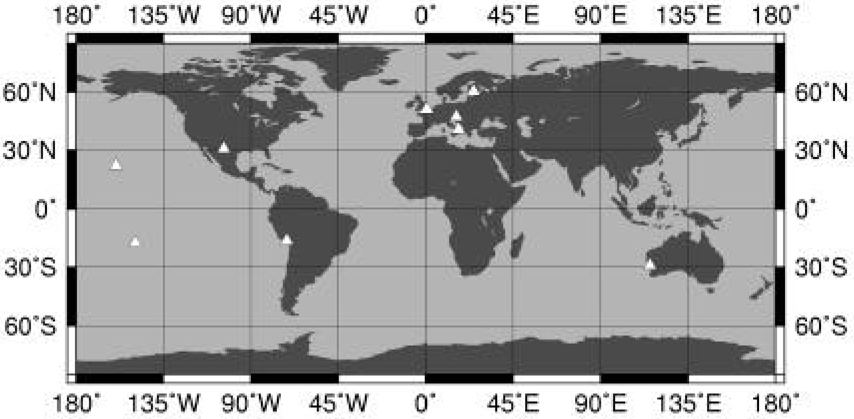

Fig 2.3 Terrestrial survey tie information, between GPS and SLR stations, used in AUSLIG processing; kokb, mdo1, yar1, mets, mate, graz, hers, areq and thti.

3. Computation Standards and Procedure

All individual GPS and SLR solutions and their normal equation matrices are computed using the MicroCosm (Martin, 1998) orbit determination and geodetic parameter estimation software. This suite of programs is a full implementation of IERS96 Conventions (McCarthy, 1996) for observable modelling, orbit modelling, stations position modelling and reference frames.. Figures 3.1 shows the combination process, that is, the inputs of the individual MicroCosm generated normal equations into the combination software SOLVE (Ullman, 1992).

Normal equation combination or stacking process was undertaken using the SOLVE (Ullman, 1992) software. Terrestrial tie vectors were applied by constraining groups of parameters together, adjusting particular parameters groups as a single parameter. The combination process proceeded by first combining the Lageos-1 and Lageos-2 SLR monthly and the weekly GPS solutions into individual single technique solutions. Each monthly SLR solution was then complimented with the corresponding weekly combined weekly GPS solution. Terrestrial ties were added as a final computation stage. The combined solution was constrained to ITRF96 coordinates, velocities and sigmas.

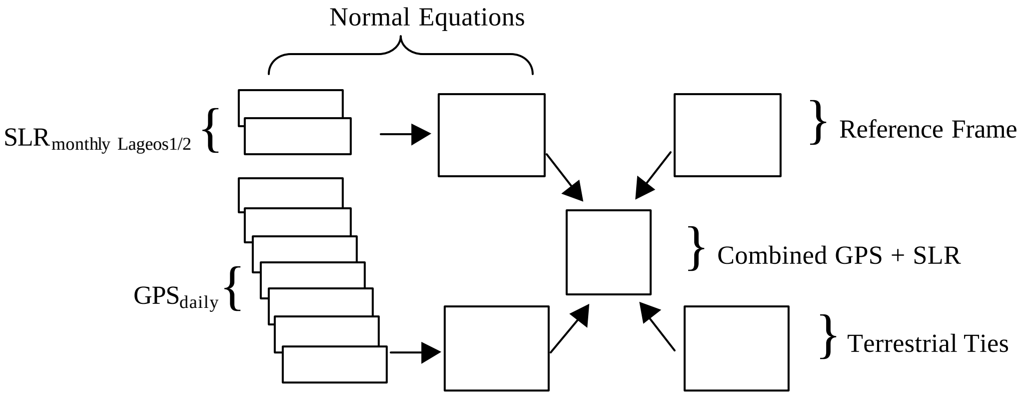

Fig. 3.1 Normal equation combination process.

The local site ties between the GPS and the SLR and between the SLR monuments and the SLR reference point are obtained from the IERS, CDDIS and IGS. For this campaign there are 10 co-located GPS and SLR stations.

4. Results and Analysis

4.1 SLR

For the individual one-month arcs for Lageos-1 and Lageos-2 the RMS of the post-fit residuals ranged between 5 and 7 mm. The weighted RMS of the post-fit residuals a one month arc of Lageos-2 data was 3.9 mm. (572 accepted normal points) and 3.5 mm. (227 accepted normal points) for Yaragadee and Stromlo respectively. This demonstrates the high quality of the solutions which are typically achieved. The CSRL096 reference frame was used for the initial data processing and normal equation generation for the individual satellites. A set of transformation parameters was determined with respect to ITRF96 at the combination stage. For the individual Lageos-1 and Lageos-2 solutions the scale and rotation components were typically at the -0.2 ppb and -0.2 mas respectively. The translation components ranged from the sub-centimetre to 2 cm. level. The 3-D RMS of the fit for the station coordinates ranged from 9 to 13 mm for each monthly combined Lageos-1 and Lageos-2 solution. That is, the combined Lageos-1 and Lageos-2 solutions are accurate to the ITRF96 at this level. The month to month repeatabilty for the station coordinates was at the 15 mm. level. Haleakala (7210), Changchun(7237) and Cagliari(7548) were excluded (outliers) from the determination of the transformation parameters. The Cagliari data was significantly downweighted. However, at the data processing stage the RMS of the post-fit residuals for Haleakala and Changchun were typically at the 4 mm. and 8 mm. level for the individual Lageos-1 and Lageos-2 solutions. Also, the month to month repeatability for the station coordinates in the east, north and up components are 11, 13 and 8 mm. and 8, 6 and 6 mm. for Halekala and Changchun respectively. This is being further investigated interms of the ITRF96 SSC and the local site ties.

4.2 GPS

Solutions were held tightly constained to ITRF96, 26 of the IGS recommended fiducial stations of the GPS stations were held as fixed in initial computations. The RMS of the post-fit residuals ranged between 9 mm and 11mm. Comparison between the trajectories of the AUSLIG determined orbits against the IGS combined orbit product indicated a RMS difference, over all satellites, at the level of 7-10 cm radially and 15-25 cm along and cross-track. Comparison between the AUSLIG weekly computed stations coordinates and the final weekly MIT global polyhedral combined solution indicated RMS differences of 9-14 mm. These are shown in table 4.1. Seven parameter transformations between the weekly MIT SSC and AUSLIG SSC are shown in Table 4.2.

Table 4.1 RMS differences; weekly MIT SSC and weekly AUSLIG SSC

GPS Week	RMS (mm)
965	9.8
969	10.6
973	14.2
978	14.8

Table 4.2 Seven parameter transformation parameters; weekly MIT SSC onto weekly AUSLIG SSC

GPS Week	T1 (cm)	T2 (cm)	T3 (cm)	R1 (mas)	R2 (mas)	R3 (mas)	Scale (ppb)
965	-0.24	-0.04	-0.17	-0.07	0.06	0.06	-1.27
969	-0.12	-0.67	0.02	-0.10	0.04	-0.04	-0.81
973	0.37	-0.61	0.33	-0.08	-0.03	-0.16	-1.34
978	0.09	-0.52	0.24	-0.08	-0.11	-0.10	-0.60

A repeatability of 5, 7, 6 mm, in the east north and up components respectively, was computed four weekly solutions. A day to day repeatability in the order of 10, 8, 17 mm, in the east north and up components respectively, was determined. Comparison of the weekly AUSLIG SSC to ITRF96 indicated RMS differences of 12-14 mm, Table 4.3. Seven parameter transformations between ITRF96 and AUSLIG SSC are shown in Table 4.4.

Table 4.3 RMS differences; ITRF96 and weekly AUSLIG SSC.

GPS Week	RMS (mm)
965	12.3
969	12.2
973	12.5
978	14.2

Table 4.4 Seven parameter transformation; ITRF96 onto weekly AUSLIG SSC

GPS Week	T1 (cm)	T2 (cm)	T3 (cm)	R1 (mas)	R2 (mas)	R3 (mas)	Scale (ppb)
965	-0.38	0.39	-0.31	0.07	0.06	0.02	-2.07
969	-0.43	-0.32	-0.07	-0.02	0.05	0.01	-2.15
973	0.09	-0.05	0.06	0.05	0.05	-0.15	-2.14
978	-0.41	-0.03	0.27	0.10	0.01	0.08	-1.66

4.3 Combination

The ITRF96 GPS SSC was used to realize the reference frame with terrestrial ties used to generate SLR coordinates where available. To validate the accuracy of the terrestrial ties a comparison was made to those used in ITRF96. Table 4.5 shows the RMS differences between SLR and GPS combined solutions.

Table 4.5 RMS differences before/after application of local tie constraints

Solution	RMS (mm)
July	2.04
August	1.45
September	2.02
October	1.87

A 20 mm magnitude difference at HERS (domes; 13212M007 and 13212S001) suggests a possible problem with the terrestrial connection between the GPS and SLR station marks, further investigation is continuing.

5. Conclusions and Future Work

Significant progress has been made in developing a system to combine high precision space geodetic techniques; successfully accomplishing the combination of GPS, SLR and DORIS. The necessary software to include VLBI normal equations from the SINEX files has also been developed. The inclusion of VLBI in the combination will therefore be undertaken for the Asia Pacific Regional Geodetic Network. It is also planned to include DORIS for this set of computations and in all future work.

Also, in order to progress this work further it is planned to investigate the relationship between the various space geodetic techniques – through combination solutions, local terrestrial ties and determination of transformation parameters. A weighting regime between the various space geodetic techniques is being investigated and developed.

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