COMBINATION OF HIGH PRECISION SPACE GEODETIC TECHNIQUES: THE ASIA AND PACIFIC REGIONAL GEODETIC PROJECT 1997

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ABSTRACT

The Asia Pacific Regional Geodetic Project 1997, (APRGP97) was undertaken under the auspices of the Working Group on Asia and the Pacific Regional Geodetic Networks, Permanent Committee on GIS Infrastructure for Asia and the Pacific, UN Regional Cartographic Conference for Asia and the Pacific. The planned major outcomes of the project, which includes the establishment (densification) of a high accuracy terrestrial reference frame with all space geodetic techniques fully integrated, and thus the infrastructure to consolidate all the national datums, are presented.

During October 1997, a first set of observations comprising a week of GPS observations, two 24-hour VLBI experiments and a month of SLR, DORIS and PRARE were undertaken. A geodetic solution, estimating satellite orbits, earth orientation parameters and station coordinates, using this comprehensive data set has been computed. Individual computations for each of the techniques were combined both at the observation and normal equation level aiming to provide a consistent multi-technique space geodetic solution.

This substantive regional data set which was observed through cooperating national agencies in the region for each technique, the computation procedure and standards employed at AUSLIG for the individual and combined solutions and the current results are presented. Further work, which will comprise of establishing a weighting regime for the different space geodetic observations in the combination solution, and a comparison of the combined solution to the ITRF96 set of station coordinates is noted.

INTRODUCTION

In order to address the need to establish a common geographic information infrastructure for the Asia Pacific Region, the 13th meeting of the UN Regional Cartographic Conference for Asia and the Pacific held in Beijing during May 1994 resolved to establish a Permanent Committee (PC) for GIS Infrastructure comprising of national surveying and mapping agencies. At the inaugural meeting of the Executive Board of the PC held in Kuala Lumpur during May 1996; four technical Working Groups (WG) were established in order to address the various components for establishing a regional GIS Infrastructure.

At the second meeting of the PC on GIS infrastructure for Asia and the Pacific convened in Sydney in September 1996, resolved that the role of Working Group 3, Asia and the Pacific Regional Geodetic Networks, was '*to establish and maintain a precise relationship between permanent geodetic observation sites across the region to* *provide a base on which to build a homogeneous Spatial Data Infrastructure (SDI) for Asia the Pacific Region*". The PC endorsed the joint cooperative Asia and the Pacific Regional Geodetic Project (APRGP97) as a step towards the establishment of a regional geodetic infrastructure and the maintenance of a geodetic network for GIS applications. This was seen as a step towards a precise regional geodetic infrastructure which could be used for consolidating national geodetic datums and for integrating regional episodic geodynamics campaigns. It will also provide the basis of a regional framework of permanent geodetic observations, which can be expanded as countries are able to add new sites.

This resolution was subsequently endorsed at the 14th UN Regional Cartographic Conference for Asia and the Pacific, held in Bangkok in February 1997. The project was also endorsed by the Asia Pacific Space Geodynamics Program (APSG) as providing an accurate reference frame for integrating scientific geodetic campaigns, and further supported by the regional VLBI network of the Asia Pacific Telescope (APT); at the Technical Workshop for APT and APSG 1996 (TWAA96) at Kashima in December 1996, (Permanent Committee on GIS Infrastructure for Asia and the Pacific, 1996).

Mandated by this resolution a co-located multi-technique geodetic campaign was observed in October 1997 throughout the Asia and Pacific region. This the Asia Pacific Regional Geodetic Network (APRGN97) incorporates a week of GPS observations including both International GPS Service (IGS) and non-IGS/national agency GPS receivers, a month of SLR observations to the geodetic satellites Lageos1, Lageos2, Stella, Starlette, Ajisai, Etalon1 and Etalon2, and a month of DORIS and PRARE observations. Additionally, two 24 hour VLBI observation sessions were observed-correlated at United States Naval Observatory (USNO) and processed at the NASA/GSFC.

The planned outcomes of the APGP97 project were;

- A high accuracy regional geodetic reference frame with all space geodetic techniques fully integrated, and thus the infrastructure to consolidate all the national datums.
- To provide a basis for a homogeneous Spatial Data Infrastructure, but having accuracies that can support any dense local and regional geodynamics campaigns along or across plate boundaries.
- To establish dialogue, cooperation and mutual support for the recently formed space geodesy organisations in the region; APSG, Western Pacific laser Tracking Network (WPLTN), APT and the PC.
- Data quality and assurance, in particular for SLR.
- Verification of the terrestrial connections between the co-located techniques.
- An assessment of the existing capabilities for space geodetic data processing and analysis {GPS, SLR, DORIS, PRARE, VLBI} in the region for appropriate expansion and/or improvement and to encourage national agencies to undertake space geodetic data processing.

A geodetic solution using this comprehensive data set producing precise orbits, earth orientation parameters and station coordinates has been computed. Individual solutions from each of the techniques have been combined at the normal equation level providing a consistent multi-technique geodetic solution.

DATA

APRGP97 includes GPS observations from 73 GPS receivers throughout the Asia Pacific region, this data set together with a further 17 global GPS receivers was observed October 12 to October 20 1997, GPS week 927 (0-6) and 928 (0-1). The data set includes observations from both the International GPS Service (IGS) and non-IGS/national agency GPS receivers. Data from a total of 90 GPS individual receivers were processed including 51 IGS receivers and 39 non-IGS/national agency receivers. Figure 1 shows the distribution of receivers in the Asia Pacific region only.

The SLR observations for the purposes of APRGP97 were coordinated by the WPLTN. It was requested that all WPLTN member stations observe the Lageos-1, Lageos-2, Stella, Starlette, Ajisai, Etalon-1 and Etalon-2 satellites at a high priority for this campaign. Table 1 gives the number of normal points of data per satellite per station observed during the month of October 1997. Figure 2 shows the distribution of the WPLTN stations.

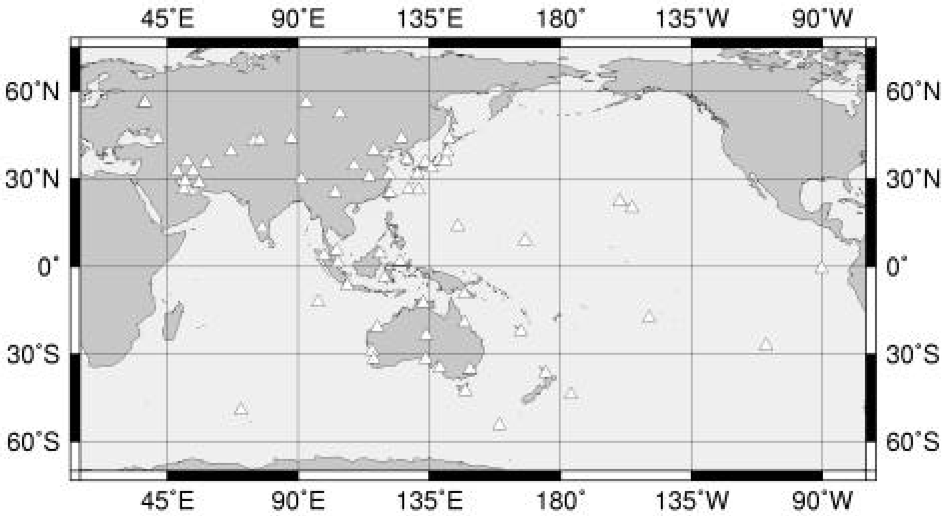

Fig. 1. Asia Pacific (APRGP97) GPS stations in the AUSLIG processing

Table 1. Number of Normal Point Observations per Satellite

Station	Lageos-1	Lageos-2	Stella	Starlette
MAID	18	12	0	0
KOMS	4	3	10	0
HALE	354	250	171	21
WUHA	5	0	0	0
CHAN	300	177	205	338
BEIJ	14	32	41	151
TOKY	5	35	32	29
KOGA	48	5	33	67
KASH	134	73	49	75
ZIMM	48	12	35	59
SHAN	117	77	59	71
SIMO	18	35	0	20
ORRO	314	283	313	759
AREQ	86	115	142	239
YARA	614	728	356	744

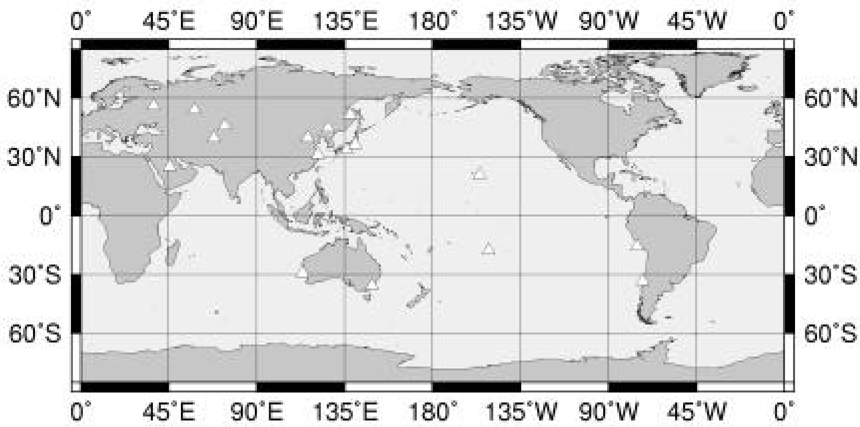

Fig. 2. Asia Pacific (APRGP97) SLR stations used in AUSLIG processing

The SPOT-2 data for the global DORIS network of stations was obtained from the Crustal Dynamics Data and Information Service (CDDIS), NASA. Figure 3 shows the distribution of the Asia-Pacific DORIS stations only.

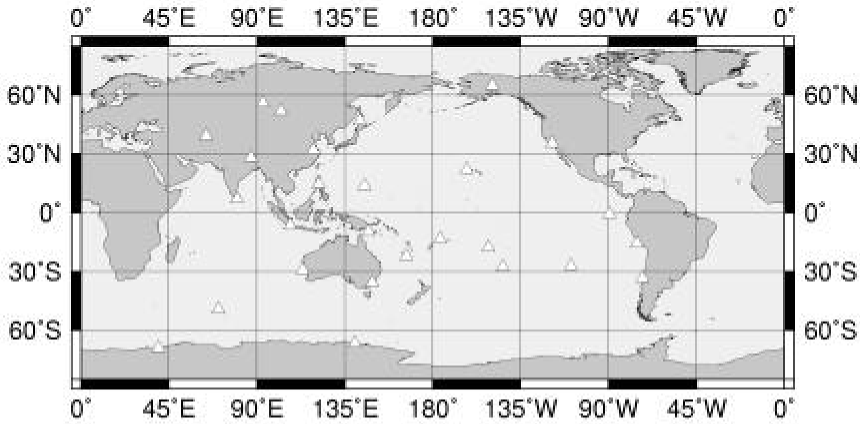

Fig. 3. Asia Pacific (APRGP97) DORIS stations used in AUSLIG processing

COMPUTATION PROCEDURE AND STANDARDS

The APRGP97 GPS, DORIS and SLR data was processed at AUSLIG using the MicroCosm software suite (Martin, 1997). Individual daily GPS solutions were combined using normal equation combination techniques. The SLR computations were done in 30-day arcs for each satellite. A solution combining the observations of four (Lageos-1, Lageos-2, Stella and Starlette) satellites was then computed. A second multi-satellite solution was computed by combining the normal equations of the four single satellite computations. The SPOT-2 DORIS data was initially computed for five five-day arcs. The five sets of normal equations were combined. All the normal equation combinations were done using SOLVE (Ullman, 1992) using supplementary MicroCosm to GEODYN format conversion software developed at AUSLIG. Estimated parameters by technique are summarised in Table 2.

Table 2. Estimated Parameters APRGP97, SLR, DORIS and GPS

Parameter	SLR	DORIS	GPS
Station Coordinates	WPLTN stations	Asia-Pacific stations	Global and Asia-Pacific stations (reference stations constrained to ITRF96 at 1mm)
UT and pole position	Daily	Daily	Daily
State vectors	30-day arc	5-day arc	1-day arc
Solar Radiation Pressure Scale factor	One per arc	One per arc	One per day
Drag	Once per day for Stella, and Starlette only	Once per day	-
General Acceleration	Once per five day constant. Once per revolution sine and cosine of the period in the along track and cross track direction.	Once per day constant. Once per revolution sine and cosine of the period in the along track and cross track direction.	Once per day Y-bias constant. Once per revolution Y-bias sine and cosine of the period.
Measurement Biases	Pass by pass range and time biases.	Pass by pass range rate and time biases. Once per arc satellite clock linear drift. Once per arc satellite clock quadratic drift. Pass by pass tropospheric scale factor at every station	Carrier Phase Ambiguities. Cycle slips. Tropospheric scale factor every two hours at every station.

Combination of Techniques

Figure 4 shows the normal equation combination scheme employed. Daily GPS solutions were first combined, incorporating global and regional solutions into a single daily solution. These daily solutions were then combined into a nine day combined solution. A four satellite SLR combined solution was computed, as was a 5 x 5 day DORIS solution. These individual technique solutions were then combined. At this stage the normal equation weighting scheme employed forced each of the technique solutions to have equal contribution. The techniques were combined by introducing local tie information, contraining co-located stations to adjust together using the SOLVE software.

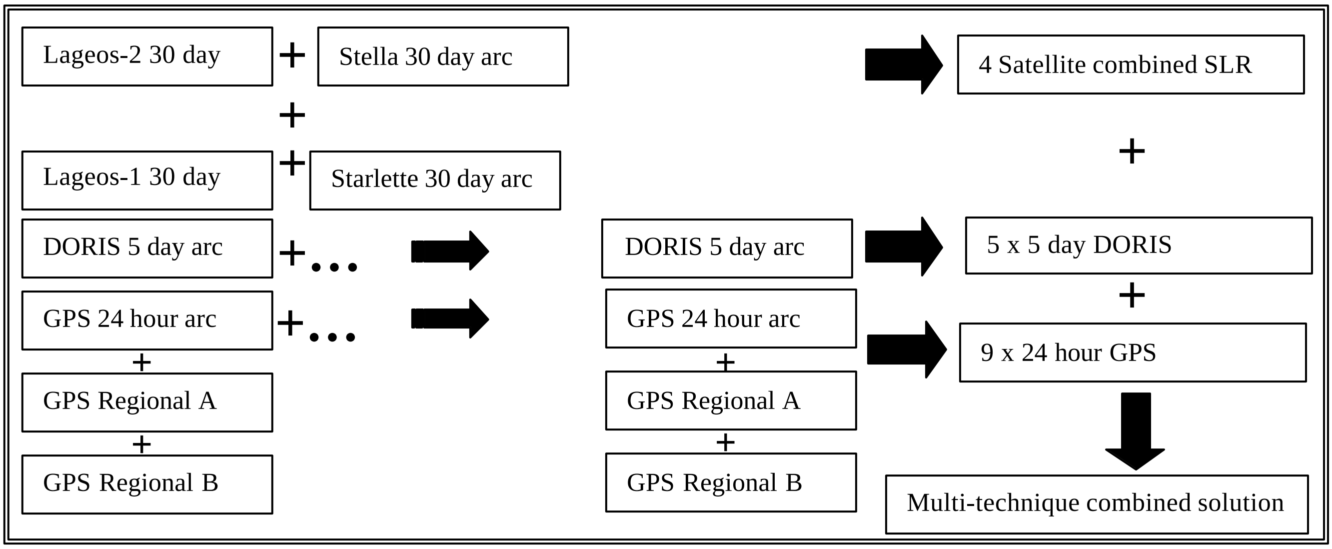

Fig. 4. Normal Equation Combination Schematic

RESULTS AND ANALYSIS

Global Positioning System (GPS)

GPS data was processed in a tied processing scheme, this process included global orbit determination and two regional solutions, see Table 3 for a station summary. The global and regional solutions were combined at the normal equation level after initial processing. To provide an indication of the quality of the AUSLIG derived orbit they were compared to the final IGS combined orbit product. After seven parameter transformation, translations between the two orbits were generally less than 20 mm except 42.2 mm in the Z component on day 97290. Small scale differences are noted, less than 0.2 part per billion (ppb) and all the rotations were less than 0.60 milli-arcsecs (mas), see Table 4 and Table 5. Mean differences in the satellite positions were always less then 0.60 cm in the radial component, whilst rms differences varied from 7.42 to 11.73 cm in this component. Rms differences in the along and cross track directions varied from 19.73 to 31.80 cm over the nine days.

All solutions were processed in the ITRF96 reference frame constraining a selected set of reference stations to the ITRF96 reference coordinates and velocities. The global network included approximately 37 stations on each day. The reference stations were constrained to 1 mm (IGS four character ID); gold, yell, algo, fair, kokb, guam, kwj1, tidb, yar1, kosg, irkt, sant, fort, mac1 and kerg. The Regional solutions included several more ITRF96 reference stations; zwen, shao, tskb. Global stations included in the regional solutions were constrained to 1mm in these solutions at their computed positions. The daily repeatability (rms) over the nine day campaign was 17, 10, 18 mm in the east, north and up components respectively, see Figure 5. Repeatabilities at asc1, dgar and ntus are marginally larger than at the other stations, further investigation is required.

Table 3. Stations Processed by Solution

Solution Type	Stations Included
Global	gold yell algo fair kokb guam kwj1 tidb yar1 auck jab1 chat madr mets kosg mate kit3 irkt mdvo sant kour fort tahi asc1 gala mas1 dgar mali usud iisc wuhn lhas mcm4 cas1 mac1 kerg maw1
Regional (A)	kokb mkea sele kstu pol2 zwen zeck usud taiw iisc shao wuhn xian taej tskb bahr beij urum cc06 kunm hsin 0029 0073 0745 0746 2001 2004 3009 6006 lada mari nilo reih rose yas1
Regional (B)	Kwj1 tidb hob2 yar1 darw tow2 karr cedu alic coco Grim dst1 pert hil1 orro iisc wuhn ntus more tawa Kual bako mana pare samp wina suwn

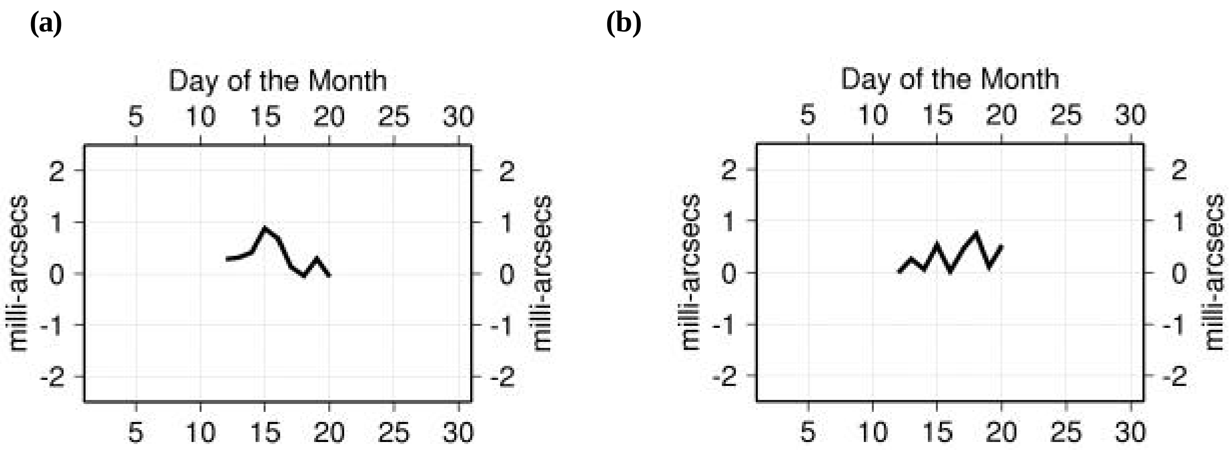

Fig. 6. IGS combined Earth Rotation parameters, gpsweek 927 and 928(0-1), compared to AUSLIG GPS computed values. (a) X-pole. (b) Y-pole.

Comparisons of the AUSLIG GPS computed pole position show consistency to the final IGS product at the sub-1 mas in both X and Y, see Figure 6.

Satellite Laser Ranging (SLR)

All solutions were processed in the CSR96L01 reference frame holding constrained to the CSR96L01 reference coordinates and velocities. There is inconsistency of the ITRF96 velocities for some Asia Pacific stations, namely Changchun. RMS differences between the AUSLIG SLR solution and ITRF96 are at the 20 mm level, see Table 7, additional testing by IERS indicates a 16 mm fit (Altamimi, 1998). Differences with ITRF96 at some WPLTN stations are due to large eccentricity differences, such as HALE and BEIJ. The poor solutions for some WPLTN stations are due to very little observed data. Table 8 gives the weighted rms-of-fit per satellite per station (mm) for the individual satellite solutions. A 2.96 ppb scale difference between ITRF96 and the AUSLIG SLR solution was noted, see Table 6. However translations are at the centimetre level, and rotations are negligible.

Table 8. Weighted RMS per Satellite per Station (mm) for Individual Satellite Solutions

Station	Lageos-1	Lageos-2	Stella	Starlette
MAID	11.4	14.2	-	-
KOMS	13.9	17.1	21.1	-
HALE	4.7	4.9	14.5	12.6
WUHA	11.0	-	-	-
CHAN	9.0	8.6	17.7	14.3
BEIJ	11.9	9.4	27.1	21.5
TOKY	13.1	8.0	18.6	17.6
KOGA	7.2	5.2	17.2	9.9
KASH	5.7	4.9	19.1	11.3
ZIMM	7.6	9.1	24.9	13.2
SHAN	10.0	9.2	22.2	18.0
SIMO	9.0	9.6	-	16.3
ORRO	5.8	5.0	14.3	8.8
AREQ	5.7	4.8	20.0	9.8
YARA	4.2	3.8	16.1	9.4
OVERALL (global)	6.3	5.9	18.9	13.1

Systematic differences between the AUSLIG and CSR96L01 solution were also noted, see Table 9. Pass by pass range and time bias were computed, Figure 8 shows a sub-set of computed values.

Table 9. Differences from between AUSLIG and CSR96L01 solution for the WPLTN Stations (mm).

Station	? Height	? East	? North
CHAN	-21	17	88
BEIJ	88	50	53
SHAN	-29	22	33
ORRO	5	-4	22

Comparisons of the AUSLIG SLR computed pole position show consistency to the final IGS product at the 2 mas in both X and Y, see Figure 7. Station performance comparisons by estimating pass by pass time and range biases for some WPLTN stations are shown in Figure 8.

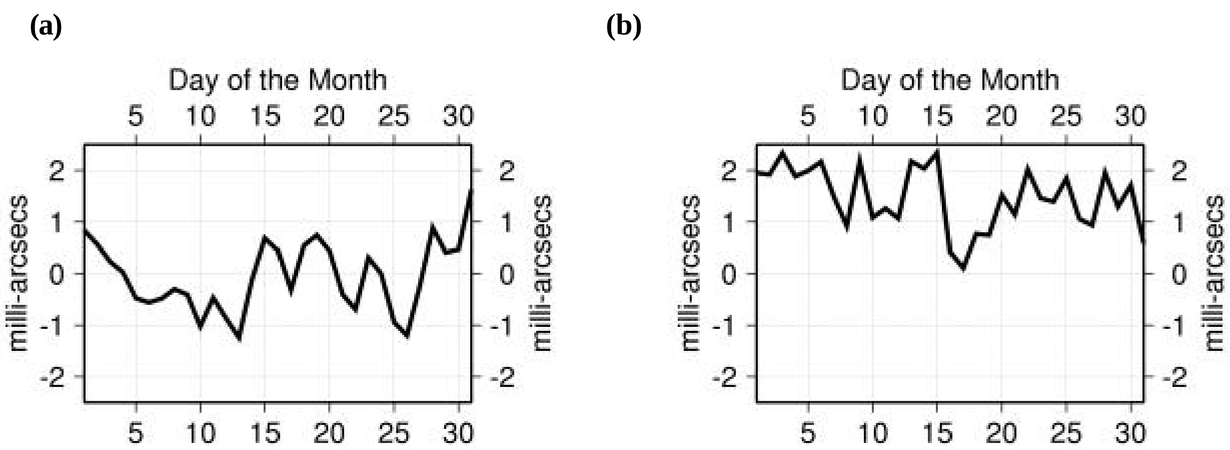

Fig. 7. IGS combine Earth Rotation parameters, gpsweek 925 to 929, compared to AUSLIG SLR computed values. (a) X-pole. (b) Y-pole.

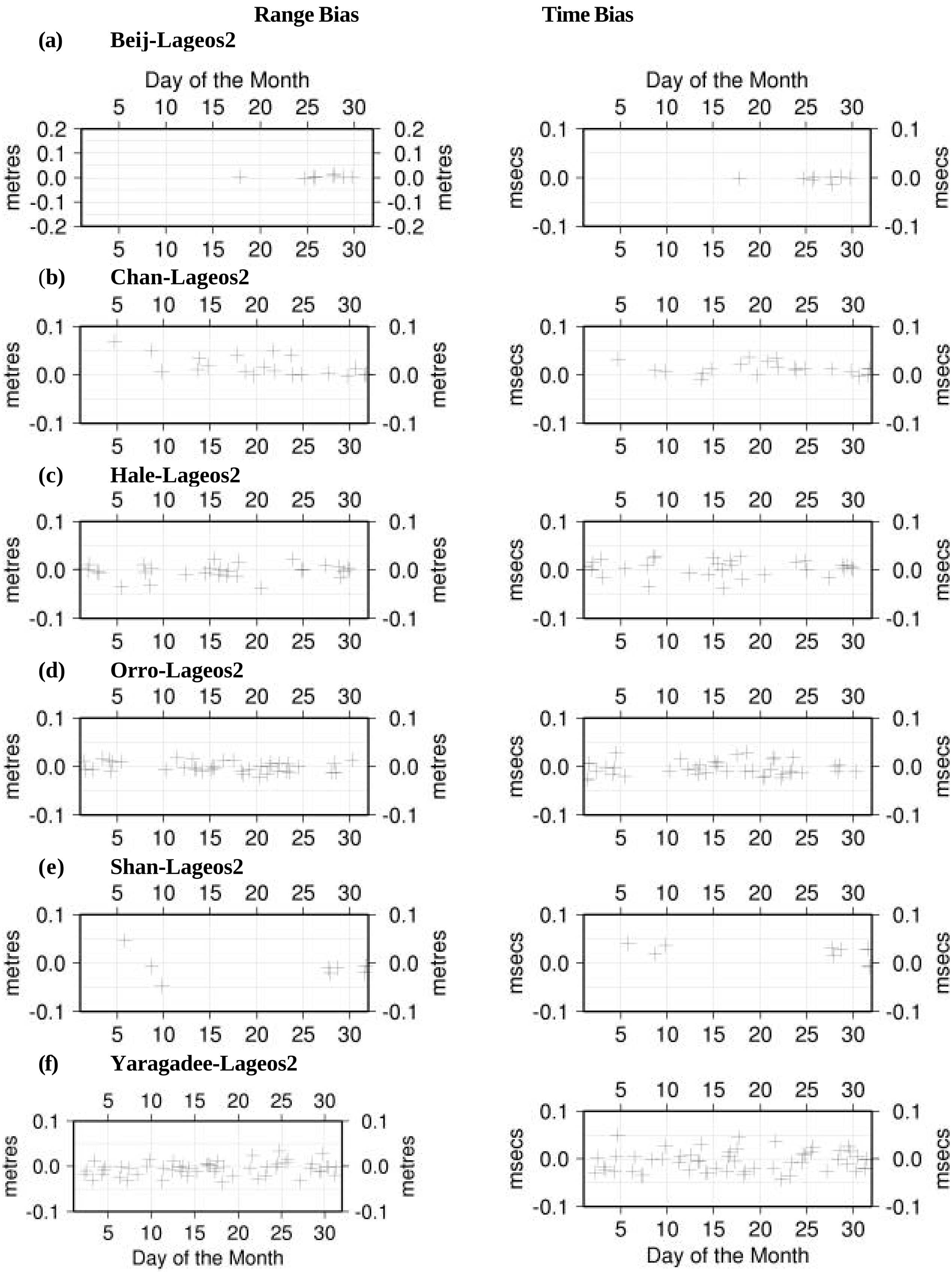

Fig. 8. Estimated pass by pass range and time biases for Lageos-2. (a) Beijing. (b) Chanchun. (c) Hale. (d) Orroral. (e) Shanghai. (f) Yaragadee.

Doppler Orbitography Radio Positioning Integrated by Satellite (DORIS)

All solutions were processed in the ITRF96 reference frame holding constrained to the ITRF96 reference coordinates and velocities. The global DORIS network processed included approximately 39 globally distributed stations. The weighted rms-of-fit per satellite per station for the individual five-day solutions was 0.8 mm/sec. Station coordinate repeatability for the estimated Asia Pacific stations is between 1.0 and 3.0 cm. Some stations with slightly higher repeatabilities are due to inconsistent results for third 5 day arc (11-16 October 1997).

(a) **(b)**

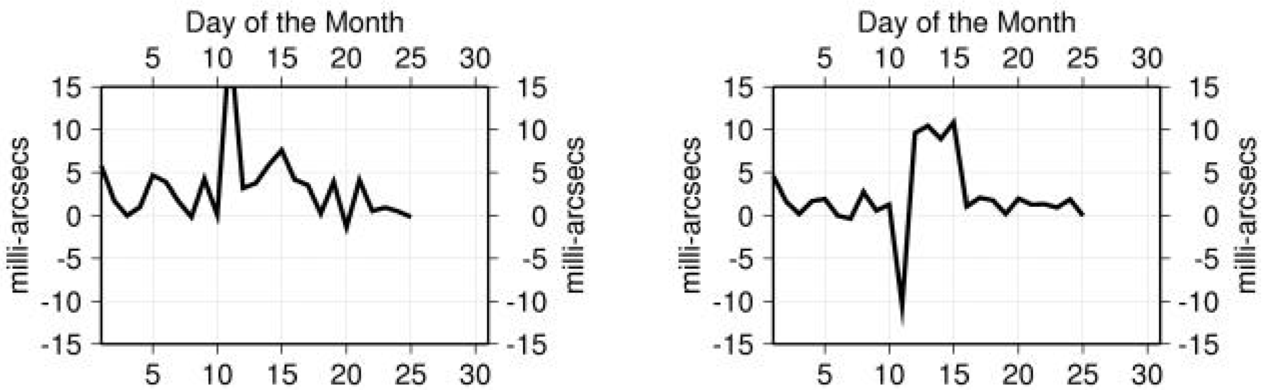

Fig. 9. IGS combine Earth Rotation parameters, gpsweek 925 to 928, compared to AUSLIG DORIS computed values. (a) X-pole. (b) Y-pole.

Comparisons of the AUSLIG DORIS computed pole position show consistency to the final IGS product at 1-5 mas in X-pole and 1-3 mas in Y-pole with the exception of the inconsistent third arc (11-16 October 1997), see Figure 9. The DORIS solution fits the ITRF96 at the 7 mm level. Total rms when fitted to ITRF96 are 3, 6 and 2 mm for East, North and Up respectively.

CONCLUSION

The multi-technique space geodetic data set from the October 1997 observation campaign and the subsequent processing resulted in a high precision, first epoch set of station coordinates, clearly fulfilling the major planned outcomes of the project.

The GPS orbits showed rms of differences from the IGS combined product of only 7 to 12 cm in the radial component. The rms of differences of the AUSLIG determined set of station coordinates (SSC) relative to the ITRF96 is at the 12 mm level. Similarly, when compared to the IGS GNAAC SSC the rms of the differences are below 20 mm. The accuracy of the APRGN97 SSC is therefore 8 mm and 5 mm for the east and north components and 15 mm in the up component.

The SLR solution for the four satellite combination showed a scale of 3 ppb, and translation parameters at the one cm level when compared to the ITRF96. The rms of differences of the SSC from the ITRF96 is 20 mm.

The first attempt DORIS solution gave a fit of 7 mm to the ITRF96 SSC.

The GPS and SLR determined pole coordinates agreed with the IGS distributed product at the sub 1-mas and 2 mas respectively. However, the DORIS solutions for the pole position varied from 1-5 mas for the X-pole and 1-3 mas for the Y-pole. The solution for the third 5-day arc for SPOT-2 showed some inconsistency. This requires further investigation.

A transformation of the full combination solution with all the techniques included will be completed as soon as the terrestrial ties between co-located techniques are finalised. Also, for the combination of all the space geodetic observations, an appropriate weighting regime is still to be studied and established.

In order to continue to densify the ITRF in the Asia Pacific region, a subsequent campaign is planned for 1998; with a view to establishing several more permanent GPS stations within the region.

ACKNOWLEDGMENTS

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Table 6. Seven Parameter Transformations Results. SSC – refers to a computed coordinate set. Transformations are applied as per McCarthy (1996).

Description	T1 (cm)	T2 (cm)	T3 (cm)	R1 (mas)	R2 (mas)	R3 (mas)	Scale (ppb)	Excluded Outliers
AUSLIG GPS SSC onto ITRF96	-0.14	-0.38	-0.24	0.06	-0.06	-0.16	-0.35	mdvi, iisc, cas1, taiw, tow2,
AUSLIG GPS SSC onto MIT GNAAC	0.73	0.08	-0.44	-0.05	-0.29	-0.17	-1.86	mas1, taiw, mcm4, wuhn
AUSLIG GPS SSC onto NCL GNAAC	0.80	-0.36	-0.93	-0.19	-0.20	0.14	-2.02	mas1, taiw, mcm4, wuhn
AUSLIG GPS SSC onto JPL GNAAC	0.87	-0.57	0.90	-0.46	-0.21	3.69	-1.73	mas1, taiw, mcm4, wuhn
AUSLIG SLR SSC onto ITRF96	-0.99	-1.38	-1.28	0.86	0.27	0.06	2.96	Hale, Komsomolsk, Beijing, Wuhan, Metshovi
AUSLIG DORIS SSC onto ITRF96	-0.17	0.20	0.47	-0.21	-0.08	0.02	-024	-

Table 7. RMS Differences after Transformation. SSC – refers to a computed coordinate set

Description	X (mm)	Y (mm)	Z (mm)	East (mm)	North (mm)	Up (mm)	Degrees of Freedom	3D (mm)
AUSLIG GPS SSC onto ITRF96	6.5	7.7	5.5	5.3	3.9	9.5	113	11.6
AUSLIG GPS SSC onto MIT GNAAC	10.0	11.1	10.0	7.3	4.3	15.9	125	18.0
AUSLIG GPS SSC onto NCL GNAAC	10.8	12.7	10.4	8.1	4.5	17.3	119	19.7
AUSLIG GPS SSC onto JPL GNAAC	11.6	8.5	11.2	8.0	4.3	15.8	128	18.3
AUSLIG SLR SSC onto ITRF96	11.4	14.9	11.0	11.7	6.3	17.2	50	21.8
AUSLIG DORIS SSC onto ITRF96	2.1	3.7	4.7	2.7	5.5	1.9	110	6.4

Table 4. Seven Parameter Transformations Results, AUSLIG Orbit onto IGS Combined Orbit Product

Description	T1 (cm)	T2 (cm)	T3 (cm)	R1 (mas)	R2 (mas)	R3 (mas)	Scale (ppb)	Excluded Outliers
AUSLIG onto IGS combined 97285	12.6	2.3	-1.3	0.02	0.16	0.08	0.0	PRN 06
AUSLIG onto IGS combined 97286	-5.1	15.5	13.6	0.25	0.38	-0.02	0.1	PRN 29
AUSLIG onto IGS combined 97287	-15.2	4.0	-13.1	0.06	0.23	0.31	0.1	PRN 29,12,21
AUSLIG onto IGS combined 97288	-8.5	27.8	-7.4	0.04	0.40	0.11	0.0	-
AUSLIG onto IGS combined 97289	3.1	20.5	35.8	-0.09	0.58	0.40	0.1	PRN 09
AUSLIG onto IGS combined 97290	11.9	-4.3	-42.2	0.40	0.06	0.68	0.2	PRN 06
AUSLIG onto IGS combined 97291	-13.7	-6.3	1.9	0.50	-0.06	0.30	-0.1	PRN 14
AUSLIG onto IGS combined 97292	25.6	9.0	-1.8	-0.02	0.40	0.08	0.0	-
AUSLIG onto IGS combined 97293	19.1	-3.9	-3.0	0.29	0.43	-0.36	0.2	PRN 10

Table 5. RMS Orbit Differences after Seven Parameter Transformation

Description	Mean Radial (cm)	Mean Along (cm)	Mean Cross (cm)	RMS Radial (cm)	RMS Along (cm)	RMS Cross (cm)
AUSLIG onto IGS combined 97285	0.65	-4.61	-5.86	7.42	25.83	25.94
AUSLIG onto IGS combined 97286	0.54	-4.99	-2.61	10.36	31.17	26.32
AUSLIG onto IGS combined 97287	-0.67	1.69	-4.16	11.73	31.80	29.56
AUSLIG onto IGS combined 97288	-0.23	3.73	1.69	8.96	25.52	24.11
AUSLIG onto IGS combined 97289	0.11	-0.55	-0.43	10.58	29.45	27.43
AUSLIG onto IGS combined 97290	-0.23	1.99	6.20	8.69	23.80	28.34
AUSLIG onto IGS combined 97291	0.04	-3.53	-2.84	9.74	27.18	24.69
AUSLIG onto IGS combined 97292	-0.62	-1.31	2.96	9.34	30.97	28.07
AUSLIG onto IGS combined 97293	-0.61	-0.62	-1.97	10.31	30.99	31.03

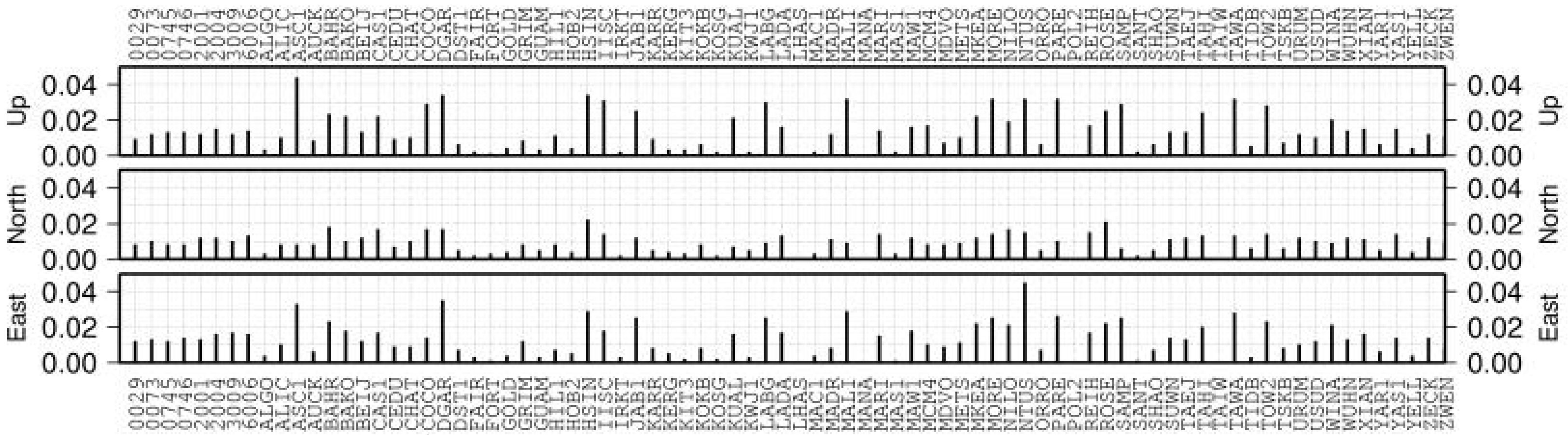

Fig. 5. Coordinate RMS (metres) of the nine day APRGP97 GPS solution