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Analysis of precipitable water vapor from GPS measurements in Chengdu region: Distribution and evolution characteristics in autumn ☆

Hao Wang [a,b,*], Ming Wei [a,b], Guoping Li [c], Shenghui Zhou [a,b], Qingfeng Zeng [a,b]

[a] *Key Laboratory of Meteorological Disaster of Ministry of Education, Nanjing University of Information Science &Technology, # 219 Ningliu Road, Nanjing, Jiangsu 210044, China*

[b] *State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, # 219 Ningliu Road, Nanjing, Jiangsu 210044, China*

[c] *College of Atmospheric Sciences, Chengdu University of Information Technology, # 24 Xuefu Road, Chengdu, Sichuan 610225, China*

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Abstract

The rainfall process of Chengdu region in autumn has obvious regional features. Especially, the night-time rain rate of this region in this season is very high in China. Studying the spatial distribution and temporal variation of regional atmospheric precipitable water vapor (PWV) is important for our understanding of water vapor related processes, such as rainfall, evaporation, convective activity, among others in this area. Since GPS detection technology has the unique characteristics, such as all-weather, high accuracy, high spatial and temporal resolution as well as low cost, tracking and monitoring techniques on water vapor has achieved rapid developments in recent years. With GPS–PWV data at 30-min interval gathered from six GPS observational stations in Chengdu region in two autumns (September 2007–December 2007 and September 2008–December 2008), it is revealed that negative correlations exist between seasonally averaged value of GPS–PWV as well as its variation amplitude and local terrain altitude. The variation of PWV in the upper atmosphere of this region results from the water vapor variation from surface to 850 hPa. With the help of Fast Fourier Transform (FFT), it is found that the autumn PWV in Chengdu region has a multi-scale feature, which includes a seasonal cycle, 22.5 days period (quasi-tri-weekly oscillation). The variation of the GPS–PWV is related to periodical change in the transmitting of the water vapor caused by zonal and meridional wind strengths' change and to the East Asian monsoon system. According to seasonal variation characteristics, we concluded that the middle October is the critical turning point in PWV content. On a shorter time scale, the relationship between autumn PWV and ground meteorological elements was obtained using the composite analysis approach.

Keywords: Global positioning system (GPS); Precipitable water vapor; Fast Fourier Transform; Autumn rain; Composite analysis

1. Introduction

As the main greenhouse gas, water vapor in the atmosphere not only affects the global climate and weather but also plays a very important role in global heat and water cycles (Duan et al., 1996; Kiehl and Trenberth, 1997). It is therefore necessary to obtain the distribution condition of water vapor in the atmosphere and to understand the effects of spatial–temporal variation of water vapor on meso- and micro-scale severe weathers' evolution and on

* Corresponding author at: Key Laboratory of Meteorological Disaster of Ministry of Education, Nanjing University of Information Science and Technology, # 219 Ningliu Road, Nanjing, Jiangsu 210044, China. Tel.: +86 025 86531438; fax: +86 025 58699771.

E-mail addresses: wanghao911@163.com (H. Wang), mingwei@nuist.edu.cn (M. Wei), liguoping@cuit.edu.cn (G. Li), general_321@126.com (S. Zhou), Zengqing0419@sina.com (Q. Zeng).

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global climate change. GPS meteorology (or GPS/MET) rapidly developed in the 1990s, GPS–PWV (GPS–precipitable water vapor) retrieved from GPS technology has had wide and important applications in the related meteorology fields. The variation of GPS–PWV stands for the water vapor budget in the air column above the area. It is useful for weather forecasters to understand water vapor evolution conditions so that they know more about the weather process in this region, such as rainfall, evaporation, convective activity, among others (Fontaine et al., 2003).

Compared to the traditional detection means, GPS has more advantages in obtaining water vapor from the atmosphere, such as high accuracy, high capacity, high spatial and temporal resolution, all-weather, near-real time, and low cost, among others (Bevis et al., 1994; Ware et al., 2000). Moreover, GPS–PWV has been certified to have the same accuracy for deriving water vapor data with microwave radiometer, the very long baseline interferometry (VLBI) and radiosondes (Rocken et al., 1993; Bevis et al., 1994; Emardson et al., 1998; Van Baelen et al., 2005). Therefore, GPS technology has drawn meteorologists' attention in recent years. At present, it is mainly used for short-term and disastrous weather forecasting, and as an independent data source for data assimilation.

Located in the east of Qinghai-Tibet Plateau and the middle of the Sichuan Basin, Chengdu region belongs to the subtropical monsoon climate and is obviously affected by the topography. Especially in autumn, the convergence of humidity, convective activity and the diurnal cycle of rainfall in this area are very regional and have typical characteristics of the basin. Owing in part to the subtropical monsoon and the warm-humid climate, nighttime rainfall in this region is very high (Guo and Li, 2009; Li, 2011). So it is necessary to study deeply the local climate within peculiar topographic situations and further to find the mechanism of rainfall in this region. In the past, many researchers have shown the precipitation distribution and its variation characteristics in this area (Feng and Guo, 1983; Xu and Lin, 1994; Bai and Dong, 2004), but only a few studies are on spatial distribution of PWV or on the factors influencing the occurrence time and intensity of autumn rainfall. Additionally, most of these studies are based on the radiosonde data (Zhai and Eskridge, 1997). Because the radiosonde technology is non-uniform in terms of station allocation and is not so good in temporal resolution (only two soundings a day) and lack of continuity about the data, research on highly variable characteristics of water vapor and rainfall mechanism related to small scale is difficult. Though Shuanggen et al. (2008a) analyzed the GPS–PWV variation over China, but the source and formation mechanism of rainfall that have obvious regional features were not well discussed; in addition, the resolution of GPS–PWV they used was 2-h interval.

In recent years, the observational network of GPS/MET (including cooperative construction with Earthquake Administration, Surveying and Mapping Administration,

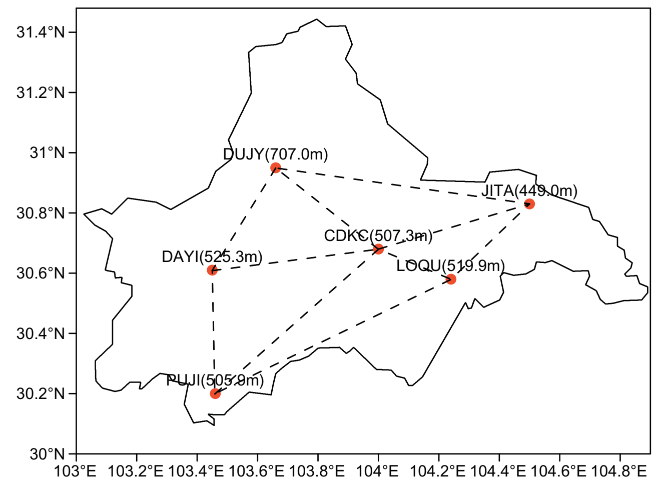

Fig. 1. Location of GPS stations (CHDC, LOQU, JITA, DUJY, DAYI, and PUJI) in Chengdu region. The number after each station name is the altitude of each GPS station.

Astronomical Observatory and Surveying and Investigation Institute) caught great attention from the meteorological departments throughout China. Regional ground-based GPS observational networks have been established in many places. In July 2007, the Chengdu Meteorological Bureau (hereinafter referred to as the CWB) and Chengdu Institute of Survey and Investigation (hereinafter referred to as CISI) set up six GPS observational network stations (Fig. 1); they are stations Chengdu (CDKC), Dujiangyan (DUJY), Jintang (JITA), Longquan (LOQU), Dayi (DAYI) and Pujiang (PUJI). The six stations are well distributed in the Chengdu plain. The longest baseline is 75 km from PUJI to LOQU, and the shortest baseline is 15.5 km from LOQU to CDKC. The 30-min interval GPS–PWV data gathered from the six GPS observational stations in this network in two autumns (September–December 2007 and September–December 2008) is used in this study, which mainly discusses the distribution characteristics and variation tendency of autumn PWV and the relationship between autumn PWV and ground meteorological elements. The data and analytical method is presented in Sections 2 and 3 is results and discussion and the conclusions are shown in final section.

2. Data and analysis

When GPS satellite lunches the radio wave through the atmosphere, the wave will be affected by the ionosphere and troposphere, thus its signals are delayed. This delay defined as the difference of signal propagation path between practicality and vacuum, which is a main factor influencing the accuracy of measurement in geodetic. However, GPS meteorology just derives the meteorological information from the delay. The delay can be classified into ionospheric delay and tropospheric delay. The ionospheric delay can be removed by dual-band technology in ground-based GPS receivers. The total delay minus the delay