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Analysis of Regionally Enhanced GPS Orbit and Clock Solutions and Contribution to Improvement of Real-Time Precise Point Positioning

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Abstract
This work experimentally examines the performance benefits of a regional CORS network to the GPS orbit and clock solutions for supporting real-time Precise Point Positioning (PPP). The regionally enhanced GPS precise orbit solutions are derived from a global evenly distributed CORS network added with a densely distributed network in Australia and New Zealand. A series of computational schemes for different network configurations are adopted in the GAMIT-GLOBK and PANDA data processing. The precise GPS orbit results show that the regionally enhanced solutions achieve the overall orbit improvements with respect to the solutions derived from the global network only. Additionally, the orbital differences over GPS satellite arcs that are visible by any of the five Australia-wide CORS stations show a higher percentage of overall improvements compared to the satellite arcs that are not visible from these stations. The regional GPS clock and Uncalibrated Phase Delay (UPD) products are derived using the PANDA real time processing module from Australian CORS networks of 35 and 79 stations respectively. Analysis of PANDA kinematic PPP and kinematic PPP-AR solutions show certain overall improvements in the positioning performance from a denser network configuration after solution convergence. However, the clock and UPD enhancement on kinematic PPP solutions is marginal. It is suggested that other factors, such as effects of ionosphere, incorrectly fixed ambiguities, may be the more dominating, deserving further research attentions.

Keywords: Continuous Operating Reference Stations (CORS), Precise Orbit Determination, Precise Point Positioning (PPP), GAMIT and Panda Software.

1. Introduction

Currently, several International GNSS Services (IGS) Analysis Centers (ACs), such as the German Research Centre for Geosciences (GFZ), the Jet Propulsion Laboratory (JPL), the Centre for Orbit Determination in Europe (CODE) and Wuhan University GNSS Research Centre in China, are generating Ultra-Rapid orbit/clock solutions that are assessed and combined by weighted average to form IGS Ultra-Rapid (IGU) products (Beutler et al, 1995). Each of the AC contributed and IGS combined daily ultra-rapid orbit products contains 48 hours of tabulated orbit ephemerides, of which the first 24 hours are estimated based on the most recent GPS observational data and the next 24 hours are the predicted orbits that enable the uses in real time applications. This redundancy affords a high measure of reliability and enhanced orbit accuracy of the published IGU orbit products.

The Ultra-Rapid orbit products contributed by IGS Analysis Centres are generated from 80 to 120 global IGS tracking stations that provide files on hourly basis. These stations are distributed reasonably evenly across the globe to provide consistent solutions for worldwide uses. The RMS values of the combined IGU solutions are generally accurate to ±3 cm for the estimated GPS orbit and ±5 cm for the predicted GPS orbit. Similarly, the Ultra-Rapid clock products are generated by several IGS Analysis Centres using global IGS hourly tracking stations for both observed and predicted solutions. The RMS accuracy for the observed clock solution is approximately 150ps, where the predicted clock solution is 3ns RMS and quickly faded to be unusable solutions for real-time Precise Point Positioning (PPP).

The IGS Real-time Pilot Project (RTPP) aimed to generate real-time IGS products (orbit and clock) to address the needs for real-time precision applications such as PPP. RTPP Analysis Centres, such as Bundesamt fur Kartographie und Geodaesie (BKG), European Space Operations Centres (ESOC), Natural Resources Canada (NRCan) and German Aerospace Centre (DLR), derive and disseminate real-time orbit and clock solutions using real-time data streams from a global network of about 50 stations. In most cases, the IGS combined Ultra-Rapid orbit products are used to fix the GPS orbits to generate the accompanying clock solutions.

Although in general the predicted orbits are of high quality, it is not uncommon to have orbit error greater than 10 cm due to eclipse and various other reasons (Kouba, 2009). As a consequence, the resultant real-time clock solutions are negatively affected. Taken together, these errors impact on the quality of positioning (PPP in particular), downgrading accuracy and increasing initialization times.

In the past decade, many hundreds of CORS stations have been deployed and operated in the Australian region by public agencies. These data are accessible for scientific purposes. A straightforward question is how these stations can be made use of to benefit GNSS users in Australia. In particular, two questions are:

- Can data sets from the regional CORS networks be used to enhance the GPS precise orbit solutions with respect to the solutions for a global network?
- Can a dense local/regional CORS networks contribute to better GPS clock and Un-calibrated Phase Delay (UPD) solutions for PPP and PPP with Ambiguity Resolution (PPP-AR)?

The concept of UPD is found in the work by Ge et al (2008), which is defined by non-integer phase biases for the widelane and narrowlane from the dual-frequency phase measurements. These satellite-specific parameters are provided together with clock corrections, in order to allow users to recover their integer ambiguities in the single differenced phase measurements (between satellites). As a result, the orbit, clock and UPD corrections can enable PPP-AR solutions.

Theoretically redundant measurements from more ground stations can potentially result in more accurate and reliable orbits and clocks solutions. To which degree the solutions can be improved, however, depend on many factors, for instance, whether the additional stations are widely distributed and produce the same high quality data as the global stations and whether the data processing software systems can deal with any biases and large errors in data well. Therefore, the practical way to answer the above questions is to compare the results with different ground station distribution scenarios.

In this paper, we study the impact of regional CORS networks on the precise GPS orbit and clock estimation and prediction. Firstly, the regionally enhanced GPS orbit is evaluated and compared with IGS Analysis Centres' Ultra-Rapid GPS solutions and the IGS final orbit solution is used as the benchmark. The section describes the processing platforms used for deriving GPS orbit solutions, namely GAMIT-GLOBK and PANDA software packages, as well as different computation schemes performed based on various network configurations. The overall orbit accuracy and within the Australian region for the estimated and predicted GPS orbit are presented. Secondly, the GPS Clock and UPD products derived from regional CORS network are evaluated with PANDA PPP and PPP-AR results. The final section summarized the work conducted to-date and recommended future works.

2. Regionally Enhanced GPS Precise Orbit Solutions

2.1 Processing platforms and configurations

The primary processing platform used for evaluating regional enhancement of GPS precise orbit solutions is GAMIT-GLOBK software package. Its overall architecture is illustrated in Figure 1. The first phase of processing is accomplished by the following operations:

- define the processing process and convert observations (*Makexp* and *Makex*)
- generate apriori orbits and nominal yaw parameters in table format (*Arc*, *Yawtab*),
- generate loading corrections (*Grdtab*),
- compute residual observations and partial derivatives from a geometrical model (*Model*),
- identify and eliminate the measurements outliers through analysing residuals (*Autcln*) and
- carry out weighted least squares solution (*Solve*).

The double passes (iteration) through the *Model*, *Autcln* and *Solve* modules serves for two purposes: 1) the model obtained from the first solution can be used to flatten the residuals, allowing for improved editing and the display of post-fit residuals for evaluation; 2) adjustments to stations coordinates are reduced to a few centimeters, assuring that non-linearity does not degrade the final estimates (Herring et al, 2010).

Depending on the timeliness requirements and the total number of stations involved, the network can be divided into smaller subnets and processed in parallel. The output of each subnet is the estimates and associated covariance matrix ("quasi-observation" or H-file) of station positions and other specified parameters. The second phase of the processing uses GLOBK to combine loose constrains parameter solutions from "H-file" over multiple subnets to derive final station coordinates and GPS orbit solution (Herring et al, 2010).

The secondary platform is the PANDA (Positioning And Navigation Data Analyst) software developed by Wuhan University, which is also used to derive the regionally enhanced GPS orbit solutions for evaluation and comparison. Figure 2 shows the software architecture and modules used. The core components of PANDA are based on the orbit integrator and state estimator. Orbit integrator is responsible for generate dynamic orbit based on initial orbit parameters and force model information, whereas the state estimator is responsible for all observation models and statistical estimations (shi et al, 2008).

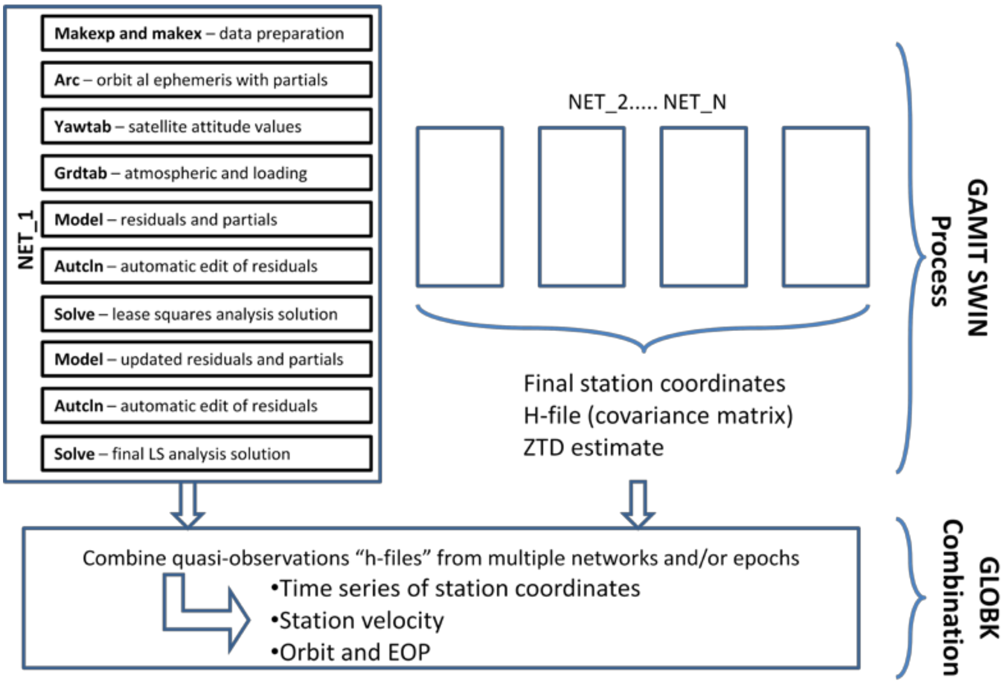

Figure 1: GAMIT-GLOBK precise orbit determination software architecture

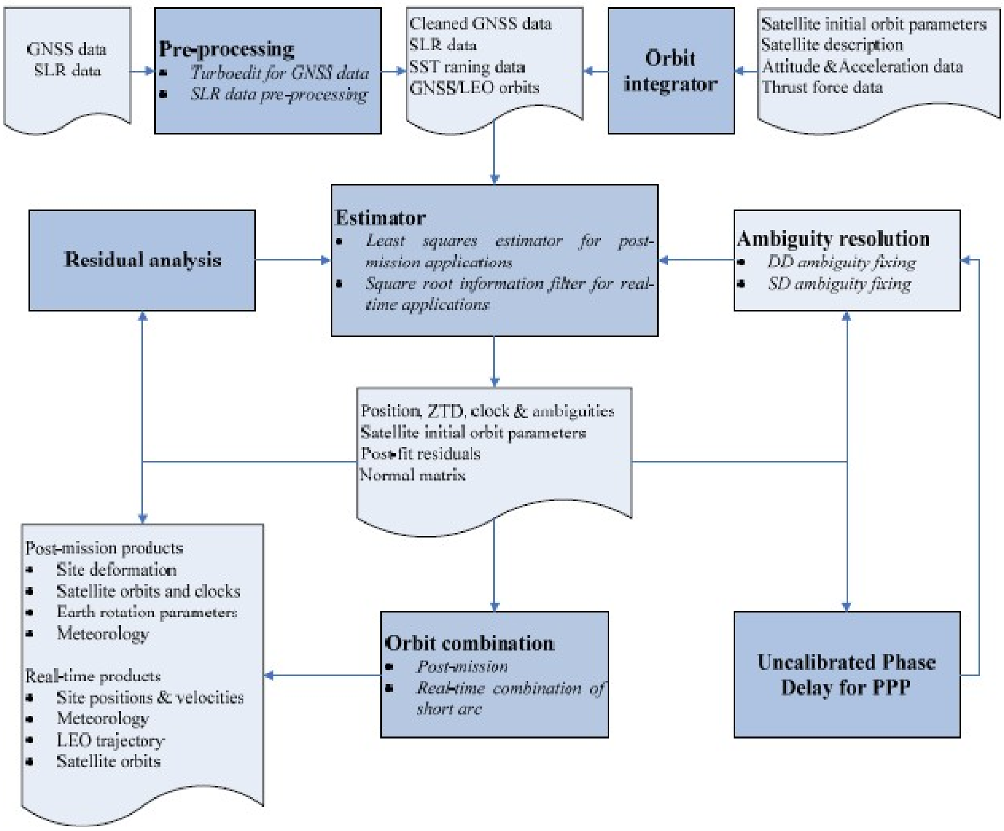

Figure 2: PANDA software architecture and modules (shi et al, 2008)

2.2 Network configurations and computational schemes

The regionally enhanced GPS products are derived from CORS networks that comprise a global evenly distributed network from IGS tracking stations added with a more densely distributed network in the Australia and New Zealand region. Figure 3 shows the three global network configurations (G65, G84 and G100) chosen for the evaluation, where G stands for Global network and 65, 84 and 100 denotes the number of stations in each configuration. G65 (green triangle) is chosen based on the network configuration used by WHU ultra-rapid orbit solution as of June 2012, G84 (red circle) is chosen based on the network configuration used by Scripps Institute of Oceanography (SIO) at University of California San Diego in their ultra-rapid orbit solutions as of January 2012 and G100 (blue square) is the extension of G65 configuration by 35 additional station chosen globally. Figure 4 shows the three regional network configurations (A20, A50 and A80) chosen for evaluation, where A stands for the Australia and New Zealand region and 20, 50 and 80 stand for the number of the regional stations. A20 network configuration (green triangle) has evenly distributed tracking stations within the region. A50 network (red circle) includes additional stations that are heavily concentrated in the southern region of Australia (lack of stations elsewhere). A80 network (blue square) includes more additional station in the New Zealand and South Pacific regions.

Figure 5 shows the GAMIT-GLOBK processing of G100A50 network configuration by dividing stations into four globally distributed subnets, each with approximately 40 stations with 3 overlapping between subnets.

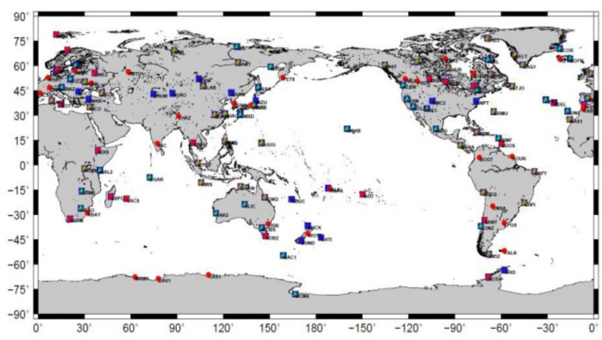

Figure 3: Distribution of Global IGS CORS stations used for regionally enhanced orbit processing. Green triangles, red circles and blue squares represent the stations chosen for the G65, G84 and G100 networks respectively.

The computations were performed over the period of 98 days, from 1st January 2012 to 8th April 2012, with daily RINEX observation files for the selected stations downloaded from IGS and Geoscience Australia (GA) FTP sites. Data arcs of 24 hours are used to determine daily precise GPS orbits which are predicted into the next 24 hours. The output is given in SP3 format which provides the coordinates for each satellite at 15 minutes interval. A total number of 12 computation schemes were performed using the GAMIT-GLOBK software for combination of global networks of G65, G84 and G100 with regional networks of A20, A50 and A100. Additionally, 4 different computation schemes were performed with the PANDA processing platform for combinations of global networks of G65 and G100 and the regional network of A50.

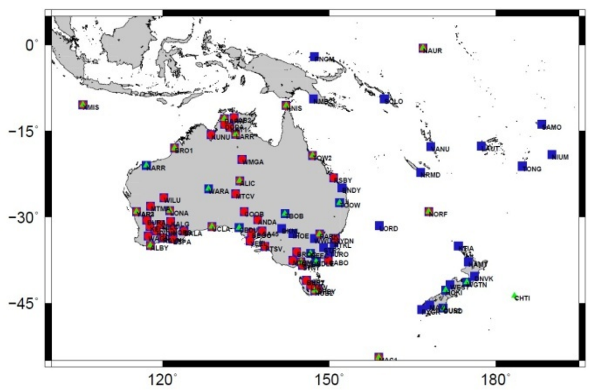

Figure 4: Regional CORS stations used for regionally enhanced orbit processing. Green triangles, red circles and blue squares represent the stations chosen for A20, A50 and A80 networks, respectively.

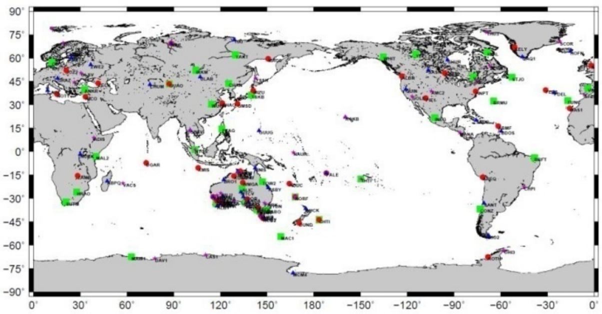

Figure 5. Station distribution of four subnets(G100A50 configuration) in the GAMIT-GLOBK processing

2.3 GAMIT-GLOBK POD processing – subnet computation evaluation

To evaluate the impact of subnet size, i.e., the number of stations of each network on the performance of the total GPS orbit solutions, G84 and G100 networks were divided into four different subnet configurations where the number of reference stations is set in each subnet to vary from 16 to 43, as shown in Table 1. Computation and evaluation were performed over a period of 7 days, from 1st Jan 2012 to 7th Jan 2012.

Table 1 summarises the RMS values of 3D GPS orbital positions for 24-hour observed and predicted orbits for different subnet portions, respectively. Overall, the combined orbital solutions from the different subnet sizes remain consistence with respect to the IGS final solutions to the level of better than 2 centimetres. This shows the high stability and robustness of the GAMIT-GLOBK software, but the network portion by a larger sub-network size always gives more consistent solutions. Strictly speaking, the RMS accuracy is actually the RMS consistence between the computed solutions and the IGS final solutions throughout the paper. As the IGS final orbital accuracy is consistently within 2 centimetres, using the RMS consistence as the accuracy indication is more appropriate when the predicted orbit solutions are compared as shown in the last column of the table. In general, the RMS accuracy in this context refers to the RMS consistence of the derived orbit solutions with the IGS final orbit solutions.

Table 1: GPS orbital accuracy derived from combination of different subnets.

			GPS Orbital Accuracy (m)	
	# of Subnets	Approx. stations	24hr Observed	24hr Predicted
G84 Network	**2**	**43**	**0.0170**	**0.0860**
	4	23	0.0175	0.0896
	5	19	0.0183	0.0903
	6	17	0.0191	0.0925
G100 Network	**3**	**34**	**0.0163**	**0.0775**
	4	26	0.0170	0.0788
	6	18	0.0186	0.0885
	7	16	0.0179	0.0821
SIU[1]	N/A		0.0217	0.0974
IGU	N/A		0.0085	0.0406

The computation time with respect to the subnet size is shown in Figure 6. It can be seen that the computation time increases exponentially with the increase of number of stations in each subnet. The computation time for 16 stations is just under 10 minutes, and increases to around 42 minutes for 42 stations. Thus, to maximize the orbital accuracy and achieving hourly orbit solution for real-time positioning, it is necessary to set the number of stations in each subnet to no more than 45 stations.

2.4 Regionally enhanced GPS orbital performance analysis

The impacts of regional enhancement are evaluated based on the derived GPS orbit, clock and Precise Point Positioning (PPP) solutions. The regionally enhanced orbit solutions are derived from both GAMIT-GLOBK and PANDA processing platforms. Since there is no GAMIT-GLOBK based clock solutions readily available for real time applications, PANDA generated GPS clock products are used for evaluation. Finally PPP module of PANDA is used to demonstrate the impact of possible enhancements on the positioning performance. Additionally, SIO generated hourly Ultra-Rapid orbit solutions, SIU, using GAMIT-GLOBK software and IGU (IGS combined Ultra-Rapid orbit solution) are collected for comparisons. It is noted that such hourly operational solutions often suffer from data availability issues.

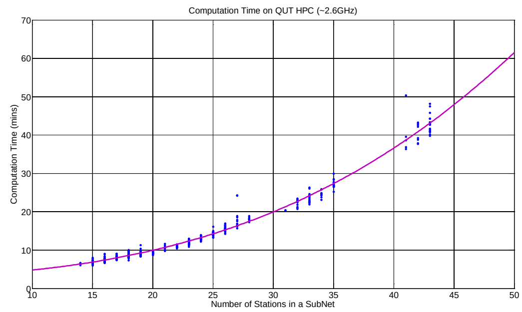

Figure 6: Computation time vs Number of stations in the Subnet

Table 2 summarises the product sources or software platforms used, computing schemes and durations of solutions in analysis. The computations involve a total of 180 reference stations collected over the period of 98 days, generate 1296 daily solutions and collect 181 daily solutions for the analysis. Launching such a large-scale and data intensive computational campaign is to lead to a more definitive conclusion about the contributions of regional networks to the GPS orbit improvement.

Table 3 summarises the RMS values of orbit solutions generated from different computation schemes with GAMIT-GLOBK and PANDA processing. Again, the RMS accuracy is the RMS consistence between the generated solutions and the IGS final orbit solutions. Orbital accuracy are summarised for the 24 hours of estimated orbit component, 24 hours of predicted orbit segment, first six hours of predicted orbit and one to three hours of predicted orbit segment.

Table 2: Summary of POD computing schemes

Institution	**Software**	**Scheme**	**Duration**
SIO	GAMIT	G84	83 days
WHU	PANDA	G65, G65A50 G100, G100A50	30 days
QUT	GAMIT	G65, G65A20, G65, A50 G65A80 G84, G84A20, G84A50, G84A80 G100, G100A20, G100A50, G100A80	98 days
IGS - IGU	IGS	Globally combined	98 days

Table 3: Accuracy of the global and regionally enhanced GAMIT and PANDA orbit solutions with respect to IGS final orbit solutions. The percentage of improvements is calculated with respect to the reference global network solution.

Orbit Accuracy with respect to IGS Final Orbit									
		24hr Estimated		24hr Predicted		6hr Predicted		1-3hr Predicted	
		RMS Accuracy	% improve	RMS Accuracy	% improve	RMS Accuracy	% improve	RMS Accuracy	% improve
GAMIT POD	G65	0.0237		0.1306		0.0617		0.0561	
	G65A20	0.0205	13.48	0.1125	13.86	0.0537	12.95	0.0484	13.65
	G65A50	0.0211	10.96	0.1131	13.39	0.0547	11.30	0.0496	11.52
	G65A80	0.0216	8.80	0.1140	12.65	0.0549	10.92	0.0505	9.95
	G84	0.0203		0.1110		0.0539		0.0487	
	G84A20	0.0190	6.26	0.1020	8.12	0.0496	8.11	0.0448	7.98
	G84A50	0.0207	-2.04	0.1119	-0.76	0.0557	-3.36	0.0516	-6.07
	G84A80	0.0198	2.58	0.1025	7.66	0.0513	4.85	0.0466	4.30
	G100	0.0192		0.1023		0.0507		0.0459	
	G100A20	0.0184	3.90	0.0963	5.86	0.0478	5.70	0.0431	6.22
	G100A50	0.0187	2.61	0.0981	4.12	0.0476	6.06	0.0431	6.25
	G100A80	0.0186	3.05	0.0981	4.08	0.0471	6.99	0.0432	6.05
PANDA POD	G65	0.0244		0.0752		0.0419		0.0397	
	G65A50	0.0225	7.84	0.0696	7.50	0.0378	9.79	0.0353	11.18
	G100	0.0201		0.0676		0.0368		0.0348	
	G100A50	0.0199	1.39	0.0655	3.14	0.0354	3.79	0.0333	4.48
SIU	G84	0.0255		0.1298		0.0669		0.0618	
IGU	-	0.0102		0.0489		0.0261		0.0239	

Firstly, the comparison between all global Ultra-Rapid orbit solutions, including GAMIT (G65, G84, G100), Panda (G65, G100), SIU and IGU, shows that the GAMIT Precise Orbit Determination (POD) processing platform can generate orbit solutions with the accuracy comparable with the SIU and WHU Ultra-Rapid solutions. It is also noticed that the PANDA produces more accurate predicted orbit solutions than GAMIT-GAMIT predicted orbits solutions.

With addition of regional networks (A20, A50 and A80) selected from the Australia and New Zealand region, the GPS orbit solutions demonstrate overall improvements in the RMS accuracy with respect to the global orbit solutions, as shown in Table 3. In general, a greater improvement in the accuracy can be seen from G65, compared to G84 and G100, with the same A20, A50 and A80 schemes. Furthermore, comparing the effects between three regional network sizes A20, A50 and A80, the GAMIT G65A20, G84A20 and G100A20 results achieve the largest improvements (3.9% to 13.86%). It is also noticed that G84A50 results show slight degradation in the accuracy compared to the G84 solutions, which may be caused by the data quality. The IGU orbit solution has the highest accuracy which is due to the consistency and reliability gained by combination of Ultra-Rapid orbit solutions contributed by several Analysis Centres (Kouba , 2009; Griffiths and Ray 2009).

To further understand the impact of the regional networks on the orbit accuracy, the orbital solutions that are visible and non-visible by any of the five chosen Australian stations (ALIC, DARW, TOW2, HOB2 and YAR3) are analysed. Figure 7 shows the GPS satellite visibility over the Australian region for the day 1, 2012. The average percentage of the visible satellite arcs is 48.6%. As shown in Table 4, the improvements of the estimated orbit solutions in the satellite passes visible over the Australian region and the rest 51.4 % of data arcs are 12.29% versus 3.02%. This finding is true for both GAMIT/GLOBK and PANDA processing results. The predicted orbits for the Australian region compared to rest of the world also show just very slight improvements, that is, 8.65% versus 7.25%.

Table 4 Accuracy of the global and regionally enhanced GAMIT and PANDA orbit solutions w.r.t the visibility over the Australian region

Orbital Accuracy over the Australian Region									
		Visible over Australian Region				Non-Visible over Australian Region			
		24hr Estimated		24hr Predicted		24hr Estimated		24hr Predicted	
		RMS	%	RMS	%	RMS	%	RMS	%
GAMIT POD	G65	0.0234		0.1228		0.0235		0.1285	
	G65A20	0.0185	20.66	0.1052	14.37	0.0209	11.01	0.1113	13.40
	G65A50	0.0190	18.62	0.1045	14.92	0.0216	7.89	0.1113	13.39
	G65A80	0.0194	16.94	0.1073	12.63	0.0223	5.17	0.1123	12.64
	G84	0.0200		0.1045		0.0202		0.1098	
	G84A20	0.0176	11.68	0.0946	9.49	0.0192	4.94	0.1006	8.30
	G84A50	0.0187	6.45	0.1030	1.52	0.0212	-4.62	0.1098	-0.05
	G84A80	0.0180	9.80	0.0956	8.57	0.0203	-0.50	0.1008	8.16
	G100	0.0189		0.0980		0.0191		0.1009	
	G100A20	0.0173	8.77	0.0889	9.21	0.0186	2.28	0.0951	5.77
	G100A50	0.0166	12.27	0.0924	5.73	0.0189	0.63	0.0965	4.30
	G100A80	0.0173	8.76	0.0926	5.47	0.0190	0.47	0.0968	4.09
PANDA POD	G65	0.0262		0.0750		0.0239		0.0742	
	G65A50	0.0218	16.65	0.0683	8.87	0.0226	5.41	0.0690	6.96
	G100	0.0202		0.0671		0.0200		0.0668	
	G100A50	0.0193	4.60	0.0642	4.40	0.0199	0.57	0.0649	2.81
Mean			12.29		8.65		3.02		7.25

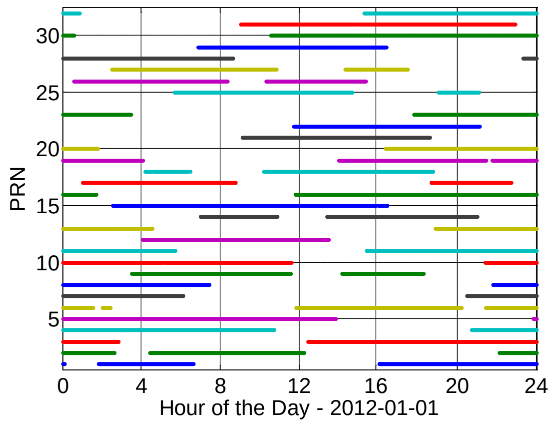

Figure 7: Visibility of GPS satellite over the Australian region that are visible by any of the five chosen CORS stations (ALIC, DARW, TOW2, HOB2, YAR3)

Results from Tables 3 and 4 clearly indicate that it is not evident that more regional stations (A50 and A80) necessarily improve the RMS consistence/accuracy with respect to the RMS consistence/accuracy obtained from less regional stations (A20). One of the explanations is the distribution of the A20 network is already widely spread over the Australia, New Zealand and Southern Pacific region. The orbital improvement is more dependent on how well the additional stations can fill the gaps of the global network, instead of on the number of regional stations.

3. Regional GPS Clock and UPD Estimations

The PANDA software real time module is a powerful engine that estimates satellite and receiver clocks second by second, while keeping the global parameters such as for satellite orbits, ground stations and Earth Rotation Parameter (ERP) etc, fixed. PANDA real time GPS clock solutions have contributed to the ITS real time services (Shi et al, 2012). The recently updated module can also output the satellite specific UPD solutions, including fractional phase ambiguity biases for widelane and narrowlanes, which can be used to recover the L1 and L2 phase measurements (Ge et al, 2008). These UPDs and their quality information, are provided with GPS orbit and clock corrections together to support real time prevision applications, such as PPP services.

Additionally, the PANDA PPP module is updated to enable PPP-AR processing with application of the UPD solutions. Figures 8 and 9 show the regional network configurations, A35 and A79, used for preliminary evaluation of the UPD and PPP solutions by the researchers at WHU and QUT. In the first test campaign, data streams from A35 reference stations denoted by green triangle in Figure 8 were used to generate high-rate clock (1sec) and UPD products, leaving the data of 6 stations excluded, thus being able to use as rover receivers (red star) to evaluate the PPP and PPP-AR performance. In the second campaign, the number of reference stations increased to A79, as shown in Figure 9, and the same 6 rover stations remain excluded for PPP and PPP-AR validations.

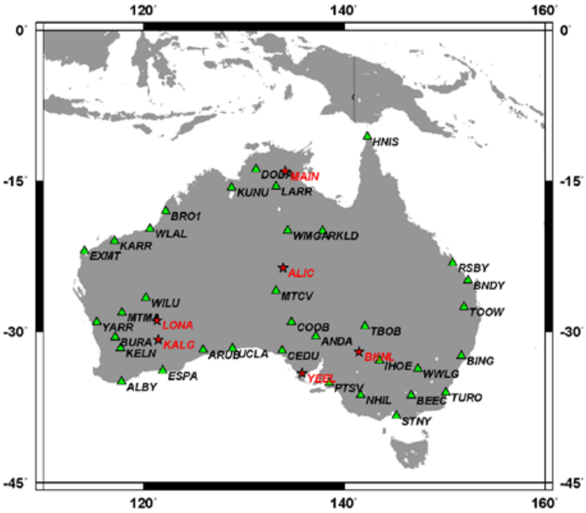

Figure 8: Distribution of CORS for the GPS CLK and UPD experimental campaign 1, including 35 stations (green triangles) for solutions and 6 stations as rover for PPP positioning evaluation (red stars).

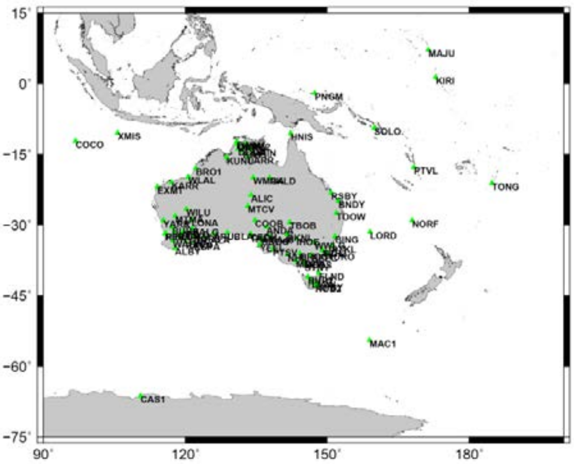

Figure 9: Distribution of CORS station for GPS CLK and UPD experimental campaign 2: 79 stations for product generation and 6 stations as rover for PPP positioning evaluation.

Figures 10 and 11 illustrate the North-East-Up (NEU) position errors of the LONA station obtained from the A35 and A79 network configurations, respectively. In both figures, the red line represents PPP-AR (fixed) solutions and blue line represents PPP (float) solutions. Results from both Figures 10 and 11 illustrate that PPP and PPP-AR solutions from the network A79 are slightly better than solutions derived from the network A35. This improvement may be caused by additional stations added surrounding the rover station LONA in the A79 network. On the other hand, from Figures 12 and 13, the NEU errors from A35 and A79 solutions for the ALIC station do not demonstrate clear improvement with the A79 network. This is most likely due to the fact that there is no additional station added surrounding ALIC station in the A79 configuration.

The overall statistics for the PPP and PPP-AR NEU errors for all the six rover stations for day 1 of 2013 are shown in Table 7. The mean and STD values are computed by simply excluding first two hours of solutions to eliminate the solutions during the convergence time. Similarly to ALIC results, there are no evident accuracy improvements for BKNL and MAIN stations in the A79 solution where there are very few stations added surrounding the rovers. Denser distribution of stations in the south west and south region may contribute to positioning improvements for KALG, LONA and YEEL stations in the A79 solutions.

Further examination of Figures 10 to 13 reveals that the PPP-AR solutions are not necessarily better than the float PPP solutions after the float solutions are convergent. In fact, the PPP-AR errors often suffer from the effects of some or all incorrectly fixed integers, while the float PPP solution NEU errors remain less volatile. When all the ambiguities are correctly fixed to their integers, PPP-AR solutions are less biased. In addition, it is observed that the convergent times in the PPP-AR solutions stations are generally shorter than the float PPP solutions. Smaller biases and shortened convergent times could be the more evident performance benefits that the PPP-AR can potentially provide with respect to the float PPP solutions.

4. Summary Remarks

This work has experimentally studied the performance benefits of a regional CORS network to the GPS orbit and clock solutions and contributions to supporting real-time Precise Point Positioning (PPP). A series of CORS network schemes have been designed to use both GAMIT-GLOBK and PANDA software packages to demonstrate the dependences of accuracy of the GPS orbits, clock and precise point positioning solutions on the ground network configurations.

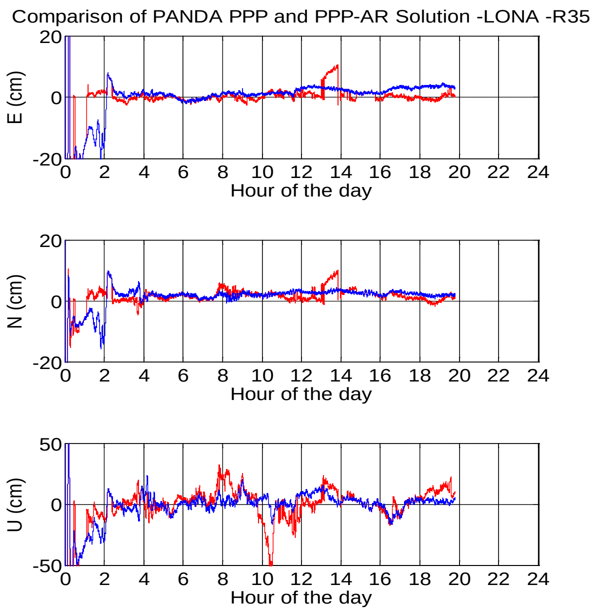

Figure 10: Comparison of PANDA PPP results for LONA station on 1/1/2013 (only 20 hours) using GPS CLK and UPD generated from 35 regional CORS stations. Red line represents PPP-AR (fixed) solution and blue represents PPP float solution

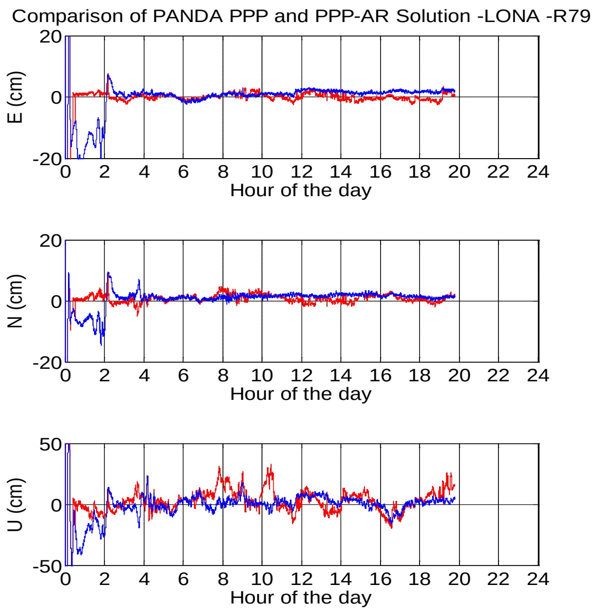

Figure 11: Comparison of PANDA PPP results for LONA station on 1/1/2013 (only 20 hours) using GPS CLK and UPD generated from 79 regional CORS stations. Red line represents PPP-AR (fixed) solution and blue represents PPP float solution.

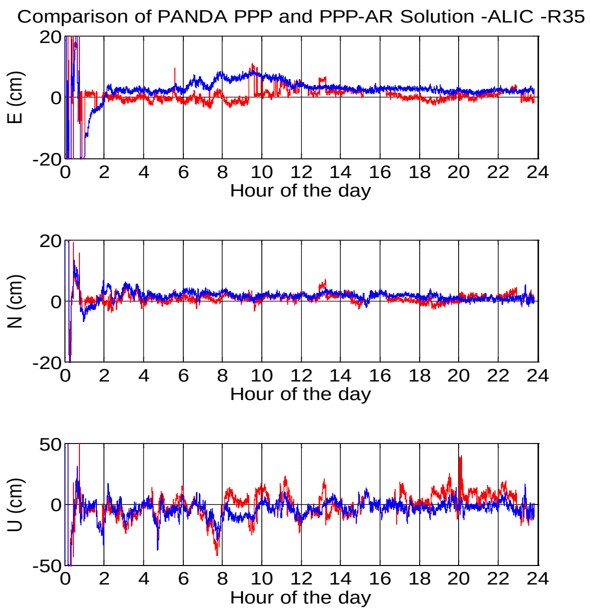

Figure 12: Comparison of PANDA PPP results for ALIC station on 1/1/2013 using GPS CLK and UPD generated from 35 regional CORS stations. Red line represents PPP-AR (fixed) solution and blue represents PPP float solution.

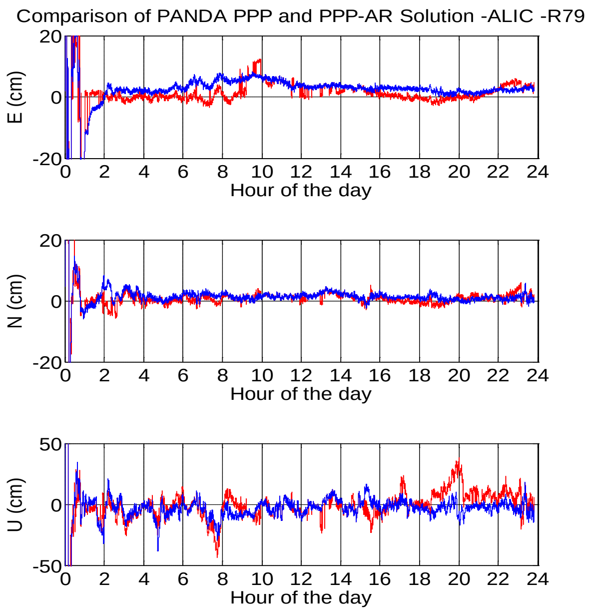

Figure 13: Comparison of PANDA PPP results for ALIC station on 1/1/2013 using GPS CLK and UPD generated from 35 regional CORS stations. Red line represents PPP-AR (fixed) solution and blue represents PPP float solution

Table 5: Statistic results of PANDA PPP NEU errors for six rover stations on day 1 2013 for A35 and A79 network configurations, generated by excluding the first two hours of solution due to convergence time

	A35 Network				**A79 Network**			
	PPP-AR		**PPP**		**PPP-AR**		**PPP**	
w.r.t the reference coordinate	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
ALIC								
E (cm)	0.82	2.07	3.26	1.75	1.53	2.49	3.16	1.57
N (cm)	0.92	1.32	1.66	1.11	0.79	1.42	1.41	1.14
U (cm)	-0.60	9.54	-3.69	5.85	-0.29	9.77	-3.20	6.11
3D RMS (cm)	1.37	9.85	5.20	6.20	1.75	10.18	4.71	6.41
BKNL								
E (cm)	-0.13	1.40	1.29	1.36	0.32	1.50	1.66	1.36
N (cm)	0.52	1.13	0.96	0.89	0.35	1.31	1.17	1.00
U (cm)	0.93	6.87	-1.16	4.46	-0.04	7.94	-0.90	4.20
3D RMS (cm)	1.08	7.10	1.99	4.75	0.48	8.19	2.22	4.53
KALG								
E (cm)	0.75	2.21	2.41	1.42	0.60	1.36	2.03	1.06
N (cm)	1.76	1.79	2.06	1.13	0.66	1.34	1.40	0.90
U (cm)	2.74	12.11	0.66	5.18	3.39	8.00	0.48	4.54
3D RMS (cm)	3.35	12.44	3.24	5.49	3.51	8.23	2.51	4.75
LONA								
E (cm)	0.53	2.04	1.62	1.71	0.00	1.06	1.13	1.34
N (cm)	1.83	1.90	2.27	1.35	0.77	1.26	1.49	1.22
U (cm)	1.79	11.14	1.41	6.01	3.43	8.50	1.05	5.21
3D RMS (cm)	2.62	11.48	3.12	6.39	3.51	8.66	2.15	5.52
MAIN								
E (cm)	-3.01	3.15	-2.88	2.77	-2.54	3.67	-3.09	2.39
N (cm)	-5.52	2.43	-5.31	1.87	-5.71	2.43	-5.65	1.79
U (cm)	-1.48	12.39	-2.92	10.05	-2.42	12.61	-2.27	10.47
3D RMS (cm)	6.46	13.01	6.71	10.59	6.70	13.35	6.83	10.89
YEEL								
E (cm)	0.60	2.05	3.59	2.79	1.02	2.28	3.60	2.15
N (cm)	0.84	1.34	1.50	1.53	0.65	1.32	1.59	1.23
U (cm)	0.76	7.37	-0.20	6.36	-0.20	5.23	0.13	5.91
3D RMS (cm)	1.28	7.77	3.90	7.12	1.22	5.86	3.94	6.41

Analysis for a total of 1379 daily GPS orbit solutions obtained from various computational schemes and from up to 180 global and regional stations have shown that the overall GPS orbit solutions can indeed be enhanced, comparing the solutions between the global networks with and without adding regional CORS stations. However, the degree of enhancement depends on how well the global and regional networks are distributed and the quality of data sets, rather than the number of additional stations. In other words, the enhancement depend more on how well the regional stations can better fill in the gaps of the global networks. This is evident from the finding that use of A50 and A80 networks has not offered additional improvement than the A20 network. Additionally, the orbital difference over GPS satellite arcs that are visible by any of the five widespread Australian CORS stations shows a higher percentage of orbital accuracy improvements, comparing to the satellite arcs that are not visible from these Australian stations. The work has not studied the potential impact of the data quality of adding stations.

The regional GPS clock and Uncalibrated Phase Delay (UPD) products have also been generated using the PANDA software real time processing module from the Australia regional CORS networks of A35 and A79 stations respectively. Analysis of PANDA kinematic PPP and kinematic PPP-AR solutions has shown some improvements in the positioning performances from the denser network configuration (79 stations) after solution convergence. However, the orbit and clock enhancement on kinematic PPP solutions somehow depend on whether there are reference stations close to the rover stations. Results from six rover stations also have shown that the PPP-AR solutions do not necessarily perform better than the float PPP solutions after the solution convergence.

This is because that the PPP-AR errors often suffer from the effects of some incorrectly fixed integers, while the floating PPP NEU errors remain less fluctuate. It is anticipated that if all the ambiguities are correctly fixed to their integers, PPP-AR solutions are less biased than PPP solutions. In addition, it is observed that the convergent times in the PPP-AR solutions stations are generally shorter than the float PPP solutions. Smaller biases and shortened convergent times could be the more evident performance benefits that the PPP-AR can potentially provide with respect to the float PPP solutions. The results suggest that other factors, such as effects of ionosphere, may be still dominating and should be paid more research attentions.

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Biography

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