Application of Ground Based GPS Technology in Rainstorm Detection

Tihui ZHOU, Linbing LYU, China

Key words: ground based GPS technology; wet delay; precipitable water vapor, accuracy analysis

SUMMARY

Heavy rain causes great loss to the whole world every year and therefore the forecast of precipitation is very important to reduce the loss of property. In recent years, the use of ground-based GPS Technology to detect water vapor has become an important approach of precipitation forecasting. This paper focuses on the study of water vapor before and after the heavy rainstorm on July 21, 2012 in Beijing area, which caused significant casualties and property damage, by using GPS water vapor detection technology. The comparison was carried out between two simulated water vapor results obtained from GPS technology (GPS/PWV) and from radio method (RADIO/PWV). The two results were then compared with the actual precipitation. The research (1) verified that GPS/PWV has the reliability and sensitivity to deter water vapor in heavy rain, and (2) worked out the wet delay conversion factor in Beijing area. This study provides the technical support of using GPS technology for forecasting rainstorm in the area of Beijing in future as well as for detecting water vapor in other areas, which have effective influences on reducing the loss caused by rainstorm.

Application of Ground Based GPS Technology in Rainstorm Detection

Tihui ZHOU, Linbing LYU, China

1. Introduction

With the development of GPS technology, GPS technology has been more and more used in various fields. Bevis proposed first the method of using ground-based GPS meteorology technology to detect precipitable water vapor (PWV). Its basic principle is to use the GPS receiver installed on the ground to measure the delay of satellite signal in the atmosphere, estimate the wet delay, and calculate the precipitable water vapor over the receiver (Bevis et al., 1992). At the beginning of the 21st century, the United States and European countries have successively carried out large-scale projects of GPS meteorology application, such as MAGIC、WAVEFRONT、GASP、NOAAGSD, by using GPS network established by surveying and mapping, earthquake and meteorology departments. Based on its crustal deformation monitoring network composed of more than 1200 continuous stations, Japan also started to study the application field of ground based GPS meteorology. Many Chinese scholars and relevant departments have also carried out a lot of research on GPS meteorology. In 2006, Shanghai Meteorological Bureau established Shanghai satellite remote sensing and measurement application center, which has become a professional organization for GPS meteorology research and application. The application of ground based GPS of precipitable water vapor in Hong Kong was studied (Chen Yongqi, et al., 2007); Wang Yong Used GPS network to retrieve water vapor (Wang Yong, et al., 2007), the construction and application of GPS water vapor retrieval system in Fujian Province has also made some achievements(Zheng Zhixin et al., 2014); the comparative research on the methods of extracting zenith water vapor content from GPS station data in China's coastal areas is also being actively carried out (Lu yongduo et al., 2016). Using GPS technology to retrieve water vapor and assimilate it into numerical weather forecast has also been studied by many experts and scholars (Nakamura h, et al., 2004; BI Y, Mao J, Li C., 2006; Yuan Zhaohong, et al., 2006; Zhang m, et al., 2007). At present, many countries in the world are also studying and applying GPS technology in water vapor detection.

2. Basic principles of ground based GPS meteorology

The neutral atmosphere of the earth will delay the propagation of GPS signal, and the atmospheric delay will bring two parts of delay. The first part refers to the delay caused by the mixture of some elements excluding all elements of water vapor, which is usually called dry delay; the second part is caused by water vapor, which is called wet delay. The atmospheric propagation delay can be calculated as follows:

$$D(EL) = DZ * DM(EL) + WZ * WM(EL) \qquad (1)$$

Where D is the total delay, EL is the altitude angle, DZ is the dry delay, WZ is the wet delay, DM is the projection function of the dry delay andWM is the projection function of the wet delay. The projection function is a mathematical model related to the altitude angle of each delay. The dry delay can be calculated by saastamoinen model, and the wet delay can be obtained by subtracting the dry delay from the total delay, the relationship between zenith wet delay and PWV is as follows:

$$PWV = \Pi \bullet WZ \tag{2}$$

Where Π is a dimensionless conversion factor related to air temperature and pressure, which is the basic principle of ground-based GPS meteorology.

The processing flow of ground based GPS inversion of Atmospheric Precipitable Water is shown in Figure 1.

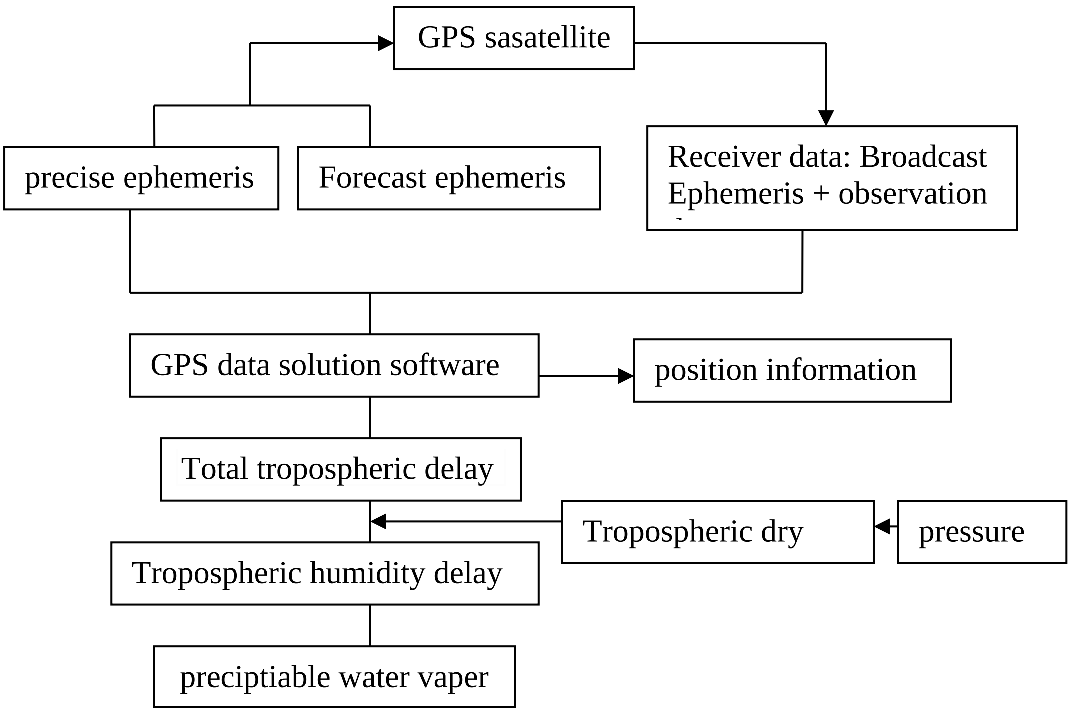

Fig.1 ground base GPS inversion preciptiable water vaper process

3. Water vapor inversion application

On July 21, 2012, a heavy rainstorm occurred in Beijing. In this paper, GPS technology was used to invert the water vapor for 11 days before and after the rainstorm, so as to verify the feasibility of using GPS technology to forecast the rainstorm weather and verify the inversion accuracy.

3.1 Site selection

The absolute PWV is obtained from long-distance measuring the selected stations. The stations involved include four IGS stations, named Beijing (BJFS), Wuhan (WUHN), Shanghai (SHAO) and Kunming (Kunm). Beijing station can download and obtain meteorological data, and the data can be obtained from CDDIS. The rainstorm occurred in Beijing on July 21, 2012, with an annual accumulated day of 203. In order to reflect characteristics of precipitable water on that day accurately, 11 days of data from July 17 to July 27, corresponding to an annual accumulated day of 199 to 209, were selected for calculation.

3.2 Extraction and precision analysis of precipitable water vapor

3.2.1 GPS data processing and precipitable water vapor extraction

GAMIT software is used to calculate the data of 11 days, and the corresponding parameters of sestel file are set before calculation. The main parameters related to GPS meteorology are as follows: (1) choice of observable is "LC_HELP". The ionospheric combination mode is adopted to minimize the influence of ionosphere; (2) interval Zen is 1. The zenith delay is estimated every hour to refine the influence of air temperature and pressure; (3) elevation cutoff is 10. Considering the combined influence of water vapor and GPS signal, the satellite altitude angle is set to 10 degrees. In order to get the precipitable water in Beijing accurately, the coordinate of Beijing station is strongly constrained. And batch process of 11 days is carried out as follow.

The command to extract the precipitable amount in GAMIT is "sh_metutil". Since the meteorological files of BJFS station can be obtained from the CDDIS, the PWV can be estimated more accurately. Taking the data of 203 days as an example, the command to extract the precipitable amount is "sh_metutil -f ozhoaa.203 -m bjfs2030.12m", The precipitation of the other 10 days can be extracted by analogy.

3.2.2 GPS/PWV analysis of BJFS station

At present, the detection of atmospheric water vapor by the world meteorological department mainly depends on the detection of sounding balloon, so in order to verify the correctness of GPS/PWV, this paper compares GPS/PWV with Radio/PWV. GPS/PWV data is obtained once an hour by GAMIT, Radio/PWV is measured every 12 hours by sounding balloon, with a long time interval. The Radio/PWV in Beijing area can be downloaded from the website of University of Wyoming.

The trend of water vapor of GPS/PWV and Radio/PWV is shown in Figure 2. It can be seen from Figure 2 that the overall trend of GPS/PWV is consistent with that of Radio/PWV, and their correlation is shown in Table 1.

Table 1 GPS/PWV and Radio/PWV relation

Station name	Average GPS/PWV (mm)	Mean deviation （mm）	Relative mean deviation
BJFS	47.78	3.67	7.7%

As shown from Figure 2, except for the day of 203, GPS/PWV and Radio/PWV data are basically consistent, which can accurately reflect the PWV content in the air. The day of 203 corresponds to July 21, which is the time of Rainstorm in Beijing. The Radio/PWV time resolution is 12 hours, which can not quickly and accurately reflect the extreme weather change of PWV, while GPS/PWV can better reflect the change of water vapor in the air.

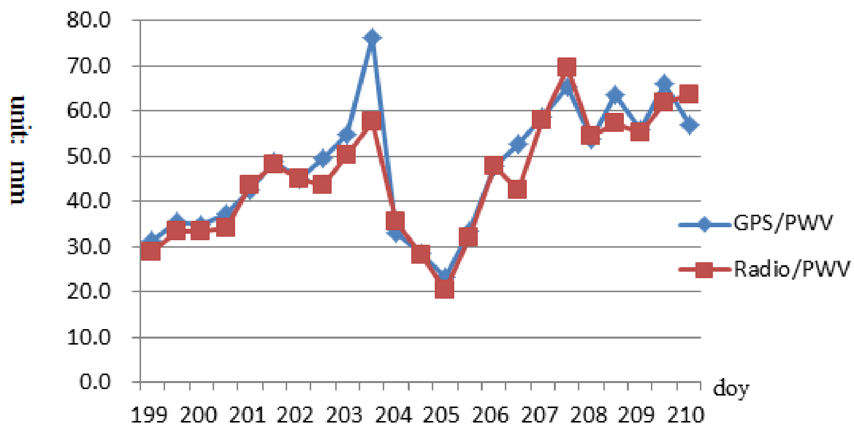

Fig.2 BJFS station doy of year 199 to 209 PWV

The day of 203 corresponds to July 21, which is the time of Rainstorm in Beijing. Beijing time is 8 hours faster than GPS time. As can be seen from Figure 3, GPS/PWV increases rapidly from 00:00 in 203 days, and reaches the peak at 10:00 on day of 203. The corresponding Beijing time is 08:00-18:00 on day of 203. The rainstorm time on July 21, 2012 is 12:30 in Beijing time, light rain begins, 14:30 turns to moderate rain, and 16:30 turns to moderate rain It turned into heavy rain at 00:00, gradually turned into rainstorm, and stopped raining after 20:00. In general, the trend of GPS/PWV reflects the trend of precipitation, the actual rainfall time is about 5 hours later than GPS/PWV, and the GPS/PWV reaches more than 60 mm when heavy rain occurs.

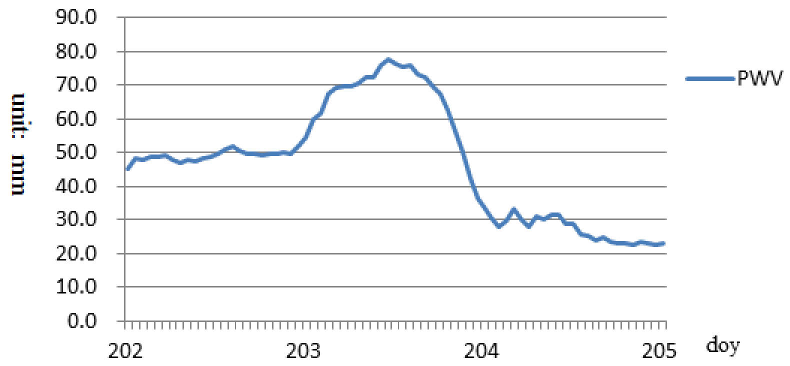

Fig.3 BJFS station day of year 202 to 204 GPS/PWV

The relationship between the trend of GPS/PWV and precipitation can refer to the actual weather conditions of that day, and the weather conditions of Beijing from July 17 to July 27, 2012 are shown in Table 2.

Table 2 BJFS station GPS/PWV relation with Beijing weather

doy	GPS/PWV（mm）	weather
199～201	30～40	Sunny to cloudy
202	40～50	Cloudy to thunderstorm
203	40～75	Heavy rain to cloudy
204	22～35	sunny
205	25～45	Cloudy to overcast
206	45～55	Cloudy to thundershower
207	45～65	heavy rain
208～209	50～65	Moderate rain to heavy rain

Considering the 8-hour time difference between Beijing time and GPS time, it can be seen from Table 2 that when the GPS/PWV value increases, the weather gradually changes from sunny to rainy weather. When rainfall occurs, the GPS/PWV value increases significantly; It can be found in Table 2 that the larger the GPS/PWV value, the larger the actual rainfall.

The wet delay is highly correlated with the amount of precipitation. The conversion factor ∏ for each period of 199 to 209 days in 2012 can be obtained by formula (2), as shown in Figure 4.

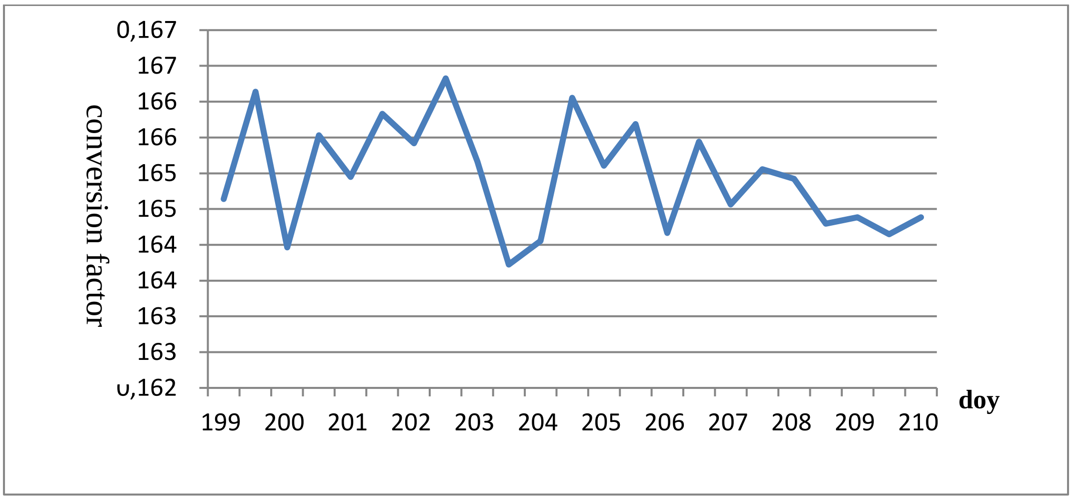

Fig.4 wet delay conversion factor

Based on the values of wet delay and precipitable water, after the conversion factor ∏ of Fig.4 is adjusted by least squares, it can be concluded that the wet delay conversion factor in Beijing is about 0.165, which provides a reference for future research on wet delay.

4. Conclusion

Based on the ground based GPS meteorology technology, this paper has carried out calculation processing on the GPS observation data of BJFS station from July 17th to July 27th, 2012, obtains the precipitation GPS/PWV, and compares GPS/PWV and Radio/PWV, And compared the weather conditions in Beijing during this period, focusing on the analysis of the changes in GPS/PWV of the heavy rain on July 21. The analysis results show that compared with Radio/PWV, GPS/PWV has a higher Time resolution, and for extreme rainstorms, it shows more accurate prediction for precipitation. When rainstorms occur in Beijing, GPS/PWV increases rapidly in a short time, with a time delay of about 5 hours. Through the wet delay and the amount of precipitation, the wet delay conversion factor in Beijing is calculated as to about 0.165. This study provides references for other areas to use GPS for rainstorm detection research. With the further maturity of ground based GPS meteorology technology, how to better assimilate the water vapor information obtained by ground based GPS into the numerical weather prediction model is the focus of the next step.

REFERENCES

Bevis M, Businger S, Herring T A, et al., 1992. GPS teteorology: remoting sensing of atmospheric water vapor using the global positioning system. *Journal of geophysical research*, 97(D14), 15787-15801.

Bi Y, Mao J, Li C., 2006. Preliminary results of 4D water vapor tomography in the troposphere using GPS. *Advances in atmospheric sciences*, 23(4), 551-560.

Chen Yongqi, Liu Yanxiong, Wang Xiaoya, et al., 2007. Some key technologies of real-time GPS water vapor monitoring system in Hong Kong. *Journal of surveying and mapping*, (01), 9-12. (In Chinese)

Lu Yongduo，Liu Sihan，Wang Chaoyang, et al., 2016. The GPS site of China's coastal data extraction based on water vapor zenith Comparative research． *Ocean forecast*, 33(2), 16-20．(In Chinese)

Nakamura H, Koizumi K, Mannoji N, 2004. Data assimilation of GPS precipitable water vapor into the JMA mesoscale numerical weather prediction model and its impact on rainfall forecasts. *Journal of the meteofological society of Japan*. 82(1B), 441-452.

Wang Yong, Liu Lintao, Hao Xiaoguang, et al., 2007. Research on the application of GPS meteorological network. *Journal of Surveying and mapping*, (02), 141-145. (In Chinese)

Yuan Zhaohong, Gu Songshan, Ding Jincai, 2006. Comparative study of numerical model prediction delay and GPS measurement. *Journal of Nanjing meteorological college*, (05), 581-590. (In Chinese)

Zheng Zhixing，Yang Xiandong, 2014．Construction and Application Analysis of Fujian GPS Water Vapor Retrieval System．*Information security and technology*, (11), 88-90．(In Chinese)

Zhang M, Ni Y, Zhang F, 2007. Variational assimilation of GPS precipitable water vapor and hourly rainfall observations for a meso scale heavy precipitation event during the 2002 mei-yu season. *Advances in atmospheric sciences*, 24(3), 509-526.

BIOGRAPHICAL NOTES

Tihui ZHOU
Tihui works as a senior engineer of the national quality inspection and testing center for surveying and mapping products of China (QICS). He has long been engaged in the quality inspection and evaluation of surveying and mapping products. His research interest is mainly focused on the quality control and quality inspection of surveying and mapping products.

Linbing LYU
Linbing works as an engineer of the national quality inspection and testing center for surveying and mapping products of China (QICS). He has long been engaged in the quality inspection and evaluation of surveying and mapping products. His research interest is mainly focused on the quality control and quality inspection of surveying and mapping products.

CONTACTS

Mr. Tihui ZHOU
National Quality Inspection and Testing Center for Surveying and Mapping Products (QICS)
No.28, Lianhuachi West Road, Haidian District
Beijing
People’s Republic of China
Email: 442002023@qq.com