J. Astron. Space Sci. 19(4), 367–376 (2002)

EVALUATION OF DATA QUALITY OF PERMANENT GPS STATIONS IN SOUTH KOREA

Kwan-Dong Park[†], Ki-Nam Kim, Hyung-Chul Lim, and Pil-Ho Park
Korea Astronomy Observatory, 61-1 Whaam-dong, Yuseong-gu, Daejeon, 305-348, South Korea
E-mail: kdpark@kao.re.kr

(Received October 17, 2002; Accepted November 21, 2002)

ABSTRACT

As of September 2002, there are more than 60 operational permanent Global Positioning System (GPS) stations in South Korea. Their data are being used for a variety of purposes: geodynamics, geodesy, real-time navigation, atmospheric science, and geography. Especially, many of the sites are reference stations for DGPS (Differential GPS). However, there has been no comprehensive and qualitative analysis published to evaluate the data quality. In this study, we present preliminary results of our assessment of the permanent GPS sites in South Korea. We have analyzed the multipath characteristics of each station using a quality-checking software package called TEQC. Another multipath analysis tool based on post-fit phase residuals was used to check the repeating patterns and the amount of the multipath at each site. The long-term stability of each station was analyzed using the root-mean-square (RMS) error of the estimated site positions for one year, which enabled us to evaluate the mount stability. In addition, the number of cycle slips at each site was derived by TEQC. Based on these series of tests, we compared the stability and data quality of permanent GPS stations in South Korea.

Keywords: GPS, TEQC, multipath, phase residuals

1. INTRODUCTION

Starting in the late 1990's, several governmental agencies began to install many permanent GPS tracking sites in South Korea, and the number of stations is over 60 as of September 2002. Many of the sites are used as reference stations for vehicle navigation in DGPS and Real-Time Kinematic (RTK) applications. Some of the sites are operated as geodetic-quality sites and their data are used for geophysical studies such as plate tectonics around the Korean Peninsula (Park et al. 2001). Certain hardware failures in the GPS receiver and antenna can cause serious errors in determining the site positions and the velocities derived from the position estimates. Especially, the geodetic GPS sites require a high-precision velocity determination at the accuracy level of 1 mm/year. To achieve this level of precision, it is mandatory to perform a careful maintenance and operation of the site. In addition, the importance of the reliable data becomes more evident in the real-time or near real-time applications because the wrong information about the reference station directly affects the regular user, causing critical positioning errors.

In this study, we have analyzed the data from every available GPS site in South Korea. We checked the number of cycle slips and the amount of pseudorange multipath on L1 (1575.42 MHz)

[†] corresponding author

and L2 (1227.60 MHz) carriers by running a program called TEQC on the observation RINEX (Receiver INdependent EXchange Format) files. We also processed the data with GIPSY-OASIS II software developed by the Jet Propulsion Laboratory (JPL) to estimate the site position. The post-fit residuals were analyzed to check their repeating patterns. The amount of the repeatability indicates the sidereally repeating error sources such as multipath and antenna phase center variations. The site velocity fitted from the time series of the site estimates was used to check the monument stability. We have found some problems at a couple of stations, and we studied possible error sources.

2. ANALYSIS TOOLS

2.1 TEQC

TEQC was designed and developed and is maintained by the University Navstar Consortium (UNAVCO) Facility. The program is named after its three main functions: Translation, Editing, and Quality Checking (Estey & Meertens 1999). With TEQC, one can extract a variety of information from a RINEX file. Some of the information we get are: the receiver clock slips, receiver cycle slips, site multipath, satellite elevation and azimuth angle, receiver clock drift, and receiver signal-to-noise ratios. Using linear combinations of the pseudorange and carrier phase observations, TEQC can also compute pseudorange multipath, ionospheric phase effects, and the rate of change of the ionospheric delay.

In this study, we used the number of cycle slips and pseudorange multipath indices (MP1 and MP2) as a tool to evaluate the data quality. The cycle slip is a receiver loss of tracking on carrier phases of L1 and L2. The phase and pseudorange measurements are modeled as (Estey & Meertens 1999):

$$\begin{aligned} L_i &= R + c(dt_r + dt_s) - I_i + N + m_i + n_i\lambda_i \\ P_i &= R + c(dt_r + dt_s) + I_i + N + M_i \end{aligned}$$

where

L_i = phase observable for frequency i (i.e. RINEX L1 or L2, converting to distance)
P_i = pseudorange observable for frequency i (i.e. RINEX P1 or P2)
R = geometric distance between the satellite and the antenna
c = speed of light
dt_r = receiver clock error
dt_s = satellite clock error
I_i = ionospheric range error for frequency i
N = neutral atmospheric delay
m_i = phase multipath for frequency i
M_i = pseudorange multipath frequency i
$n_i\lambda_i$ = integer wavelength phase ambiguity for frequency i

where the dual frequencies are 1575.42 MHz ($i = 1$) and 1227.60 MHz ($i = 2$) for GPS. The signs of the ionospheric range error terms are opposite due to the ionosphere being dispersive at GPS frequency and the pseudorange measurements traveling at the group delay velocity.

The two multipath indicators that we use are derived as (Estey & Meetens 1999):

$$MP1 \equiv M_1 - \left(1 + \frac{2}{\alpha - 1}\right) n_1\lambda_1 + \left(\frac{2}{\alpha - 1}\right) n_2\lambda_2 - \left(1 + \frac{2}{\alpha - 1}\right) m_1 + \left(\frac{2}{\alpha - 1}\right) m_2 \quad (1)$$

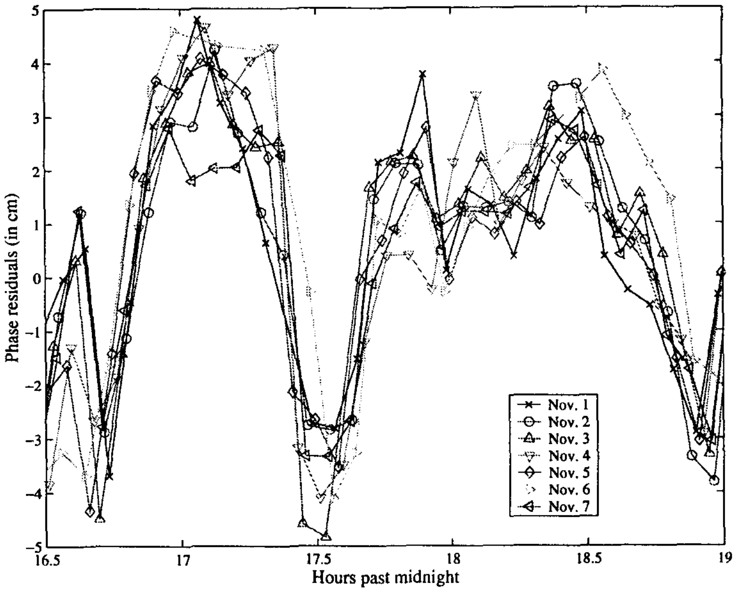

Figure 1. An example of repeating patterns of post-fit phase residuals between DAEJ and GPS satellite SVN 32.

$$MP2 \equiv M_2 - \left(\frac{2\alpha}{\alpha-1}\right) n_1\lambda_1 + \left(\frac{2\alpha}{\alpha-1} - 1\right) n_2\lambda_2 - \left(\frac{2\alpha}{\alpha-1}\right) m_1 + \left(\frac{2\alpha}{\alpha-1} - 1\right) m_2 \quad (2)$$

where α is defined as f_1^2/f_2^2. The bias terms (the second and third terms in Equations (1) and (2)) are caused by the phase ambiguities and are assumed to be a constant unless there is a slip in the tracking of L1 or L2. Hence, in practice, the 'DC' component of MP1 and MP2 is removed, and only the root mean square variation of these linear combinations is reported (Estey & Meertens 1999). There is also the additional effect of the phase multipath, but this is much smaller in magnitude than the P-code multipath.

2.2 GIPSY-OASIS II

The GPS data were processed with GIPSY-OASIS II (Webb & Zumberge 1993) developed by JPL. We used the standard precise point-positioning technique, which takes precise GPS satellite positions and satellite clock corrections from a global analysis. Data from each station are analyzed by estimating receiver-specific parameters with receiver-specific data; satellite parameters are held fixed at their values determined in the global solution (Zumberge et al. 1997). In the precise point-positioning mode of GIPSY-OASIS II, values for parameters representing non-fiducial satellite orbits and clocks are fixed in the estimation process. Thus, the estimated site positions are in a loosely constrained reference frame (e.g. a non-fiducial frame). The estimated site positions are then transformed into the International Terrestrial Reference Frame (ITRF) 2000 system using JPL-provided transformation files. The non-fiducial approach (Blewitt 1998, Heflin et al. 1992) allows us to transform the station position estimates to any desired reference frame.

2.3 Post-fit phase residuals

Because the geometry between the GPS satellite constellation and a specific receiver-reflector

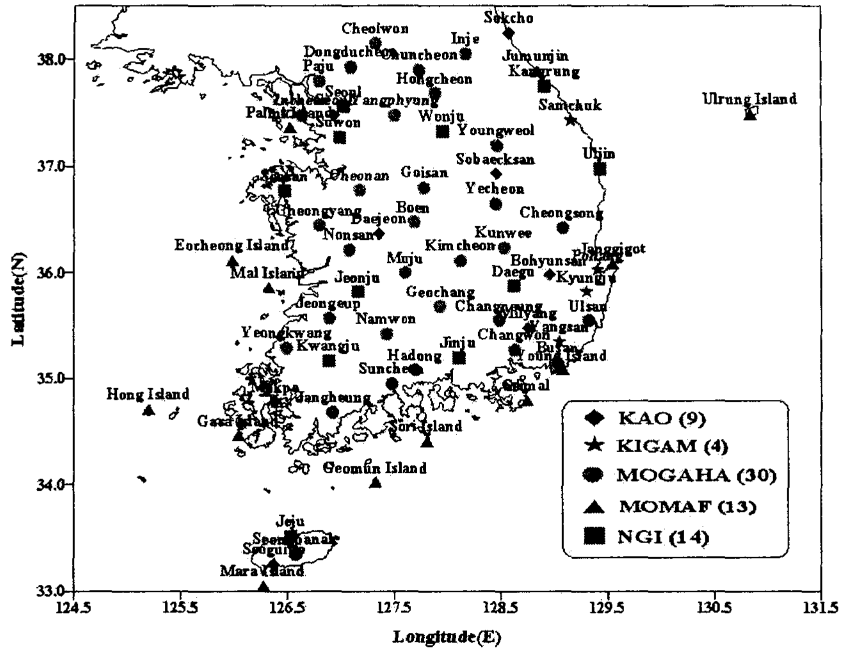

Figure 2. Map of Korea GPS Network sites with their responsible agencies. All of them are continuously operating permanent GPS stations.

location repeats each sidereal day ($23^h 56^m 4^s$), the geometry-dependent errors such as multipath and the phase center offsets show the same pattern for consecutive days. However, daily GPS position estimates are usually based on the solar day ($24^h 0^m 0^s$). When several days of GPS data are processed, this $3^m 56^s$ ($= 236^s$) delay in time is manifested in the form of repeating patterns of the post-fit residuals.

Post-fit residuals are the difference between the actual observations and the computed or modeled observations. In the case of a perfect model, the residual would be zero. In practice, however, dynamic force and measurement model errors affect the estimated parameters. Thus post-fit residuals can indicate the presence of un-modeled effects in the observations. Incorrectly modeled tropospheric mapping function, multipath, radio interference and radome effects can contribute to the variations of the residuals.

We shifted the post-fit residuals by $3^m 56^s$ each day for alignment with sidereal time to average out the site-specific errors other than the sidereally repeating errors. Summed and averaged at each epoch, the post-fit phase residuals can be plotted to show the repeating pattern (Park 2000). The residuals were extracted for each pair of a GPS satellite and a GPS station. Summing all satellite-station pairs and averaging over several days enable us to obtain the site-specific sidereally repeating errors.

An example plot is shown in Figure 1. The phase residuals in Figure 1 were obtained between the IGS site DAEJ and GPS SVN 32 for seven days in November 2000. The repeating patterns can be easily seen from the figure. Especially the patterns show an excellent repeatability in the hours from 16:45 through 17:45. Another set of perfect match is observed in the later hours in the plot.

Table 1. Number of permanent GPS sites in South Korea and data availability for the period of May 2000 through April 2001. The GPS data from KIGAM and NGI were not available to us as of September 2002.

Responsible Agency	Number of sites	Number of sites with publicly available data	Number of sites analyzed
KAO	9	9	5
KIGAM	4	0	0
MOGAHA	30	30	29
MOMAF	13	13	6
NGI	14	0	0

When the patterns do not repeat, we conclude the sidereally repeating errors are not dominant in the corresponding azimuth and elevation angles.

3. GPS DATA SETS

We have collected every data we could get from each responsible agency. Table 1 lists the responsible agencies with data availability. Korea Astronomy Observatory (KAO) has a total of nine sites. Their data are used for studies on geodynamics and meteorology. Also, they are providing real-time DGPS and RTK service. Korea Institute of Geoscience and Mineral Resources (KIGAM) has four sites and its data are used for geological studies within a specific area of Korea. Ministry of Maritime Affairs and Fisheries (MOMAF) is operating a total of 13 sites: eight of them are reference stations and the rest are monitoring stations. MOMAF reference stations are sending out DGPS information for maritime navigation. Ministry of Government Administration and Home Affairs (MOGAHA) currently has 30 sites. They are mainly used for generating cadastral maps. National Geographic Institute (NGI) is operating 14 sites for land survey. The map of all permanent sites is shown Figure 2.

The data sets analyzed for this study were taken from May 2000 through April 2001. Instead of processing the whole year's worth of data, we picked the beginning seven days each month. Then we used TEQC to compute the multipath indices (MP1 and MP2) and the number of cycle slips. We also processed the data with GIPSY-OASIS II to get post-fit phase residuals and the position estimates.

We found a couple of problems in the way they name their RINEX files. The RINEX files from MOMAF sites did not have correct header information. They did not list 'Marker Name', 'Marker Number', 'Observer/Agency', and etc. in the RINEX header. In addition, the RINEX files should be named like *SSSSDDDX.YYO* for an observation RINEX file. The *SSSS* is a four-character station ID name, and *DDD* is the day number of the year, and *YY* is the year. In the place of *X*, it is an accepted convention to use "0" for daily RINEX files and lower case alphabet characters ("a" through "x") to denote the hour numbers: e.g. "a" for the first hour and "x" for the last hour of the day. However, the RINEX files of MOMAF stations do not conform to these specifications. Especially, they use the full name of the site location (e.g. Jumunjin) in their filenames. Thus, we picked four-character station names by ourselves (refer to Table 2).

Values of MP1 and MP2, and the number of cycle slips from seven days each month were averaged to compute monthly averages. Then monthly averages were used to compute a yearly average for each site. The reason to compute monthly averages was to check if we could observe any seasonal changes. Park (2000) could observe an annual trend in the time-shifted post-fit phase

Table 2. Results of TEQC tests (MP1, MP2, and number of cycle slips) and mean RMS of the time-shifted post-fit phase residuals for each site. MP1 and MP2 are in meters, and post-fit phase residuals are in cm. The number of cycle slips is per 1000 observations.

	Site ID	Location	MP1	MP2	Cycle Slips / 1000	Post-fit Phase Residuals
KAO	DAEJ	Daejeon	0.29	0.85	1.59	0.50
	JEJU	Jeju Island	0.20	0.59	1.12	0.39
	MKPO	Mokpo	0.21	0.86	1.67	0.37
	MLYN	Milyang	0.22	0.66	1.16	0.34
	SKCH	Sokcho	0.26	0.81	1.13	0.40
MOGAHA	BOEN	Boen	0.22	0.63	1.17	0.48
	CHAN	Cheonan	0.21	0.52	0.98	0.44
	CHCN	Chuncheon	0.21	0.52	0.88	0.51
	CHJU	Jeju Island	0.30	0.86	2.48	0.56
	CHLW	Cheolwon	0.22	0.53	0.92	0.45
	CHNG	Changneung	0.21	0.54	0.98	0.48
	CHSG	Cheongsong	0.23	0.51	0.95	0.50
	CHYG	Cheongyang	0.21	0.51	0.99	0.49
	DOND	Dongducheon	0.22	0.58	0.86	0.47
	GOCH	Geochang	0.21	0.54	0.94	0.46
	GSAN	Goisan	0.22	0.61	0.88	0.48
	HADG	Hadong	0.22	0.57	1.17	0.47
	HONC	Hongcheon	0.23	0.59	0.95	0.48
	INCH	Incheon	0.22	0.58	0.75	0.46
	INJE	Inje	0.22	0.57	0.92	0.48
	JUNG	Jeongeup	0.24	0.65	1.30	0.49
	KIMC	Kimcheon	0.22	0.54	0.97	0.49
	KUNW	Kunwe	0.27	0.73	1.49	0.57
	MUJU	Muju	0.30	0.69	1.00	0.49
	NAMW	Namwon	0.21	0.50	1.04	0.50
	NONS	Nonsan	0.25	0.55	1.06	0.50
	PAJU	Paju	0.23	0.63	0.97	0.54
	PUSN	Busan	0.22	0.61	1.26	0.47
	SONC	Suncheon	0.21	0.53	1.04	0.47
	WOLS	Ulsan	0.26	0.63	1.13	0.48
	YANP	Yangphyung	0.24	0.59	0.94	0.55
	YECH	Yecheon	0.22	0.51	0.95	0.52
	YONK	Yeongkwang	0.21	0.48	0.97	0.55
	YOWL	Youngweol	0.23	0.53	0.95	0.49
MOMAF	EOCH	Eocheong Island	0.30	0.89	2.44	0.46
	GEOM	Geomun Island	3.21	4.31	83.33	
	JUMN	Jumunjin	0.24	0.79	3.21	0.44
	MARA	Mara Island	0.23	0.76	5.15	0.40
	PALM	Palmi Island	0.28	1.11	2.90	0.51
	YEON	Young Island	0.32	0.86	3.16	0.40

residuals at many sites. This was believed to be caused by an increased amount of water vapor in the warm season which could not be accurately modeled by available wet tropospheric models.

4. RESULTS

The results of this study are described here in two sections. The first section will discuss the pseudorange multipath indices MP1 and MP2 and the number of cycle slips. These three quantities are the output from TEQC. Another set of results in the first section is based on the mean RMS of the time-shifted post-fit phase residuals. In the second section, we will discuss the site velocities obtained from post-processing the GPS data using GIPSY-OASIS II.

4.1 TEQC and mean RMS of the time-shifted post-fit phase residuals

The GPS antenna type used by every KAO site is a Trimble choke ring antenna (Trimble Model Number 29659.00). All the stations operated by MOGAHA and MOMAF are equipped with Trimble Micro-centered antennas with ground planes (Trimble Model Number 33429.00). Every station we analyzed has the same kind of receiver, Trimble 4000SSI. Because every site has the same kind of receiver, we can objectively evaluate the data quality based on the multipath indices (MP1 and MP2). The reason is because values of MP1 and MP2 are dependent on the receiver and the receiver firmware (Park 1998). In addition, those sites equipped with the same kind of antenna should be equally affected by phase center variations because the variations are dependent on the antenna type. Thus, the differences in the mean RMS of time-shifted post-fit phase residuals can be attributed to the multipath.

We listed the values of MP1 and MP2 and the number of cycle slips in Table 2. The number of cycle slips detected by TEQC is converted to the number of cycle slips per 1000 observations. From Table 2, the pseudorange multipath errors are 20-30 cm on L1 and 50-80 cm on L2. Values of MP1 and MP2 are quite acceptable except for a few cases. Notably, the MP1 and MP2 values of the MOGAHA sites are relatively lower than those for the KAO and MOMAF stations. The mean RMS of the time-shifted post-fit residuals ranges from 0.34 to 0.57 cm. The mean RMS values of the residuals are lower for the KAO sites. The reason is because every KAO station is equipped with Trimble choke ring antennas while the MOGAHA and MOMAF antennas do not have choke rings. It is well known that choke rings are very effective in suppressing the multipath interference.

The number of cycle slips from the MOGAHA sites is less than one on the average sense. However, a significantly more cycle slips were detected from CHJU, which is a MOGAHA site located in Jeju Island. At CHJU, the mean RMS value of the time-shifted post-fit residuals was also one of the highest among the MOGAHA sites. In addition, CHJU shows a significantly higher value of MP2 (0.86) than the other MOGAHA sites (The average MP2 value of MOGAHA sites was 0.58). Because CHJU had the highest number of cycle slips and one of the highest RMS values of the time-shifted post-fit residuals, we believe there is some problem with the site. Based on our investigation, we suspect that the trees nearby the CHJU tracking site are causing the problem.

The MOMAF site in Geomun Island (GEOM) exhibits an extremely strange behavior. The MP1 and MP2 values of GEOM are exceptionally high: the averages are 3.21 and 4.32 for MP1 and MP2, respectively. These values are about an order of magnitude higher than the averages of the MOGAHA sites. In addition, the number of cycle slips is about 83 out of 1000 observations. Due to the so many cycle slips, GIPSY-OASIS II could not process the data at all. It stopped in the pre-processing mode of the data processing because there were less than 10 good points in each orbit arc (Webb & Zumberge 1993). We believe the possible causes for this peculiar behavior should be related to the unstable monument structure, so an immediate attention and investigation is required. In general, more cycle slips are observed at MOMAF sites than KAO and MOGAHA sites.

4.2 GPS-determined site velocities

As described earlier, we have processed the beginning seven days each month from May 2000 through April 2001. The estimated site positions were expressed in the local north, east and up components (Usually this reference system is referred as the NEV frame). The local NEV position estimates were de-meaned, and then a linear fit was performed to compute the three-dimensional site velocity. Because of the short length of the data span, we did not consider the vertical velocity in this study. For a meaningful interpretation of the uplift velocity, we need to have at least two years

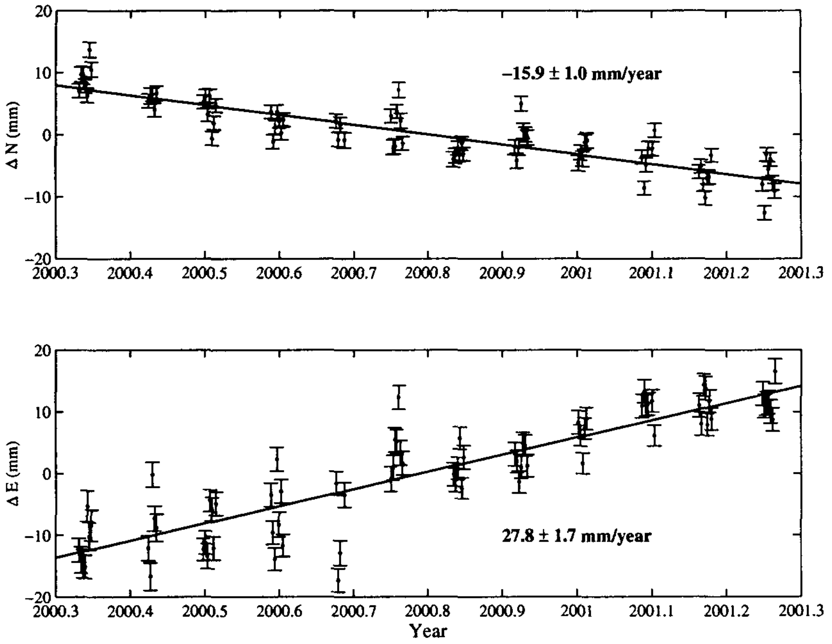

Figure 3. North and east components of site estimates for CHCN after subtracting the mean values of the north and east coordinates. The velocity was determined by fitting a linear velocity to the data. The velocity is denoted in mm/year with the 1-σ error. CHCN is a MOGAHA site in Chuncheon.

worth of continuous daily height estimates. Due to the same reason, we did not attempt geophysical interpretations based on the horizontal velocities obtained here. Figure 3 shows an example of the north and east components of GPS-determined positions of a MOGAHA site in Chuncheon (CHCN). The derived velocity in Figure 3 implies that the site is moving at 3.2 cm/year in the southeast direction toward the Japanese islands. Because we have processed only seven days each month, the data points (i.e. site position estimates) in the figure is not continuous.

The horizontal velocities (in mm/year) of every site we analyzed are listed in Table 3. The north and east velocities are shown with their 1-σ errors. We also computed the RMS errors about the linear fit. Since the site positions are transformed into ITRF 2000, the site velocities in Table 3 are absolute velocities, not relative velocities with respect to a certain reference (e.g. fiducial) station. The MOMAF sites show relatively high RMS values in both directions. The highest RMS of 9.2 mm was observed at YEON located in Young Island in Busan. A possible reason for higher errors at the MOMAF sites is the high wind. All of the MOMAF sites are exposed to the high wind because they are located either in the coastal region or on the island (Four out of five MOMAF sites in Table 3 are located on the island). Another possible explanation of the high RMS values observed at YEON is that there is a radar transmitter near the site. Because the GPS antenna is located less than 50 meters away from the facility, it must be adversely affected by the strong radar signals. Also, the sky visibility at YEON is not excellent due to the nearby mountain.

We found that abnormal velocities were observed at a MOGAHA site in Cheonan (CHAN). The

Table 3. Site velocities in the local north and east directions. The error in the velocity is 1-σ error. The RMS error was computed with respect to the linear fit. The site locations are listed in Table 2.

Agency	Site ID	North Velocity		East Velocity	
		V_N (mm/year)	RMS (mm)	V_E (mm/year)	RMS (mm)
KAO	DAEJ	-13.0±1.2	3.1	25.7±1.9	4.8
	JEJU	-10.5±1.7	3.4	22.1±2.8	5.4
	MKPO	-9.70±2.8	3.8	32.2±3.3	4.5
	MLYN	-11.6±1.4	3.3	30.1±2.1	4.9
	SKCH	-16.9±1.2	2.8	29.0±2.3	5.4
MOGAHA	BOEN	-15.2±1.1	2.8	32.9±2.6	6.5
	CHAN	-28.4±2.3	3.9	9.3±3.9	6.7
	CHCN	-15.9±1.0	2.6	27.8±1.7	4.3
	CHJU	-11.4±1.4	3.2	24.6±2.2	5.1
	CHLW	-17.1±1.1	2.7	28.3±2.3	5.7
	CHNG	-10.2±1.2	2.9	33.0±2.3	5.2
	CHSG	-15.3±1.2	2.7	23.9±1.8	4.3
	CHYG	-13.2±1.4	3.4	29.7±2.0	5.2
	DOND	-15.0±1.2	2.8	25.2±2.2	5.3
	GOCH	-13.5±1.2	3.0	28.1±2.0	5.0
	GSAN	-15.0±1.0	2.6	26.7±2.2	5.6
	HADG	-19.3±1.5	3.5	35.7±2.3	5.3
	HONC	-15.1±1.2	2.7	25.6±1.9	4.5
	INCH	-16.8±1.3	3.0	19.3±2.0	4.6
	INJE	-15.3±1.1	2.8	28.0±1.8	4.4
	JUNG	-19.2±1.4	3.4	21.0±2.5	6.1
	KIMC	-15.9±1.2	2.9	28.6±2.1	5.1
	KUNW	-13.6±1.2	2.8	26.0±2.3	5.4
	MUJU	-15.6±1.3	3.0	24.3±2.1	4.6
	NAMW	-16.7±1.2	2.7	28.1±1.9	4.5
	NONS	-15.1±1.5	2.8	24.6±2.6	4.8
	PAJU	-12.1±1.1	2.7	25.6±2.1	5.2
	PUSN	-29.2±1.5	3.9	20.8±1.9	4.8
	SONC	-12.2±1.3	3.1	23.3±2.0	5.0
	WOLS	-13.7±1.3	2.9	25.4±1.8	4.0
	YANP	-17.0±1.3	2.6	22.2±2.1	4.3
	YECH	-15.5±1.1	2.8	24.2±1.8	4.5
	YONK	-20.2±1.4	3.3	16.4±2.2	5.4
	YOWL	-15.4±1.1	2.3	24.1±2.1	4.3
MOMAF	EOCH	-19.2±1.5	3.7	26.8±3.0	7.7
	JUMN	-18.6±1.6	3.2	22.3±2.9	5.9
	MARA	-19.1±2.3	4.8	31.4±3.5	7.0
	PALM	-16.9±1.4	3.7	25.7±2.7	6.7
	YEON	-28.2±2.5	5.2	24.3±4.4	9.2

east velocity was 9.3 mm/year, which is only about one third of the average east velocity of ~27 mm/year. In addition, its north velocity was -28.4 mm/year, which is almost twice higher than the average north velocity of ~15 mm/year. We believe that the unstable monument at CHAN is causing the unusual velocity because an unstable monument can make the antenna to move or tilt very slowly. However, a through investigation is required to find out the exact reason for the abnormal behavior at the site.

From Table 3, we conclude that most of the KAO and MOGAHA sites are qualified as high-precision geodetic GPS stations. By processing many years of data, we should be able to use those sites for geophysical studies such as plate tectonics and seismology. However, we should not ignore that a couple of the MOGAHA sites showed abnormal behaviors, which might be possibly resulted from the unstable monument or the unfavorable environment at the site. Thus, we should carefully evaluate the performance of each site before its data can be used in high-precision GPS applications.

5. CONCLUSIONS AND FUTURE WORK

Several quality-checking tools were introduced in this study. TEQC is readily available at no cost, and it is easy to implement because one can run the program on the RINEX file without any kind of pre-processing. Another advantage is that the quality-checking procedure using TEQC can be fully automated. We have used other analysis tools such as the mean RMS value of the time-shifted post-fit residuals to evaluate the data quality of permanent GPS sites. Based on these tools, we found several problematic sites. We observed too many cycle slips at one of those sites, so the data could not be post-processed with GIPSY-OASIS II. The site velocities computed from the three-dimensional site positions were used to evaluate the site stability. We found that the MOMAF stations show slightly higher error values, and part of this is believed to be the high wind environment to which the MOMAF sites are exposed.

The series of tests we did should help the responsible agency to better operate and maintain their sites. In addition, we are currently developing an automated quality-checking procedure, which will promptly alarm us of the abnormal outage of data flow or hardware failures. We could not obtain the GPS data from KIGAM and NGI. We hope their data be available to us in the near future so that we can analyze them and evaluate their quality.

ACKNOWLEDGMENTS: We like to thank MOGAHA and MOMAF for sharing their GPS data with us. This work was supported by Ministry of Science and Technology via grant M2-0104-11-0012-01-A02-06-001-2-0.

REFERENCES

Blewitt, G. 1998, in GPS for Geodesy, eds. P. J. G. Teunissen & A. Kleusberg (New York: Springer), pp.231-270

Estey, L. H., & Meertens, C. M. 1999, GPS Solutions, 3, 42

Heflin, M. B., Bertiger, W. I., Blewitt, G., Freedman, A. P., Hurst, K. J., Lichten, S. M., Lindqwister, U. J., Vigue, Y., Webb, F. H., Yunck, T. P., & Zumberge, J. F. 1992, GRL, 19, 131

Park, K.-D. 1998, EOS Transactions, Supplements, 79(40), F183

Park, K.-D. 2000, Ph.D. Thesis, The University of Texas at Austin

Park, P. H., Chwae, U., Ahn, Y. W., & Choi, K. H. 2001, Earth, Planets and Space, 53, 937

Webb, F. H., & Zumberge, J. F. 1993, An introduction to the GIPSY/OASIS-II (Pasadena: JPL)

Zumberge, J. F., Heflin, M. B., Jefferson, D. C., Watkins, M. M., & Webb, F. H. 1997, JGR, 102(B3), 5005