# ENHANCING THE PRECISION OF GPS STATIC RELATIVE POSITIONING USING THE OCEAN TIDE LOADING CORRECTION

Ta-Kang Yeh[1] Ming-Han Chang[1] Yuei-An Liou[2] Chun-Sung Chen[1]

1. Institute of Geomatics and Disaster Prevention Technology, Ching Yun University, bigsteel@cyu.edu.tw
2. Institute of Space Science, National Central University

**ABSTRACT:**

The ocean tide loading (OTL) is an important factor for the GPS positioning, especially in the height direction. The shorter of the distance to the ocean, the larger of the error by the OTL. The influence will be changed when we measure in different place and the order of magnitude is from few centimeters to ten centimeters. In this study, more than ten kinds of the OTL models were collected and applied on the GPS static relative positioning in Taiwan. The GPS observations including five stations were obtained from Nov. 9, 2004 to Feb. 23, 2005 and we used the Bernese GPS software to execute the data processing.

In this period, the average amplitudes of the 3-D coordinates are as follows: N is 0.4 cm, E is 0.7 cm, h is 1.8 cm at Kinmen station; N is 0.7 cm, E is 1.3 cm, h is 2.3 cm at Lanyu station; N is 0.5 cm, E is 0.7 cm, h is 2.0 cm at Matsu station; N is 0.6 cm, E is 0.6 cm, h is 2.0 cm at Penghu station and N is 0.5 cm, E is 1.2 cm, h is 1.7 cm at Hsinchu station. Moreover, we will analyze the advantage and disadvantage of every kind of the OTL models in different environments to offer some information to the GPS users and enhance the precision of the GPS positioning.

**KEY WORDS:** GPS, ocean tide loading, positioning precision, correction parameter

## 1. FORWARD

By collecting ocean tide loading (OTL) effect models and observations and apply them to the error corrections of GPS static relative positioning, we develop theories from this research and analyze its accuracy as well as reliability. Although there are already dozens of famous global OTL effect correction models in the international community, such as GOT00.2, FES99, CSR4.0, NAO.99b, TPXO.6.2, Schwiderski, etc, they are not necessarily suitable for researches conducted in coastal areas in Taiwan. Therefore, we hope utilize GPS data obtained on the Taiwan Island and its off-shore islands and adopt different models to get a picture of how OTL effects influence the accuracy of GPS static relative positioning, in the hope that we provide GPS users with useful information for their reference.

When it comes to related international studies, according to the studies of Baker, in Newlyn, the UK, the vertical error of OTL can be as high as 12 cm (Baker et al., 1995). Dragert indicates that in Holberg, which is located in the coast of Canada, the influence of OTL on vertical error can result in a figure as high as 8 cm (Dragert et al., 2000). Penna and Baker take the coastal area in north-west Australia as their research subject and find out that the influence of OTL on vertical error can bring about a figure as high as about 10 cm, its oscillation cycle is about 6 hours (Penna and Baker, 2002). According to our estimation, this is due to the influence of semidiurnal tide. Khan and Scherneck take the coastal areas in Alaska, the United States, as their concentration and conduct their analysis on a baseline which is approximately 500 km long. They use gravity measurement and GPS to verify its OTL model (Khan and Scherneck, 2003). Zahran analyzes the influence of OTL on the displacement of inland tide gauge stations in a global viewpoint: the displacement can be as high as 2 cm, with a baseline variation as high as 2 mm. In addition, he has also found out that the nearer the station is to the shore, the more influence it suffers from OTL (Zahran et al., 2005).

Bos and Scherneck, two Swedish scientists, provide a webpage where users can calculate OTL for free. The webpage automatically calculates the parameters of partialtide for the users to conduct corrections (Bos and Scherneck, 2006). Physical Oceanography Data Center, JPL, NASA, also provides its online visitors with relative tidal correction data obtained by using TOPEX/POSEIDON satellite altimetry technology for their correction reference (PO.DAAC, 2006). As theories of ocean tide and solid earth tide are becoming well-developed, IERS, International Earth Rotation Service spent an entire chapter to dwell on the correction of solid earth tide and ocean tide data at tide gauge stations in their 2003 technology report (Dam et al., 2003). With a pursuit of higher accuracy on earth measurement in developed countries around the world, the influence of OTL should also be taken into account in this respect.

## 2. THEORIES OF OCEAN TIDE LOADING CALCULATION

Just as the measurement of its influence on tidal gravity, to measure the influence of OTL on tidal position, we can utilize the Green function and height integration. The formula is as follows (Yang et al., 1996):

$$U_r = \iint \sigma(\theta', \lambda') U(\psi) ds'$$

$$U_\theta = \iint \sigma(\theta', \lambda') V(\psi) \cos A ds'$$

$$U_\lambda = \iint \sigma(\theta', \lambda') V(\psi) \sin A ds'$$

$$U(\psi) = \frac{Rh'_\infty}{M} \sum_{n=0}^{\infty} P_n(\cos\psi) + \frac{R}{M} \sum_{n=0}^{\infty} (h'_n - h'_\infty) P_n(\cos\psi)$$

$$V(\psi)=\frac{Rl'_\infty}{M}\sum_{n=1}^{\infty}\frac{1}{n}\frac{dP_n(\cos\psi)}{d\psi}+\frac{R}{M}\sum_{n=1}^{\infty}(nl'_n-l'_\infty)\frac{1}{n}\frac{dP_n(\cos\psi)}{d\psi}$$

$$\sigma(\theta',\lambda')=\rho_0\cdot H(\theta',\lambda')$$

The $U(\psi)$ and $V(\psi)$ in the formula are kernel functions. Its calculation method, tide models, and gravity measurement are totally the same with the calculation of tidal gravity. Therefore, the formula goes as follows:

$$U(\psi)=\frac{R}{M}\left[h'_\infty\sum_{n=0}^{\infty}P_n(\cos\psi)+\sum_{n=0}^{\infty}(h'_n-h'_\infty)P_n(\cos\psi)\right]$$

$$V(\psi)=\frac{R}{M}\left[l'_\infty\sum_{n=1}^{\infty}\frac{1}{n}\frac{dP_n(\cos\psi)}{d\psi}+\sum_{n=1}^{\infty}(nl'_n-l'_\infty)\frac{1}{n}\frac{dP_n(\cos\psi)}{d\psi}\right]$$

Let

$$U'(\psi)=\sum_{n=0}^{\infty}(h'_n-h'_\infty)P_n(\cos\psi)$$

$$V'(\psi)=\sum_{n=1}^{\infty}(nl'_n-l'_\infty)\frac{1}{n}\frac{dP_n(\cos\psi)}{d\psi}$$

In addition, because

$$\sum_{n=1}^{\infty}\frac{1}{n}\frac{\partial P_n(\cos\theta)}{\partial\theta}=-\frac{\cos\left(\theta/2\right)\left[1+2\sin\left(\theta/2\right)\right]}{2\sin\left(\theta/2\right)\left[1+\sin\left(\theta/2\right)\right]}$$

With the substation of the formula, the result goes as follows:

$$U(\psi)=\frac{R}{M}\left[h'_\infty\frac{1}{2\sin\left(\psi/2\right)}+U'(\psi)\right]$$

$$V(\psi)=\frac{R}{M}\left[-l'_\infty\times\frac{\cos\left(\psi/2\right)\left[1+2\sin\left(\psi/2\right)\right]}{2\sin\left(\psi/2\right)\left[1+\sin\left(\psi/2\right)\right]}+V'(\psi)\right]$$

Then, with $U'(\psi)$ and $V'(\psi)$ obtained from the calculation, along with the data of the radius of the earth and the mass of the earth, we now have the measurement result of $U(\psi)$ and $V(\psi)$. With a further calculation of global integration, we will be able to know the levels of radial, vertical, and horizontal displacement resulted from OTL at any place in the world.

## 3. DATA PROCESSING AND ANALYSIS

We take Fenglin station, which locates in east Taiwan, as our GPS base station in this research. This is mostly because east Taiwan lies near to the Pacific Ocean, and the depth of the Pacific Ocean is far greater than that of the Taiwan Strait next to the west Taiwan coast. Therefore, it is under less influence of OTL effect and is suitable to serve as a GPS base station to perform successive data processing. Our observations come from the period between November 9th, 2004 and February 23rd, 2005. We obtain GPS data from Kinmen station with a consecutive six-day observation, Lanyu station with a consecutive three-day observation, Matsu station with a seven-day observation, Penghu station with a six-day observation, and Hsinchu with a consecutive four-day observation. The locations of these stations are shown as in Figure 1. When conducting the calculation, one unit equals to three hours. As for the data processing, we use Bernese, which is developed by University of Bern, Switzerland, as our calculation software. In addition, partialtide parameter figures obtained from OTL models are used to conduct comparative analysis of positioning accuracy.

The calculation of partialtide parameters is conducted through free calculation webpage http://www.oso.chalmers.se/%7Eloading/index.html provided by two Swedish scientists, Bos and Schernck. Its merely requires users to key in approximate coordinates and choose to correct the model online. Then, it will automatically calculate partialtide parameters for its users to conduct correction. The goal of this research is to testify the level of influence OTL has on GPS positioning accuracy. Therefore, NAO.99b is adopted to conduct the correction, and with many other tide models we will skip shallow sea areas when conducting calculation. Figure 2 shows the areas from which no corrected data is produced in each model. This is mostly because the influence of OTL is small in areas such as the Mediterranean Sea, the Black Sea, and the Baltic Sea; therefore, even when we skip these areas and do not conduct corrections, the result will not be much different. Taiwan is located on the west side of the Pacific Ocean that belongs to deep ocean areas. Moreover, oceanic areas around Taiwan are included in the ocean tide model calculation under discussion here in this research.

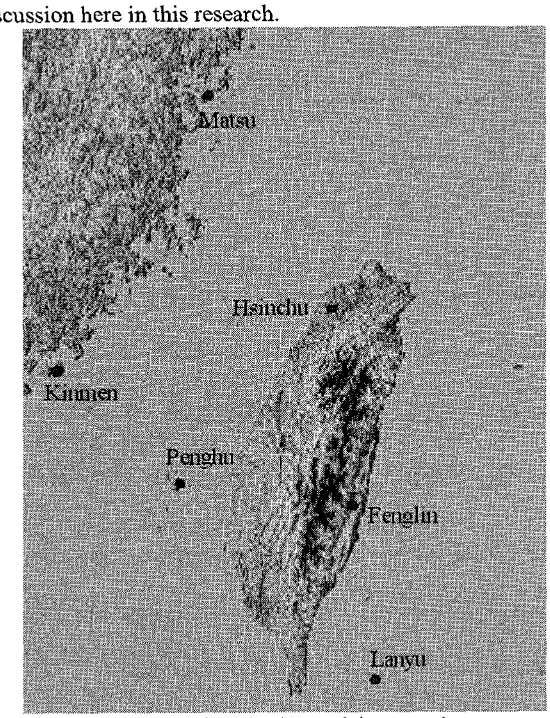



Figure 1. The locations of these stations

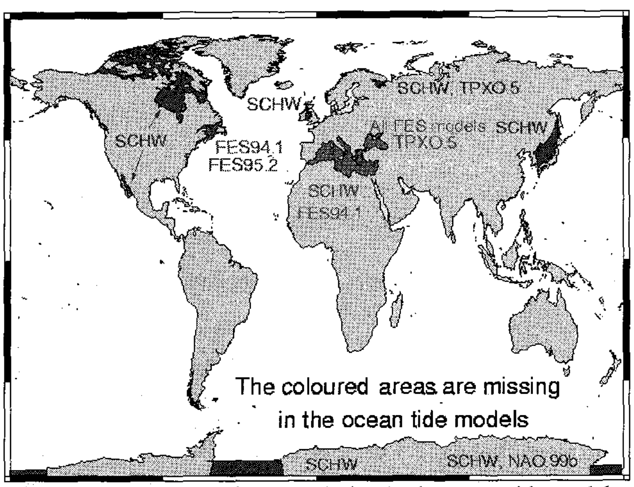



Figure 2. Water areas that are missing in the ocean tide models (Bos and Scherneck, 2006)

## 4. RESULTS

We take Fenglin station in Taiwan as our base station in this research. Without OTL correction, the variation figures of the N coordinates at Kinmen, Lanyu, Matsu, Penghu, and Hsinchu are shown in Figure 3. The maximum and average vertical amplitude figures of each station are as follow: Kinmen station, 2.4 cm and 0.4 cm, Lanyu station, 3.3 cm and 0.7 cm, Matsu station, 2.2 cm and 0.5 cm, Penghu station, 3.0 cm and 0.6 cm, and Hsinchu station, 3.2 cm and 0.5 cm.

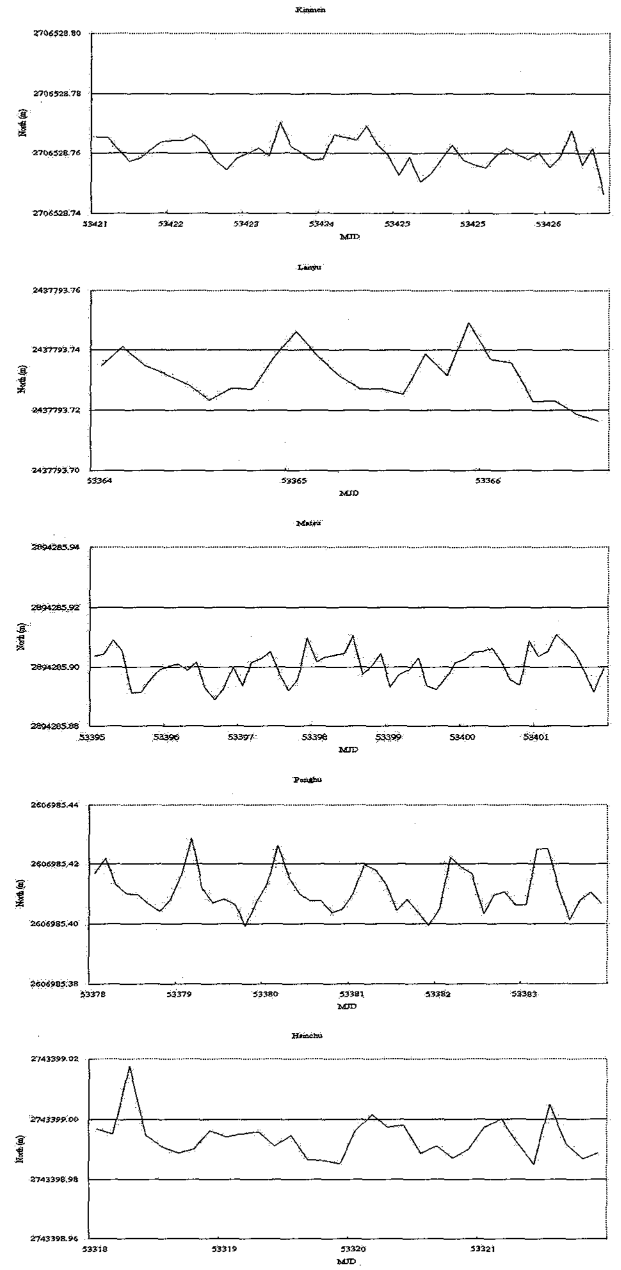


Figure 3. The N coordinates at Kinmen, Lanyu, Matsu, Penghu, and Hsinchu

Likewise, the variation figures of the E coordinates are shown in Figure 4. The maximum and average vertical amplitude figures are as follow: Kinmen station, 6.3 cm and 0.7 cm, Lanyu station, 9.4 cm and 1.3 cm, Matsu station, 4.6 cm and 0.7 cm, Penghu station, 4.3 cm and 0.6 cm, and Hsinchu station, 10.4 cm and 1.2 cm.

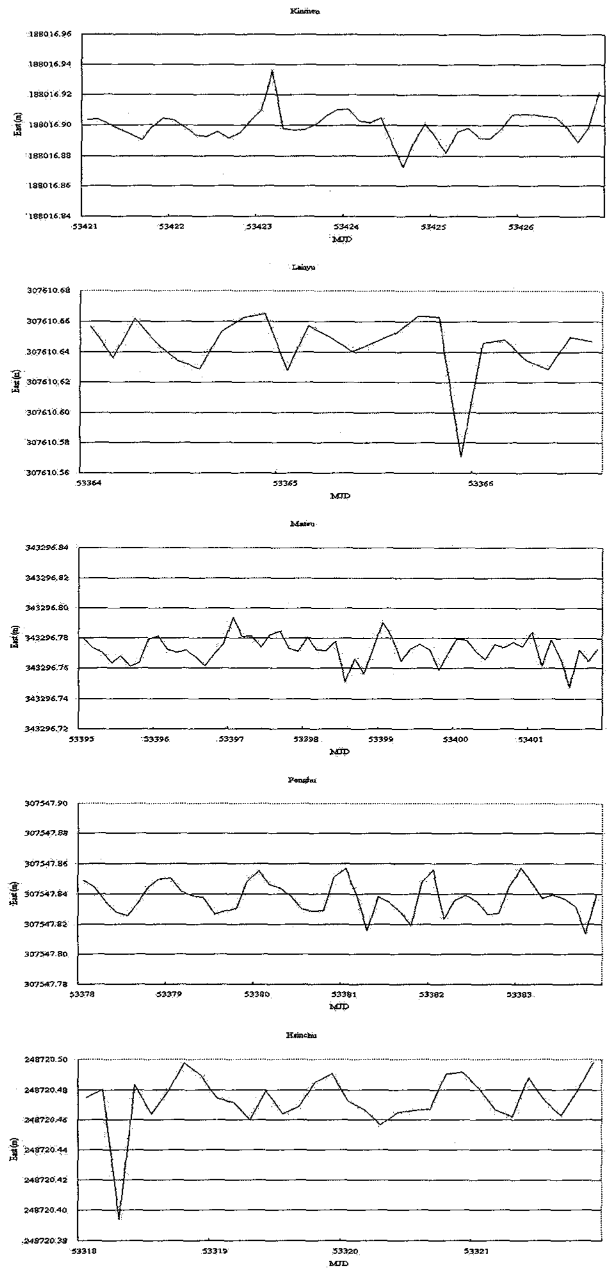
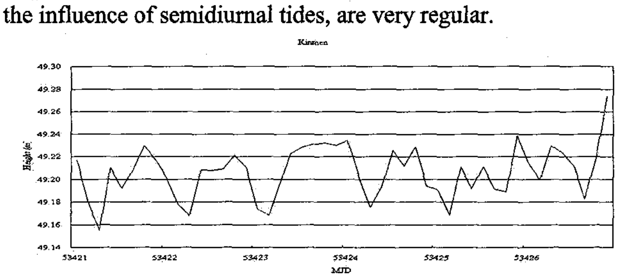


Figure 4. The E coordinates at Kinmen, Lanyu, Matsu, Penghu, and Hsinchu

Likewise, the variation figures of the h coordinates are shown in Figure 5. The maximum and average vertical amplitude figures are as follow: Kinmen station, 11.9 cm and 1.8 cm, Lanyu station, 13.9 cm and 2.3 cm, Matsu station, 11.7 cm and 2.0 cm, Penghu station, 9.7 cm and 2.0 cm, and Hsinchu station, 12.1 cm and 1.7 cm. From Figure 5, we can see that the amplitude figures at Kinmen, Matsu, and Penghu stations, under the influence of semidiurnal tides, are very regular.



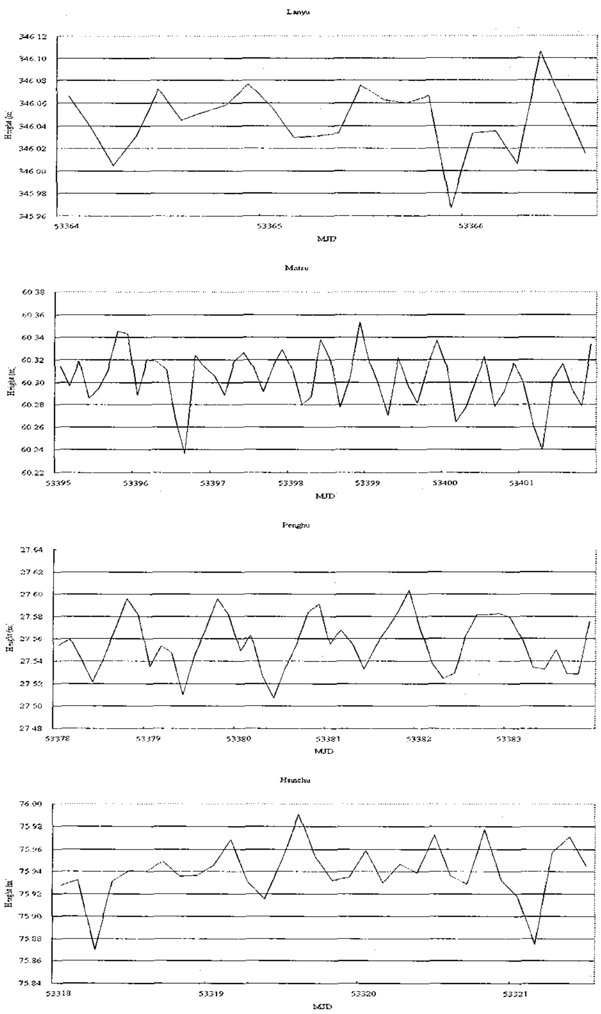



Figure 5. The h coordinates at Kinmen, Lanyu, Matsu, Penghu, and Hsinchu

## 5. CONCLUSIONS

In Taiwan, ocean tide loading, indeed, would cast influence on GPS positioning accuracy, especially when it comes to the error of height. Its level of influence varies according to different observation points. Generally speaking, the closer the tide gauge station is to the shore, the greater error OTL brings about. The number can be as big as several or even ten centimeters.

During this period, at each station, the maximum and average vertical amplitude figures of three dimensional coordinates are as follow: at Kinmen station, the maximum amplitude figures of N, E, and h are respectively 2.4 cm, 6.3 cm and 11.9 cm, while its average amplitude figures are 0.4 cm, 0.7 cm, and 1.8 cm; at Lanyu station, the maximum amplitude figures of N, E, and h are respectively 3.3 cm, 9.4 cm and 13.9 cm, while its average amplitude figures are 0.7 cm, 1.3 cm, and 2.3 cm; at Matsu station, the maximum amplitude figures of N, E, and h are respectively 2.2 cm, 4.6 cm and 11.7 cm, while its average amplitude figures are 0.5 cm, 0.7 cm, and 2.0 cm; at Penghu station, the maximum amplitude figures of N, E, and h are respectively 3.0 cm, 4.3 cm and 9.7 cm, while its average amplitude figures are 0.6 cm, 0.6 cm, and 2.0 cm; at Hsinchu station, the maximum amplitude figures of N, E, and h are respectively 3.2 cm, 10.4 cm and 12.1 cm, while its average amplitude figures are 0.5 cm, 1.2 cm, and 1.7 cm.

Judging from the research result, we find out that, without ocean tide corrections, the errors caused by OTL effects range from several centimeters to ten meters. In addition, Kinmen station is away from the coast for about 1.5 km, Lanyu station about 0.1 km, Matsu station away from the coast for about 1.3 km, Penghu station away from the coast for about 0.3 km, and Hsinchu station away from the coast for about 12 km. As a result, we can infer from the research that the nearer the station is to the coast, the greater influence OTL has on it. When conducting high-accuracy GPS measurement tasks, we should take ocean tide models into account to conduct corrections. In this way, we will be able to improve the accuracy and reliability of GPS relative positioning. What's more, since the phase lags resulted from the OTL effect has not yet been taken into consideration in this research, in future studies, this can also be a subject under discussion. As for whether this will be able to improve the accuracy of GPS positioning, we will leave it for successive studies to testify the supposition.

## 6. REFERENCES


Baker, T. F., D. J. Curtis, A. H. Dodson, 1995. Ocean Tide Loading and GPS, *GPS World*, pp. 54-59.

Bos, M. S. and H. G. Scherneck, 2006. Ocean Tide Loading Provider, Onsala Space Observatory, http://www.oso.chalmers.se/~loading/.

Dam, T. V., H. P. Plag, O. Francis, P. Gegout, 2003. GGFC Special Bureau Loading: Current Status and Plans, *IERS Technical Note 30*, International Earth Rotation and Reference System Service, pp. 180-198.

Dragert, H., T. S. James, A. Lambert, 2000. Ocean Loading Corrections for Continuous GPS: A Case Study at the Canadian Coastal Site Holberg, *Geophysical Research Letter*, Vol. 27, No. 14, pp. 2045-2048.

Khan, S. A. and H. G. Scherneck, 2003. The M2 Ocean Tide Loading Wave in Alaska: Vertical and Horizontal Displacement, Modelled and Observed, *Journal of Geodesy*, Vol. 77, pp. 117-127.

Penna, N. T. and T. F. Baker, 2002. Ocean Tide Loading Considerations for GPS Processing Around Australia, *Geomatics Research Australasia*, No. 77, pp. 1-26.

PO.DAAC, 2006. TOPEX/POSEIDON Tides Models,Physical Oceanography Distributed Active Archive Center, http://podaac.jpl.nasa.gov/toppos/toppos_tides.html.

Yang, Z., S. Manabe, K. Yokoyama, T. Jike, K. Heki, 1996. Comprehensive Ocean Tide Loading Parameters of Sites in East Asia with Spherical Harmonic Method, *Gravity, Geoid and Marine Geodesy*, pp. 343-350.

Zahran, K. H., G. Jentzsch, G. Seeber, 2005. World-Wide Synthetic Tide Parameters for Gravity and Vertical and Horizontal Displacements, *Journal of Geodesy*, Vol. 79, pp. 293-299.