# AN INVESTIGATION BY USING CORS TO DETECT THE COORDINATE REFERENCE FRAME DISTORTION IN TAIWAN

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**ABSTRACT:** Plate motion will cause earthquakes, volcanic eruptions and other natural disasters. Plate motion especially non-linear motion can also change the relationship between stations in the reference frame. Therefore, a rational and reliable reference frame is needed to ensure the Euclidean integrity quality. Taiwan is located along the bounding of the Eurasian and the Philippine plate, and is therefore a region of non-rigid motion and therefore will shift and rotate in different directions due to the changing stress field. ITRF2008 is a fixed single term linear model utilizing data across the 5 years span of 2003-2008. It is not able to precisely model the non-linear motion of the crustal in the Taiwan region, after the 1999 Jiji earthquake. This study will show the complex non-linear model that is necessary to describe the Taiwan region by constructing a Reference Frame over Taiwan from 21 Taiwan's CORS stations.

**KEY WORDS:** GNSS, CORS, plate motion, velocity field,

## 1. INTRODUCTION

The reference coordinate system of Taiwan is Taiwan Datum 97(TWD97), which was built in 1997 by using Global Positioning System. The frame is International Terrestrial Reference Frame 1994 (ITRF94) and ellipsoid is Geodetic Reference System 1980(GRS80). Now the reference frame has been updated to ITRF08 in 2010. Taiwan is located along the boundary of the Eurasian and the Philippine Sea Plate, the Central Range to the west is on Eurasian Plate and the Central Range to the east is on Philippine Sea Plate. The NNE-trending Longitudinal Valley in eastern Taiwan is wildly considered an active collision boundary between the Philippine Sea Plate and the Eurasian plate (Shui-Beih Yu and Kuo 2001). Off the coast of eastern Taiwan, the Philippine Sea plate is subducting beneath the Eurasian Plate that caused Ryukyu Trench, Ryukyu arc, Okinawa Trough and so on (Shui-Beih Yu , Horng-Yue Chen et al. 1997). Because of the collision boundary, there is a region of non-rigid motion that will shift and rotate in different directions due to the changing stress field. Therefore, we can't precisely model the crustal in Taiwan region by using a fixed single term linear model like ITRF2008. There is a situation often occurs that government people doing Cadastral survey by GPS, the difference between measured coordinates and the announcement coordinates are in centimetre level. If we fix the announcement points in adjustment, it will cause the whole GPS network a serious distortion, therefore, this study is expected to analyze the time series and velocity by processing data from Taiwan 21 CORS stations through 2013 and 2014. The purpose is to try to find out a suitable reference frame strategy for Taiwan.

## 2. DATA PROCESSING

In this study, the data from Taiwan's 21 CORS stations is offered by Century Instrument Company in Taiwan. This GPS network has continuously received GPS signal since 2013. The sampling interval of data is 30 seconds and the cut off angle is 15°. These stations were named in sequence from TA01 to TA21, and are uniformly distributed around Taiwan, with 20 stations on Taiwan Island and one on Penghu Island. The distribution of these stations is shown in Figure 1. In addition, it is notable that there are five stations (TA04, TA19, TA13, TA18, TA12) located next to the Longitudinal Valley in eastern Taiwan which is considered as collision boundary between two plates. Except local stations, some IGS stations are also used, and both local and global stations were processed together in order to fix our local stations into global frame. The principles of choosing global stations depend on data quality and network geometric strength. There is the list of IGS stations as follow: karr, twtf, usud, ksmv, tnml, bjnm, irkt, darw, tow2, guam, mcil, ccj2, stk2, gmsd, lhaz, kunm, xian, shao, bjfs, xmis, ptgg. The stations are shown in Figure2.


Figure 1. 21 CORS stations in Taiwan

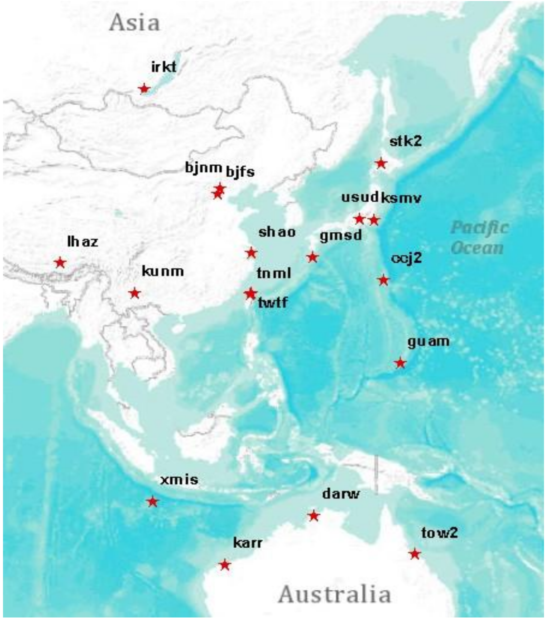


Figure 2. Distribution of IGS stations

In this study, all available epoch measurement and continuous GPS data are processed by GAMIT/GLOBK software v.10.6 which was developed by MIT (Massachusetts Institute of Technology), SIO(Scripps Institution of Oceanography) and CfA(Harvard Smithsonian Center for Astrophysics). GAMIT is a program to process phase data to solve baseline and GLOBK is a Kalman filter for combining daily solution into global network, coordinate compensation, position time series computation and so on (Casula 2015). The parameters setting and processing strategies are described in detail by the following paragraph.

In order to get the positions of Taiwan's CORS stations with velocity, there are many steps to do. First, we should set the environment, GAMIT can download IGS station's observation data and precise IGS orbits automatically if the site.default(file to control the use of stations in the processing) table was filled with the ID of IGS stations that we want to process.(Herring, King et al. 2015) Then after checking the sestbl.(setup file) table, GAMIT can do batch processing day by day.

There are the parameters setting about GAMIT:

1. Use known ground reference station for satellite orbit estimation.
2. The pole tide model, solid earth tide model and ocean tide model are considered into correction.
3. The Saastamoinen model was used to estimate the dry and wet parts of the atmospheric delays, and the global pressure and temperatures model(GPT50) were adopt as apriori delay correction (Boehm, Heinkelmann et al. 2007)
4. The solid earth tides and pole tides model is IERS2003 and the ocean tide model is FES2004.
5. IGS stations were processed together with local stations in loose-constrain, 0.05 meter for X, Y, Z.

Procedure of GAMIT can be divided into few parts, ***makex*** for observation pre-process, ***arc*** for calculating satellite orbits, ***model*** for building normal equation and estimate residuals, ***autcln*** for bias detection and remove cycle clip, ***solve*** for least square adjustment and analysis (Herring, King et al. 2015). After the daily solution finished, next step is to fix our local network into ITRF08, GLOBK combines local h-files and MIT's H-files, which contains loose-constrain weighted least squares estimates of coordinates, atmospheric models, variance-covariance matrix, satellite orbits and so on (Dong, Herring et al. 1998, M. Dubbini, P. Cianfarra et al. 2010, Casula 2015).

In this study, daily solutions were grouped into many clusters in the interval of five days rather than combining daily solutions day by day. The reason for doing this is to reduce the influences of noise, and the velocity trend can be seen more easily in the interval of five days than one day. The position of each station and its accuracy can be estimated in five day's cluster, and the time series for NEU (North, East, Up) components can be plotted by 73 clusters in 2014 data. By combining 73 clusters together can get the velocity, accuracy and position of each station. The flow chat of this study is shown in Figure3.

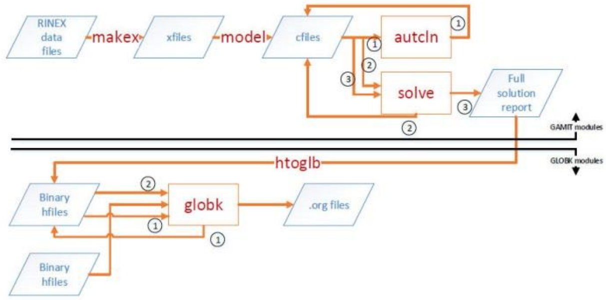


Figure 3.

## 3. RESULTS AND ANALYSIS

GAMIT's daily solutions were iterated by least-square algorithm several times in the process in order to get a better quality. While GAMIT finished the processing, there is a summary file that can be used to determine the result of phase processing. By reading the daily summary file, we can check if all of the data were calculated, or the uncertainties are acceptable or not. Most of the wide-lane (WL) and narrow-lane (NL) phase ambiguities in each daily solution were fixed in the percentages between 80%-95% in this study. The percentages of WL should be greater than 85% unless it had short sessions or noisy pseudo-ranges. On the other hand, the percentages of NL should be greater than 80%, it depends on session length, size and configuration of the network, quality of the orbits and a priori coordinates, atmospheric conditions (Herring, King et al. 2015).

The reliability of GAMIT's daily solutions can be checked by the repeatability and it can be plotted like Figure 4, an example of one of Taiwan station. The results of most stations are in high accuracy (millimetre-level). However, there are few days solutions are not in the expectation because of bad data quality. With a long term observation, the influences of worse data will be reduced so that it won't hurt the result. For example, Figure 4 shows the repeatability of TA06 in three components, each blue point represents the station's position with its accuracy and the line length of each point represents its standard deviation. There is an obvious bad data at about day 25-30, and the standard deviation at that day is bigger than the other days in 2014 at this station. But the influence of that day's data will be decreased in GLOBK program by giving a rather low weight which corresponds to its accuracy (T. A. Herring, M. A. Floyd et al. 2015).

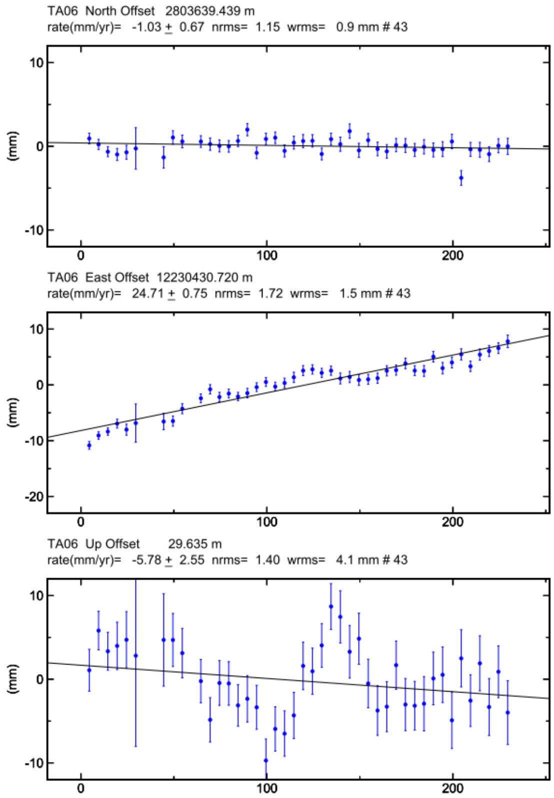


Figure 4. Repeatability plot of TA06 in 2014

After processing two years' data by GAMIT, we tried to run two years of data separate in GLOBK in order to analyze the difference of velocity in two years. An ***org.file*** is a report produced by GLOBK, the summary position and velocity estimates from GLOBK can be extracted form ***org.file***. In order to ensure subsequent analysis's accuracy, it is necessary to check the GLOBK's output report. The parameter estimates of 2013 and 2014 were tabulated in Table1.

Table 1. The accuracy of each station in E, N, U.

| Station ID | 2013 $\sigma_E$ (mm) | 2014 $\sigma_E$ (mm) | 2013 $\sigma_N$ (mm) | 2014 $\sigma_N$ (mm) | 2013 $\sigma_H$ (mm) | 2014 $\sigma_H$ (mm) |
|---|---|---|---|---|---|---|
| TA01 | 0.47 | 0.55 | 1.13 | 1.24 | 7.97 | 7.72 |
| TA02 | 0.49 | 0.73 | 1.13 | 1.31 | 7.97 | 7.86 |
| TA03 | 0.45 | 1.28 | 1.10 | 1.67 | 7.92 | 8.54 |
| TA04 | 0.50 | 0.55 | 1.13 | 1.23 | 7.97 | 7.69 |
| TA05 | 0.61 | 0.55 | 1.17 | 1.22 | 8.01 | 7.66 |
| TA06 | 0.48 | 1.03 | 1.11 | 1.49 | 7.93 | 8.18 |
| TA07 | 0.45 | 0.55 | 1.11 | 1.23 | 7.94 | 7.68 |
| TA08 | 0.47 | 0.55 | 1.12 | 1.23 | 7.95 | 7.70 |
| TA09 | 0.48 | 0.56 | 1.12 | 1.23 | 7.96 | 7.70 |
| TA10 | 0.49 | 0.56 | 1.13 | 1.25 | 8.00 | 7.74 |
| TA11 | 0.46 | 0.54 | 1.12 | 1.23 | 7.95 | 7.70 |
| TA12 | 0.47 | 0.55 | 1.13 | 1.24 | 7.97 | 7.72 |
| TA13 | 0.49 | 0.56 | 1.13 | 1.24 | 7.98 | 7.72 |
| TA14 | 0.46 | 0.55 | 1.11 | 1.22 | 7.93 | 7.67 |
| TA15 | 0.45 | 0.54 | 1.11 | 1.22 | 7.93 | 7.67 |
| TA16 | 0.52 | 0.58 | 1.14 | 1.24 | 7.99 | 7.72 |
| TA17 | 0.52 | 0.58 | 1.14 | 1.24 | 7.99 | 7.71 |
| TA18 | 0.46 | 0.56 | 1.12 | 1.24 | 7.97 | 7.72 |
| TA19 | 0.46 | 0.55 | 1.12 | 1.23 | 7.96 | 7.70 |
| TA20 | 0.45 | 1.24 | 1.11 | 1.64 | 7.93 | 8.52 |
| TA21 | 0.47 | 0.55 | 1.13 | 1.24 | 7.97 | 7.71 |

In Table 1, the average of 2013 and 2014 differential sigma E are 0.481 mm and 0.653 mm, both of them are in high precision. The average of 2013 and 2014 differential sigma U are 1.124mm and 1.290 mm, they are slightly higher than E component but still around 1mm. The differential sigma U is as exception, larger than other two components at around 8mm. In addition, we can found that there are highly correlations both in stations and years.

Velocity of each stations were estimated from GLOBK by combining a year data, we can also extract the velocity from ***org.file*** . In order to present the complex characteristics of Taiwan region, it is an easy way to display these velocities by plotting rather than listing them. The velocities of each station were plotted as vector with topographic map, Figure 5 is estimate of the velocity field in 2013 and Figure 6 is in 2014.

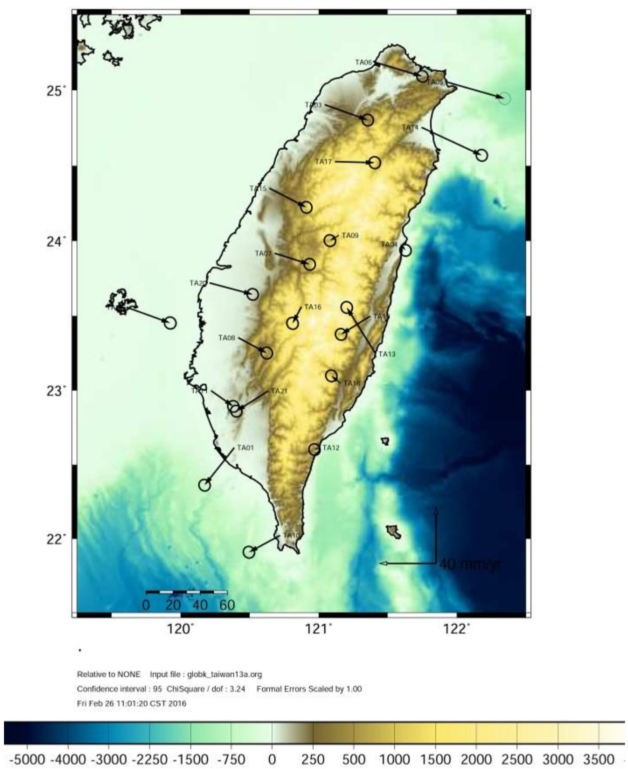


Figure 5. The velocity field of Taiwan's station in 2013

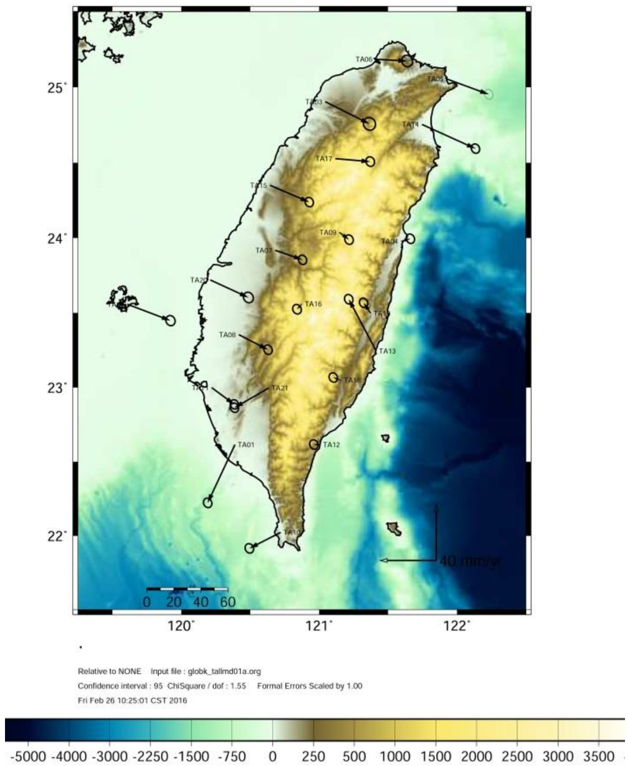


Figure 6. The velocity field of Taiwan’s station in 2014

The velocity field of Taiwan’s stations can be divided into several parts according to the characteristics of the velocity, the north part of Taiwan is going East 30-40mm per year; the west part along the coast line and Penghu island has the same direction as the north part; the south part of Taiwan was squeezed out to south west because the Philippine Sea plate is subducting beneath the Eurasian plate. It’s worth noting that the velocity field of stations around the Central Range and Longitudinal Valley like TA09, TA16, TA04, TA13, and TA19 have different characteristics in two years. TA09 and TA16 are located in the Central Range, both stations have very little horizontal movement comparing to others because the Central Range was pushed up by plate motion. The circle located in the tip of the arrow is the error ellipse of velocity, since the velocity is very small, the direction of velocity of TA09 and TA16 are not reliable.

TA04, TA13, and TA19 are located in eastern coast line besides Longitudinal Valley, TA04 is around the collision boundary that has the same condition with stations located in Central Range. TA13 is located eastern coastline has the direction in northwest that against to most of the stations. The most interesting thing is TA19 has very different direction of velocity in two years, it is going south and west for 12.7mm and 20.3mm in 2013, but it is going north and west for 7.2mm and 4.87mm in 2014.

## 4. CONCLUSIONS

It is such a complicated crustal movement situation in Taiwan that can be seen from two graphs above. Even only one year of data is considered, we can see that there is still an obvious frame distortion in Taiwan. Various regions of the island move in different directions with a great velocity difference. In this situation, the national coordinate reference system should be updated very frequently to catch up the change of coordinates. Especially in eastern Taiwan, that is around the collision boundary having significant non-linear motion of crustal. But it will be little inadequate to determine the trend of this region by only two years data. In the future work, it is necessary to have a long term data more than two years in order to find out a suitable strategy.

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