ESTIMATING NEAR REAL TIME PRECIPITABLE WATER FROM SHORT BASELINE GPS OBSERVATIONS

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ABSTRACT:

Water vapor in the atmosphere is an influential factor of the hydrosphere cycle, which exchanges heat through phase change and is essential to precipitation. Because of its significance in altering weather, the estimation of water vapor amount and distribution is crucial to determine the precision of the weather forecasting and the understanding of regional/local climate. It is shown that it is reliable to measure precipitable water (PW) using long baseline (500-2000km) GPS observations. However, it becomes infeasible to derive absolute PW from GPS observations in Taiwan due to geometric limitation of relatively short-baseline network.

In this study, a method of deriving Near-Real-Time PW from short baseline GPS observations is proposed. This method uses a reference station to derive a regression model for wet delay, and to interpolate the difference of wet delay among stations. Then, the precipitable water is obtained by using a conversion factor derived from radiosondes. The method has been tested by using the reference station located on Mt. Ho-Hwan with eleven stations around Taiwan. The result indicates that short baseline GPS observations can be used to precisely estimate the precipitable water in near-real-time.

KEY WORDS: GPS, Precipitable Water, Taiwan

1. INTRODUCTION

Water vapor is an influential factor in atmosphere compared to steady gases such as nitrogen, oxygen. Water exchanges energy with varying temperatures, and absorbs energy with increasing amount of water content in the atmosphere. It also exhausts or stores energy within phase changes. This characteristic of water is greatly deal with global climate, ex., the forming and transforming of storm systems.

Thus, a faithfully and quickly estimated precipitable water in atmosphere is going to increase the understanding of regional/local climate and benefit the weather forecasting.

This study concentrates on extracting precipitable water from observations of GPS. Observations of GPS is free of the limitation of day or night or weathers. It is good for long period observations and continuity.

The traditional GPS observations for PW estimating is situated in a large network of observing stations. This network must has baseline which is the distance of 2 stations longer than 500 km. Within the short-baseline network, a relative tropospheric delay between two stations is only available other than absolutely tropospheric delay for each station. This study suggests a method to aid this difficulty of short-baseline network by setting a reference station on Mt. Ho-Hwan (HUAN) in high altitude. The choosing of this reference station is because of the high altitude (about 3,300 m) of station, which mean less water vapor content in the air and fluctuate smaller. This feature of high altitude is significant on building a more stable model than sea level altitude. The PW of HUAN station is derived from long-baseline method by adding stations outside from Taiwan, and statistically develop a PW model for HUAN to build a absolutely troposphere delay. Together with the relative troposphere delay from short-baseline network method, an absolute troposphere delay if obtainable for every stations in this short-baseline network.

The other matter is the converting factor between wet delay(WD) and PW. The absolute troposphere delay can be separated into dry delay(DD) and wet delay(WD) due to the existing of influential water vapor. The converting factor is about 0.16 in constant, but it is different in different season, location, and weathers. Thus a converting factor derived from radiosonde of Taiwan is developed to estimate suitable converting factor in Taiwan.

Finally, a trial of this technique was held with 11 GPS observing stations located in Taiwan.

2. PROCEDURE

2.1 Basic Idea

The processing of this study begins with extracting the amount of GPS signal being retarded in troposphere, in terns of TD (total delay). This study resolve TD from GPS observations with a software BERNESE 5.0, a GPS processing application developed by University of Bern, Swiss. There comes a problem with the short-baseline network of Taiwan, with this problem, a relative delay between two station is only available for data processing. The first work to do is build a PW model for reference station HUAN.

First, the surface meteorological data is easier to be acquired. We hope to find a relationship between it and PW. From the former research [Pei-Li Tseng], we consider parameters e, e/T, e/T^2, and P to build a model of PW of HUAN station. The PW and surface pressure of HUAN is highly unstable. And the relations between PW and surface pressure is low, so the surface pressure is temporary excluded. And then sort the data into seasons

1. Spring, Jan 18 ~ Mar 30.
2. Summer & Autumn, Jul 20 ~ Oct 14.
3. Winter, Oct 17 ~ Dec 31.

Then regresses the parameters of Equation (1) season by season

$$PW = a_1 + a_2 e + a_3 \frac{e}{T} + a_4 \frac{e}{T^2} \quad (1)$$

With the developed PW model of HUAN, The total delay (TD), also called absolutely delay, of HUAN is modeled. And the difficulty of situation short-baseline network can be fixed. Firstly, estimate the relative delay from HUAN to other stations. Secondly, adding relative delay and HUAN modeled absolutely delay. Then the problem is solved and TD for each station in a small frame is feasible.

Using the GPS observations from 14 stations around Taiwan, meteorological data from 12 stations around Taiwan, and GPS observations from 6 station of outside Taiwan with Bernese 5.0 to resolve troposphere delay (TD). And then use meteorological data in Saastamoinen model to estimate dry delay (DD). The wet delay (WD) is TD minus DD.

$$\mathrm{WD} = \mathrm{TD} - \mathrm{DD} \quad (2)$$

After the WD is unveiled, simply multiplies WD with a converting factor (π) will get precipitable water (WD).

$$\mathrm{PW} = \mathrm{WD} * \pi \quad (3)$$

The accurately way to get a converting factor is determining its characteristics which is regional specified in stead of using it as a constant.

The converting factor is a function of time and space, according to documents [Bevis, 1992; Liou, 2001], to build a model of converting factor π with radiosondes data.

The first step to build model of converting factor π is to pull temperature T, dew point temperature T_d, and altitude H data from radiosonde data. And then calculate partial pressure of water e using dew point temperature T_d

$$e = 6.11 * 10^{\frac{7.5 * T_d}{237.7 + T_d}} \quad (4)$$

Converting factor is a function of weighted mean temperature T_m, and T_m is a function of partial pressure of water e and temperature T.

$$T_m = \frac{\int_H^\infty \frac{e}{T} dz}{\int_H^\infty \frac{e}{T^2} dz} \quad (5)$$

Integrate partial pressure of water and temperature from altitude of station. And compute weighted mean temperature T_m from each data of radiosonde. Radiosonde measures twice everyday, 8AM and 8PM in Taiwan time zone (UTC+8). Compute every weighted mean temperature T_m of recently 4 years (2003-2006) and compare with surface temperature T_s to find out the relations between weighted mean temperature T_m and surface temperature T_s,

$$T_m = a * T_s + b \quad (6)$$

Using Equation (6) to develop a T_m model for Taiwan region.

The upper figure of Figure 1 shows distribution of weighted mean temperature T_m (lower value) and surface temperature T_s (higher value) over a year, the unit in horizontal axis is in 0.5 day, starts from January 1st and ends at December 31st. The unit of vertical axis is in absolute temperature. There is an obvious gap between surface temperature T_s and weighted mean temperature T_m, other than that, their trend is similar. The lower figure of Figure 1 shows the correlation of surface temperature T_s and weighted mean temperature T_m, their distribution shows a positive correlation with a correlation coefficient 0.70724.

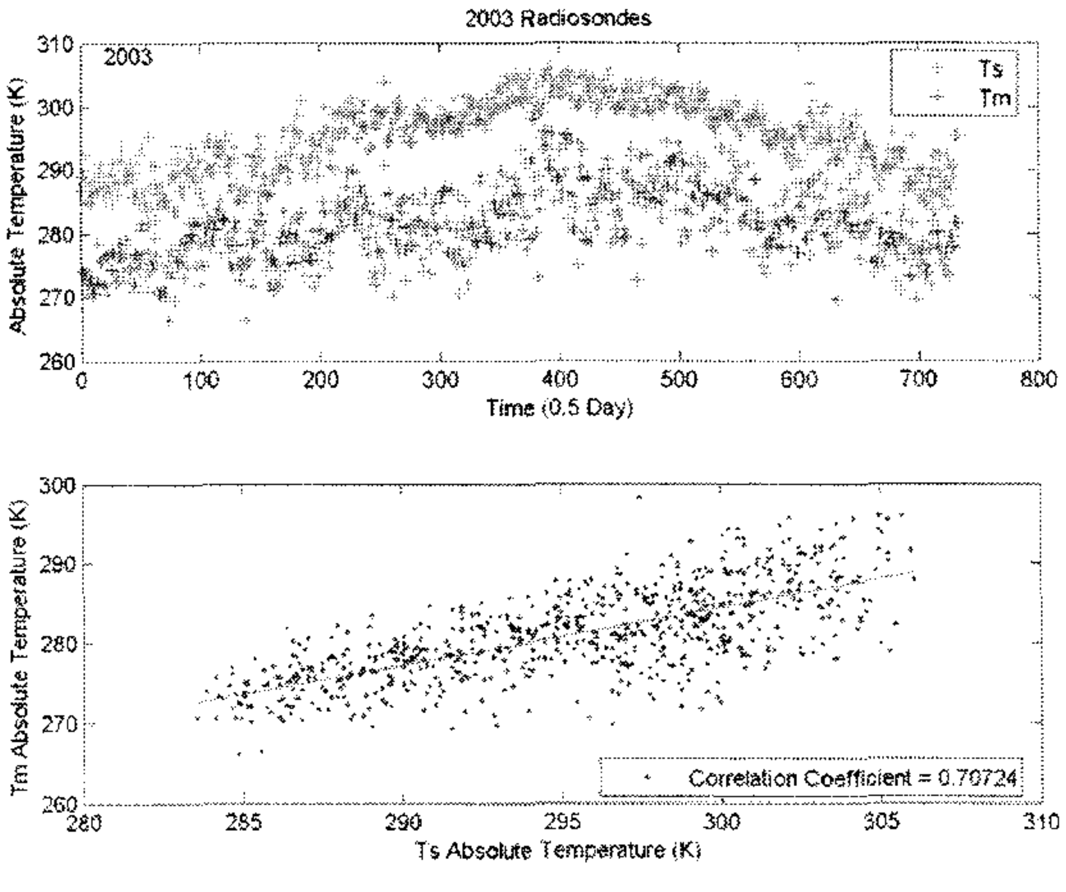

Figure 1. The surface temperature T_s and weighted mean temperature T_m distributions over a year (upper). Correlation of surface temperature T_s and weighted mean temperature T_m and its correlation coefficient (lower).

Thus, a converting factor π is obtained from developed local T_m model. And PW is available through Equation (3).

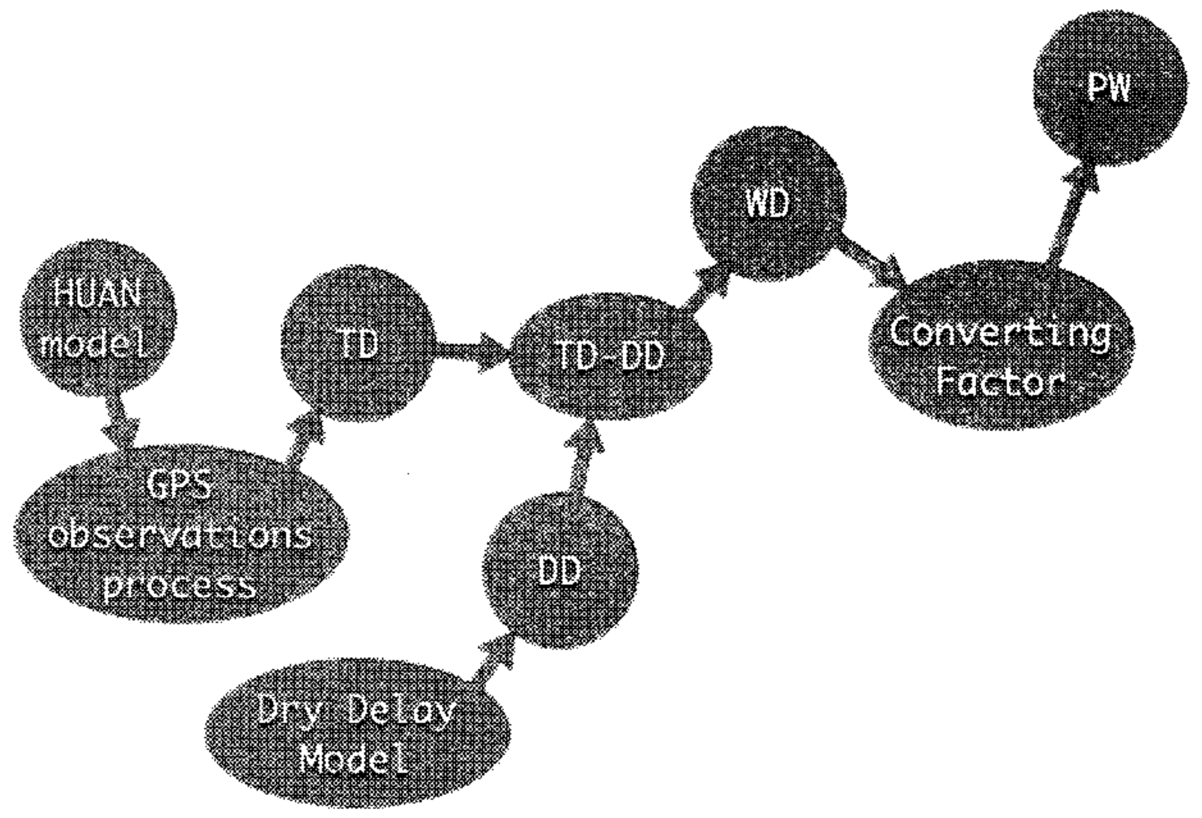

Figure 2. Workflow of data processing.

2.2 Observation Stations

14 stations of GPS observations in Taiwan: YMSM, FLNM, PKGM, KDNM, TMAM, MZUZ, KMNM, FUGN, LNDO, PLAN, NSHE, HUAN, PEPU, SLIN.

6 stations outside of Taiwan: TSKB(Tsukuba, Japan), GUAM(Dededo, Guam), LHAS(Lhasa, P.R.C.), WUHN (Wuhan, P.R.C.), USUD(Usuda, Japan), NTUS (Singapore).

12 stations of meteorological data: all stations of Taiwan exclude FUGN and LNDO.

This study begins with collecting GPS observations from 14 Taiwan stations, meteorological data from 12 taiwan stations, and six outside Taiwan stations. And then process these observations by Bernese 5.0 to build a PW model for reference station HUAN and then total delay cause by troposphere of each station can be determined. And then input station meteorological data to Saastamoinen model to determine dry delay. And then total delay minus dry delay is wet delay. Wet delay times converting factor is PW. The converting factor varies over time and spaces. This converting factor is derived by regress observables from years of radiosonde data.

2.3 Campaign

There are kinds of processing strategies in Bernese GPS software 5.0:

Table 1. Strategies used in overall process.

Strategy	*Description*
long-base	*Taiwan network adds with foreign stations. Regards as true value.*
short-1	*Process with long-baseline method in Bernese GPS software 5.0 and use tropospheric parameters of HUAN*
short-2	*Process with short-baseline method in Bernese GPS software 5.0, and then add a constant value to its result, relative delay.*
model-1	*Short-1 take out total delay of HUAN to become a relative delay with respect to HUAN, and then add model HUAN delay to it to become total delay.*
model-2	*Take out the constant value from Short-2 and add model HUAN delay to it to become total delay.*

The strategies listed in Table 1 includes that resolve a short-baseline network of Taiwan in either short-baseline or long-baseline resolving method in Bernese GPS software 5.0, and consider the effect of using model HUAN or not.

3. RESULT

In the result, here shows the total delay distribution of station, PLAN, and the differences between each strategy. Inspecting Figure 3, it is clear to figure out differences between short-1 and model-1 that trend of model-1 is smoother and has less fluctuation than short-1, and the curve of model-2 is closer to true value.

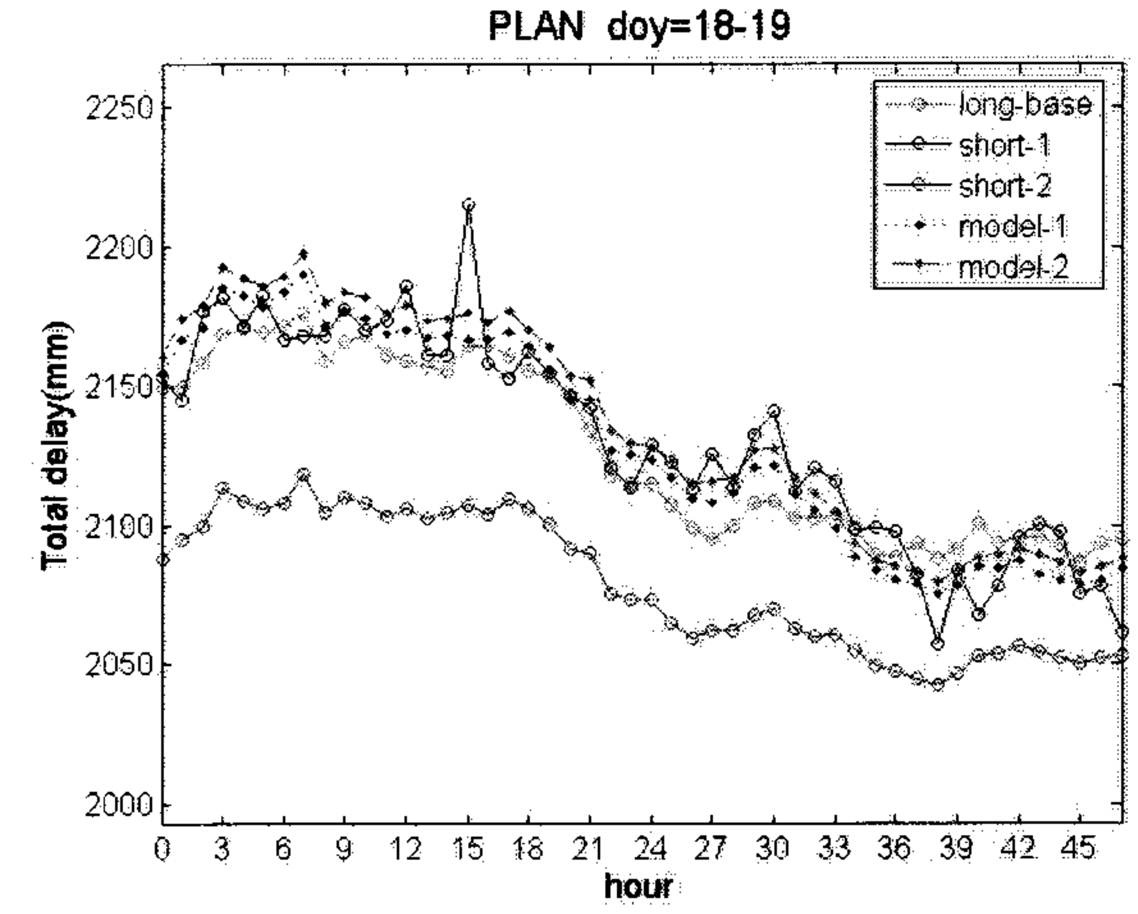

Figure 3. Comparison of total delay with different strategies used in station PLAN of day-of-year 18-19.

Inspecting Figure 4 and Figure 5, they are the error distributions of each strategy with respect to true value. It is obviously showed the error distribution peaks of model-1 and model-2 are thiner than short-1 and short-2, which mean the error distributions spread closer. The peaks of model-1 and model-2 are closer to zero.

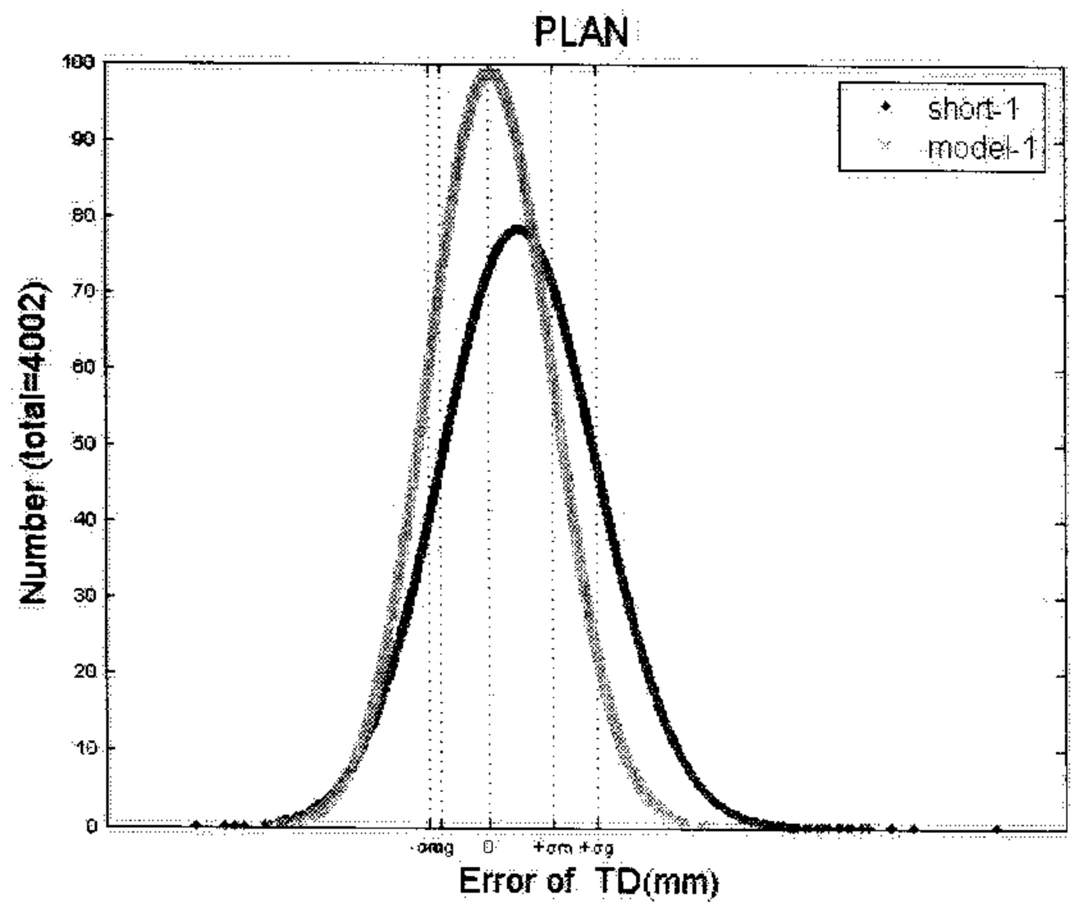

Figure 4. Error distribution of strategy short-1 and model-1 in station PLAN. σg and σm represent standard deviations of strategy short-1 and model-1 with respect to true value.

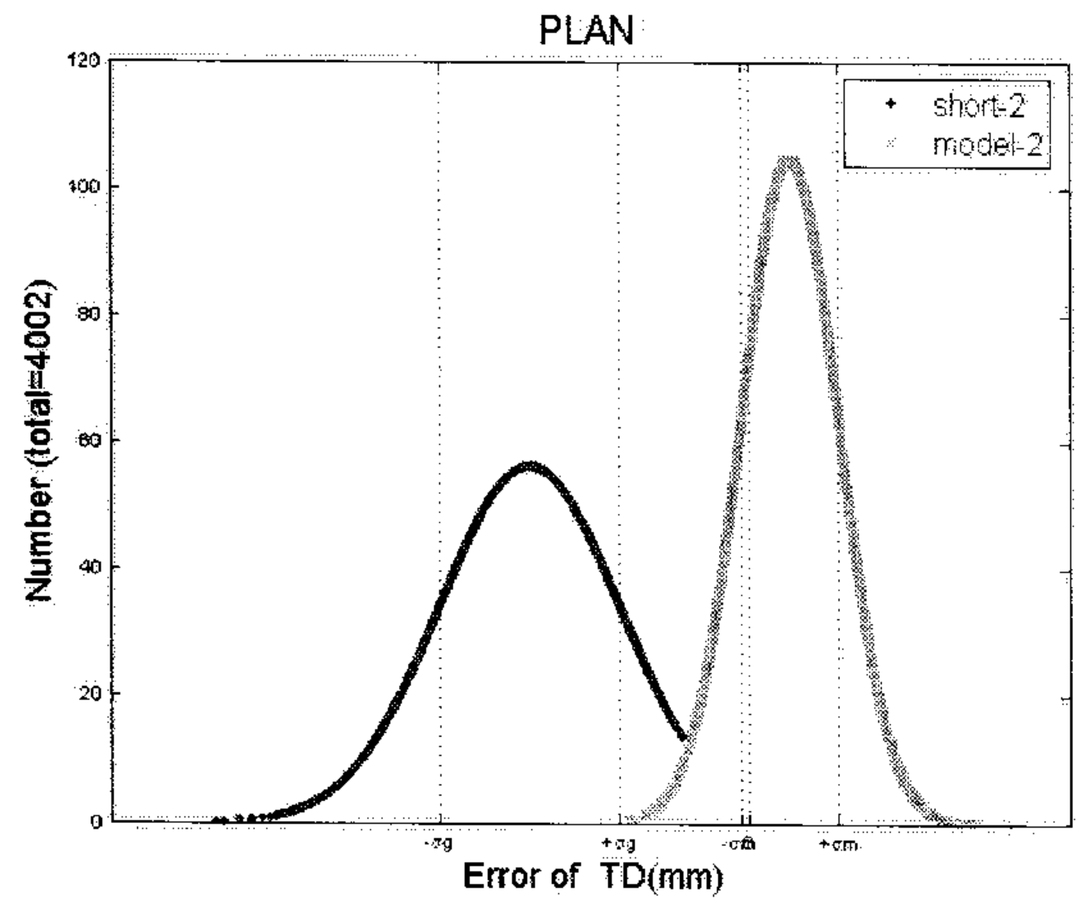

Figure 5. Error distribution of strategy short-2 and model-2 in station PLAN. σg and σm represent standard deviations of strategy short-2 and model-2 with respect to true value.

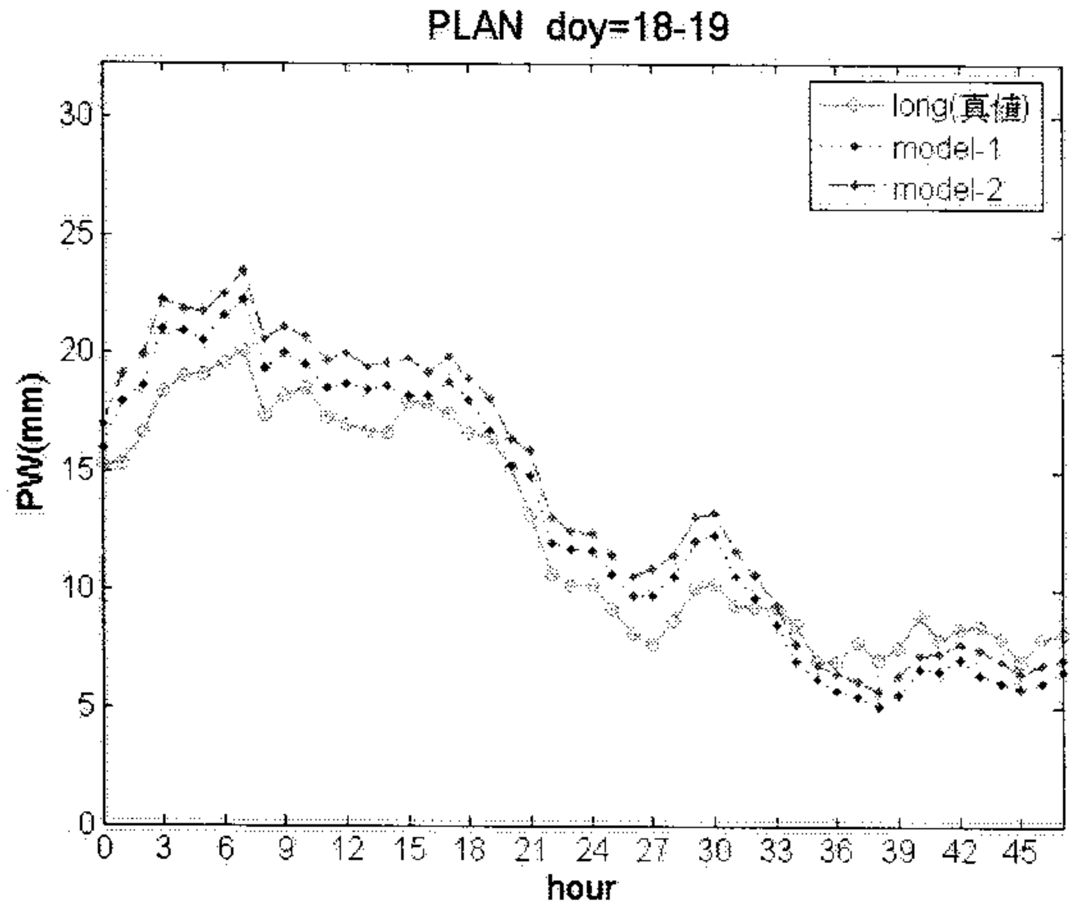

Figure 6. Comparison of PW derived from model-1 and model-2 to true value of station PLAN of day-of-year 18-19.

PW can be calculated from processing and converting of total delay. Inspecting Figure 6, it is estimated PW from model-1 and model-2. The accuracy of model-1 derived PW is better than model-2, because there is an offset exists in model-2 and decreases accuracy of model-2. The precision of model-2 is better than model-1, because the standard deviation of model-2 is less than model-1.

The effect of using only stations which are located inside Taiwan island, which is short-baseline network, is faster on data acquisition because of no need of data requisition from foreign station, and the cycle slips occur less because of the better quality of observation data of GPS. These effects benefits the data processing, makes it process faster in near real time.

4. CONCLUSION

The strategies developed by this study aid the problem of highly correlative characteristics of troposphere happens in short-baseline network.

Those modified strategies, model-1 and model-1, have obviously corrected PW.

The effect of using only stations which are located inside Taiwan island, which is short-baseline network, is faster on data acquisition because of no need of data requisition from foreign station, and the cycle slips occur less and quality of GPS observation data is better. These advantages benefits the data processing, makes it process faster in near real time. The whole procedure of PW estimation can be done in a hour with well collected of all the data and information needed.

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