Experiment on Driving Precipitable Water Vapor from Ground-Based GPS Network in Chengdu Plain

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Abstract  The estimates of total zenith delay are derived using Bernese GPS Software V4.2 based on GPS data every 30 s from the first measurement experiment of a ground-based GPS network in Chengdu Plain of Southwest China during the period from July to September 2004. Then the estimates of 0.5 hourly precipitable water vapor (PWV) derived from global positioning system (GPS) are obtained using meteorological data from automatic weather stations (AWS). The comparison of PWV derived from GPS and those from radiosonde observations is given for the Chengdu station, with RMS (root mean square) differences of 3.09 m. The consistency of precipitable water vapor derived from GPS to those from radiosonde is good. It is concluded that Bevis’ empirical formula for estimating the weighted atmospheric mean temperature can be applicable in Chengdu area because the relationship of GPS PWV with Bevis’ formula and GPS PWV with radiosonde method shows a high correlation. The result of this GPS measurement experiment is helpful both for accumulating the study of precipitable water vapor derived from GPS in Chengdu areas located at the eastern side of the Tibetan Plateau and for studying spatial-temporal variations of regional atmospheric water vapor through many disciplines cooperatively.

Keywords  precipitable water vapor; global positioning system; remote sensing

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Introduction

Precipitable water vapor (PWV) is also called atmospheric water vapor. It is defined as the total amount of water vapor in a column of air above the surface. It shows the atmospheric water content and water resource in the air. At present, the main technology for sounding PWV is radiosonde, wave radiometer vapor (WRV) and global positioning system (GPS). Radiosonde, which is usually used in meteorological routine operations, is difficult to use in spatial-temporal sounding for atmospheric water vapor with high resolution. The knowledge about data with high resolution and spatial-temporal distribution of water vapor is insufficient. With the rapid development of GPS meteorology and increasing perfection of its technology, ground-based GPS technology has become an effective and high time resolution technology in sounding atmospheric water. It can
make up the serious insufficiency of radiosonde data with spatial-temporal resolution and provide the information of atmospheric water vapor with high precision, large capacity and quick variation. In this study, atmospheric water vapor derived from GPS is called GPS PWV in brief.

Bevis et al. proposed the principle of estimating atmospheric water vapor using ground-based GPS. Some institutes of astronomy, survey and meteorology in China have done some experiments gradually on sounding atmospheric water using ground-based GPS since the mid 1990s. These experimental data mostly come from permanent tracking stations of international GPS geodynamics service (IGS) and a few temporary GPS monitor stations. However, they are short in observation sessions and have continuity errors, and these experiments focus only on Hong Kong, Shanghai, Wuhan, Beijing and some coastal areas of China. GPS data were usually processed by free software GAMIT which was developed by the Massachusetts Institute of Technology (MIT). Therefore, further experiments of measuring PWV derived from GPS in western areas of China have a significant meaning and application values in the construction of GPS observation network broadly in scale, applying GPS PWV in weather forecast and exploiting water resource in the air.

1 GPS data and meteorological data

The Chengdu Plain, which is located in the Sichuan Basin at the eastern side of the Tibetan Plateau, is notable for its geographic effect. The characteristics of water vapor, convection and precipitation are unique. The Earthquake Bureau of Sichuan Province started a plan to build the “Sichuan GPS observation network” in 2002, and the ground-based GPS network in Chengdu as one part of this plan formally started operations in summer 2004. Based on GPS data obtained every 30 s from the first measurement experiment of this regional ground-based GPS network (Fig.1) during the period from July to September 2004, the estimates of total zenith delay in this paper are derived using Bernese software V4.2 which is a scientific, educational and commercial software developed by the University of Bern, and have many excellent functions. The estimates of 0.5 hourly PWV derived from GPS are obtained through combining the observations coordinate with surface pressure and temperature data supplied by automatic weather stations (AWS), and meteorological observational data every 60 min was first transformed to every 30 min by linear interpolation method. By comparing GPS PWV and those estimated by using pressure, temperature and dew point temperature data every 12 h obtained from Chengdu Digital Radiosonde from the surface to upper troposphere (200 hPa), the precision of this ground-based GPS experiment is given.

2 Method for estimating PWV from GPS

The total delay of GPS signal in the air is composed of tropospheric delay and ionospheric delay. By using the TRIMBLE 5700 dual frequency GPS receiver, the ionospheric delay is eliminated automatically. The estimates of total delay, called tropospheric zenith total delay (ZTD), are derived using GPS data analytic software (Bernese GPS software V4.2). The difference between the GAMIT and Bernese software is that the major differential GPS of Bernese software has the most stable station while GAMIT has the longest baseline. Moreover, Bernese software contains a set of analytic schemes for short baseline GPS network. More accurate tropospheric delay is obtained by using short baseline data from regional GPS network without long baseline data (for
example IGS tracking stations). Therefore, it is applicable for the Chengdu regional GPS network (the longest baseline is only 99 km). The mapping function for estimating total delay is the Niell function, the satellite altitude angle is 20°, and the coordinates of every GPS station are obtained by using GAMIT/GLOBK synchronized global IGS data in the frame ITRF2000.

The estimates of 0.5 hourly ZTD sequence are available by processing software day by day. ZTD is composed of zenith hydrostatic delay (ZHD) and zenith wet delay (ZWD). Saastamoinen model is adopted to estimate ZHD which is as follows:

\[
ZHD = 10^{-6} \frac{k R_p}{g_w M_d},
\]

where, \(k\) is the standard pressure; \(R_p\) is the pressure on the top of troposphere; \(\rho_w\) is the pressure of atmospheric water vapor; \(g_w\) is the average gravity acceleration of tropospheric air column, i.e., \(g_w(\varphi) = 9.784(1-0.00266\cos2\varphi-0.00028\sin^2\varphi)\), where \(h\) is the average geodetic height, \(q\) is the specific humidity of air (unit is g/kg). The specific humidity at every isobaric surface can be calculated by the formula:

\[
q = \frac{621.98e}{p - 0.378e},
\]

where \(p\) is the pressure (unit is hPa).

The water vapor pressure \(e\) in every isobaric surface is available by using dewpoint temperature \(T_d\) according to the equation:

\[
e = 6.107 \times e^{0.078T_d},
\]

where \(a = 21.87\) and \(b = 237.29\) when temperature is higher than 0℃.

\[
e = 21.87e^{-0.078T_d},
\]

where \(a = 17.26\) and \(b = 265.49\) when temperature is lower than -55℃.

4 Measure precision of GPS PWV

SONDE PWV is dervied based on the vertical profiles of pressure, temperature and dewpoint temperature derived from digital radiosonde twice every day. The comparison of GPS PWV and SONDE PWV in the period of this study is shown in Fig.2. Their correlation coefficient is 0.913, the average deviation is 0.48 mm, and the root mean square (RMS) is 3.09 mm. At present, the precision of PGS PWV is 1-2 mm in North America, 2.66-3.70 mm in Japan, and 2.9-5.0 mm in China. Therefore, the GPS observation data from the first experiment in Chengdu has high precision, is a long time series and has good continuity, and is helpful for further analysis of temporal variation of GPS PWV.
5 Applicability of Bevis’ empirical formula

ZWD can be transformed into precipitable water by non-dimensional parameter of portionality \( \Pi \); however, the calculations of this parameter have to use the weighted tropospheric temperature \( T_w \), which is defined as:

\[
T_w = \frac{\int (P_v/T) dz}{\int (P_v/T^2) dz} = \frac{\int_0^\infty (e/T) dz}{\int_0^\infty (e/T^2) dz}
\]

where \( e \) and \( T \) is the water vapor pressure and the absolute temperature of one level in the zenith direction, respectively. Since the spatial-temporal distribution of \( e \) and \( T \) is alternative, the estimates of \( T_w \) are alternative too. Numerical integral of radiosonde data is the most precise method for calculating \( T_w \), but it is not suitable to calculate GPS PWV by using observation data obtained from meteorological routine sounding twice daily. In Bevis’ empirical formula, \( T_w \) can be estimated using ground air temperature with high time resolution derived from an automatic weather station. It can meet the demand of high time resolution in calculating GPS PWV. Bevis’ empirical formula was obtained using regressive calculation based on 8718 times radiosonde data covering an area of 27°N-65°N in America for two years; whether it is suitable for other areas or not is still to be determined. Thus, the key problem in ground-based GPS meteorological application is how to calculate tropospheric weighted mean temperature in real time and at high resolution.

Bevis’ empirical formula is adopted in processing GPS PWV in this paper. In order to test the application of this formula in Chengdu and the influence of two methods for calculating \( T_w \) on GPS PWV, the relevant GPS PWV was calculated using numerical integral of radiosonde data twice everyday (Beijing time 08:00 and 20:00) during the period from July to September 2004. Comparison of PWV derived from GPS and those from calculation of radiosonde data is given. The precision of this experiment is confirmed. Moreover, it is concluded that Bevis’ empirical formula for estimating the weighted mean tropospheric temperature is applicable in Chengdu areas. The results of this experiment also show the feasibility of GPS technology monitoring atmospheric water vapor in this plain, which establish the foundation for studying spatial-temporal variation of atmospheric water and exploiting atmospheric water resource through many disciplines.

6 Conclusions

The estimates of GPS PWV are available using Bernese GPS software V4.2 based on GPS data from the first measurement experiment of a ground-based GPS network in Chengdu Plain during the period from July to September 2004. The comparison of PWV derived from GPS and those from calculation of radiosonde data is given. The precision of this experiment is confirmed. Moreover, it is concluded that Bevis’ empirical formula for estimating the weighted mean tropospheric temperature is applicable in Chengdu areas. The results of this experiment also show the feasibility of GPS technology monitoring atmospheric water vapor in this plain, which establish the foundation for studying spatial-temporal variation of atmospheric water and exploiting atmospheric water resource through many disciplines.

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