Retrieval of the Change of Precipitable Water Vapor by GPS Technique

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Abstract  The feasibility of GPS precipitable water vapor (PWV) is discussed based on the comparison of Radiosonde and GPS PWV where the correlation coefficient is 0.94 and the RMS is 4.0 mm. PWV change in the Chinese mainland in 2004 is graphed with the gridding method of splines in tension, according to the GPS data of the crust monitor observation network in China, combined with relevant meteorology information. According to the distribution of the annual amount of rainfall in the country, it can be concluded that the total trend of the PWV is diminishing from the south-east coastalland to the north-west inland. The PWV reaches its maximum during July and August, and the minimum is reached during January and February. According to the PWV, from high to low, all districts can be ranked as south-east coastaland, the inland and the tableland.

Keywords  GPS-meteorology; precipitable water vapor; zenith wet delay; zenith tropospheric delay

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Introduction

Water vapor is a highly variable parameter in atmospheric processes and it plays a crucial role in atmospheric motions on a wide range of scales in space and time. Limitations in humidity observation accuracy, such as temporal and spatial coverages, often lead to problems in numerical weather prediction, in particular, in the prediction of clouds and precipitation. The verification of water vapor simulations in operational weather forecasts and climate modeling is also difficult because of the lack of high temporal and spatial resolution data. Ground-based GPS networks have been proposed as a possible data source to improve both model validation and the initial model state in the weather forecasts because the GPS receivers are portable and economic and the GPS measurements are not affected by rain and clouds[1].

Many authors carried out studies to increase the accuracy of the technique for GPS-based PWV estimation, typically using a small number of stations. Rocken et al. were the first to demonstrate the agreement between WVR and GPS-derived relative estimates of integrated water vapor (IWV), with a level of agreement of about 1kg/m²[2]. Emardson et al. detected instrumental biases due to antenna radomes and the resulting contamination of network solutions[3]. This study used data independent from the other instruments such as water vapor radiometers to demonstrate the accuracy of the data. It has been demonstrated that the IWV can be retrieved using ground-based GPS observations with the same level of accuracy as radiosondes and microwave radiometers[4-6].

In this study, PWV change in the Chinese Mainland in 2004 is graphed with the gridding method of splines in tension, according to the GPS data of the crust monitor observation network of China (CMONOC), combined with the relevant me-
teorology information. According to the distribution of Chinese annual amount of rainfall, it can be concluded that the total trend of the PWV is diminishing from the south-east coastland to the north-west inland.

1 GPS stations’ distribution of CMONOC

In the study, the GPS technique is used to retrieve the PWV change in the Chinese Mainland. The data is the GPS data of CMONOC in 2004. The GPS stations’ distribution of CMONOC is shown in Fig.1.

![Fig.1 GPS stations’ distribution of CMONOC](image)

The zenith tropospheric delay (ZTD) is calculated daily by GAMIT10.2 and the IGS ephemeris is consistent with the GPS data of CMONOC. The interval of the GPS data is 30 s and the observation time is from 00 to 24 hours. In the process of GPS data analysis, the ZTD is the absolute estimate values if the baselines’ length are above 500 km; otherwise it is just relative estimated value\(^{[4,6,8]}\). The ZTD of CMONOC is the absolute estimate values for the length of most baselines above 500 km.

2 PWV retrieval by GPS data

2.1 Comparison of GPS PWV and radiosonde PWV

In order to retrieve the change of GPS PWV, we should verify the reliability of GPS PWV solved with the data from the CMONOC project. We calculated the ZTD of the CMONOC project from the 190th day (July 9, 2002) to the 199th day (July 18, 2002), distilled the ZTD of the SHAO station and computed the PWV with the pressure and temperature of the site. We also computed the PWV with the radiosonde data. Fig.3 shows the result of the comparison of GPS PWV and radiosonde PWV.

From ten days of data, the differences between radiosonde PWV and GPS PWV have a standard deviation of 4 mm in delay, difference of 0.24 mm in delay, and correlation coefficient of 0.94. So it can be concluded that the accuracy of GPS PWV is sufficed and the GPS PWV of CMONOC is reliable.

![Fig.2 Comparison of radiosonde PWV and GPS PWV](image)

With the comparison of radiosonde PWV and GPS PWV, it can be concluded that the accuracy of GPS PWV is sufficed and the GPS PWV of CMONOC is reliable.

2.2 Calculation of GPS PWV of CMONOC

The meteorology parameters of GPS stations of CMONOC have been collected. In order to get the PWV, four steps should be done. Firstly, ZTD can be derived by use of the software GAMIT10.2. Secondly, ZHD can be worked out with meteorology parameters. Thirdly, ZWD is the difference of ZTD and ZHD. Finally, PWV can be achieved by ZWD multiplied by \(0.15\).

3 PWV changes of Chinese Mainland in 2004

According to the PWV of GPS stations, we adopted a grid method for a linearity calculation and plotted the figures of PWV changes of the Chinese Mainland in 2004. All figures for every month are shown in Fig.3.
We analyze all the GPS PWV changes in 2004. The general trend of the GPS PWV change is that it is descended from the southeast coast to the northwest interior, which is identical to the distribution of the Chinese annual amount of rainfall. The trend of the GPS PWV change is consistent with the change of the atmospheric circumstance in China. The Aleutian low pressure is significant in spring, autumn and especially in winter. During these seasons the northern area of China is dominated by a Mongolian high pressure, and there is a large difference between the Aleutian low pressure and the Mongolian high pressure. So, the atmosphere flows from the mainland to the Northern Pacific. From October to April, the GPS PWV in the northern part is low, and in January or February the PWV is at the lowest. When the shoot-point of the Sun moves to the north, the Aleutian low pressure and the Mongolian high pressure are diminished. Therefore, the warm and damp airflow coming from the South substitutes for the dry and cold airflow in the Northern China. The GPS PWV ascends because the season-wind coming from the southeast carries a lot of water vapor to most areas in China. From April to September, the GPS PWV of the Middle and Northern areas in China is high and it is at its highest in July or August. In September, the season-wind withdraws from the Northeast to the Southern China and the GPS PWV of the Southeast
descends. The PWV of the southern part are the highest in China, owing to the warm and damp airflow coming from the southeast. Even so, in July and August, due to the influence of typhoons, the GPS PWV of the southern coastland is the highest in the year.

4 Conclusions

GPS is an effective method for monitoring PWV change. It can continuously demonstrate the temporal and spatial distribution of the atmospheric water vapor. This study shows the seasonal change of the PWV in different areas in China. The general trend of the change of the GPS PWV in China is that it descends from the southeast coast to the northwest inland, which is identical to the distribution of the annual amount of rainfall. The GPS PWV in Chinese mainland reaches its maximum in July or August, and its minimum in December. The values of the GPS PWV in the southeast coast are the highest and the lowest in the northwest interior.

References

[1] Bevis M, Businger S, Herring T A, et al.(1992) GPS meteorology: remote sensing of atmospheric water vapor using the global positioning system[J]. *J Geophys Res*, 97: 15 787-15 807

[2] Rocken C, Hove T, Johnsson J, et al.(1995) GPS/STROMGPS sensing of atmospheric water vapor for meteorology[J]. *J Atmos Oceanic Technology*, 12:468- 478

[3] Emardson T R, Johansson J, Elgered G(2000) The systematic behavior of water vapor estimates using four years of GPS observations[J]. *IEEE Transactions on Geoscience and Remote sensing*, 38:324-329

[4] Duan Jingping, Bevis M, Fang Peng, et al.(1996) GPS meteorology: direct estimation of the absolute value of precipitable water[J]. *J Appl Meteorol*, 35:830-838

[5] Elgered G, Johansson J M, Ronnang B O, et al.(1997) Measuring regional atmospheric water vapor using the Swedish permanent GPS network[J]. *Geophysical Research Letters*, 24:2 663-2 666

[6] Liou Y, Huang C, Teng Y(2000) Precipitable water observed by grounded-based GPS receivers and microwave radiometry[J]. *Earth Planets Space*, 52:445-450

[7] Herring T A, King R W, McClusky S C(2006) GAMIT reference manual[R]. Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA

[8] Li Zhenghang, Xu Xiaohua, Luo Jia, et al.(2003) Inversion of the distribution and variation of ZWD over the Three Gorge area with GPS observation[J]. *Geomatics and Information Science of Wuhan University*, 28(4): 393-396 (in Chinese)