Article ID: 1006-8775(2016) 04-0535-09

A PRELIMINARY STUDY ON THE QUALITY CONTROL METHOD FOR GUANGDONG GPS/PWV DATA AND ITS EFFECTS ON PRECIPITATION FORECASTS IN ITS ANNUALLY FIRST RAINING SEASON

LI Hao-rui (李昊睿)[1], DING Wei-yu (丁伟钰)[1], XUE Ji-shan (薛纪善)[1, 2], GAO Yu-dong (高郁东)[1],
ZHANG Xu-bin (张旭斌)[1], HUANG Hua-dong (黄华栋)[3]
(1. Guangzhou Institute of Tropical and Marine Meteorology/Guangdong Provincial Key Laboratory of Regional Numerical Weather Prediction, CMA, Guangzhou 510080 China; 2. Chinese Academy of Meteorological Sciences, Beijing 100081 China; 3. Guangdong Meteorological Observatory, Guangzhou 510080 China)

Abstract: We first analyzed GPS precipitable water vapor (GPS/PWV) available from a ground-based GPS observation network in Guangdong from 1 August 2009 to 27 August 2012 and then developed a method of quality control before GPS/PWV data is assimilated into the GRAPES 3DVAR system. This method can reject the outliers effectively. After establishing the criterion for quality control, we did three numerical experiments to investigate the impact on the precipitation forecast with and without the quality-controlled GPS/PWV data before they are assimilated into the system. In the numerical experiments, two precipitation cases (on 6 to 7 May, 2010 and 27 to 28 April, 2012 respectively) that occurred in the annually first raining season of Guangdong were selected. The results indicated that after quality control, only the GPS/PWV data that deviates little from the NCEP/PWV data can be assimilated into the system, has reasonable adjustment of the initial water vapor above Guangdong, and eventually improves the intensity and location of 24-h precipitation forecast significantly.

Key words: GRAPES; 3DVAR; quality control; data assimilation; GPS precipitable water vapor
CLC number: P445 **Document code:** A
doi: 10.16555/j.1006-8775.2016.04.008

1 INTRODUCTION

With the development of numerical weather prediction (NWP), computer application and novel technologies on atmospheric detection, much progress has been made in NWP in China though differences remain as compared with advanced operational systems overseas. It is mainly attributed to the serious insufficiency in both the amount and capability of detected data involved, especially in the aspect of satellite and radar data application. The domestic level of NWP is thus compromised due to poor initial model values. It is therefore the current focus to work intensively on applying assimilated detection data in constructing operational systems for regional NWP in order to improve short-term weather (especially precipitation) forecasting.

Water vapor is an essential atmospheric composition that plays a key role in weather evolution and climate change. At present, the data of water vapor is available twice daily through conventional means in all parts of the world. Due to the loosely distributed sites of observation and infrequent times of observation, it is difficult for it to reflect the spatio-temporal variations of water vapor, especially, when weather processes of relatively small scale happen, it is extremely difficult to analyze water vapor with high precision. Since Bevis et al. [1] argued that the precipitable water vapor (PWV), retrieved with a ground-based global positioning system (GPS), can be used in weather forecasting, much of the study has shown that the ground-based GPS meteorology promises to have extensive prospect of application (Wang et al.[2]; Zhang et al. [3]; Li et al. [4]; Gu et al. [5]; Wang et al. [6]; Wang et al.[7]). As shown in some studies (Ding[8]; Yao[9]), the variation of GPS/PWV is well corresponding to rain processes, which can be exploited to determine forecasting criteria of GPS/PWV to forecast rainfall. According to Yuan[10], who worked on three-dimensional variational assimilation of GPS-based PWV data, the assimilation improves the capabilities of forecasting 6-h and 24-h accumulated rainfall with the fifth generation Penn State/NCAR Mesoscale Model (MM5). Research outside China also showed that assimilated GPS/PWV data in NWP models helps improve the analysis of humidity field to improve model forecast, especially

---

Received 2014-11-30; **Revised** 2016-08-05; **Accepted** 2016-11-15

Foundation item: Natural Science Foundation of Guangdong Province (2016A030313140); Project 973 (2015CB452802); Natural Science Foundation of China (41405104); Science and Technology Program of Guangzhou City (201604020012)

Biography: LI Hao-rui, Ph. D., Senior Engineer, primarily undertaking research on numerical prediction and data assimilation.

Corresponding author: LI Hao-rui, e-mail: hrli@grmc.gov.cn

with regard to short-term forecast of rainfall and cloud cover (Guo et al.[12]; Kou et al.[13]; Kou et al.[14]; Smith et al.[15]; De and Zou[16]).

In accordance with three planning programs of various national to provincial institutions, the Guangdong Meteorological Bureau, in conjunction with the Guangdong Bureau of National Land Resources, set up in 2009 a ground-based GPS observation network composed of 80 base stations across the province. The network is currently issuing real-time GPS/PWV data and providing weather forecasters with information on the distribution and variation of water vapor that is high in both spatial and temporal resolution. It is, however, impossible to expect the information of atmospheric precipitable water vapor from the network to be error-free all the time and there are still some differences between the distribution of water vapor it detects and that of the NCEP reanalysis. If such differences are known and can be confirmed, then the data can be used appropriately (WMO[17]). In view of the fact that work related to quality control of the GPS/PWV data is still absent, this work aims at giving better technical support to the operational weather forecasting. In this work, the ground-based GPS/PWV data from August 2009 to August 2012 in Guangdong will be analyzed and a reasonable scheme for controlling the quality of the data will be formulated based on computational equations for GPS/PWV and associated background information, in order to turn the GPS/PWV data into a source of reliable information on the distribution and variation of water vapor. In addition, two rains of the annually first rainy season, one from May 6 to 7, 2010 and the other from April 27 to 28, 2012 were chosen and experiments of numerical assimilation were conducted to analyze and discuss how the GPS/PWV data adjusts the initial humidity field and improves the 24-h accumulated rainfall amount before and after the quality control.

2 DATA AND METHODS OF QUALITY CONTROL

2.1 *Data*

The GPS/PWV data is retrieved from the measurements, once per hour, of the ground-based GPS observation network in the province. It is mainly used to provide information on water vapor on the ground surface. As the background in the assimilation experiment, the NCEP reanalysis gridpoint data (with a resolution of 1° ×1°) is mainly for computation of NCEP/PWV and comparison with the GPS/PWV data.

2.2 *Method of quality control*

The control of data quality is an indispensable step prior to the assimilation. First, the ground-based GPS/PWV data from August 2009 to August 2012 is analyzed to set its climatological limits as the criteria in the initial processing. The monthly mean of the data is determined over the province. As the data contains some values that deviate much from the mean (also known as outlying data) and they pose much influence in the computation of arithmetic average of the data, it is difficult to distinguish the outlying data from the original data. To minimize such possibility, three averages are determined: arithmetic mean, median and a so-called "dual-weighted mean" (WMO[17], see Fig.1). It is known from Fig.1 that the three averages differ little and the outlying data has little effect on their computation. These means all have significant seasonal variation; they are relatively low in winter and become the lowest in December while being relatively high in summer and reaching the highest in June. It is noted that the three averages almost coincide with each other in August 2009 while they differ greatly in March 2010. From the distribution of the GPS/PWV values taken for all the observation sites and time in the two months (Fig.2), it is known that the closer the three averages are to each other, the more symmetric the PWV distributes. Most of the PWV values are more in the median than on the two sides. In the wet season, the range of PWV values is far from the y-axis, i.e. high PWV values are with large humidity, while most of them are more than 20 mm, and there is little data that is larger than 80 mm (Fig.2a). In the dry season, the range of the PWV data is closer to the y-axis, indicating that low PWV values are with small humidity and there is little data that is more than 55 mm (Fig.2b). Based on the variation of the averages (Fig.1) and the distribution

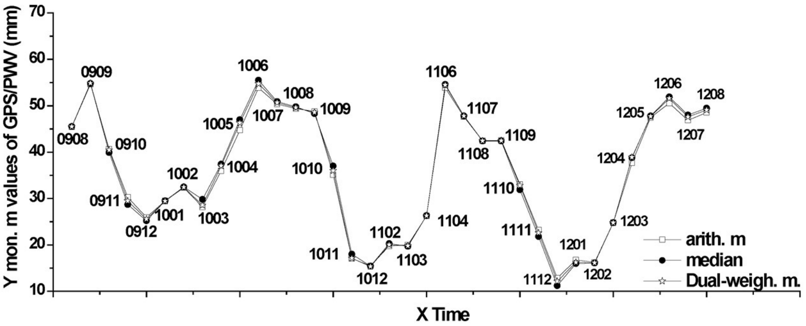

Figure 1. The GPS/PWV averages for August 2009 to August 2012. The meaning of curves: arithmetic mean (shallow dots); median (solid dots); dual-weighted mean (shallow stars). 0908 indicates August 2009 and the rest follows this rule.

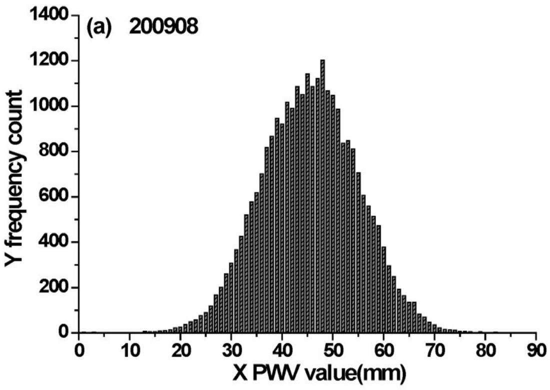

Figure 2. Distribution of the values taken in the GPS/PWV data for August 2009 (a) and March 2010 (b).

of the GPS/PWV values in different month, a reasonable range of the GPS/PWV values is presented in Table 1. In the first step of the quality control, a total of 2.64% of the data is removed as they are out of the reasonable range.

Figure 3 gives the distribution of the GPS/PWV data at 04:00 and relative humidity from surface observation stations at 06:00 in Guangdong province on August 28, 2009. The 06:00 data were chosen for comparison because there were no such data for 04:00. The PWV value at a station in Shangchuan was 85 mm (indicated by the red circle in Fig.3), much higher than those of the surrounding stations. For the distribution of the relative humidity near the surface stations (Fig.3b), it is relatively low at the surface in Guangdong and no high values are found around Shangchuan. As a result, 85 mm should be considered an outlying value and needs to be deleted. Following the quality control criterion listed in Table 1, the value can be removed effectively. If the observed value differs too much from the background value during the data assimilation, the system will adjust the latter unreasonably to result in the failure of the forecast. It is then necessary, after the deletion of the outlying data, to determine the atmospheric precipitable amount that is retrieved from the NCEP reanalysis (denoted as NCEP/PWV), and to compare the result with the GPS/PWV in determining whether or not the observed value can be included into the parameters of quality control in the assimilation system.

Table 1. Range of values taken by the GPS/PWV data.

Period of time	Jun. to Sept.	Dec. to Mar.	Apr. to May/ Oct. to Nov.
Values/mm	20 to 80	5 to 55	10 to 70

$$w=\frac{1}{\rho_{\text{water}}g}\int_{0}^{p_0} q\,dp=\frac{1}{\rho_{\text{water}}g}\sum_{0}^{p_0} q\Delta p \qquad (1)$$

Then, the information of temperature, pressure and humidity in the NCEP reanalysis is interpolated into the points of GPS observation and the atmospheric precipitable amount is determined following Eq. (1). In this way, each of the GPS observation stations has two time series, one being GPS/PWV, retrieved from the GPS observations, and the other being the NCEP/PWV, computed from the NCEP/PWV. Fig.4 gives the differences between GPS/PWV and NCEP/PWV for annually averaged GPS sites over the four years. It is clear that most of the curve values are negative, i.e. the

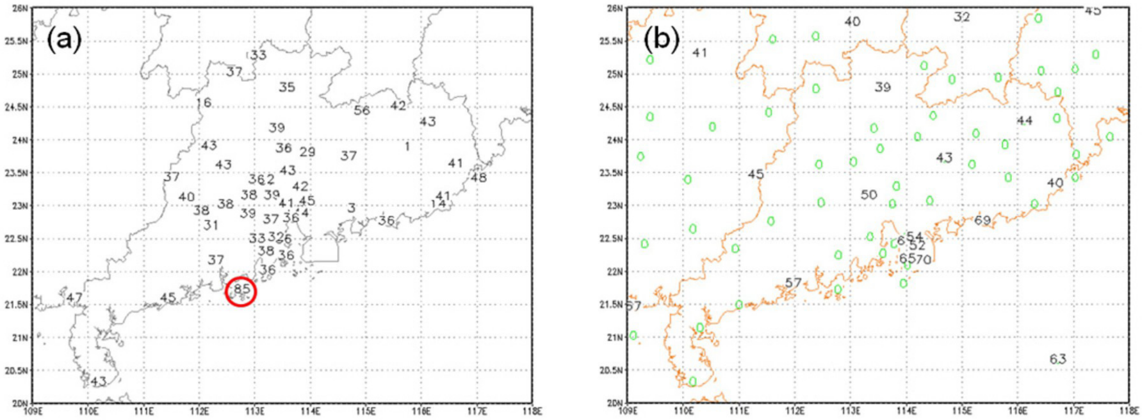

Figure 3. Distribution of the GPS/PWV data at 04:00 (a) and relative humidity from surface observation stations at 06:00 (b) in Guangdong province on August 28, 2009.

mean of GPS/PWV is less than that of NCEP/PWV, especially after 2009. It is noted that differences determined by the stations constructed by Guangdong Meteorological Bureau (with serial numbers from 1 to 18 and from 27 to 31) are relatively small and mainly fall between −4 and −8 and have relatively large number of samples in determining the averages (Figure omitted). Based on the results of Fig.4, the values of 2, 4, 6, 8 and 10 are chosen as the criteria of the second step of the quality control. It is shown in numerical experiments that the choice of 6 for the criterion can both guarantee that sufficient amount of observations are incorporated into the assimilation system and the system is prevented from being affected by erroneous data. In other words, it is equivalent of specifying that those data are not allowed to be in the assimilation system when the absolute value between its observation and the background value is more than 6.

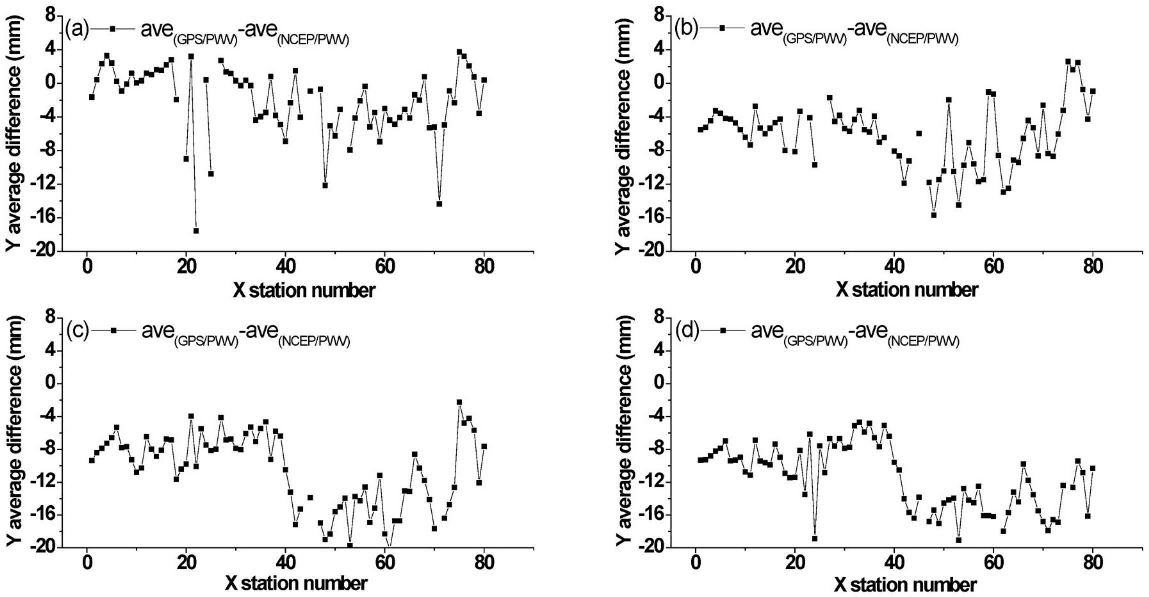

Figure 4. Differences of annual mean between the GPS/PWV and NCEP/PWV for 2009 (a), 2010 (b), 2011 (c) and 2012 (d). The abscissa is for the serial number of the observation station.

3 ASSIMILATION SYSTEM, NWP MODEL AND SETTING OF NUMERICAL EXPERIMENT

3.1 *Assimilation system and NWP model*

The assimilation system used in this work is a three-dimensional variational assimilation system, called GRAPES, which was developed by the NWP center of the Chinese Academy of Meteorological Sciences. It reduces the issue of three-dimensional variational assimilation into a minimization issue for the following objective function.

$$J(x)=\frac{1}{2}\left[(x-x_b)^{\mathrm{T}}B^{-1}(x-x_b)+(H(x)-y_o)^{\mathrm{T}}O^{-1}(H(x)-y_o)\right] \quad (2)$$

where x is the analytic variable, x_b the background field, H the observational operator, y_o the observation field, B the covariance matrix for the background error, O the covariance matrix for the observational error, and the superscript “T” indicates the matrix transposition. J, the objective function, contains the information on both the background field and the observation. By determining the distribution of x when J reaches the minimum, the analytic variable x can be solved to assimilate the data. The analyzed field so determined also consists of the information on the background field and observations. The three-dimensional variational approach is the extended wing of the optimal interpolation; as it is free from the restriction of a linear relationship between the observed and analyzed quantity, it can assimilate such conventional data as radiosondes as well as such unconventional data as satellite remotely sensed data.

The GRAPES-Meso, a next-generation mesoscale regional model used as an NWP model, shows quite good forecasting skill at the Guangzhou Regional Meteorological Center (Ding et al. [18]) and plays an important role in routine weather forecast and research (Xue et al. [19]). Employing equal-interval longitude/latitude gridpoints in the horizontal direction and the Arakawa-C format, the model has a horizontal resolution of 0.18° ×0.18° and 55 vertical layers. Its main physical schemes include Simplified Arakawa Schubert (SAS), a cumulus parameterization scheme, WSM6, a microphysical process, SLAB, a land surface process, RRTM (for longwave radiation), and ECMWF (for shortwave radiation).

3.2 *Setting of numerical experiments*

In this work two cases of rain, one on May 6 to 7, 2010 and the other on April 27 to 28, 2012, were chosen for the numerical experiment, for which the same settings were used for the two processes of rain (see Table 2).

4 ANALYSIS OF THE RESULTS OF NUMERICAL EXPERIMENTS

4.1 *Case study of the rain on May 6 to 7, 2010*

Due to the effect of an upper-level trough on May 6 to 7, 2010, heavy to very heavy rain occurred in northern Guangdong, with some areas having torrential rain. The initial time is set at 00:00 UTC May 6 for the numerical experiments and the settings are shown in Table 2.

Table 2. Settings of the numerical experiments.

Name of Experiment	Description of experiment
Control	Background field directly used in forecasting without assimilation
GPS	Only GPS/PWV data is assimilated without quality control and data from all stations incorporated into assimilation system
GPSQC	Only GPS/PWV data is assimilated with quality control and all quality-controlled data incorporated into assimilation system

It is known from Fig.5 that only when the absolute value of the differences between the GPS/PWV observations and the NCEP/PWV data is less than 6.0 mm, the data is allowed to be incorporated into the assimilation system, and most of these quality-controlled data is within the main area of rain during the process studied. It is noted that the GPS/PWV value in northern Guangdong and Pearl River Delta is larger than the NCEP/PWV value (as shown by the solid squares). It is known from the distribution of initial-time humidity increment determined from the assimilation (Fig.6) that if the initial field of humidity is adjusted without quality control (i.e. all GPS/PWV data obtained at the initial time is allowed to be in the assimilation), the atmosphere over the province is generally dry and the humidity increment shows an extensive stretch of negative values as it is compared with the background field, because the negative deviation (as indicated by the hollow circles) is relatively large between most of the GPS/PWV values and the NCEP/PWV values. With quality control, however, such deviation becomes smaller and half of the GPS/PWV values are a little larger than the NCEP/PWV values. The adjusted field of humidity increment is highly positive over Zhaoqing and Guangzhou while being still negative over the eastern part of Guangdong (Fig.6b). At the time, a strong southwesterly air stream is active at 850 hPa over the province (Fig.7), favorable for the water vapor in the area of positive increment to be transported downstream.

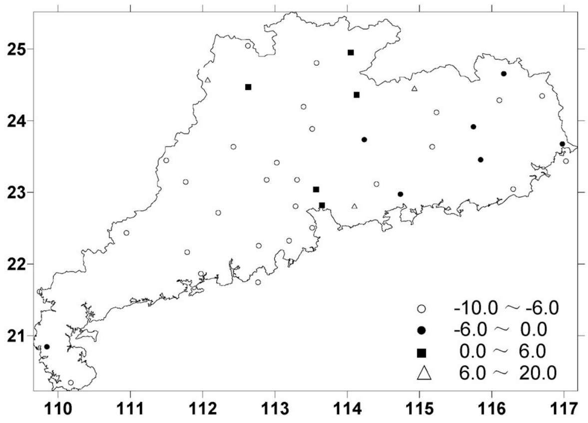

Figure 5. Distribution of the GPS/PWV data obtained at 00:00 UTC May 6, 2010. Differences between the GPS/PWV observations and corresponding NCEP/PWV data are indicated by dots of different shapes. After quality control, only the data whose absolute value of the difference is less than 6 mm (shown by the solid circles and solid squares) is allowed into the assimilation system.

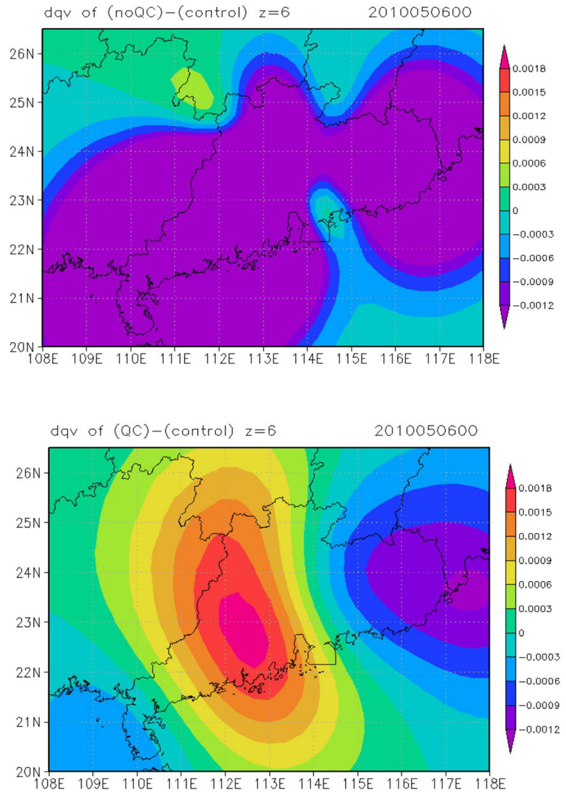

Figure 6. Assimilated fields of humidity increment at the initial time without quality control (a) and with quality control (b).

As shown in the distribution of observed rainfall for the studied process (Fig.8a), the rain mainly occurred in the Pearl River Delta and areas east of Zhaoqing, or generally within the Guangdong province. It is known from the 24-h accumulated rainfall amount forecasts by the numerical experiment (Fig.8b to 8d), the rainfall forecast by the control fails to predict the

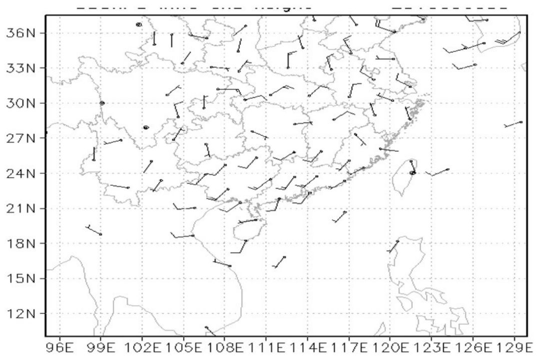

Figure 7. Wind field at 850 hPa for 00:00 UTC May 6, 2010 (radiosonde data).

intense rain that occurred in the central, northern and eastern parts of the province and the TS score for intensity levels above the torrential rain is 0.0. Because no quality control is applied, the water vapor at the initial time is reduced above Guangdong due to the effect of the observations of large negative deviations. After the quality control, these observations have been removed and the GPS/PWV data in the assimilation system adjusts the humidity reasonably so that water vapor is increased at the initial time in central Guangdong and due to a southwesterly air current more water vapor is transported to the area of rain to increase the intensity level of the forecast rain. As a result, a centre of precipitation occurred over northern Guangzhou and the area of Huizhou, which is close to the observed intensity of the rain, and the TS score for intensity levels above the torrential rain also increases to 0.44, improving the 24-h rainfall forecast.

4.2 *Case study of the rain on April 27 to 28, 2012*

Affected by a southerly flow on April 28, 2012, there was very heavy or even torrential rain in most of the central and southern parts and the rain was moderate to heavy or even very heavy in the northern part of the province. Fig.9 gives the distribution of the observed rain and the 850-hPa wind field. It is shown that the rain was quite intense in Guangdong and the area in which it reached the intensity level of torrential rain was quite large and the low-level southerly flow

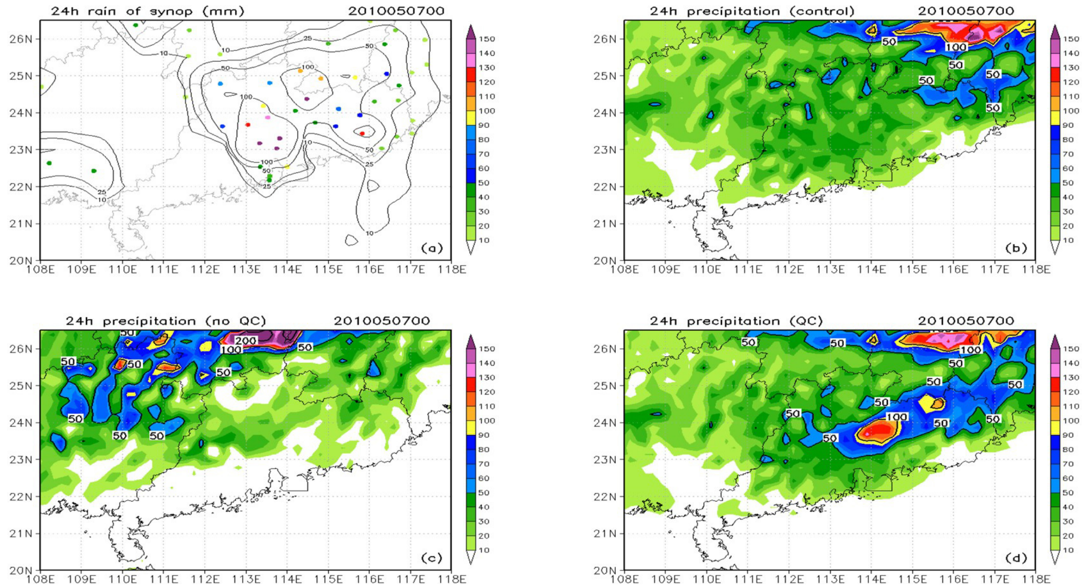

Figure 8. The 24-h accumulated rainfall amount of the observation (a) and the numerical experiments of Control (b), GPS (c), GPSQC (d) for 00:00 UTC on May 7, 2010.

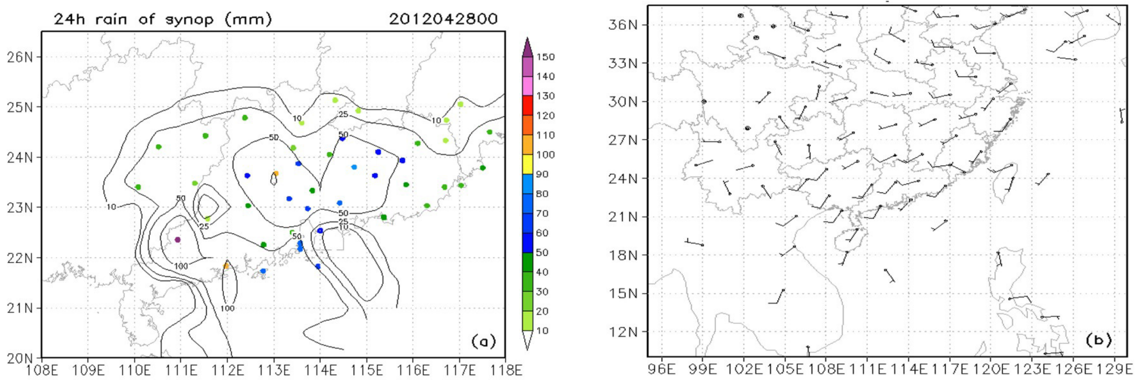

Figure 9. The 24-h observed rainfall on April 28 (a) and 850-hPa wind field at 00:00 UTC on April 27, 2012 (b).

was quite strong. The settings of the numerical experiments are shown in Table 2.

It is known from the distribution of the data included in the assimilation system before and after the quality control (Fig.10) that the GPS/PWV value is always less than the NCEP/PWV value. With quality control, only the data (shown by black and solid dots) is incorporated into the assimilation system. While making good forecasts of the intensity level and area of rain inside the province, the control experiment gives significant amount of false alarms about the intensity level of torrential rain (Fig.11a). Without quality control, however, the water vapor is much reduced at the initial time in the province due to the effect of large negative deviation (figure omitted). The rainfall forecast is improved in terms of the rate of false alarm, but it greatly weakens the forecast of the intensity level and coverage of heavy rainfall in Guangdong (Fig.11b). With quality control, the initial amount of water vapor is much decreased only in the northern and eastern part of the province. Though with a strong southerly airflow, water vapor transported downstream decreases correspondingly due to the much reduced water vapor at the initial time. Meanwhile, an obvious dry tongue exists in northern Guangdong that checks the water vapor from being carried further north (figure omitted) and is conducive to its accumulation over the area of rain. Therefore, the resultant forecast of 24-h

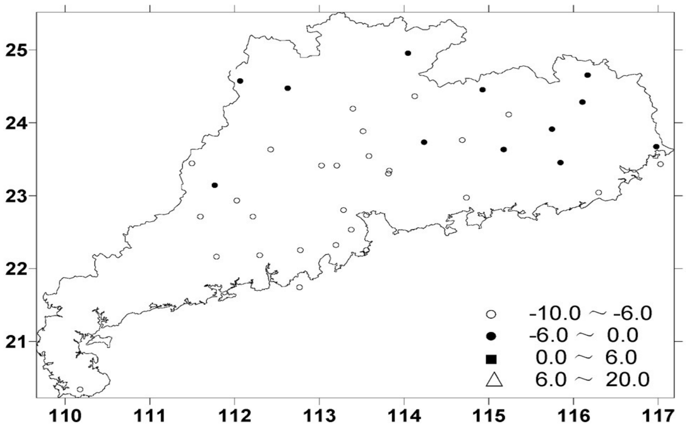

Figure 10. Same as Fig.5 but for 00:00 UTC on April 27, 2012.

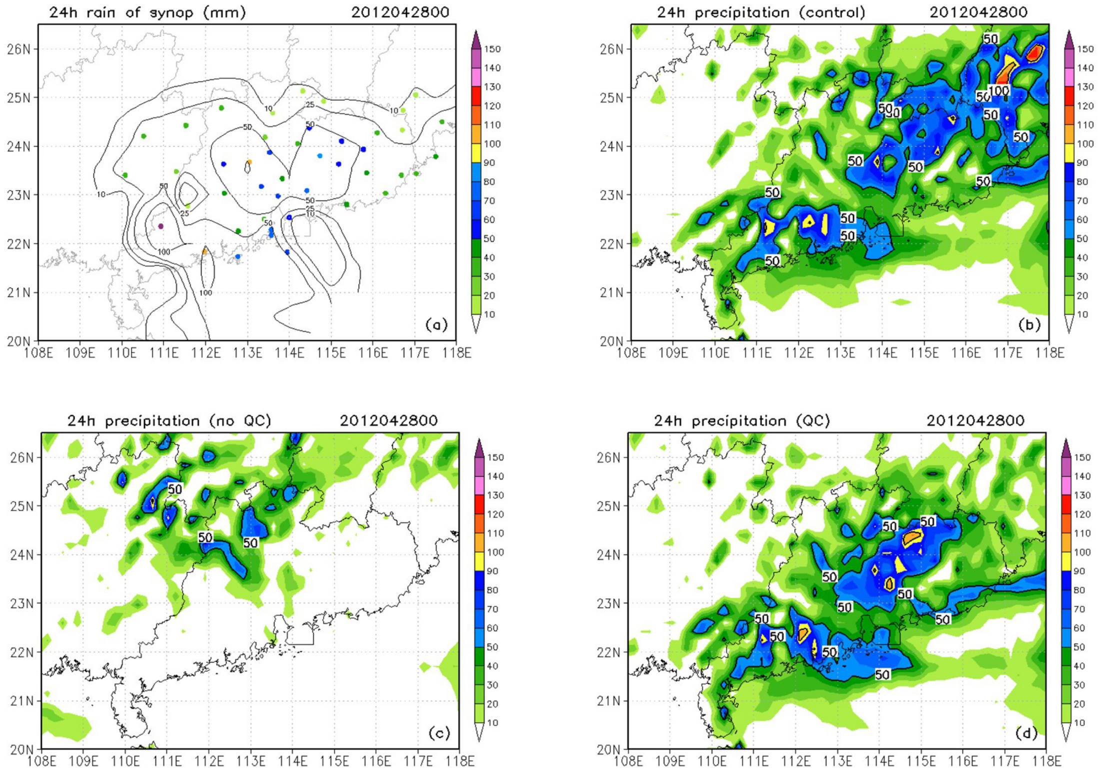

Figure 11. Same as Fig.8 but for April 28, 2012.

accumulated amount of rainfall so obtained is not only efficient in improving the false alarm rate of rainfall forecast outside of Guangdong, but also maintains the quality of the rainfall forecast inside it as compared to that of the control. The TS score is thus increased from 0.29 for the control to 0.39 for rainfall at the heavy rain or above level of intensity.

5 CONCLUSIONS AND DISCUSSION

(1) As shown in our study of the GPS/PWV data from August 2009 to August 2012, it is significantly seasonal; it is high in summer, usually climbing to the maximum in June, and low in winter, dropping to the bottom in December. Reasonable ranges of values are set for controlling the quality of GPS/PWV data in different month and outlying data are deleted reasonably.

(2) For the raining process from May 6 to 7, 2010, only the data processed with quality control is allowed to be included in the assimilation system for adjustment of the background humidity. As a result, the initial humidity is increased upstream of the rain area, conducive to the water vapor being transported towards the rain area to improve the forecast 24-h accumulated rainfall amount and the model capacity in rain forecasting.

(3) For the raining process from April 27 to 28, 2012, the initial humidity is reduced efficiently due to quality control to decrease the water vapor being transported downstream, improving the false alarm rate for the intensity level of torrential rain in the control.

By reasonably removing the outlying data with a quality control scheme, the data incorporated in the assimilation system can be used to adjust the field of initial humidity in a reasonable and efficient way, improving the model capacity of forecasting 24-h accumulated rainfall amount.

The purpose of this study is to use the information of water vapor appropriately in numerical prediction on the basis of the GPS/PWV data. Therefore, the method of quality control established here is only for screening the GPS/PWV data before it is included into the assimilation system. Besides, the improvement of rainfall forecast by assimilated GPS/PWV data is also subject to other factors, such as initial model values, model background errors and GPS/PWV observational errors. In this study, only two cases of rain are selected for study and some preliminary results are determined in the experiment. More numerical experiments are needed to study the effect of the assimilation of GPS/PWV data on rainfall forecast.

REFERENCES:

[1] BEVIS M, BUSINGER S, HERRING T A, et al. GPS meteorology: Remote sensing of atmospheric water vapor using the global positioning system [J]. J Geophys Res, 1992, 97(D14): 15 787-15 801.

[2] WANG Xiao-ya, ZHU Wen-yao, YAN Hao-jian, et al. Preliminary results of precipitable water vapor monitored by ground-based GPS [J]. Sci Atmos Sinica, 1999, 23(5): 605-612 (in Chinese).

[3] ZHANG Bin, XUE Gen-yuan, ZHANG Shuang-cheng. On the near real-time derivation of precipitable water vapor in the atmosphere by ground-based GPS of Zhejiang province based on IGS ultra tracking stations [J]. J Trop Meteorol, 2009, 25(2): 222-226 (in Chinese).

[4] LI Hong-li, WAN Rong, XIE You-cai. Application of ground-based GPS water vapor in LAPS [J]. J Trop Meteorol, 2010, 26(6): 702-709 (in Chinese).

[5] GU Xiao-ping, WANG Chang-yao, WANG Wen, et al. Research on the local correction model of atmospheric dry delay in GPS remote sensing water vapor [J]. J Trop Meteorol, 2005, 11(1): 78-85.

[6] WANG Yong, LIU Lin-tao, HAO Xiao-guang, et al. The study of the compute project and reliability of quasi-real-time ground-based GPS precipitable water vapor [J]. J Trop Meteorol, 2007, 23(2): 177-181 (in Chinese).

[7] WANG Yong, LIU Yan-ping, LIU Lin-tao, et al. The study of directly calculating precipitable water vapor with zenith tropospheric delay of GPS network [J]. J Trop Meteorol, 2007, 23(5): 510-514 (in Chinese).

[8] DING Jin-cai. Review of weather prediction verifying techniques [J]. J Nanjing Inst Meteorol, 1995, 18 (1): 143-150 (in Chinese).

[9] YAO Jian-qun. Analysis of the characteristics of GPS precipitable water vapor for a rainstorm in Shanghai on August 22, 2004 [C]//Collection of Papers on Techniques of Weather Forecasting. Beijing: China Meteorological Press, 2005: 36-41 (in Chinese).

[10] YUAN Zhao-hong. Variational assimilation of GPS precipitable water into MM5 mesoscale model [J]. Acta Meteorol Sinica, 2005, 63(4): 391-404 (in Chinese).

[11] DING Jin-cai, YUAN Zhao-hong, YANG Yin-ming, et al. Evaluation of the continuous experiment of 3-dimensional variation assimilation of GPS/PWV data into MM5 model to improve the precipitation forecasts [J]. Meteorol Mon, 2007, 33(6): 11-18 (in Chinese).

[12] GUO Y R, KUO Y H, DUDHIA J, et al. Four-dimensional variational data assimilation of heterogeneons mesoscale observations for a strong convective case [J]. Mon Wea Rev, 2000, 128 (3): 619-643.

[13] KOU Y H, GOU Y R, WESTWATER E R. Assimilation of precipitable water vapor into mesoscale numerical model [J]. Mon Wea Rev, 1993, 121(4): 1 215-1 238.

[14] KOU Y H, ZOU X, GOU Y R. Variational assimilation of precipitable water using a nonhydrostatic mesoscale adjoint model [J]. Mon Wea Rev, 1996, 124(1): 122-147.

[15] SMITH T L, BENJAMIN S G, SHWARTZ B E, et al. Using GPS-IWV in a 4-D data assimilation system [J]. Earth Plants Space, 2000, 52(2): 921-926.

[16] DE P M, ZOU X. A case study of the variational assimilation of GPS zenith delay observations into a mesoscale model [J]. J Appl Meteorol, 2001, 40 (9): 1 559-1 576.

[17] WMO. Guide to meteorological instrument and methods of observation[R]. WMO-No 8, 2008.

[18] DING Wei-yu, WAN Qi-lin, YAN Jing-hua, et al. Impact of the initialization on mesoscale model prediction in

South China [J]. J Trop Meteorol, 2006, 12(1): 83-84.

[19] XUE J S, CHEN D H, CHEN X. Great advancement in developing new generation NWP model system in China [C]// Chinese Academy of Meteorological Sciences Annual Report. Beijing: China Meteorological Press, 2003: 8-9.

Citation: LI Hao-rui, DING Wei-yu, XUE Ji-shan et al. A preliminary study on the quality control method for Guangdong GPS/PWV data and its effects on precipitation forecasts in its annually first raining season [J]. J Trop Meteorol, 2016, 22(4): 535-543.