DEVELOPMENT OF METHOD FOR EXTRACTING LOW-LEVEL TROPOSPHERIC MOISTURE CONTENT FROM GROUND BASED GPS DERIVED PRECIPITABLE WATER VAPOR (PWV)

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ABSTRACT

Water vapor in the lower troposphere (low-level moisture) plays an important role in the development of deep convection over tropical region.The vertical profile of atmospheric moisture has been conventionally observed using radiosonde but the temporal and spatial resolutions are very low. On the other hand, recent development Global Positioning System (GPS) satellite data processing makes it possible to estimate the total moisture content in an atmospheric column as Precipitable Water Vapor (PWV) with far better temporal and horizontal resolution.However, for tropical meteorological studies, close monitoring of the changes in low-level moisture is more important.We developed a simple but effective technique to extract low-level (from surface up to 700 mb level) tropospheric moisture content from ground based GPS derived PWV. In this method, the upper-level PWV is estimated from global data and then subtracted from the total PWV. First, we analyze GPS data observed on July 27 – August 2, 2010 at GPS-BAKO station (6.491^0 S - 106.849^0 E) during which radiosondes were also lauched at 6-hour interval. Upper-level PWV was calculated from three global data i.e. gridded GPS Radio Occultation (RO), NCEP and ECMWF data and compared with those estimated from radiosonde.The results show that ECMWF data provide best estimate of upper-level PWV for extracting lower-lever moisture from GPS derived PWV.We applied the method to analyze GPS data observed during January through December 2009. It is of interest to note that the composite diurnal variation of low-level PWV at GPS-BAKO station is quite consistent with the characteristics of sea-breeze intrusion over Jakarta area as revealed by previous study.Moreover,it is also found that an increase in low-level moisture tends to be followed by convective activity. These results demonstrate that, combined with the use of global model data, ground based GPS observations are quite effective for monitoring low-level moisture variations in tropical region.

Keywords *: PWV, troposphere, low level moisture, GPS, GPS-RO, NCEP, ECMWF*

1. INTRODUCTION

The deep convection will only occur if the rising air parcels originating near the surface of the layer (Holton,2004). Hadi et al. (2002) showed that an inversion layer can isolate the humidity in the planetary boundary layer below an altitude of 3 km. The horizontal movement of water vapor in the lower layer becomes important to know its role in determining regional weather and climate patterns.The characteristics of atmospheric dynamics over tropical region specially in Indonesian maritime continent had a strong diurnal convective activity (Johnson *et al.*,1987; Nuryanto, 2011). Thus, observations of low level moisture is needed for monitoring the evolution of convective processes.

Monitoring of atmospheric moisture conventionally observed through a network of synoptic meteorological which is limited to the observation point on the surface (Middleton and Spilhaus, 1953).Total content of water vapor in the troposphere is conventionally analysed from radiosonde data which are very limited (only twice a day and considerable expense), and also using aircraft with AMDAR System which is only measured atmospheric profiles at certain times, such as during take off and landing.

The invention of the technique to estimated the moisture content in the atmosphere using the Global Positioning System (GPS) as an alternative observation, which propagation of GPS signals received from the satellite at ground receivers as a delay by the atmosphere. Tropospheric delay consists of two components, namely the hydrostatic components/ dry and moisture content of the atmosphere/ wet (Gabor,1998). Combined wet and dry components is called the Zenith Total Delay (ZTD) are estimated using the mapping function of the GPS signal to the zenith direction. The hydrostatic delay or Zenith Hydrostatic Delay (ZHD) can be calculated from the surface or the antenna pressure (mb).ZHD is used as a subtraction factor of the ZTD for Zenith Wet Delay (ZWD) (Gutman, 2004). ZWD is associated with the moisture content (Integrated Water Vapour/ IVW) or PWV can be calculated from the average temperature (Tm) and Π factor, Bevis *et al.* (1994).

Bevis *et al.* (1992) ZWD from ground based GPS extracted water vapor content, which is consistent with the radiosonde observations.Suitability observations for PWV from GPS and radiosonde has also been confirmed in various locations, in Japan, Yoshihira *et al.* (2000) and in Indonesia, Hadi et al.(2010). The other hand, the observations of atmospheric water vapor content is also done with the space based GPS Radio Occultation (GPS RO) technique, Wickert *et al.* (2001).Today, some of the satellite constellation designed to GPS RO observations have operated as GPS/ MET, CHAMP,SAC-C,GRACE and FORMOSAT-3/COSMIC, Yen *et al.*(2010). COSMIC data, observations of temperature and moisture profiles in the atmosphere can be done globally (Rocken, 2005; Anthes *et al.* (2000; 2008); Fong *et al.* (2008; 2009). Daily PWV GPS RO profile and radiosonde around Jakarta had showed a good correlation (Noersomadi, 2010). The application of GPS techniques, both ground based and space based, can complement the weakness and limitations in several conventional techniques of water vapor observations. Further research, comparison GPS PWV, PWV radiosonde and Numerical Weather Prediction (NWP) global data had been done (Yang *et al.* (1999); Cucurull *et al.* (2000)), and for NCEP global data, Boccolari *et al* (2006).

PWV ground-based GPS exctracted high temporal resolution, but limited vertical resolution, meanwhile GPS RO has advantages in vertical resolution but limited in time and observation points.Even though, accuracy of GPS PWV as well as radiosonde measurements and NWP global model. However, it only extracted total water vapor contents in atmosphere, not low-level moisture yet. Therefore, it is necessary to develop techniques for extracting low-level tropospheric moisture content based on the combination of ground and spaced GPS data, radiosonde and global NWP data.

2. DATA

In this research used ground based GPS data and meteorological data at GPS-BAKO station (Geospatial Information Agency/ BIG at 6.491^0 S - 106.849^0 E, Cibinong,Indonesia. GPS RO data from FORMOSAT-3 (Taiwan's Formosa Satellite Mission) and Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC). Radiosonde data Soekarno - Hatta (Soetta) Meteorological Station, Tangerang, Indonesia. Also PWV

GPS and PWV radiosonde on BAKO on July 27 - 2 August 2010, as the result of a joint research BIG and ITB. Global NWP water vapor from National Centers for Environmental Prediction (NCEP) and The European Centre For Medium-Range Weather Forecasts (ECMWF).

3. ESTIMATION OF LOW-LEVEL MOISTURE

3.1 Calculation PWV

GPS-BAKO data (RINEX) processed using Bernese 5.0 software to generate ZTD every hour using precise point positioning by Saastamoinen apriori model for tropospheric correction for Niell dry and wet mapping function.ZHD calculated by the local surface pressure by the following formula:

$$ZHD = (2.779 \pm 0.0024)\frac{Ps}{f(\lambda, H)} \quad (1)$$

Ps is the surface pressure (mb) and f (λ, H) is a factor for the variation of gravitational acceleration with latitude and high pressure on the antenna (mb).ZHD is used as a subtraction factor ZTD for calculating ZWD (Gutman, 2004).

$$ZWD = ZTD - ZHD \quad (2)$$

ZWD used to calculate the PWV by considering the average temperature (Tm) which Tm = 70.2 + 0.72Ts (Ts=surface temperature). Π depends on location of GPS receiver, weather conditions and seasons (Bevis et al.,1994).

$$PWV = \Pi(Tm) * ZWD \quad (3)$$

GPS RO contain air pressure, geopotential height,air temperature,Vp (H2O vapor pressure) and refractivity by time, latitude and longitude. PWV calculated by WMO standard formulation (Nakamura et al, 2004) :

$$PWV = \frac{1}{g}\int_{pt}^{ps} q\,dp \quad (4)$$

where q is the specific humidity in g/kg, g is the acceleration of gravity (m/s^2), ps and pt is atmospheric pressure at the surface (reference heigh). For calculating a specific humidity used Causius-Clapeyron equation :

$$q = k_1 \frac{e}{(p - k_2 e)} * 1000 \quad (5)$$

where the value of k_1= 0,622 dan k_2= 0.378.

3.2 Extraction technique of low-level tropospheric moisture content

Basically low-level moisture retrieved based on the differences of the total PWV from ground based GPS and the upper-level PWV. For extracting low-level tropospheric moisture content applied the combination of the total PWV from ground based GPS with various techniques.The first technique is the difference of the total PWV GPS-BAKO and PWV GPS RO from the surface to the upper-level and secondly from surface 2 -700 mb. The third technique is the difference of the total PWV ground based GPS and the upper-level PWV radiosonde (above 700 mb). The last techniques are the differences of the total PWV ground based GPS-BAKO and the upper-level global NWP data, using NCEP for fourth techniques and fifth technique using ECMWF (figure 1).

4. RESULT

4.1 Study cased on July 27–August 2,2010

Limited radiosonde observation around Jakarta is only represented by Soetta Meteorological Station. Hadi et al. (2010) expressed that a sufficiently strong correlation between PWV Radiosonde launched around GPS-BAKO station and PWV Radiosonde Soetta. Reinforced the previous study, PWV Radiosonde BAKO compared to PWV Radiosonde Soetta,

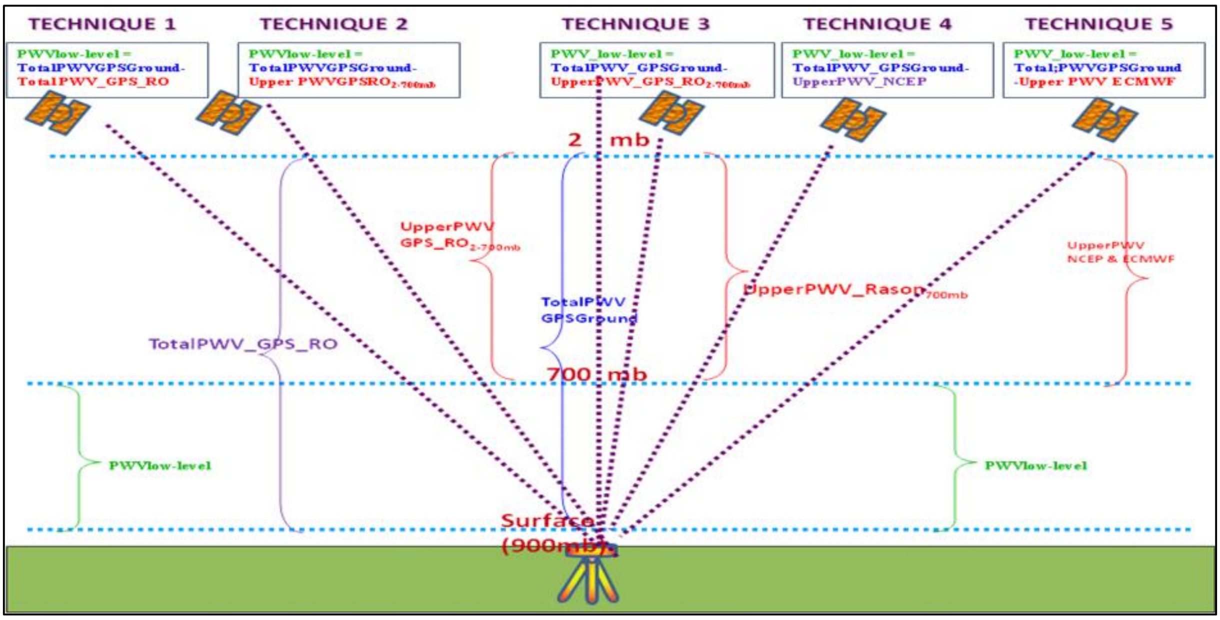


Figure 1. Extraction Techniques of Low-Level Moisture

PWV GPS-BAKO, also PWV NCEP and ECMWF Bako (figure 2). The comparison shown the correlation coefficient of PWV GPS-BAKO and PWV Radiosonde Bako 0.76, and 0.5 with PWV Radiosonde Cengkareng. PWV Radiosonde BAKO and PWV Radiosonde Soetta shown 0.67, which demonstrated that PWV can be used to represent PWV Radiosonde BAKO.

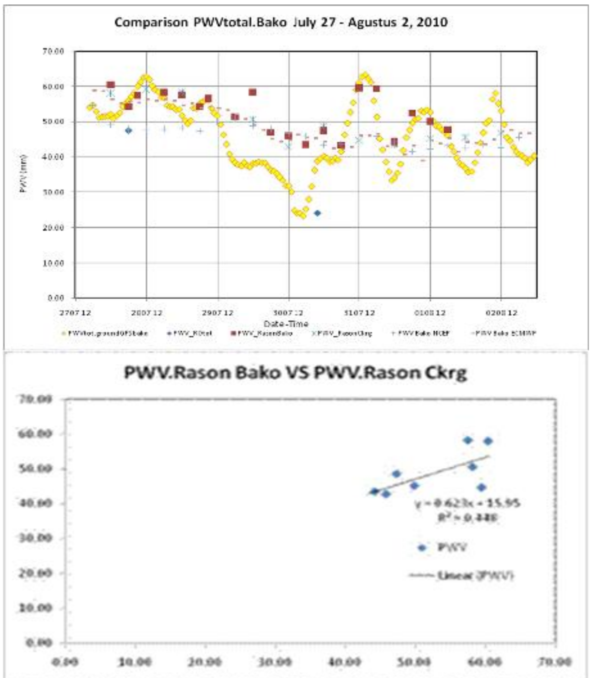


Figure 2. Comparison PWV July 27 – August 2, 2010

Extraction of low-level moisture using GPS-BAKO and GPS RO by the techniques 1 shown low-level PWV is not very significant when compared with low-level PWV Radiosonde BAKO and by the technique 2, low-level PWV is more significant, but still had the limitation of amount of data caused by the sparsed observation of GPS RO. Lower - level PWV by the technique 3, both of radiosonde BAKO and Soetta represented lower - level

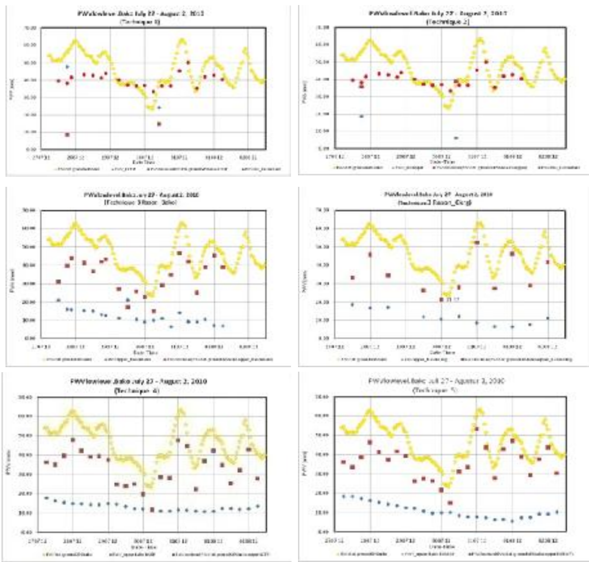


Figure 3. PWVlow-level by the extraction techniques

PWV, also for the technique 4 and 5 (figure 3). Those 5 techniques are compared with the technique 3 is used as a reference low-level PWV (PWV GPS-BAKO and upper-level PWV Radiosonde BAKO). The smallest error shown by the technique 5 (PWV GPS-BAKO and upper-level PWV ECMWF).

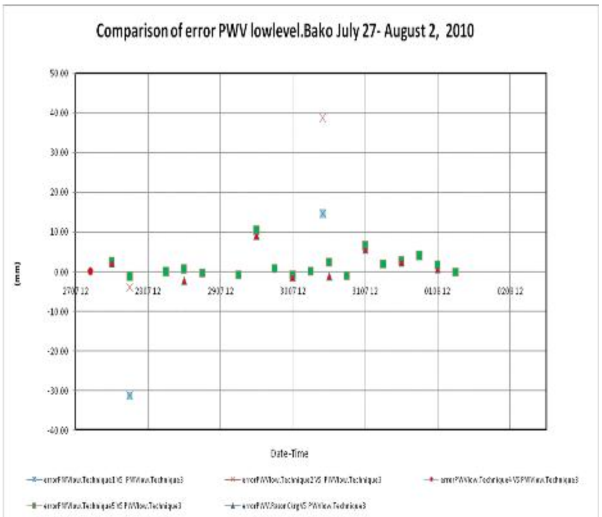


Figure 4. Comparison of error low-level PWV BAKO

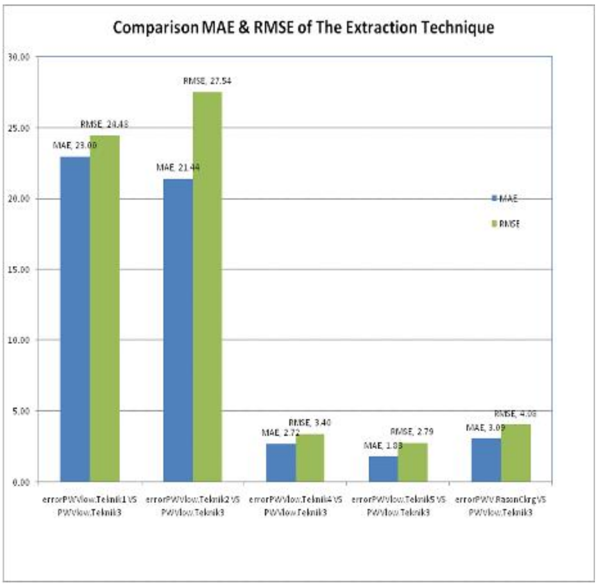


Figure 5. MAE and RMSE PWVlow-level by the extraction techniques

MAE 1.83 and RMSE 2.79 (figure 5) by the correlation coefficient is 0.952 (Table 1). Thus it can be considered as the best techniques for extraction of low-level moisture content.

Table 1. Correlation of the extraction technique

PWV low-level	Coef.Corr
Technique 4 - Technique 3	0,946
Technique 5 - Technique 3	0,952
RasonSoeta-Bako (Technique3)	0,934

4.2 Study cased low-level PWV by extended data period in 2009

Base on cased on July 27 - August 2, 2010, it stated that the best technique 5 is the combination of the total PWV GPS-BAKO and upper-level PWV ECMWF, so it applied for extended data in 2009. Low-level PWV BAKO in 2009 by these technique generated diurnal variation as shown figure 6.

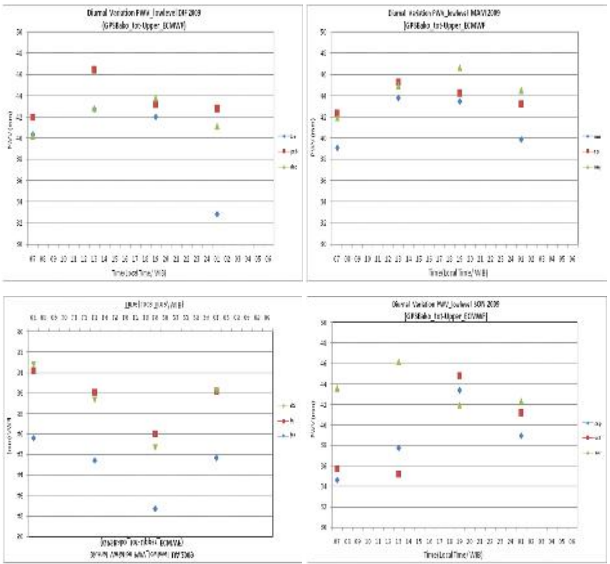
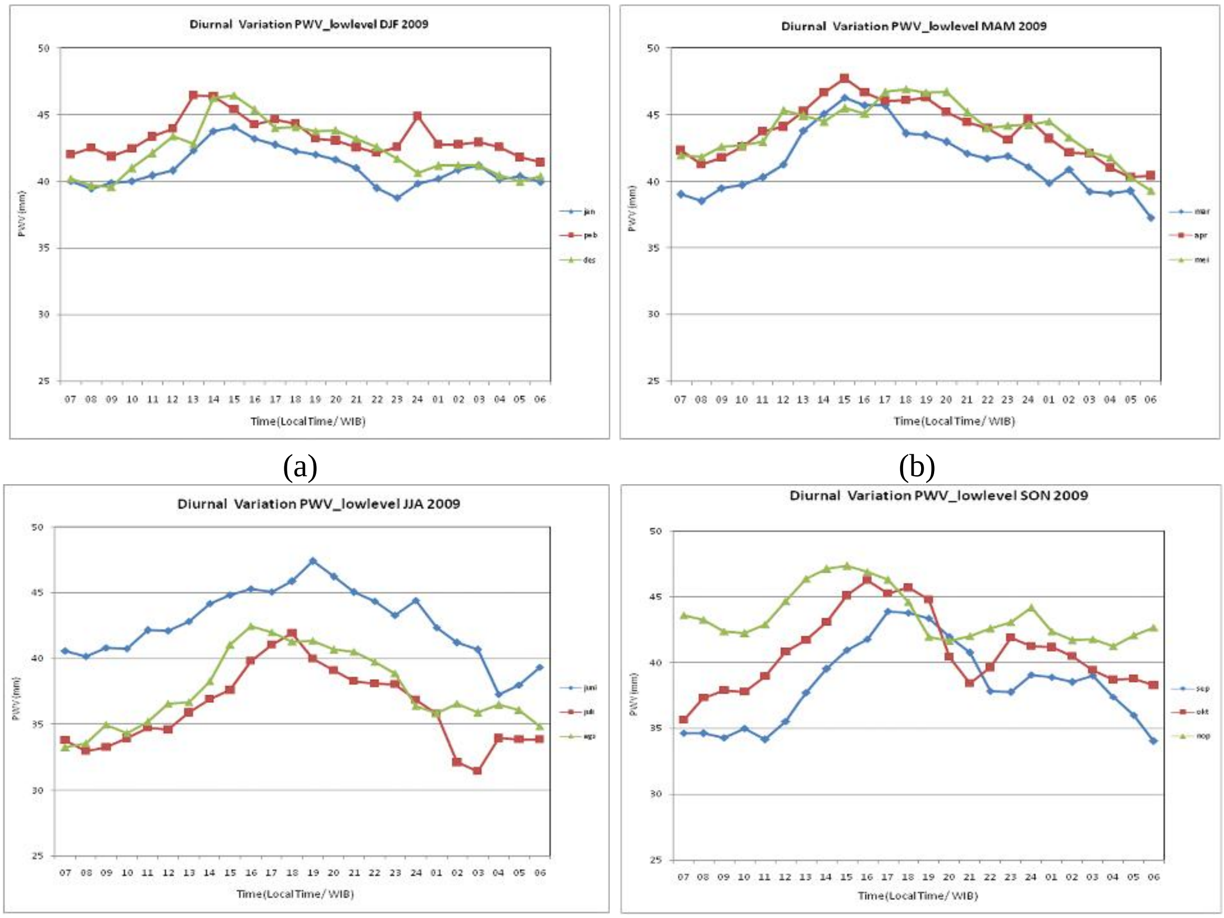


Figure 6. Diurnal variation PWV_low-level by the best technique

Diurnal variation low-level PWV confined every 6 hours, for completing to every hour, applied a linear interpolation on the upper-level PWV ECMWF. Based on the linier interpolation, diurnal variation of low-level moisture content in 2009 shown in figure 7,(a)in the period of the rainy season (DJF), (c)dry season (JJA) and for the transition periods in figure (b) MAM and (d)SON.



(a) (b)

(c) (d)

Figure 7. Diurnal variation PWVlow-level (a) DJF, (b) MAM, (c) JJA, (d) SON in 2009

5. ANALYSIS OF LOW LEVEL MOISTURE

Diurnal variation of low level moisture in the rainy season (DJF) increased in the afternoon at 13:00-14:00 Local Time / WIB and declines to the afternoon, evening until dawn, but in February the instantaneous fluctuation increased at 24.00 Local Time / WIB and decreased until dawn. In the transition periods (MMA), the enhancement of low-level moisture occurred during the late afternoon to evening around 15:00-16:00 Local Time / WIB, then continued to decrease until the evening to dawn, except in May which maximum low-level moisture occurred at 17:00 to 20:00 Local Time / WIB. Meanwhile in the SON period, the enhancement occurred at 11.00 WIB and reached the maximum in the afternoon at 15:00 to 17:00 Local Time / WIB, then decreased until the evening, the instantaneous increased by midnight and be continued to decrease until before dawn. For the dry season (JJA), low-level moisture concentration occurred during the late afternoon with maximum at 16:00 to 19:00 Local Time / WIB, then continued to decline until dawn. Generally during 2009, the average of low-level moisture content is 41.25 mm, with the minimum is 31.43 mm in July at 03.00 WIB, and 47.71 mm for maximum in April at 15:00 Local Time / WIB.

Composite analysis of diurnal of low-level PWV at GPS-BAKO station in the dry season is slower than in the rainy season, as well as the enhancement of low-level moisture tends to be followed by convective activity. In the rainy season convective activity began in the morning around 10.00 WIB and reached the maximum during the daytime around 13:00 - 15:00 Local Time / WIB. Meanwhile in the dry season there was a lag time around 1 hours, at 12.00 Local Time / WIB and reached the maximum activities in the afternoon to evening around 17:00-19:00 Local Time / WIB. It consisten with the characteristics of sea-breeze intrusion over Jakarta area as revealed by previous study (Hadi et al. 2002;2007).

The relationship of low-level moisture and convective activity demostrated by convective indices which obtained from imagery MTSAT-IR1 satellite based on the temperature of the cloud tops near area GPS-BAKO station.By graphical analysis in hour for February 2009 indicated diurnal variation of low level moisture and convective indices shown a relatively significant (figure 8).

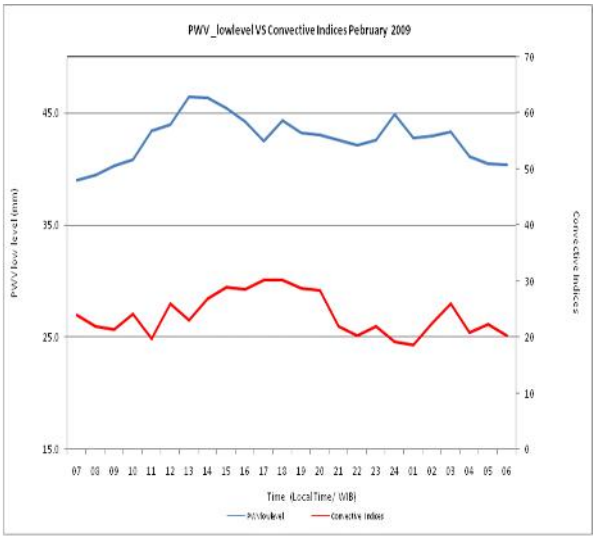


Figure 8. Relationship of PWVlow-level vs convective indices Pebruary 2009

6. CONCLUSION

Development of processing GPS data to estimate the total PWV is not estimated yet for extracting low-level moisture content which is important for developing of deep convection over tropical region. The simple of effective technique for extracting low-level tropospheric moisture content from ground based GPS had developed by the combination of upper-level PWV from GPS RO, NCEP and ECMWF data and compared by radiosonde. Based on GPS data observed in July 27 – August 2, 2010 generated the best technique to extract low-level moisture is calculated the difference between total PWV GPS-BAKO and upper-level PWV ECMWF. Applied the best technique for extended GPS-BAKO data observed during January through December 2009 indicated that the composite diurnal variation of low-level PWV is quite consistent with the characteristics of sea-breeze intrusion over Jakarta area. Moreover, also the enhancement in low-level moisture tends to be followed by convective activity. For further research, these best effective methods will be applied by several ground based GPS stations over western region of Java, so it can be known spatio temporal variation and movement of low level moisture.

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