PRELIMINARY STABILITY TEST FOR THE REGIONAL GPS TRACKING STATIONS IN TAIWAN

C. C. Chang and R. G. Chang
Department of Surveying and Mapping Engineering
Chung Cheng Institute of Technology
Tahsi, Taoyuan, Taiwan 335, ROC

Abstract

A regional GPS tracking network consisting of eight permanently operating GPS stations in Taiwan and its offshore islands has worked since 1995, in order to establish a high accuracy geodetic network purely based on GPS observations. These GPS stations aim to act as the core stations for establishing a high accuracy three-dimensional reference frame and motivating some other geodetic and geodynamic applications in Taiwan. The GPS measurements of this network are to be expected to an accuracy of a few millimeters. This is to be achieved, through the use of high accuracy GPS technique, by linking this network of stations to several primary stations of the ITRF (IERS Terrestrial Reference Frame). Two one-week GPS data from the preliminary stage of measurements made at these regional GPS tracking stations were collected to compute the network adjusted coordinates and test for their stabilities in three-dimensional components. A test of tropospheric modelling was also carried out to investigate the effectiveness of using associated surface measured meteorological data in high accuracy GPS network adjustment.

Introduction

GPS has been the most recent and most important advance in space geodetic techniques over the last 20 years. Due to its high positioning accuracy and effectiveness of extending the working range from local, regional to continental scale, GPS has now almost entirely surpassed terrestrial methods for high precision geodetic works. Hence, there has been a tremendous interest over the past 5 to 10 years in using GPS to connect some geodetic stations to a global geocentric reference frame for many geodetic applications.

Followed with its economic development and civil applications in Taiwan, a large number of traditional geodetic control points have been found to be seriously damaged or lost. In order to re-establish a high accuracy geodetic network purely based on the GPS observation, a regional GPS tracking network in Taiwan area consisting of eight permanent GPS tracking stations have been set up and operated since 1995.

The growth of continuously operating regional GPS network has been one of the most recent trends in GPS, so this regional GPS tracking network in Taiwan was originally designed to work as the core network for any scale of GPS observations made in this area. These regional GPS tracking stations were also expected to provide their high accuracy three-dimensional coordinates for some high accuracy geodetic, geodynamic, and navigation applications. The coordinate of these tracking stations, therefore, have to be accurately determined and constantly monitored, with respect to a global reference frame.

The network adjustments based on the two one-week GPS observations made in a short time interval were independently carried out with a precise ephemeris calculated by the IGS (International GPS Service for Geodynamics). This aims to measure zero movement of these regional tracking stations between the two one-week GPS measurements, in order to prove the potential of GPS for accurate positioning in Taiwan. The effectiveness of using surface measured meteorological data, opposing to the software-defined standard meteorological data, for tropospheric modelling was also tested with two GPS data sets in the network adjustments.

Data Sets and Data Processing for GPS Network

The data sets used to test the zero movement of eight regional GPS tracking stations were taken from the GPS observation carried out from 30 April to 6 May 1995 and from 11 June to 17 June 1995. The data for each week of GPS observation was taken from seven consecutive days, with twenty-four hour data observed at three IGS stations nearby this area, including USUD in Japan, SHAO in China, and TAIW in Taiwan, and also recorded at eight regional GPS tracking stations located in Taiwan and its offshore islands (see Figure 1). Data from these IGS stations and regional GPS tracking stations were all obtained using Rogue SNR-8 receivers. Two tested data sets were expected to demonstrate insignificant coordinate differences during the short time interval between the two one-week GPS observations.

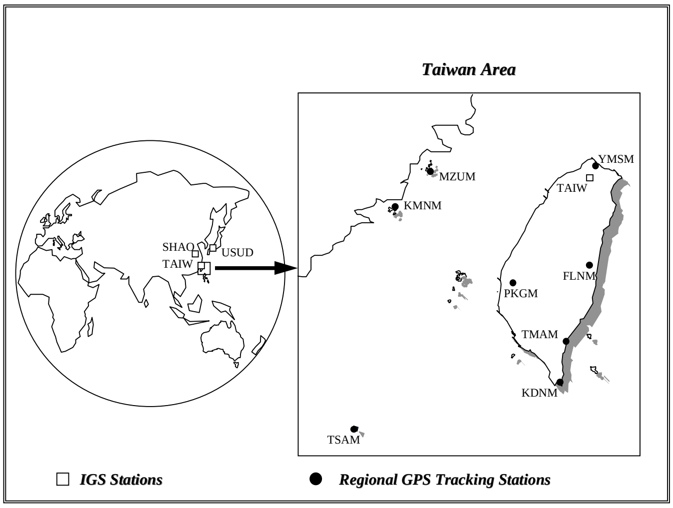

Figure 1 Regional GPS tracking stations in Taiwan area

The GPS network solutions were carried out using the GPS Analysis Software (GAS), developed by the University of Nottingham. The IGS precise ephemeris was used to provide the satellite orbit information in the tests. During the two one-week GPS observations, the IGS precise ephemerides used were for GPS week 799 and 805, respectively. A summary of the options used in the data processing is given in Table 1.

Table 1 Data processing options for the GPS solutions

Reference Frame Definition	
Stations Fixed:	USUD, SHAO, TAIW
Coordinate Source:	ITRF94 GPS Stations *[Boucher et al, 1996]*
Tectonic Plate Model:	ITRF94 Velocity Field *[Boucher et al, 1996]*
Reference Epoch:	1995.35
Models Applied	
Ionospheric Delay:	L1/L2 Frequency Combination
Tropospheric Delay:	MAGNET Model, with a Standard Atmosphere
Antenna Phase Center:	Elevation Angle Dependent Model *[Schupler, 1992]*
Earth Body Tides:	IERS Standards *[McCarthy, 1996]*
Adjusted Parameters	
Data Sessions Defined:	14 x 12 hours / session
Stations:	Position (X,Y,Z) of Regional GPS Tracking Stations
Satellites:	Fixed to IGS Precise Ephemeris
Tropospheric Delay:	Zenithal Scale Factor per Station, per Session (Solved as a First Order Polynomial)
Ambiguities:	Integer Free

Results and Analysis for GPS Network Adjustments

Once GPS solutions have been obtained, e.g. 14 single-session network solutions in each one-week GPS observation, the repeatability tests on successive single-session solutions can be performed to test the precision, based on the root mean square deviation of each single-session solution from the weighted mean.

The indicator of accuracy can be tested through the week-to-week agreement for all the regional GPS tracking stations. The so-called week-to-week agreement, also seen as a test of stability, is the discrepancy between the two one-week GPS solutions, which is based on the assumption that the site movement at all the regional GPS tracking stations is theoretically less than a centimeter level over the one month short time interval between the two one-week GPS observations.

The network adjustment solutions are now detailed. The precision and accuracy for the GPS solutions are estimated by two indicators, namely session-to-session coordinate repeatabilities and week-to-week coordinate agreements.

Session-to-Session Coordinate Repeatabilities. The session-to-session repeatabilities, based on the station coordinates, for each one-week GPS observation, namely GPS Week 799 and Week 805, are summarized in Table 2.

Table 2 RMS coordinate repeatabilities for the GPS solutions

Component	GPS Week 799	GPS Week 805
N (mm)	6	7
E (mm)	13	19
H (mm)	16	26

The session-to-session repeatabilities can show the quality of data collected during the two one-week GPS observations. The horizontal coordinate repeatabilities are consistently better than 10 mm in North component and 20 mm in East component. The height repeatabilities are as expected to be worse than the horizontal coordinate repeatabilities with a level of better than 30 mm for both sets of solutions.

It can also be seen that the Week 805 precisions are generally worse than the Week 799 precisions, by around 1 mm in North component, 6 mm in East component, and 10 mm in height. This level of coordinate uncertainty implies that the GPS observations made at the preliminary stage of operation for the GPS tracking stations in Taiwan were not in a very stable condition.

Week-to-Week Coordinate Agreements. The stability test, i.e. the consistency of these two one-week GPS observations, for the regional GPS tracking stations can be carried out by using the week-to-week coordinate agreements. The three-dimensional coordinate agreements between the two one-week GPS observations are given in Table 3.

Table 3 Week-to-week coordinate agreements for the GPS solutions (values shown are Week 805 minus Week 799)

Station	N(mm)	E(mm)	H(mm)
MZUM	-2	3	39
KMNM	3	9	50
FLNM	4	-4	41
PKGM	-2	1	48
TMAM	2	9	62
RMS	3	6	49

The week-to-week coordinate agreements represent the quality of the data from the two one-week GPS observations, with RMS agreements in horizontal coordinates of 3 mm in North component, 6 mm in East component, and around 50 mm in height. The week-to-week coordinate agreements show a normal level of performance on the horizontal coordinates, based on the network adjusted solutions using precise ephemeris. However, the agreements in height are much worse than expected. It is, therefore, important to test more GPS data sets to investigate the coordinate accuracy of height for the GPS tracking stations in Taiwan.

Surface Measured Meteorological Data Applied to Tropospheric Modelling

In order to improve the GPS accuracy, a standard tropospheric model is normally used in the GPS data processing to provide an estimate of the tropospheric zenith delay at a site. It is believed that the standard atmospheric models provide a broad approximation of expected tropospheric conditions, but they ignore the actual atmospheric conditions. Alternatively, surface measured meteorological data are able to be introduced to practically estimate the tropospheric delay errors. A test of applying such surface measured meteorological data to the tropospheric modelling was carried out for GPS observations made at some GPS tracking stations in Taiwan.

Data Availability. A total of four GPS stations, as a part of the continuously operating GPS tracking stations in Taiwan, were selected to test the effect of the tropospheric delay modelling. These four GPS stations, located at YMSM, PKGM, FLNM, and MZUM, were chosen mainly based on the consideration of their geographic distributions in Taiwan and its offshore islands.

Two GPS data sets used for the tropospheric tests were obtained from 8 January to 10 January 1996, and from 22 July to 24 July 1996, respectively. These two three-day data sets were measured in two different seasons, i.e. winter and summer in the same year, to present the most different atmospheric conditions. Surface measured meteorological data were also collected at the GPS sites, provided at one hour intervals for the measurements of temperature, pressure, and relative humidity.

Test Model and Strategy. The tests of tropospheric modelling for the two GPS data sets, namely Winter 96 and Summer 96, were performed with a 12-hour session of GPS data for all the baselines, where FLNM was fixed to its GPS coordinates defined by a longer term of observations.

The surface measured meteorological data sets were practically applied with the Saastamoinen atmospheric model during the GPS network adjustments. The results were then compared to those obtained by alternatively using the Bernese-defined standard meteorological data.

Results and Analysis. The session-to-session repeatabilities based on the results of using Saastamoinen atmospheric model with different types of meteorological data, i.e. defined and measured data, are shown in Table 4. The so-called season-to-season coordinate differences are also shown in Table 5 for the GPS solutions based on using two types of meteorological data.

Table 4 RMS coordinate repeatabilities for the GPS solutions based on two types of meteorological data

Coordinate Component	Winter 96		Summer 96	
	Defined Data	Measured Data	Defined Data	Measured Data
N (mm)	10	10	13	13
E (mm)	23	23	35	35
H (mm)	38	37	30	30

Table 5 Season-to-season coordinate differences for the GPS solutions based on two types of meteorological data (values shown are Summer 96 minus Winter 96)

	Defined Data			Measured Data		
Station	N (mm)	E (mm)	H (mm)	N (mm)	E (mm)	H (mm)
PKGM	-5	14	-18	-4	16	-18
YMSM	2	25	-2	1	26	-5
MZUM	-1	39	53	-2	39	55
RMS	3	28	32	3	29	34

It is clear that the repeatabilities are not effectively improved in all three coordinate components when the surface measured meteorological data were used to estimate the tropospheric delay, where a level of 1 mm difference is only found in height for the Winter 96 solution. However, it can be seen from Table 5 that the season-to-season coordinate differences are increased by 1 or 2 mm in RMS when the surface measured meteorological data were applied.

As surface measured meteorological data are believed to be easily affected by calibration problems and not completely representative of the atmospheric conditions dominating in the upper troposphere, the software-defined meteorological data is somehow still effective to be applied with a standard atmospheric model for tropospheric modelling.

Conclusions and Suggestions

This paper aims to show the preliminary tests for the GPS data observed at the regional GPS tracking stations in Taiwan. An overall summary of the research results is given as follows:

1. Based on the precise ephemeris network solutions carried out for the GPS tracking stations at their early operating stage, the coordinate repeatabilities were shown to be better than 10 mm in North component, 20 mm in East component, and 30 mm in height. However, a 10 mm difference in height repeatability between two one-week GPS observations was shown to be not consistent for the quality of GPS data collected.
2. The coordinate agreements between two one-week GPS observations made in a very short time interval were found to be around 5 mm in horizontal components. However, the agreements in height were found to be significantly biased by a level of 50 mm.
3. The use of surface measured meteorological data was not able to effectively improve the precision of the GPS network solutions, comparing with those obtained by using the software-defined standard meteorological data. The reason is possibly the often biased surface measured data caused by the calibration errors of the measurement equipment, systematic and random observation errors, radiation effects on the equipment, and ground proximity effects *[Brunner and Tregoning, 1994]*.

Acknowledgments

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References

Boucher, C, Z Altamimi, M Feissel and P Sillard (1996), *Results and Analysis of the ITRF94*, IERS Technical Note 20, Observatoire de Paris.

Brunner, F K, and P Tregoning (1994), Tropospheric Propagation Effects in GPS Height Results Using Meteorological Observations, *Australian Journal of Geodesy, Photogrammetry, and Surveying*, Vol 60, pp 49-65.

McCarthy, D D (editor) (1996), *IERS Conventions (1996)*, IERS Technical Note 21, Observatoire de Paris.

Schupler, B R (1992), GPS Antenna Pattern Data - 11 February 1992, *Personal Communication from B R Schupler*, Bendix, USA.