Diurnal Variation of Precipitable Water Vapor Based on GPS Observations

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Abstract : GPS observation has been performed since August, 2001 at Khon Kaen in Northeast of Thailand to obtain the Precipitable Water Vapor (PWV) and to understand the characteristics of its seasonal and diurnal changed. A Trimble 4000 SSi receiver and a Trimble microcentered L1/L2 antenna were used for the observation. The GPS data were recorded by every 30 second for 24 hours a day. The three hourly PWV were calculated from the Zenith Tropospheric Delay (ZTD). The surface meteorological measurements (air pressure and temperature) were mainly obtained from Thai Meteorological Department. The results show that the variation of PWV changed with a large amplitude (vary from 20 to 60 mm.). For dry season, PWV was increased before rain and decreased after rain. It is found that, in wet season PWV was almost constant at about 60 to 70 mm. The variation of precipitable water vapor change was small in the wet season because of nearly saturated water in the atmosphere supply continuosly by monsoon. The comparison of diurnal variation of PWV were examined between dry and wet season. The results showed that the difference of diurnal change of the two seasons was small and PWV had the minimum value at 4-7 am in the morning, it increased from the afternoon to the midnight.
Keyword : Global Positioning System (GPS), Precipitable Water Vapor (PWV), Diurnal variation

1. Introduction

Atmospheric water vapor change is important for the meteorology radiation budget and global hydrological cycle. The water vapor produces convective activity and precipitation, which play important role in atmospheric dynamics. It is difficult to measure the vapor change in the upper atmosphere. Traditionally its diurnal variation is primarily examined by the observation from the radiosonde sounding, which is normally lunched for a daily, therefore, insufficient to capture the characteristics of the diurnal variation. Recently, the GPS observation provide certain attractive advantages : a better spatial coverage, all weather, cost effectiveness and continuous measurements of precipitable water vapor. On the other hands, GPS observation is usually performed to obtain precise positions for the geodetic survey or to monitor of the land deformation. The microwave of GPS delays when it passes through the ionosphere and the troposphere. The delay makes errors in the positioning but they are good signals to get information on atmosphere conditions. A number of studies have investigated about water vapor using GPS observation. The excess path delay caused by the ionosphere is depend on the wavelength and it can be estimated by using the data of two wavelength from the satellites. After removing the effects of the ionosphere, we can get the delay due to the troposphere. The delay due to troposphere consists of the hydrostatic delay by the dry gas (called the dry term) and the other delay by the water vapor (called the wet term). The dry term can be estimated precisely from the barometer data and we can get the wet term. The amount of the water vapor can be obtained by transforming the wet term to precipitable water vapor (PWV).

In this study, the GPS observation is investigated the diurnal variation by mean of PWV and examined the characteristics of PWV change in the dry and wet season. Three hourly of PWV was calculated from GPS data from August 2001 to December 2002 at Khon Kaen of Thailand.

2. Data Observation and Analysis Method

Observation by using GPS receiver has been performed at Khon Kaen since August 2001. A Trimble 4000SSi receiver and a Trimble microcentered L1/L2 antenna are used in the present observation. GPS antenna has been set on a tripod on a roof of a building of the Department of Agricultural Engineering, Khon Kaen University. The GPS data were received at 30 seconds intervals and they were recorded to the hard disk automatically once a day. The data obtained in the period from August 2001 to December 2002 were processed using GAMIT software by referring to seven IGS stations at Shanghai, Yaragadee, Tsukuba, Guam, Lhasa, Cocos and Singapore. The atmospheric delay of GPS was estimated from GPS data. The Zenith Tropospheric Delay (ZTD) were obtained at one-hour intervals by

constraining its coordinates within 3 mm in horizontal component and 5 mm in the vertical component. The Zenith Hydrostatic Delay (ZHD) was estimated from surface pressure, latitude and ellipsoidal height of the observation station. The three hourly air pressure data by Khon Kaen station of the Thai Meteorological Department (TMD) were used to obtain of this dry terms. The Zenith Wet Delay (ZWD) was obtained by subtracting ZHD from ZTD. The ZWD was converted into atmospheric PWV by using II parameter. The weighted mean temperature (Tm) was estimated from surface temperature (Ts). Air pressure, surface temperature, relative humidity and rain gauge data were provided from TMD. The relation between these equations are given by the followings expression :

$$\mathbf{ZTD} = \mathbf{ZHD} + \mathbf{ZWD} \quad (1)$$

$$\mathbf{PWV} = \mathbf{II} \,.\, \mathbf{ZWD} \quad (2)$$

$$\mathbf{II} = \frac{10^5}{[\mathbf{Rv}.\{\, \mathbf{k_2} - \mathbf{k_1}(\mathbf{Mv}/\mathbf{Md}) + (\, \mathbf{k_3}/\mathbf{Tm})\}]} \quad (3)$$

$$\mathbf{Tm} = 70.2 + 0.72\mathbf{Ts} \quad (4)$$

$$\mathbf{ZHD} = (2.2779 \pm 0.0024)\frac{\mathbf{P_{GPS}}}{\mathbf{f(ø,H)}} \quad (5)$$

$$\mathbf{f(ø,H)} = (1 - 0.00266\, \mathbf{cos^2ø} - 0.00028\mathbf{H}) \quad (6)$$

Where ZTD is Zenith Troposphere Delay, ZHD is Zenith Hydrostatic Delay (dry term), ZWD is Zenith Wet Delay, PWV is Precipitable Water Vapor, II is parameter, Rv is gas constant of water vapor (461.518), k_1 = 77.60 $\pm$ 0.08 (K/hPa), k_2 = 71.98 $\pm$ 10.82 (K/hPa), k_3 = (3.754 $\pm$ 0.036)x10^5 (k^2/hPa), Mv is molecular weight of water vapor (18.0152 kg/kmol), Md is molecular weight of dry atmosphere (28.9644 kg/kmol), Tm is man temperature (Kelvin), Ts is surface temperature (Kelvin), P_{GPS} is pressure of the observation site (hPa), ø is latitude of the observation site (rad), H is ellipsoidal height of the observation site (km). Diurnal variation of PWV from August 2001 to December 2002 were studied.

3. Results and Discussion

1) Diurnal Variation

The analysis was divided into two period, the wet season period (from May to October) and the dry season (from November to April)

Fig.1 and Fig.2 showed the average diurnal cycle in each period of three hours (local time) for wet and dry season. All values were shown in term of deviation from mean (mean value was set as zero). The difference of diurnal variation of the two periods was small (the amplitude is 1.85 mm for wet season and 1.46 mm for dry season). The PWV decreased in the morning and had a clear minimum value at 7 am (in wet season) and 4 am (in dry season). It increased in the afternoon, had the maximum and keeped high value of PWV from the evening to the midnight in wet season. Its maximum peak was clear in dry season but unclear in wet season. The mean of the three hourly rainfall highly increased in he evening of the wet season, therefore the PWV was high value from the afternoon to midnight.

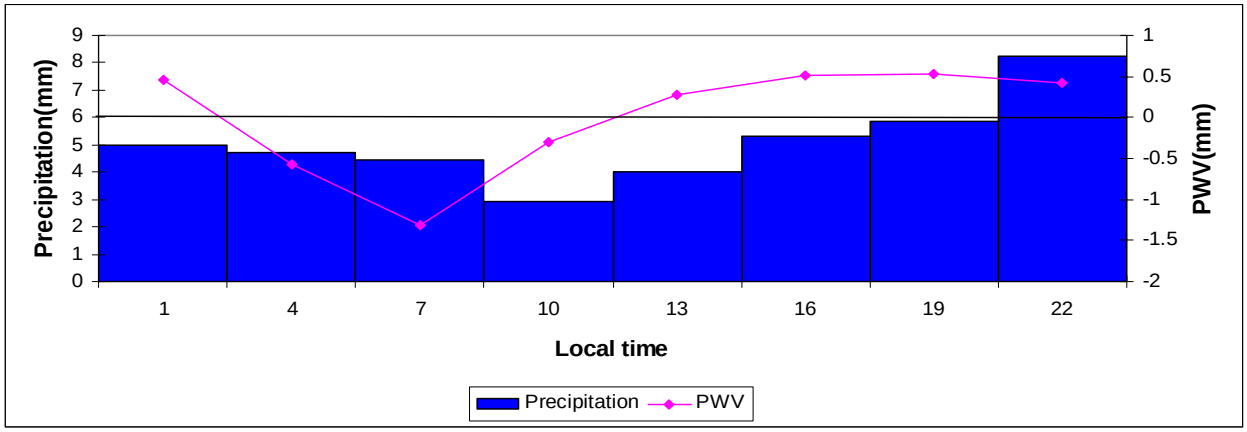

Fig. 1 The mean diurnal variation of PWV in the wet season of 2002

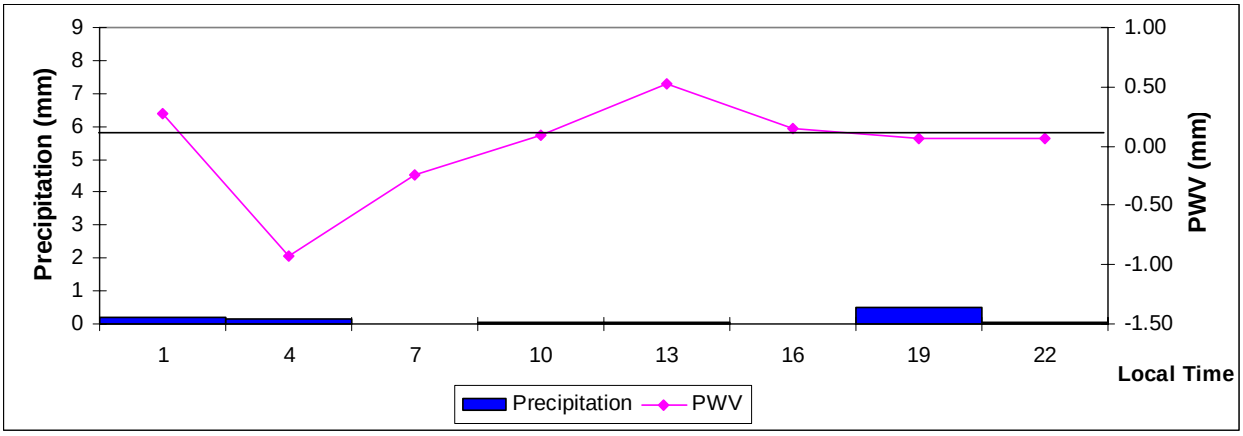

Fig. 2 The mean diurnal variation of PWV in the dry season of 2002

2) Seasonal Variation

Fig. 3 and Fig. 4 showed the PWV values change (in a line) in wet season of the year 2001 and 2002. The precipitation (Three hourly) were also shown in this figure (in a bar graph). They were found that, PWV are almost constant to be from 60 mm to 70 mm without any changes even when it rains. There features seem to be associated with other PWV-GPS stations in Thailand. In the monsoon break of the middle of July 2002, The PWV obtained decreased by about 10 mm. It is noted that, in the middle of October before the end of wet season, PWV decreased rapidly and was the lowest, these characteristics are similar both in the year 2001 (35mm) and 2002 (20mm).

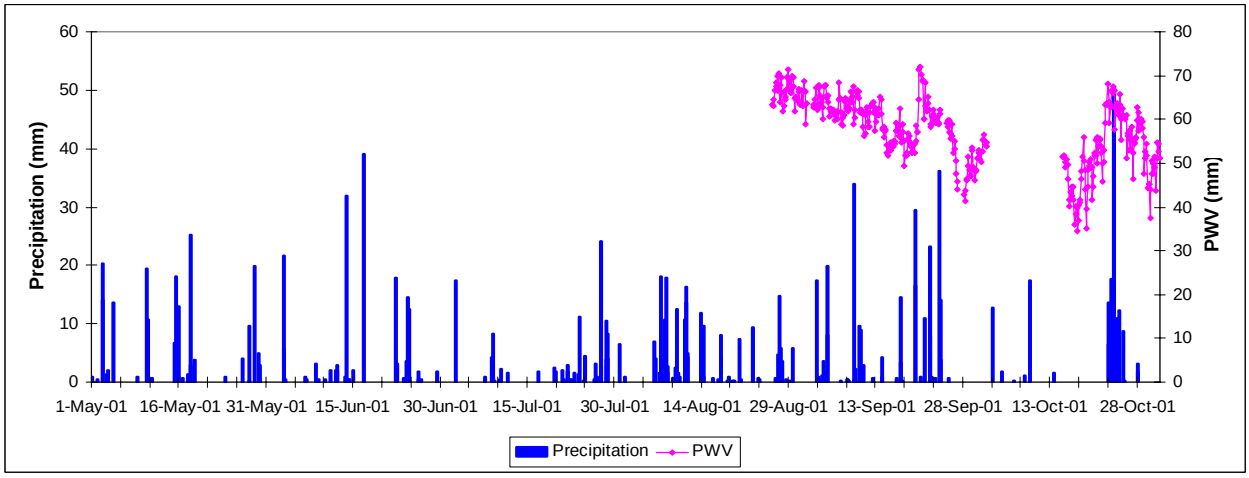

Fig. 3 PWV changed (3 hourly) and precipitation in the period of wet season 2001

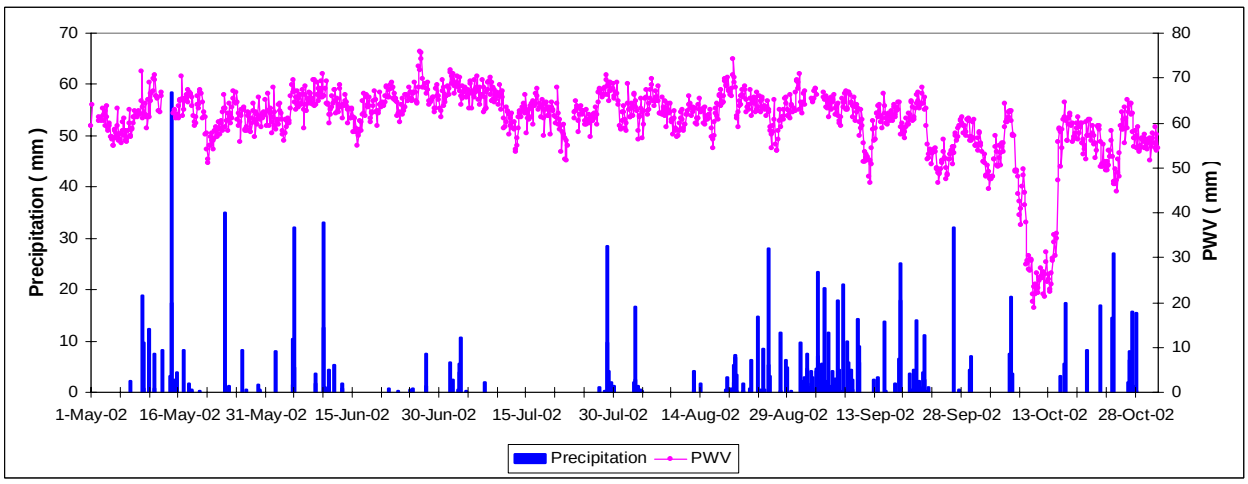

Fig. 4 PWV changed (3 hourly) and precipitation in the period of wet season 2002

Fig. 5 shown the PWV change in dry season, it changed widely in the range of 20 mm to 60 mm. The variation of about 1 or2 weeks duration is prominent in PWV with large amplitude of about 40 mm. It is noted that PWV decreased rapidly after the end of wet season and continuously increased before starting of wet season. It is clear difference in change of PWV between the dry and the wet season, but variation of PWV is smaller in the wet season.

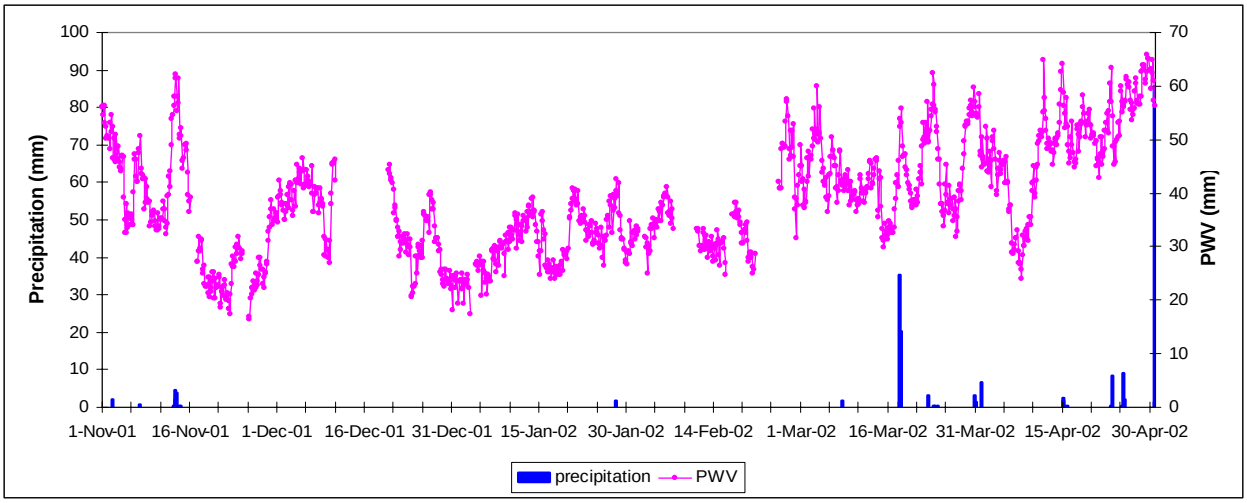

Fig. 5 PWV change (3 hourly) and precipitation in the period of dry season (November 2001-April 2002)

3.3) Comparison of Temperature and Pressure

The air temperature and air pressure were investigated to better understand the relationship of PWV, precipitation, temperature and pressure. Fig.6 and Fig.7 showed the temperature and pressure change during the period of wet season in 2001 and 2002. It was found that the characteristics of temperature and pressure of both two years are almost similar. At Khon Kaen, in the wet season, the mean temperature of the both years are about 27 ^{0}C and the mean air pressure are 1006 hPa. The temperature is high, the pressure is low. It was noted that, from the middle of June to the middle of July, there was a small amount and abandon of rainfall, the pressure keeped in lower values. It is different from September to October, The pressure was higher while the rainfall increased.

Fig.8 showed the change of temperature and pressure during the dry season 2002. At Khon Kaen, from November to January, the temperature is usually lower, but higher from March to April. On the other hands, the pressure value is contrary.

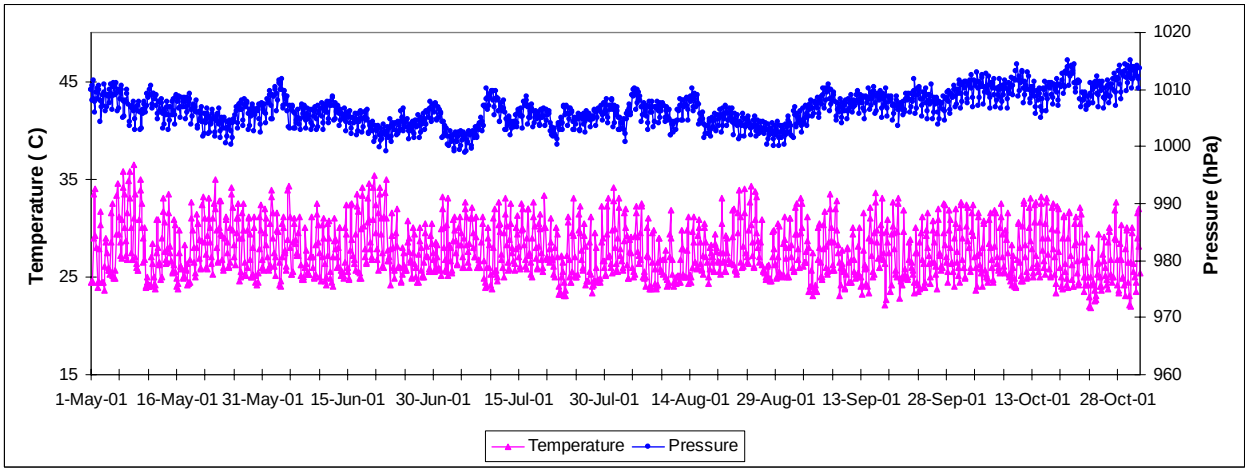

Fig.6 Change of temperature and pressure in the period of wet season 2001

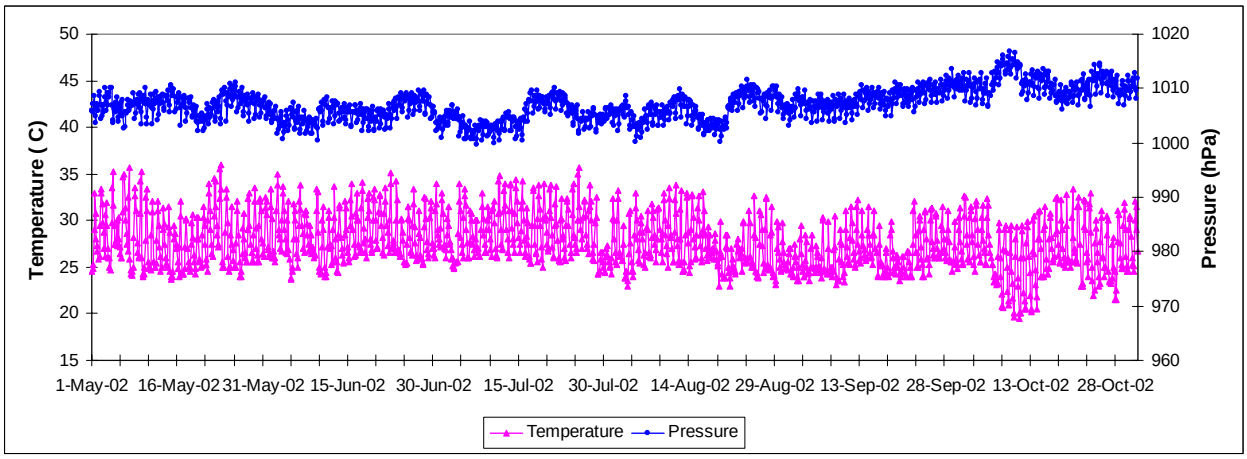

Fig.7 Change of temperature and pressure in the period of wet season 2002

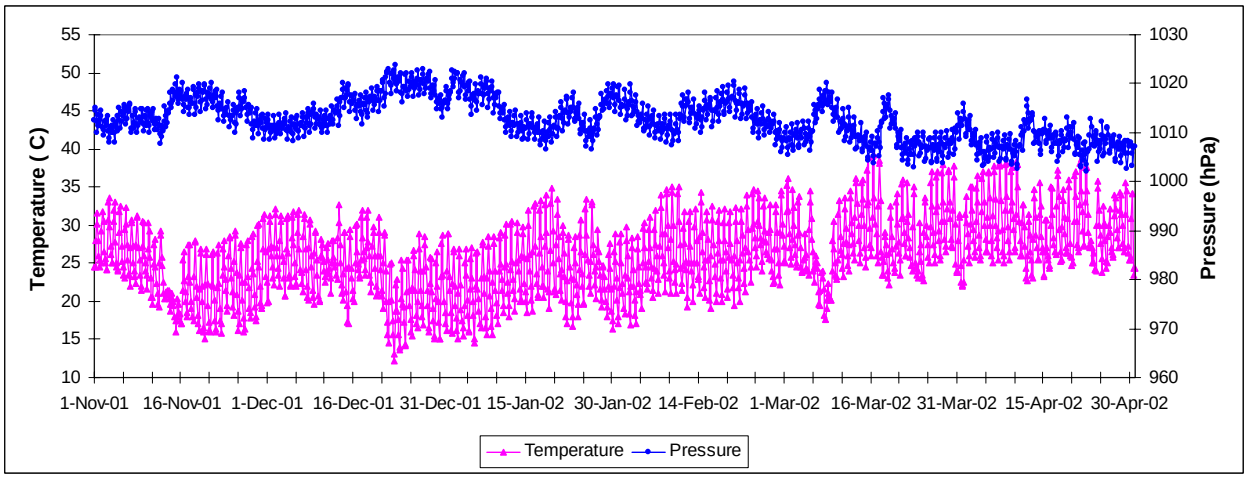

Fig.8 Change of temperature and pressure in the period of dry season 2002

4. Conclusion

This study, the precipitable water vapor was estimated from GPS observation at Khon Kaen, northeastern of Thailand. The GPS data obtained from August 2001 to December 2002 with high time resolution were processed. It was clear different in PWV change during dry and wet season. In the dry season, PWV changed widely in the range of 20 mm to 60 mm with 1 or 2 weeks duration. PWV increased before rainfall and decreased after rainfall. In the wet season, however, change of PWV was much smaller than that in the dry season, although PWV keeped at high value and almost constant between 60 mm to 70 mm.

The diurnal variation by mean of PWV in dry and wet season was investigated. The difference of diurnal change of the two seasons was small and they showed that the PWV had the minimum value at 4-7 am in the morning, it increased in the afternoon and keeped with the high value from the evening to the midnight.

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