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Quality analysis of the campaign GPS stations observation in Northeast and North China

Yaxuan Hu, Lin Cheng, Xiong Wang*

Second Monitoring and Application Center, China Earthquake Administration, Xi'an 710054, China

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ABSTRACT

TEQC is used to check the observations quality of 173 GPS campaign stations in the Northeast and North China. Each station was observed with an occupation of 4 days. The quality of the 692 data files is analyzed by the ratio of overall observations to possible observations, *MP*1, *MP*2 and the ratio of observations to slips. The reasons for multipath and cycle slips can be derived from the photos taken in the field. The results show that the coverage of trees and buildings/structures, and the interference of high-voltage power lines near the stations are the main reasons. In a small area, the horizontal velocity field in the period 2011–2013 is exemplified, where the magnitudes and directions of the 4 stations' rates are clearly different with that of other stations. It seems that the error caused by the worse environment cannot be mitigated through post processing. Therefore, these conclusions can help the establishment of GNSS stations, measurements, data processing and formulating standards in future.

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1. Introduction

The large North China is one of the most important regions with strong earthquakes in mainland China, where several $M \geq 7$ earthquakes occurred in the history. The disasters caused millions of deaths. But now, this area not only has become the most populated and developed area in China, but also it has been one of the key earthquake monitoring regions for many years. Especially, the seismic activities become more active after the 2008 Wenchuan earthquake and the 2011 Japan earthquake. A series of medium and strong earthquakes occurred frequently after these earthquakes. The co-seismic horizontal displacement is from millimeter to centimeter and the station with the maximum movement (about 35 mm) after the Japan earthquake [1]. To acquire the recent crustal horizontal movement features, the intensive GPS stations have been constructed. Most of them were built and observed since 1999. Among them, the 173 GPS stations

* Corresponding author.
E-mail address: happy_hu6921@sina.com (Y. Hu).
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located in 38.80°–53.49°N, 115.17°–134.29°E were observed and photographed in 2015 by the Second Crust Monitoring and Application Center (SCMAC), China Earthquake Administration (CEA).

There is no doubt that a good quality of the observation data can guarantee the correct analysis and explanation. The continuous stations established with high quality have been studied by some researchers [2–4]. Although the campaign stations have been established a long time, the studies about them are rare. The data quality of the repeated observation in some stations is weakened by the changing surroundings. The multipath effect and the cycle slips which always cause errors should be considered.

The GPS measurement errors come from the transmitting process of the satellite signals. The errors of ionosphere refraction and troposphere can be reduced through some models, whereas the multipath effect becomes a major error source because it is connected not only to the satellite's space structure [5], the signals direction and reflection coefficients, but also to the distance between the reflector and observation station. There is no more perfect model now. The error varies with the surface property of the reflection around antenna. The reflection could be grounds, hills, buildings and so on [6]. The experiments confirmed that the error of the pseudorange multipath could reach meter level in the general reflections, and about 4–5 m affected by the highly reflective objects. Furthermore, the lock-lose and cycle slips occur frequently. It would cause about 5 cm periodical errors in the distance by the phase deviation, and it would be ±15 cm in the elevation [7]. Therefore, the multipath effect cannot be ignored in the precise GPS navigation and measurement [8]. Some advices and methods are proposed. The location with the suitable and better surrounding should be given priority to consideration and selection [9], such as above elevating angle 10°–15°, no barrier and high-voltage line around the sites, the choke ring antenna and prolonging the observation time. In fact, the stations couldn't be selected with the ideal environments. Moreover, the environments of some stations could become worse in time and further influence the data quality.

The cycle slip is a unique and key issue in the carrier phase measurement which determine the integer ambiguity resolution. It could be caused by many reasons [10]. The common reason is that the satellite signals are interrupted by the tall buildings, hills, trees and so on. The second reason is that the low signal-noise ratio is caused by the dramatic ionosphere changes or the low satellite elevation. The third one is the low signal-noise ratio was caused by the electromagnetic interference near the station, multipath effect, and degradation of receiver performance. All the above-mentioned issues show the cycle slips are related to the observation surroundings and the performance quality of the receivers.

In this paper, the quality of 173 stations, 692 files observed in 2015 and other times are checked and analyzed. The influences are summarized from the reports of checking quality and the photos taken in the field. The conclusion will help establish GPS stations, select data files for post processing and formulate the related technical standards, and so on.

2. Quality checking and the station surrounding analysis

2.1. *TEQC introduction*

TEQC was designed and developed, and also it is maintained by the University Navstar Consortium (UNAVCO) facility in Boulder, Colorado. The program is named after its three main functions—translating, editing, and quality checking (QC). It allows the user to translate from the binary receiver format to the standard Receiver Independent Exchange (RINEX) format, to edit existing RINEX files, and to quality-check the data before post processing. Here, we check the quality using the QC portion [11], which is a process for quality checking static and kinematic dual-frequency GPS and GLONASS. The basic step is that linear combination (LC) of the pseudorange and carrier phase observations are used to compute (1) $L1$ pseudorange multipath for C/A- or Pcode-observations, (2) $L2$ pseudorange multipath for Pcode-observations, (3) ionospheric phase effects, and (4) the rate of change of the ionospheric delay. Information about the receiver clock slips, receiver cycle slips (receiver loss of tracking of $L1$ and/or $L2$), site multipath, satellite elevation and azimuth angles, receiver clock drift, receiver signal-noise ratios and other useful parameters and tracking statistics is written to a summary file. The QC report is called *.S which gives the main useful components related to the stations surroundings and data quality. $MP1$, $MP2$ and *o/slps* (complete observation/slips above 10° elevation) are always collected and studied. $MP1$ evaluates the pseudorange multipath and $MP2$ shows the pseudorange multipath and the noise intensity of the receivers. *o/slps* is always represented as CSR, which can be calculated with the formula:

$$CSR = \frac{1000}{o/slps}$$

The QC results show $MP1$, $MP2$ and CSR of two-thirds of International GNSS Service (IGS) stations were less than 0.5, 0.75 and 10 respectively [12]. In addition, the percentage of the observations (complete observation/possible observation) above 10 degrees elevation in the paper could reveal the real conditions of the stations. According to the provisions of Crustal Movement Monitor [13], the percentage of the GPS reference stations should be more than 85%, $MP1$ and $MP2$ should be less than 0.5 m. The percentage of the GPS campaign stations should be more than 80%.

2.2. *QC the GPS stations in Northeast China and some areas of North China*

The GPS stations in Northeast China and some areas of North China were observed again by SCMAC in 2015. The location of GPS stations is shown in Fig. 1. The stations were established at the end of the last century. Seven continuous stations were constructed with higher technical request based on the provisions [9]. The 2015 observations were carried out with the receiver of LEICA GX1230, TPS NET – G3A, and TPSTPSCR. G3 choke ring antenna. Each station was observed more than 23 h each day with an occupation of 4 days.

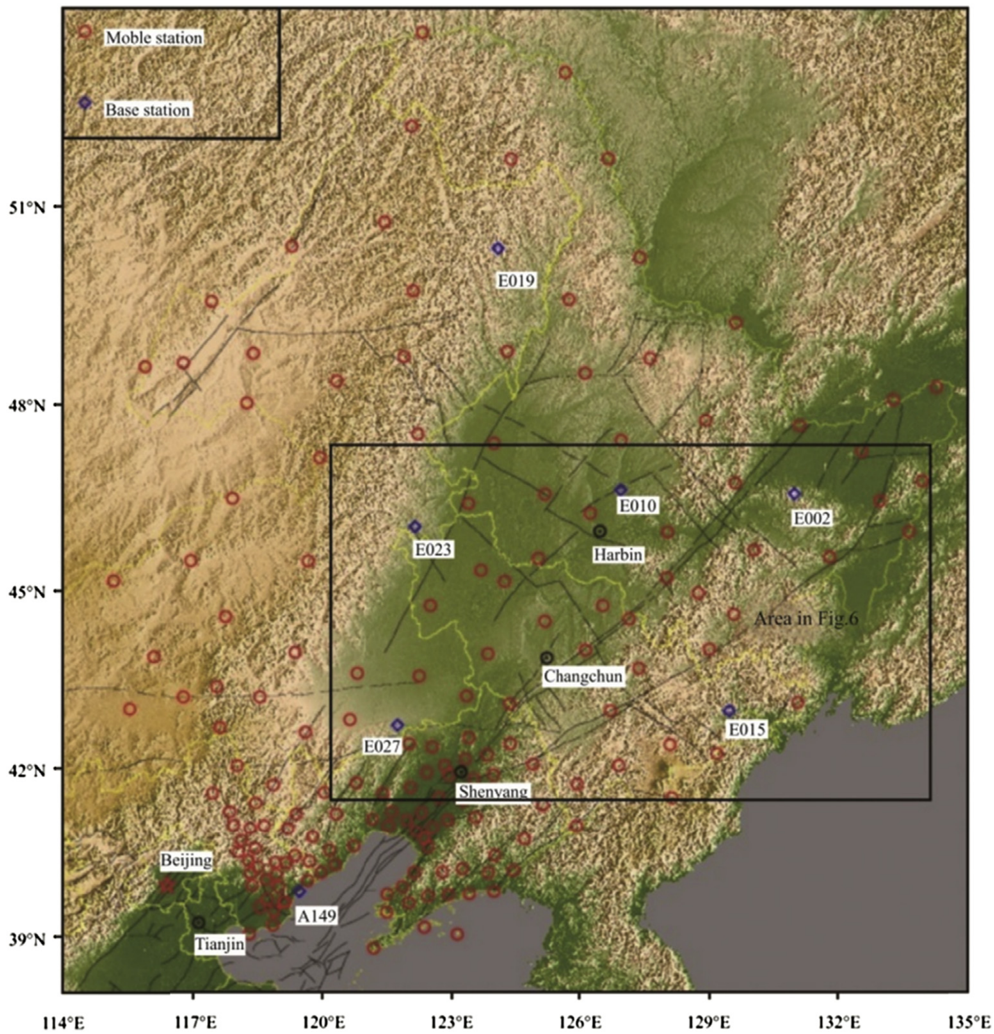

Fig. 1 – Distribution of the GPS stations (◇ continuous station, ○ campaign station).

After quality checking with TEQC, the statistics of the percentages are shown in Fig. 2, which illustrates the percentages of the most observations are more than 85% (665 files, more than 96% of the total stations). The percentages of the 7 stations [E010, E016, E022, E002, E006, E036 and A145 (27 files)] are less than 85%, which are shown in Table 1.

Table 1 – Percentages of the observations.

Items	Percentages		
	70%	70%–80%	80%–85%
Number of files	4	12	11
Stations	E010	E016/E022/E002	E006/E036/A145

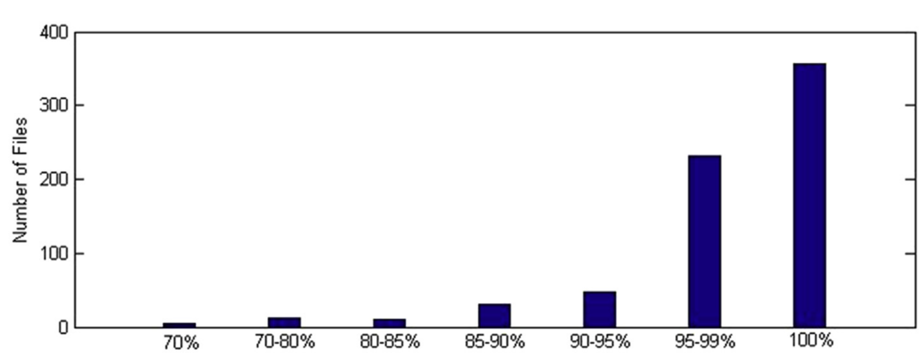

Fig. 2 – Percentages of all the observations.

According to the standard of $CSR < 10$, $MP1 < 0.5$, $MP2 < 0.75$ [3], we check the qualities. The results show 34 stations (130 files, $MP1 > 0.5$) and 17 stations (62 files, $MP2 > 0.75$) cannot meet the standard. They are divided into three classes to do the statistical analysis.

(1) $MP1/MP2 > 1.00$ is shown in Table 2. The station photos which reveal the bad surroundings are shown in Fig. 3.

Table 1 and Fig. 3 illustrate three quarters of the stations with bad quality mainly because the surrounding trees. Other 3 stations are mainly affected by the buildings and structures. The observation percentages of 6 stations (except E036) are less than 85% (Table 1). The percentage of E010 is the smallest which is affected by the tall buildings in two directions. The percentages of E016, E002 and E022 are less than 80%, because the trees coverage is large. The data quality of E022 and A145 has been affected severely by more coverage of the trees with rich leaves and they have the larger multipath ($MP1$, $MP2 > 2.00$) than others. The percentages of the rest of 12 stations with less coverage are more than 80%. E002 and E010 were built as continuous stations in 1998. According to the specification [2], the basic pillars should be longer than 2 m and shorter than 5 m above the ground, and the antenna should be higher than 350 mm above the roof. By analyzing the environments of the two stations in 2015, it cannot meet the requirement of a good observation condition.

(2) $MP1/MP2$ being 0.7–1.00 are shown in Table 3. The photos revealing the bad surroundings are shown in Fig. 4.

Table 3 and Fig. 4 illustrate half of the stations are shaded by the trees. Other 3 stations are affected by the reflection of the buildings and/or structures. The observation percentage of E036 is less than 85%. It could be affected by the tall buildings in one direction. E035 and E007 are affected by the smaller structures. Though E015 was built as continuous stations in 1998 based on the specification [2], it has been affected by the trees.

(3) CSR of E022 and E020 are more than 10. E020 are affected by the trees. Combining the study on $MP1$, $MP2$, the statistics of the stations with $CSR > 3$ in more than 1 day are shown in Table 4. The photos of E020 and A121 are shown in Fig. 5.

Table 4 suggests that there are 4 stations (9 files) with $CSR > 10$. The CSR of E022 and E020 are greater than 10 in all 4 days, and E022 has unqualified $MP1$, $MP2$ and smaller percentage. The $MP1/MP2$ of E020 are 0.52–0.59 and 0.59–0.7 respectively, which are slightly larger than the provisions [9]. The percentage of E020 is 89–92%. The CSR of A145 and A121 are larger than 10 in only one day. There is a high-voltage power line near A121. Figs. 3–5 show that the cycle slips may be caused by the interference around the stations, such as trees, woods and high-voltage line.

2.3. An example of the velocities affected by data quality

In order to analyze the influence of the changing surroundings on the data quality and the value of the velocity, here we give an example shown in Fig. 6. This example illustrates the velocities of some GPS stations in Northeast China. The velocities are calculated by GAMIT/GLOBK software which has some useful modules to improve the precision, such as Autcln in the data editing [14,15]. Autcln uses the residuals written to the C-file by model, performs automatic editing, and writes an output C-file with outliers removed, cycle-slips repaired, and extra bias flags inserted for slips that cannot be reliably repaired. The bias flags over large gaps could be removed based on a chi-square rest, or the unrepaired slips could be calculated as unknown parameters. Moreover, some thresholds are given for data deletion. The Nsigma criterion can be used to edit the phase residuals. LC residuals that are less than Nsigma will be flagged. If a station's Root Mean Square (RMS) is greater than max RMS, its data will be completely removed from the solution. Therefore, the gross error could be eliminated in the data processing. From the photos and the stations descriptions, their stabilities are checked and recognized. So the velocities are at a same precision level. Furthermore, the precisions are random and will achieve the precision requirement after post processing. Fig. 6 shows obviously that the horizontal rates become larger from west to east because of the 2011 Japanese earthquake, which is

Table 2 – $MP1/MP2 > 1.00$.

No.	Station	MP1 (m)				MP2 (m)				Percentages of observations (%)				Reflections
1	A126	1.08	1.11	1.15	1.07	1.38	1.28	1.18	1.35	92	92	92	92	Trees
2	A145	2.14	2.22	2.22	2.29	2.39	2.60	2.40	2.59	84	84	85	83	Trees
3	E006	1.59	1.4	1.49	1.59	2.04	1.65	1.81	1.87	82	83	83	83	Trees
4	E016	1.37	1.38	1.38	1.25	1.52	1.45	1.39	1.45	76	75	75	74	Trees
5	E022	2.43	2.19	1.90	1.81	2.76	2.84	2.47	2.43	77	77	76	75	Trees
6	E043	1.27	1.15	1.27	1.17	1.21	1.17	1.39	1.33	89	89	89	89	Trees
7	E309	0.82	0.81	0.81	0.88	1.03	0.98	1.02	0.91	92	92	92	91	Trees
8	EB02	1.29	1.13	1.14	1.16	1.44	1.62	1.41	1.49	89	85	90	90	Trees
9	E002	0.94	1.14	1.15	1.00	0.94	1.05	1.35	1.16	77	78	78	79	Trees
10	E038	1.06	0.96	1.08	1.03	1.01	1.00	1.05	1.13	85	85	86	85	Buildings
11	E010	1.07	1.12	1.26	1.20	0.98	0.98	0.99	0.99	62	62	62	62	Structures
12	E040	1.17	1.28	1.20	1.18	1.30	1.28	1.13	1.26	87	86	86	86	Structures

Fig. 3 – Stations and their surroundings (*MP1*/*MP2* > 1.00).

Table 3 – *MP1*/*MP2* being 0.7–1.00.

No.	Station	*MP1* (m)				*MP2* (m)				Percentage of observations (%)				Reflections
1	A127	0.78	0.77	0.81	0.80	0.82	0.92	0.90	0.82	93	93	93	92	Trees
2	E015	0.78	0.76	0.82	0.79	0.73	0.81	0.75	0.77	92	91	91	92	Trees
3	E051	0.70	0.75	0.67	0.73	0.70	0.79	0.69	0.70	92	92	92	92	Trees
4	E035	0.83	0.92	0.82	0.90	0.94	0.95	0.89	0.95	90	89	88	89	Structures and trees
5	E036	0.82	0.77	0.82	0.83	0.76	0.69	0.70	0.76	84	84	84	84	Buildings
6	E007	0.71	0.75	0.70	0.74	0.63	0.73	0.68	0.66	92	92	92	90	Structures

Fig. 4 – Stations and their surroundings (*MP*1/*MP*2 being 0.7–1.00).

Fig. 5 – Parts of the stations and their surroundings (CSR > 3).

consistent with the results of Chen et al. [16], whereas, E002, E022, EB02 and E309 are apparently different from that of nearby stations in directions and/or magnitudes.

The data qualities observed in 2011 and 2013 are studied. The *MP*1 and *MP*2 are shown in Table 5. That suggests the data were affected by multipath in one or two period observations. The multipath error can be calculated as the following equation [6]:

Table 4 – CSR > 3.

No.	Station	CSR				No.	Station	CSR			
1	E022	18	19	21	23	6	EB02	9	8	5	4
2	E020	11	12	10	10	7	E002	3	4	2	3
3	A121	8	9	10	9	8	A126	2	4	3	2
4	A145	8	8	7	11	9	E309	4	4	5	5
5	E006	4	5	4	4	10	E035	2	3	5	3

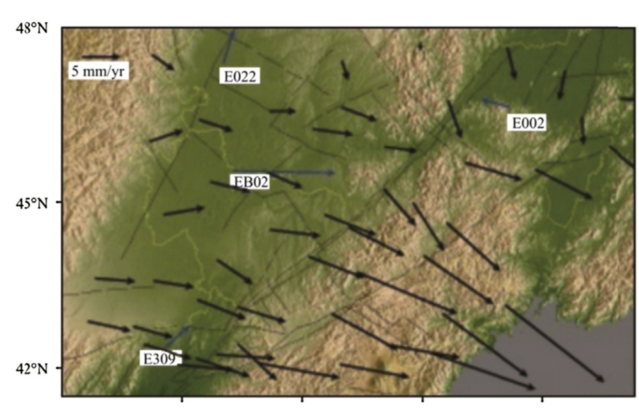

Fig. 6 – Horizontal velocities of GPS campaign stations (2011–2013, relative to Eurasia plate).

Table 5 – Observation qualities of E002, E022, EB02 and E309.

No.	Station	Year	MP1				MP2			
1	E002	2011	1.24	1.19	1.28	1.18	1.29	1.35	1.41	1.41
		2013	0.69	0.65	0.65	0.70	0.61	0.64	0.64	0.67
2	E022	2011	1.68	1.53	1.53	1.53	1.68	1.86	1.71	1.70
		2013	1.82	1.92	2.10	2.12	1.98	2.11	2.37	2.07
3	E309	2011	0.50	0.46	0.46	0.47	0.54	0.53	0.59	0.58
		2013	0.37	0.45	0.41	0.41	0.45	0.50	0.46	0.49
4	EB02	2011	0.32	0.30	0.35	0.31	0.32	0.34	0.44	0.38
		2013	1.04	1.02	1.08	1.07	1.03	1.22	1.17	1.20

$$\varphi = \mathrm{arctg}\left(\frac{\alpha \sin\theta}{1 + \alpha\cos\theta}\right)$$

$$\theta = \frac{4\pi H \sin z}{\lambda}$$

where φ is the multipath error in the carrier phase measurement; α is the reflection coefficient; θ is the phase delay; H is the height of antenna from ground; z is the angle between the reflection and ground; λ is the carrier wavelength.

The reflection is the major factor. The velocities suggest that the data processing could not reduce the errors from the bad surroundings.

3. Discussion and conclusions

There are some special requirements prescribed by the specifications [2] and provisions [9] for the stations when they are selected and established. The requirements are (1) the GPS equipments should be set up and operated conveniently, (2) the altitude angles of the surrounding obstructions are no more than 15°, (3) the distances between sites and powerful radio emissions (such as TV, radio and microwave stations) should be longer than 200 m, (4) the high-voltage power lines should be 50 m away from the sites, and (5) there should be no objects which will strongly reflect the satellite signals (such as large buildings) around the stations. After the stations were established, the requirements could be satisfied in a short period and the qualities are good [4,17,18], while it is difficult to preserve the good environments for a long time. The environmental conditions might become worse and deteriorate the observation qualities further in future.

From the above, it is inferred that the tree coverage around the continuous or campaign stations is the major reason of the bad data quality. Yang et al. [19] checked the quality observed in the woods, radar station, high-voltage transmission line, lakes and so on. The results demonstrate cycle slips, signal diffraction and multipath effect are the most influenced factors worsen the data quality when the GNSS antenna is under trees. The results also proved by the example in this paper. The buildings (structures) seriously affect the satellite signals, and then the percentages of the observations become very small. The reflections of the trees around the GPS campaign stations are the main reason. The second factor affected the data quality are from buildings, structures and high-voltage lines and so on. Though there are many methods to make up for the multipath effect and to repair the cycle slips, it is almost impossible to obtain a good accuracy through the post processing of the data with more cycle slips. Therefore, the process such as selecting receivers, station locations and observations should be paid more attention in advance.

Considering the multipath and cycle clips influence the data quality, the stations should be selected and established in the places where there is no reflection and interference. The places should be avoided where there is high-rise buildings, lakes or trees with thick leaves which would interrupt the GPS signals, while the sites are the ideal places with poor reflection, such as bushes, lawn, plowed land and rough ground for the stations [3]. The hillside is also unsuitable for the sites. When the hill slope is too large, the satellite signal could be affected by the antenna barrier above the cut-off elevation angle. Even though the slope is small, the reflection signals could also enter the antenna from the suppression plates of the antenna and result in multipath error. In order to ensure a long-term observation of the stations, a good observation condition should be kept and the growing trees around the stations should be taken into consideration in particular.

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Yaxuan Hu, Senior engineer of Second Monitoring and Application Center, China Earthquake Administration. Graduated as a postgraduate from school of Earth and Space Sciences of University of Science and Technology of China in 2004. Mainly engages in the researches on crust deformation data processing and analysis and earthquake prediction.