ASSESSING THE STABILITY OF THE NEW MARINE DGPS STATION OF HONG KONG AND ITS CONNECTION TO THE WGS84 DATUM

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ABSTRACT

The permanent DGPS station of Marine Department, located on Kau Yi Chau Island in Hong Kong, has begun its operation in 1996. One of the factors which affects the quality of the differential corrections generated by the station is the accuracy of its reference coordinates in the WGS84 datum. Although the station is positioned over one of the existing trigonometric stations of Hong Kong datum whose position is also known in the WGS84 datum, the accuracy of the known coordinates needs to be verified independently. We have used two months data to calculate repeated baselines from this station to five IGS core stations located in China, namely, Wuhan, Shanghai, Xian, Lhasa, and Taiwan using the GAMIT software. Sub-centimeter rms baseline error has been demonstrated during this period. These results indicate stability of GPS measurements over a long period of time well beyond expectations. We have used the estimated baseline vectors to connect Kau Yi Chau station to the ITRF94 and subsequently to the WGS84 datum. Preliminary results indicate centimeter and decimeter level agreement in latitude and longitude between the known reference coordinates and the ones derived from ITRF-94 connection. We have observed, however, over three meters of discrepancy in height.

INTRODUCTION

The Marine Department of Hong Kong Government has established a permanent DGPS station on Kau Yi Chau Island, Hong Kong in 1996 (abbreviated as HKPO). The station is equipped with a Trimble 4000SSE GPS receiver with compact L1/L2 and G/P antenna.

One of the factors which affects the quality of the differential corrections generated by the station is the accuracy of its reference coordinates in the WGS84 datum. Although the station is positioned over one of the existing trigonometric stations of Hong Kong datum whose position is also known in the WGS84 datum, the accuracy of the known coordinates needs to be verified independently.

Continuos observations collected during November and December 1996 were processed together with the data of other five IGS (International GPS Service for Geodynamics) core stations located in China to calculate the station's precise coordinates in WGS84. The ancillary stations used in this process are located in Lhasa,Tibet (LHAS), Shanghai (SHAO), Taiwan (TAIW), Wuhan (WUHN), and Xian (XIAN). The distribution of these stations is shown in Figure 1. Among these stations, the longest baseline is 3018km from LHAS to TAIW while the shortest is 643km from

WUHN to XIAN.

In this study we first discuss the data and the computational procedures used in calculating baselines among different stations. The results show that the baseline length repeatability is about 1cm for observation periods of approximately two months. Th coordinates of HKPO in ITRF94 is then calculated using a network adjustment by fixing the coordinates of TAIW station in ITRF94 and checking the coordinates of SHAO station in ITRF94. Finally, the coordinates of HKPO in ITRF93 are transformed to the WGS84 datum.

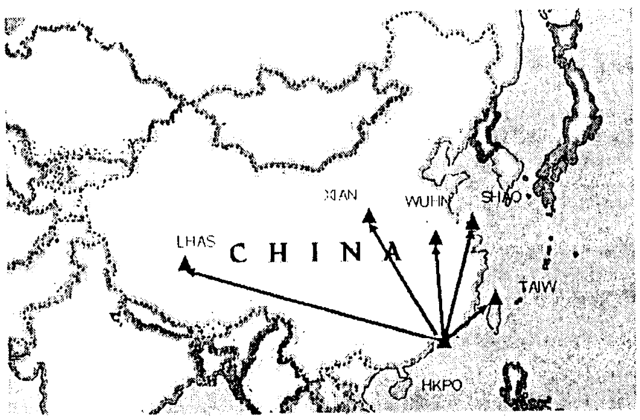

Figure 1. Distribution of ancillary stations and HKPO

DATA HOLDINGS

The data holdings of HKPO, LHAS, SHAO, TAIW, WUHN, and XIAN stations are presented in Figure 2. All the stations are equipped with ROGUE receivers except HKPO. TAIW and SHAO stations began their routine operations after IGS'92 global GPS campaign. WUHN, LHAS, and XIAN stations are also IGS permanent stations.

As compared to the others, HKPO station has only begun its operation late last year. It was established for marine navigation. We processed only the data observed in November and December of 1996. Consequently, despite the availability of large amount of data, only two months of overlapping GPS observations have been used in this study.

Station	X	Y	Z
TAIW	4928936.8970	2681234.5060	3024781.8700
SHAO	4675666.0970	3275369.5840	2831733.1580

Table 1. Coordinates of TAIW and SHAO at epoch December 1, 1996.

The precise ephemeredes used in the computations refer to ITRF94 (IERS - International Earth Rotation Service - Terrestrial Reference Frame). The ITRF94 station coordinates for these stations (at epoch 93.0) were obtained from a combination of VLBI , GPS, SLR and DORIS solutions submitted to the IERS's Central Bureau in 1995.

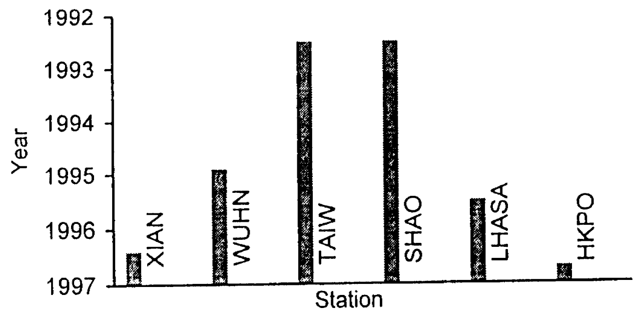

Figure 2. Data holdings of HKPO, LHAS, SHAO, TAIW, WUHN, and XIAN stations.

The adopted epoch for the HKPO observation data is December 1, 1996 corresponding to the middle of observation span. Among these stations, only TAIW and SHAO are class C stations in ITRF94 and other stations are not part of the reference frame. The ITRF94 coordinates of TAIW and SHAO at epoch December 1, 1996 are given in Table 1. They were calculated from positions and velocities provided by IERS referring to ITRF94 whose epoch is 1993.0. Note that TAIW coordinates and the velocities are calculated (adjusted) in the realization of the ITRF94 reference frame. However, although the position of the SHAO station is adjusted, its velocity is derived from NNR-NUVEL1 plate motion model. Since the orientation of the network is provided by the precise ephemeris of IGS, the only constraint needed for the solution is to fix one station. Therefore, during data processing TAIW station was first fixed to the its known values whereas SHAO station position was assumed to be unknown to compare the calculated results against the known position as a check.

GPS DATA PROCESSING MODEL

The GPS analysis software GAMIT developed at MIT and Scripps Institute of Oceanography has been adapted for processing the observations and for performing the network adjustment (King and Bock 1995). The software makes use of the following ionosphere-free combination of phase

$$\phi_{LC} = \frac{1}{1-g^2}\phi_{L1} - \frac{g}{1-g^2}\phi_{L2}$$

where ϕ_{L1} and ϕ_{L2} are observed phases on L1 and L2, and g is the ratio of the frequencies of L2 and L1. Another combination used is given by,

$$\phi_{LG} = \phi_{L2} - g\phi_{L1}$$

which is called "LG". In LG observable, all geometrical (due the station and satellite configuration) and other non-dispersive delays (e.g., the troposphere) are canceled, so that we have a direct measure of the ionospheric variations. One-cycle slips in L1 and L2 are of course difficult to detect in the LG phase in the presence of high ionospheric noise since they are equivalent to only 0.221 LG cycles. Using LC and LG observables, GAMIT calculates double difference observations and forms the normal equations for the solution.

To determine the integer ambiguities for the data at hand, pseudo-range P1 and P2, available on the two GPS bands, are used. In other words, "wide-lane" (WL) combination of L1, L2, P1, and P2 can be formed. This combination is free of both ionospheric and geometric effects and is simply the difference in the integer ambiguities for L1 and L2,

$$WL = n_2 - n_1 = \phi_{L2} - \phi_{L1} + \left(P_1 + P_2\right)\frac{f_1 - f_2}{f_1 + f_2}$$

This WL observable is used to fix cycle slips in one-way data, but should be combined with LG and doubly differenced LC to rule out slips of an equal number of cycles at L1 and L2. To resolve the wide-lane ambiguities (ambiguities difference between L2 and L1) both the pseudoranges and the "phase wide-lane" with ionospheric constraints were used (ibid).

Although GAMIT can also solve for the state vector, we made use of satellite ephemeris from the IGS service referring to ITRF94. The software incorporates a weighted least squares algorithm to estimate the relative positions of a set of stations by fitting to doubly differenced phase observations (LC).

A zenith delay parameter for each site is estimated to account for the tropospheric model errors. The cycle slips are detected and repaired automatically and manually.

The adopted statistical model consists of station coordinates, tropospheric delay corrections, and ambiguities as parameters. The influences of ionospheric delay are almost eliminated by adopting the combination observable LC. The satellite clock differences come from broadcast ephemeredes. The receiver clock differences were calculated from observed pseudo-range and approximate station position.

DATA PROCESSING RESULTS

We have obtained network solutions to sessions with 24 hours data span using the GAMIT software for two months data. All session normal equations were subsequently combined to obtain a total solution for two months data.

Figure 3 shows the repeatability of baseline vectors and lengths. The root mean square, rms, error of each session for both plane components (East-West and North-South components), is less than 1cm. The height component reaches up to 3 cm. When compared to the other baselines height errors, the HKPO heights exhibit more variability but overall all baseline vertical components are markedly different than the other baseline components. Together with the rms error of the baseline length, which is about 7mm, these results show that, overall the baseline accuracies are comparable to the other station data even though the HKPO station is not designed for this purpose.

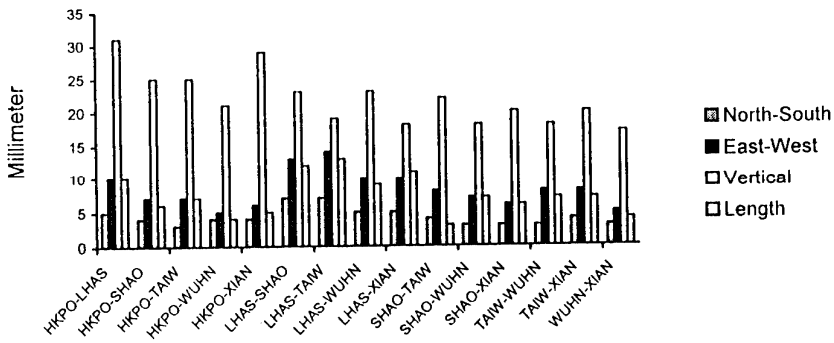

Figure 3. Baseline length and component rms error among different stations.

Figure 4, 5, 6 depict the standard deviations of HKPO station position components. Although the errors of each session solution (standard deviations are indicated by error bars in the figures) for all components are almost the same magnitude from session to session, they exhibit periodic variations that may be due to the effect of various modeling errors systematic in nature. The sources of this variability will not be discussed in this study. In most cases, the variations remain within 1 to 3 cm range.

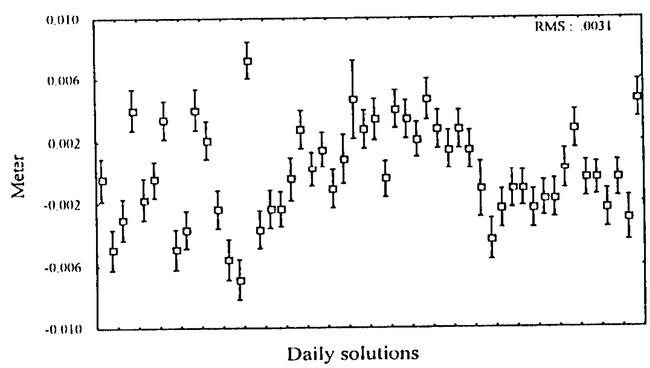

Figure 5. Standard Deviation of Latitude of HKPO

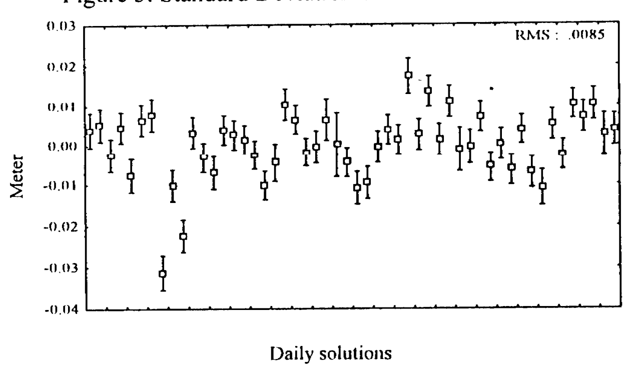

Figure 6. Standard Deviation of Longitude of HKPO

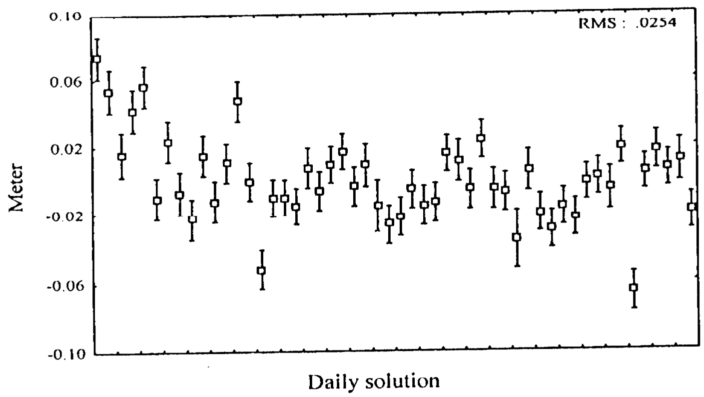

Figure 7. Standard Deviation of Height of HKPO

COMBINED SOLUTION

The daily session solutions are informative for analyzing time dependent history of baseline variations. Nevertheless, their average values over time are not formally representative of the accuracy of the overall solution. We have obtained a total solution by combining the normal equation of each daily solution using

$$N_i \delta x = C_i$$

where N_i, C_i, are the normal equation related matrix and vector for each session i, and δx is the correction vector for the parameters to be estimated common to all solutions. It can be shown that the combined solution can be obtained using the following relationships[1],

$$\left(\sum_i N_i\right)\delta x = \left(\sum_i C_i\right)$$

In the solution, the fixed TAIW station coordinates were updated to the middle of the data span (i.e. December 1, 1996 to account for the effect of the plate motion on this station and also the precise ephemeris for the satellite positions which refer to the middle epoch of each session).

The adjusted coordinates of each station referring to ITRF94 and their standard deviations are given in Table 2. They exhibit better statistics as compared to the average results of each indi-

[1] Since the data span is about two months, too short for the effect of the plate motions, each session normal matrices need not to be to be shifted to a common approximate set of coordinates. But still, since the approximate coordinates of each session are different, the normal equations were modified to have common approximate values.

vidual solution since the correlations among the parameters are also taken into consideration.

Station	X	σ	Y	σ	Z	σ
HKPO	-2408854.4211	.0004	5391041.8647	.0007	2403590.5383	.0003
LHAS	- 106937.5228	.0004	5549269.7211	.0007	139215.8218	.0004
SHAO	-2831733.1611	.0004	4675666.1346	.0006	3275369.5917	.0003
TAIW	-3024781.8700	--	4928936.8970	--	2681234.5060	--
WUHN	-2267749.0391	.0004	5009154.4141	.0006	3221290.8226	.0004
XIAN	-1735212.2155	.0004	4976839.7456	.0007	3580538.1011	.0004

Table 2. Coordinates of each station in ITRF94 at epoch Dec. 1, 1996 and their standard deviations from the combined solution. Results are in meters.

To provide an independent check for the total solution, we have compared the estimated coordinates of the SHAO station against the values independently calculated by IERS using not only GPS data but also SLR and VLBI data. Since the IERS solution refer to the ITRF94 frame during the same year, to account for the effect of plate motion from 1994 to 1996, the SHAO station coordinates were corrected using the NNR-NUVEL1A global plate motion model. Differences between the two sets of solutions, shown in Table 3, are about few millimeters on X and Z components and 4 centimeters for the Y components indicating that the current solution is reliable.

ΔX	ΔY	ΔZ
-0.0031	-0.0376	0.0077

Table 3. Coordinate differences of the calculated values of the SHAO station in this study from the ITRF94 published values. Differences are in meters.

TRANSFORMATION TO THE WGS84 COORDINATES

Having determined the adjusted position of stations in the ITRF94 system, the corresponding coordinates in the WGS84 datum can now be calculated. Although, the transformation parameters are not readily available, it can be achieved by applying the existing seven-parameter similarity transformations from ITRF94 to ITRF92, then, ITRF92 to WGS84 (NOAA, 1993).

Station	X	Y	Z
HKPO	-2408854.509	5391041.014	2403590.763
LHAS	- 106937.640	5549268.878	3139216.058
SHAO	-2831733.222	4675665.197	3275369.743
TAIW	-3024781.937	4928936.005	2681234.686
WUHN	-2267749.117	5009153.497	3221291.004
XIAN	-1735212.298	4976838.814	3580538.279

Table 4. Cartesian coordinates of each station in WGS84 datum. Results are in meters.

Table 4 shows the coordinates of the stations referring to WGS84 datum results of these transformations. The corresponding geodetic coordinates are given in Table 5.

Station	Latitude (d m s)	Longitude (d m s)	Height (m)
HKPO	22 17 2.607245	114 4 34.712044	114.0818
LHAS	29 39 26.442164	91 6 14.350910	3624.1839
SHAO	31 5 58.735135	121 12 1.604954	21.5446
TAIW	25 1 16.810693	121 32 11.560972	43.4138
WUHN	30 31 53.972397	114 21 26.145340	25.2831
XIAN	34 22 7.241095	109 13 17.376734	462.8793

Table 5. Geodetic Coordinates of Each Station.

When compared to the existing WGS84 coordinates for the HKPO station, the above results show discrepancies of 3.87 meters in height (referring to the top of the station), 0.0191 arcsecond in latitude (0.59m) and –0.0015 arcsecond in longitude (-0.05m). Most of these differences can be attributed solely to the inaccuracies of the WGS84 coordinates of the Hong Kong GPS network which are derived from a single fixed Doppler station.

CONCLUSION

We have demonstrated that the whole network is providing continuous baseline monitoring with standard deviation better than 1 cm over two months data. In particular, the coordinate standard deviations of the permanent DGPS station of the Marine Department of Hong Kong are better than 1cm for the horizontal component and 2 to 3cm for the height component. The results show that the data quality for the dual-band Trimble 4000SSE equipped station HKPO is performing well beyond the requirements of the Hong Kong Marine DGPS activities.

Since the WGS84 coordinates of the station have been obtained through the most accurately realized reference frame ITRF94 together with high precision baseline observations, they are capable of connecting the Hong Kong Datum to other datums in the region.

A pleasant by-product of this investigation is that the data will enable us to monitor Eurasian plate stability with accuracy comparable to the other existing GPS stations in the region.

ACKNOWLEGEMENT

We gratefully acknowledge the use of the software GAMIT provided by MIT of USA. This study is performed using the grants provided by the Area of Excellence Project, Faculty of Construction and Land Use, The Hong Kong Polytechnic University.

REFERENCES

Dong, D-N., and Y. Bock. 1989. GPS network analysis with phase ambiguity resolution applied to crustal deformation studies in California, *Journal of Geophysical Research*, 94, 3949-3966.

Feigl, K. L, D. C. Agnew, Y. Bock, D.-N. Dong, A. Donnellan, B. H. Hager, T. A. Herring, D. D. Jackson, R. W. King, S. K. Larsen, K. M. Larson, M. H. Murray, Z.-K. Shen. 1993. Measurement of the velocity field in central and southern California, *Journal of Geophysical Research*, 98, 21667–21712.

King, R.W and Y. Bock, 1995. Documentation of the GAMIT GPS software v. 9.5, *Mass Inst. Of Technology and Scripps Inst. of Oceanography.*

NOAA, 1993. Ephemeris Announcement, *National Geodetic Survey.*