Ocean Loading Tides Corrections of GPS Stations in Antarctica

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Abstract  This paper describes the ocean loading tides corrections of GPS stations in Antarctica, such as the Great Wall station and Zhongshan station. Based on the theory of ocean loading tides, the displacement corrections of ocean loading tides on GPS stations in Antarctica are calculated by using the CRS4.0 ocean loading tides model. These corrections are also applied to GPS data processing. The GPS data are analyzed by the GAMIT software with and without these corrections. We compared and analyzed the GPS baseline components to get the differences. The results show that the ocean tidal displacement corrections have obvious effects upon GPS baseline components. Therefore, we should not ignore the ocean loading tides corrections of GPS stations in Antarctica to obtain precise and reliable results.

Keywords  GPS; ocean loading tides; model

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Introduction

Since 1995, the SCAR Epoch Crustal Movement Campaigns (formerly SCAR Epoch GPS Campaigns) have been carried out under the umbrella of the Scientific Committee on Antarctic Research, Geoscience Standing Scientific Group (GSSG), the former working group on geodesy and geographic information. Every year, the GPS surveying lasts about three weeks. The main goals of the SCAR Epoch Crustal Movement Campaigns are to provide geodetic observation for geodesy, lithosphere, and geodynamics in Antarctica.

With the development of high-precision GPS technology, GPS has been used in geodynamics in Antarctica where high measurement precision is required. For instance, the Chinese Antarctic Center of Surveying and Mapping of Wuhan University researched and obtained the crustal deformation field of Antarctica by processing GPS data from 1997 to 2004. According to the velocity field provided by the result, the institution concluded that the Antarctic Plate is moving toward the South American Plate, and the Australian Plate is moving away from the Antarctica Plate. Also, the velocity of GPS stations in West Antarctica is greater than that in East Antarctica, and the velocity field shows that the Antarctic Peninsula is the active region in Antarctica[3].

As we know, the ocean loading tide has an effect on the deformation and additional potential of the earth, which causes the errors in GPS stations. This is called the ocean loading tides correction. There are many factors that affect GPS data processing, such as satellite ephemeris, ionosphere and troposphere delays, receiver clock errors, multipath, and so on. If GPS is used in geodynamics, we must take into account the ocean tides’ effects on GPS stations to im-
prove the accuracy. The ocean loading tides corrections of stations near the ocean are bigger than those of inland stations\cite{2}. Antarctica is the only continent in the world that is surrounded by oceans. These include the Pacific Ocean, Atlantic, and Indian Ocean around Antarctica; its coastline is about 2,470,000 km long. Therefore, we must consider the ocean loading tides corrections of the stations in Antarctica. This paper calculates the effect of ocean loading tides on Antarctic GPS stations by using the CRS4.0 ocean loading tidal model. What is more, the GPS baseline components are computed by GAMIT software with and without these corrections. We draw some conclusions through comparing and analyzing the baselines repeatedly.

1 Ocean loading tides correction model

In a spherical coordinate system, the station’s displacement affected by ocean loading tides can be described by faulting integral as follows:

\[
(\phi, \lambda, t) = \int \rho H(\phi', \lambda', t) G(\theta, A) ds',
\]

(1)

where \(\rho\) is density of seawater; \((\phi, \lambda)\) and \((\phi', \lambda')\) are the coordinates of the station and loading site in spherical coordinate system; \(A, \theta\) are the azimuth and distance between station and loading site; \(ds'\) is loading cell; \(H\) is instantaneous tidal altitude; \(G\) is Green’s function.

In Eq.(1):

\[
T(\phi, \lambda, \Delta) = \int \rho H(\phi', \lambda', t) G(\theta, A) ds',
\]

(2)

where \(\rho\) is density of seawater; \((\phi, \lambda)\) and \((\phi', \lambda')\) are the coordinates of the station and loading site in spherical coordinate system; \(A, \theta\) are the azimuth and distance between station and loading site; \(ds'\) is loading cell; \(H\) is instantaneous tidal altitude; \(G\) is Green’s function.

In Eq.(1):

\[
H = \left[ A_v A_u A_d \right]^T \quad G = \begin{bmatrix} u(\theta) \\ v(\theta) \cos A \\ v(\theta) \sin A \end{bmatrix}
\]

where \(A_v, A_u, A_d\) are corrections caused by ocean loading tides in the vertical direction, north-south direction and east-west direction, respectively. Green’s functions in the vertical and horizontal direction are presented as follows:

\[
G(\theta)_{\text{vertical}} = \frac{kR}{g} \sum_{n=0}^\infty h_n' P_n(\cos \theta),
\]

\[
G(\theta)_{\text{horizontal}} = \frac{kR}{g} \sum_{n=0}^\infty l_n' \frac{\partial}{\partial \theta} P_n(\cos \theta)
\]

(3)

where \(k\) is gravitational constant; \(R\) is radius of the earth; \(g\) is the constant of gravity; \(h_n'\) and \(l_n'\) are \(n\) order load Love’s number.

2 Results and analysis

According to Eq.(1) and Eq.(3), the authors computed amplitudes and phases of the ocean loading tides displacement corrections of the GPS stations in Antarctica by using the CRS4.0 ocean tidal model, such as the Great Wall station, the Zhongshan station, and so on. The amplitudes and phases are caused by 11 principal components of tidal wave \((M_2, N_2, S_2, K_2, K_1, O_1, P_1, Q_1, M_4, M_6, S_6)\). The CRS4.0 model was provided by Texas University. The ocean tidal displacement corrections of the Great Wall station and Zhongshan station are presented in Table 1.

We processed SCAR GPS data observed in 2004 which were provided by the Chinese Antarctic Center of Surveying and Mapping of Wuhan University, and we also downloaded some IGS data. In processing the GPS data, we compared and analyzed the results with and without adding the ocean loading tides corrections.

First, the authors processed the data on 038 (day of year) in 2004 with GAMIT software. In processing, we used IGS precise ephemeris to compute the baseline every two hours. Fig.1 describes the differences from 0:00 to 24:00 on 038 of 2004.

![Fig.1 Differences of baseline components affected by ocean tidal displacement corrections in a day](image)

Fig.1 Differences of baseline components affected by ocean tidal displacement corrections in a day.
Table 1  Ocean tidal displacement corrections

| Station name       | component | U/amplitude/m | EW/amplitude/m | NS/amplitude/m | U/ phase(°) | EW/ phase(°) | NS/ phase(°) |
|--------------------|-----------|---------------|----------------|----------------|-------------|--------------|--------------|
| The Great Wall station | $M_2$     | 0.021 93      | 0.002 66       | 0.001 62       | 89.1        | 105.8        | -163.0       |
|                    | $S_2$     | 0.008 88      | 0.002 45       | 0.001 09       | 134.8       | 107.4        | -109.6       |
|                    | $N_2$     | 0.003 34      | 0.000 69       | 0.000 35       | 59.1        | 110.2        | 157.4        |
|                    | $K_2$     | 0.002 3       | 0.000 72       | 0.000 30       | 140.4       | 107.8        | -107.2       |
|                    | $K_1$     | 0.014 25      | 0.001 30       | 0.001 18       | -114.6      | 141.5        | 33.3         |
|                    | $O_1$     | 0.015 85      | 0.000 79       | 0.000 60       | -133.9      | 160.1        | 11.5         |
|                    | $P_1$     | 0.004 88      | 0.000 41       | 0.000 38       | -115.2      | 141.3        | 31.3         |
| Zhongshan station  | $M_f$     | 0.001 71      | 0.000 05       | 0.000 04       | 20.7        | -173.8       | -58.1        |
|                    | $M_w$     | 0.001 29      | 0.000 08       | 0.000 06       | 18.2        | -178.1       | 73.5         |
|                    | $S_{nw}$  | 0.000 96      | 0.000 01       | 0.000 01       | -180.0      | -180.0       | 0.0          |
|                    | $M_2$     | 0.004 80      | 0.000 47       | 0.002 36       | 6.1         | -12.1        | 14.6         |
|                    | $S_2$     | 0.002 66      | 0.000 63       | 0.001 12       | 124.0       | 28.3         | 105.2        |
|                    | $N_2$     | 0.001 60      | 0.000 06       | 0.000 62       | -23.5       | -37.5        | -10.0        |
|                    | $K_2$     | 0.000 78      | 0.000 18       | 0.000 33       | 128.6       | 29.9         | 110.2        |
|                    | $K_1$     | 0.008 24      | 0.001 18       | 0.001 40       | 77.9        | 24.5         | 92.3         |
|                    | $O_1$     | 0.008 83      | 0.001 20       | 0.001 93       | 76.2        | -7.3         | 83.4         |
|                    | $P_1$     | 0.002 81      | 0.000 10       | 0.000 49       | 78.0        | 21.9         | 91.7         |
|                    | $Q_i$     | 0.001 96      | 0.000 26       | 0.000 46       | 74.1        | -18.7        | 79.6         |
|                    | $M_f$     | 0.001 09      | 0.000 04       | 0.000 15       | 17.3        | -151.0       | 25.5         |
|                    | $M_w$     | 0.000 66      | 0.000 02       | 0.000 09       | -1.7        | -41.1        | -21.9        |
|                    | $S_{nw}$  | 0.000 66      | 0.000 03       | 0.000 10       | -180.0      | 0.0          | -180.0       |

of baseline components (from the Great Wall station to Zhongshan station) affected by ocean tidal displacement corrections in a day. In the figure, the unit of x-axis is hour; the unit of y-axis is millimeter; 1 means North direction; 2 means East direction; 3 means Up direction.

Fig.1 indicates that the differences of baseline components affected by ocean tidal displacement corrections in a day change periodically. The graph is similar to a sine wave. The whole differences are comparatively big because only 2 hours’ observations are chosen. From the figure, we can conclude that the differences of vertical direction are bigger than that of the horizontal direction. In the vertical direction, the biggest difference reaches 40 mm, so the ocean tidal corrections have an obvious effect upon the GPS baseline.

In addition, the authors did another test. We collected continuous GPS data of the stations in Antarctica and other 11 IGS stations located in Antarctica or around it. We processed the data of day of year from 033 to 041. The strategy of daily solution is similar to the one described in the reference[3]. The difference is that the ocean loading tidal corrections are either applied to GPS data processing or not. Fig.2 shows the differences of the baseline component (from the Great Wall station to Zhongshan station). In the figure, x-axis is day of year; y-axis is differences of baseline components in mm; 1 means North direction; 2 means East direction; 3 means Up direction.

From Fig.2, periodicity is not very obvious because of the low number of days. In the horizontal direction, the biggest difference is about 6 mm. However, the values in the vertical direction are bigger than those in the horizontal direction; the biggest one is up to 8mm. The figure shows that the whole differences are comparatively smaller than those in Fig.1 because the data we analyzed are 24-hour daily solutions. Therefore, in Antarctica, the plan to collect continuous GPS data of 24-hour has been selected so that we can obtain precise results as much as possible. Though the ocean loading tides displacement corrections are only
several millimeters, we should not ignore them.

3 Conclusions

This paper describes the ocean loading tides corrections of GPS stations in Antarctica. Based on the theory of ocean loading tidal model, the displacement corrections of GPS stations in Antarctica are calculated. These corrections are applied to GPS data processing. The GPS data are analyzed by GAMIT with and without the ocean loading tides corrections.

By analyzing the results of GPS data processing, we find that the ocean loading tides corrections have obvious effect upon the GPS stations in Antarctica. What is more, the differences in the vertical direction are bigger than those in the horizontal direction; and the effect on long term observation is smaller than that on short term observation. Therefore, GPS observation should be continuous as long as possible. Also, we should not ignore the ocean loading tides correction when processing the GPS data so that we can obtain precise and reliable results.

References

[1] Jiang Weiping (2001) The systematical error analysis of baseline processing in GPS network[J]. Geomatics and Information Science of Wuhan University, 26(3): 196-199
[2] Xu Daxin (1998) Ocean Loading tides correction of GPS stations[J]. Crustal Deformation and Earthquake, 18(3): 33-35
[3] E Dongchen, Zhang Shengkai, Yan Li, et al (2005) The establishment of GPS control network and data analysis in Grove mountains[C]. The Fifth SCAR Antarctic Geodesy Symposium, Lviv, Ukraine
[4] E Dongchen, Jiang Weiping, Zhan Biwei, et al (2005) The crustal deformation field of Antarctica derived from GPS surveys: 1997 through 2004[C]. IAG Conference, Cairns, Australia
[5] Liu Jiyu (2003) GPS satellite navigation theory and method[M]. Beijing: Science Press (in Chinese)
[6] Zhou Zhongmo, Yi Jiejun, Zhou Qit(1997) GPS satellite surveying theory and application[M]. Beijing: Surveying and Mapping Press (in Chinese)