Application of Atmosphere Precipitation Resources Distribution Remote Sensed by Ground-based GPS in the West of Taiwan Strait

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Abstract. In this work, the ground-based GPS data in the West of Taiwan Strait was used to remote sense atmospheric Precipitation Water Vapor (PWV) in Fujian, and dynamically analyzed the spatial pattern change characteristics of PWV, combined with meteorological data, in order to quantitatively analysis the relationship between the GPS remote sensing of atmospheric precipitation and the local rainfall. The results showed that the ground-based GPS remote sensing atmosphere precipitation data could be detected the distribution pattern and the variation characteristics of water over Fujian, and play a good indication role in dynamic monitoring of the change of the precipitation process. Moreover, it could be found plenty of PWV content was a necessary but not sufficient condition of precipitation in the comparison of atmosphere with precipitation PWV of the specific station and the practical of the precipitation, also was closely connected with the local thermodynamic lifting condition. PWV changes were not necessarily closely corresponding to the station of precipitation, but it had a positive effect in the local station with the occurrence of precipitation.

Introduction

The Precipitation Water Vapor (PWV) in the atmosphere was an important component to affect the changes in the weather, and its spatial and temporal distributions were changed quickly, which physical/chemical processes played an important role in the atmosphere, affecting the radiation balance, energy, transportation, the formation of clouds and precipitation. Moreover, the water potential was the important mechanism of the transmission energy to transfer atmosphere from the equator to the poles, which impacted significantly the release of the potential of the atmospheric vertical stability, the formation and evolution of the storm and radial radiation energy balance [1-5]. When the GPS signals traversed through the troposphere of atmosphere, the GPS signals happened to delay affected by the refraction of troposphere. On account of the considerable correlation between the signal delay and atmospheric parameters, the PWV could be measured by used remote sensing technology for detection of atmospheric parameters from the available GPS data. Because the ground-based GPS data could provide continuity and high precision of precipitation data, which played an increasingly important role in weather prediction and climate change, and was extremely valuable for some areas where the forecast temporal resolution was demanded highly or ground observed stations were distributed sparsely.

At present, the experiments of 55 GPS stations of the United States showed that the PWV remote sensed by the ground-based GPS data could reflect the distributions of atmospheric humidity, but also the precisions were significantly higher than other types of humidity observation system. Moreover, the relative humidity of atmosphere had the absolute advantage in the three-hours forecast, which could improved significantly the precipitation forecast effect. Bevis[6] first put forward the principle of using ground-based GPS to estimate the PWV of atmosphere in the United States in 1992. The Westford experiment of some institutions of the United States and Canada proved further that the technology of GPS data could be measured the PWV feasibly. Wang and Zhu [7] carried out firstly the domestic experiment of GPS storm of Shanghai in 1997, the results showed that almost real-time and high precision PWV GPS could be obtained

continuously from the GPS data, and could be well corresponded with the rainfall process. Li and Mao[8] used GPS data and IGS ephemeris inversion of East Asia in the summer of 1997 to retrieved the PWV of Shanghai and Wuhan, and the root mean square error were less than 5 mm. In the study, the distribution regularities of PWV in Fujian were analyzed by remote sensing from the the ground-based GPS stations data , and the characteristics of the PWV in precipitation process were deep expatiated comparatively combined with the meteorological data in observed stations.

System Model and Analysis Method

When the radio waves of GPS satellite passed through the atmosphere, the delay of satellite signal happened with the reduction in speed and the bending of the path because of electronic interference and refractions of the stratosphere and troposphere atmosphere, mostly due to the affection by the atmosphere of the troposphere and the stratosphere. In order to accurately measure the atmospheric precipitation, the troposphere delay of neutral atmosphere should be isolated from other positioning errors firstly, and converted the delay of the neutral atmosphere to the moisture content of the atmosphere. The mathematical expression of additional path length caused by the troposphere refraction could be represented as followed (1):

$$\Delta L = \int_L (n(s)-1)ds + (G-R) \tag{1}$$

Where ΔL was the additional distance influenced by the atmospheric refraction of GPS signal, L was the propagation path, $n(s)$ was the refractive index, G was transmission length, and R was the linear distance. Most experiments showed that 90% of the troposphere delay was caused by the dry gas of the atmosphere, which known as dry delay, the remaining 10% was caused by water vapor, which known as the wet delay. Moreover, the dry delay could be simulated ideal atmosphere in hydrostatic equilibrium, therefore was also called the static delays. Troposphere delay in zenith direction of static delay and wet delay was expressed as (2):

$$\Delta L = \Delta D_{z,dry} M_{dry}(E) + \Delta D_{z,wet} M_{wet}(E) \tag{2}$$

Where ΔD_z was the troposphere delay in the zenith direction, and $M(E)$ was mapping function in the same elevating angle. Therefore, the wet delay (Zw) Minus could be calculated by eliminated the Zenith hydrostatic delay (Z_h) from the zenith troposphere delay, which formula was as followed(3):

$$Z_w = 10^{-6} \cdot PW\left[R_v\left(k_2' + \frac{k_3}{T_m}\right)\right] \tag{3}$$

Where R_v was a constant of atmospheric precipitation as 461.495 $\mathrm{J/(Kg \cdot K)}$, and the PW was calculated by the numerical transformation using the following relationships as followed:

$$PW = \prod \cdot Z_{\mathrm{W}} \tag{4}$$

$$\prod = 10^6\left[R_v\left(\frac{k_3}{T_m} + k_2{}'\right)\right]^{-1} \tag{5}$$

$$T_m = \frac{\int (e/T)dz}{\int (e/T^2)dz} \tag{6}$$

Where T_m was the weighted mean temperature.

Characteristics Analysis of PWV

The study area was Fujian province (23°33′-28°20′ N 115°50′-120°40′ E), which located in the

Southeast China. There were mostly mountainous and hilly terrain and a few arable lands, and the climate was subtropical marine monsoon climate influenced by seasonal exchanged warm or cold air current. The 62 GPS observations data of the 139th day covering the entire province scope was selected as an example in the research, and the PWV was retrieved by using ground-based remote sensing interpretation software for correlation analysis.

Daily Spatial Characteristics of PWV

To obtain the daily spatial characteristics of PWV in Fujian, the four time interval PWV data of 00, 08, 16 and 24 hour were selected and corrected. Subsequently, the abnormal data sites were removed and the results were imported into the Surfer software for drawing, as shown in the Figure 1:

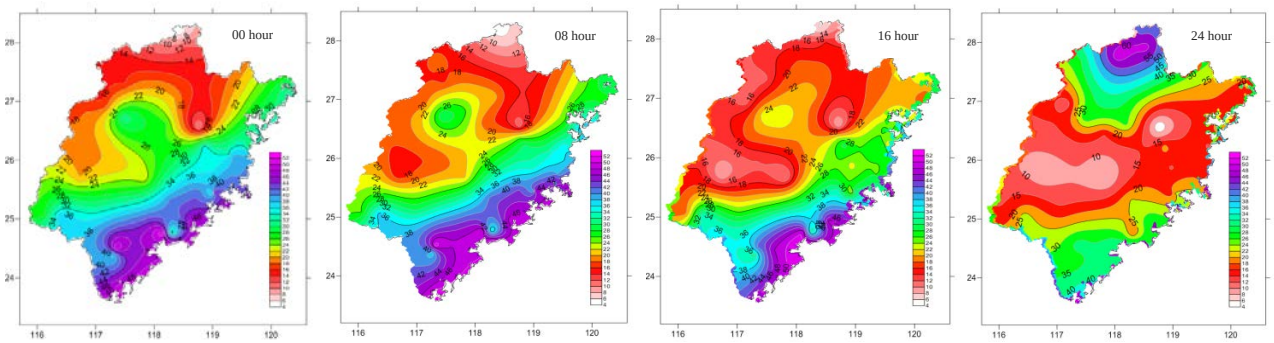

Fig.1. Dynamical change of PWV retrieved by ground-based GPS data in Fujian

The analysis revealed that the PWV of 00 hour above Fujian were distinct differences between the south and the north, while the PWV of the northwest were generally less than 20 mm and the PWV of the central regions lied between 20 to 35 mm, the PWV value in southeastern coastal areas were high between 40 to 60 mm. Subsequently, the PWV of 08 hour were changed quickly and the low PWV areas of northwest were expanded further to central regions, while high PWV areas of southeast coastal regions basically remained unchanged. To 16 hour, low PWV areas in northwest were further expanded, which ranges covered almost two-thirds of the province, but the high PWV areas between 40 to 60 mm were decreased greatly and the highest value of PW was dropped below 50 mm, only lied in the coastal parts of the counties and cities located in South Fujian Golden Delta. At 24 hour, the low PWV areas expanded further to south, the original high PWV areas of southeast had disappeared. Noteworthy, the new high PWV areas happened in in some counties of Nanping. From the analysis above, the results showed that the spatial distribution of PWV of the 139th day changed with the time in Fujian, the PWV of southeast coastal areas decreased over the time in accordance with the meteorological data, which indicated the end of process of undergoing a precipitation process. Because the PWV of north and central region were generally low not enough to rain, the high PWV areas of 24 hour appeared and heralded a new round of the precipitation process over northern Nanping areas.

Analysis of Relation of Change of PWV and Precipitation

Due to abundant atmospheric moisture was one of the necessary conditions of precipitation, other factors were also very important such as local precipitation favorable dynamic conditions and thermal conditions. In order to study the relationship of atmospheric precipitation and PWV, four representative stations such as Luoyuan, Pinghe, Wuping and Fuding, were selected respectively to analyze in the study.

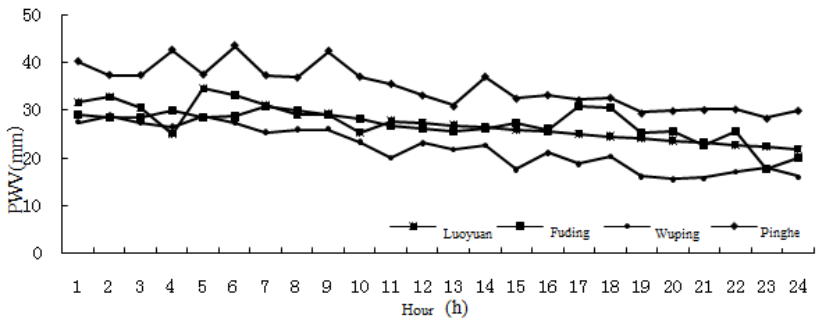

Fig.2. PWV can be comparative analysis of PWV and atmospheric precipitation in different GPS stations

As could be seen from figure 2, the PWV of four GPS stations was declined entirely as time passed, the PWV of Pinghe where was located in South Fujian was higher than the others. Moreover, the PWV of Pinghe fluctuated in 40 mm during the time of the 00 hour to 10 hour. However, the PWV of Fuding and Luoyuan were under the 40 mm and decreased significantly, and PWV of Wuping were lower under 30 mm because of mountainous interior landform, where water shortage was a major cause of no precipitation.

In contrast with meteorological data of automatic observed stations, Pinghe station as only one of four representative stations happened to rainfall, which relationship with precipitation as shown in figure 3. It could be found that the PWV of the atmosphere did not present a good index of precipitation in relationship with automatic meteorological stations from figure 3. When the PWV decreased about 3 mm during 00 hour to 01 hour, the rainfall appeared about 2 mm. Nevertheless, the precipitation had maximum of 19 mm during 01 hour to 02 hour regardless of no change of PWV at the same moment. Subsequently, the precipitation decreased with time on the whole and the rainfall ended at 08 hour, although the PWV changed obviously in the process, the trend of PWV declined over time. For the reason, there lied two factors lead to non-synchronous relation: one was the same geographical position between PWV station and meteorological station in Pinghe, and discontinuity of the precipitation led to that the correlation of two point precipitation was not strong, the other was PWV was not sufficient condition to produce precipitation, local thermal conditions, dynamic conditions and terrain factors were important to rainfall too. Anyhow, a certain number of atmospheric precipitation was the key factor that could produce rainfall, then the PWV based on ground-based GPS data was a very good index station of regional precipitation.

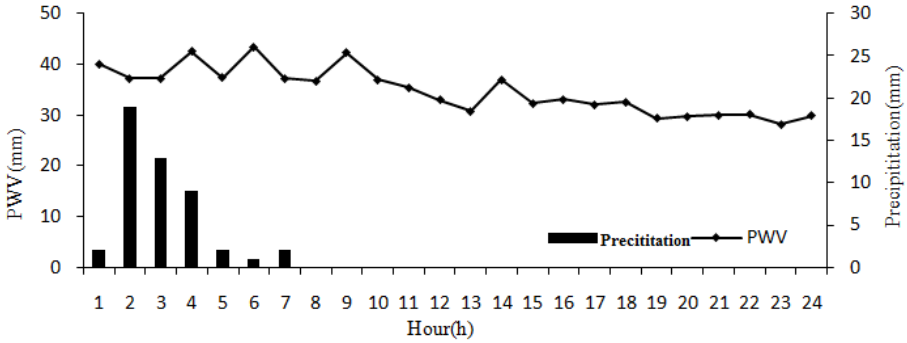

Fig.3. Comparative relationship of PWV and precipitation of meteorological station in Pinghe

Conclusion

The distribution patterns and change characteristics of PWV over Fujian based on the ground-based GPS data was analyzed in the study, and the relationship of PWV of representative ground-based stations and actual precipitation of meteorological stations was comparatively analyzed, then the following conclusions were shown as:

Ⅰ. The distribution patterns and dynamical change of PWV were reflected to forecasting precipitation during the whole process of rainfall, which were good indicator for the occurrence, development and ending of rainfall.

Ⅱ. Abundant atmospheric precipitation was a necessary condition for rainfall, but not a

sufficient factor from the experiments of ground-based GPS stations, while the local thermal conditions, dynamic conditions and terrain factors were important to rainfall. Moreover, the change of PWV did not reflected the actual precipitation of meteorological station immediately, which was very suitable for the following occurrence of regional rainfall.

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