STUDY OF MOISTURE TRANSPORT ON LOW LEVEL TROPOSPHERE BASED ON GPS DATA OBSERVATION RELATED TO THE EVOLUTION OF THE CONVECTIVE PROCESS

Kristianto Aries[1],Widiyantoro Sri[2], Hadi Wahyu Tri[3], Wijaya Darmawan Dudy[4]

Graduate Student[1], Faculty of Earth Sciences and Technology, Bandung Institute of Technology,
E-mail : ais_aries@students.itb.ac.id; ariesmed@yahoo.com

Professor[1], Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology
E-mail : sriwid@geoph.itb.ac.id

Lecturer[4], Faculty of Earth Sciences and Technology, Bandung Institute of Technology,
E-mail : tri@meteo.itb.ac.id

Lecturer[4], Faculty of Earth Sciences and Technology, Bandung Institute of Technology,
E_mail : dudy@gd.itb.ac.id

ABSTRACT

Water vapor is one of the climate and weather variables that plays an important role in energy balance in the atmosphere, which the distribution of water vapor content in the atmosphere spatially and temporally in local and global scale is closely related to the distribution of clouds and precipitation in a region. Distribution of water vapor is also closely related to the movement / transport of water vapor to understand the physical processes in the atmosphere. Water vapor in the lower troposphere (Low Level Moisture) play a role in determining the instability and the rising of tropospheric air parcels mechanism for the growth of the rain's cloud.

The techniques of water vapor observations have been carried out to date, with some of the characteristics, strengths and weakness of each, both with synoptic meteorological observations, or by the radiosonde measurements. The development of remote sensing technologies are increasingly sophisticated, the measurement of the distribution of water vapor transport can be carried out using satellite-based technology, one with a Global Positioning System (GPS) as a complement to the observation of water vapor with high spasial temporal resolution, continuously and near real time. Nevertheless information of water vapour (Precipitable Water Vapour / PWV) in the atmosphere resulting from ground-based GPS observations still have limitations, only a total content of water vapor in the atmospheric column with a certain radius, so is necessary to apply a method that combines the space GPS (Radio Occultation) and based GPS observational data. Further analysis of the data SWD ground-based GPS, a tomographic technique can be used to monitor the movement of water vapor from the lower to the upper layer in relation to convective processes in the region of Western Java.

This research focused on the study of water vapor in the lower troposphere by a combination of methods based GPS observations of ground and space based GPS. With the hope of detecting water vapor in the lower troposphere by using a combination of data PWV ground-based and space-based GPS, so it can be seen spasio temporal patterns and variations, and be able to identify the type of local convective moisture convergence zone in the formation and growth of convective activity, and the evolution of water vapor 3D tomography technique to reconstruct the GPS data in relation to convective rain systems.

KEY WORDS : Precipitable Water Vapour ,GPS, Tomography

1. INTRODUCTION

Water vapor is one of the climate and weather variables plays an important role in energy balance in the atmosphere. Qu et al. (2005) and Furumoto et al. (2005) stated Maritime Continent of Indonesia (BMI) is a climatic zone dominated by convective activity that involves the movement of large amounts of water vapor. The system of movement / transport of water vapor plays an important role in the formation of convective cloud activity due to the abundance of water vapor supply (Wu et al.,2003) . However, the deep convection will only happen 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. In this case, the horizontal movement of water vapor in the lower layer becomes important to know its role in determining regional weather and climate patterns. Cross-equatorial moisture transport (TKLE) is one indicator of the occurrence of the monsoon break in BMI, which is a form of intra-seasonal variability is important (Hermawanto,2011). The other characteristics of atmospheric dynamics in BMI was a strong diurnal convective activity (Johnson et al., 1987; Nuryanto, 2011). Nuryanto (2011) shows that there are local convective modes with different phases. Thus the necessary observations of water vapor in detail, especially in the lower troposphere layer to monitor the evolution of convective processes in the BMI.

Monitoring of atmospheric moisture conventionally observed through a network of synoptic meteorological using a thermometer, and psychrometer and hygrometer, but the result 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). Also the observation carried out using aircraft mounted wind sensor and temperature, where the data is sent to the surface of the station using the system AMDAR. The limitation of this observation is usually measured atmospheric profiles at certain times, such as during take off and landing aircraft, with areas limited to around the airport.

In addition, the techniques of satellite remote sensing has also been developed, including the invention of the technique to estimated the moisture content in the atmosphere using the Global Positioning System (GPS) as an alternative observation. Propagation of GPS signals received from the satellite at ground receivers on earth undergo a delay by the atmosphere. Signals are also have the dispersive effect when passing of the ionosphere and the non-dispersive effects of the troposphere. Tropospheric delay consists of two components, namely the hydrostatic components (dry), which depends on the gas dry air in the atmosphere and contributes about 90% of the delay. The other component is a component that depends on the wet moisture content of the atmosphere (Gabor, 1998). Assuming static equilibrium and the ideal gas law, the hydrostatic delay is a linear function of the total surface barometric pressure and can be modeled in the millimeter level of accuracy Bevis et al. (1992).

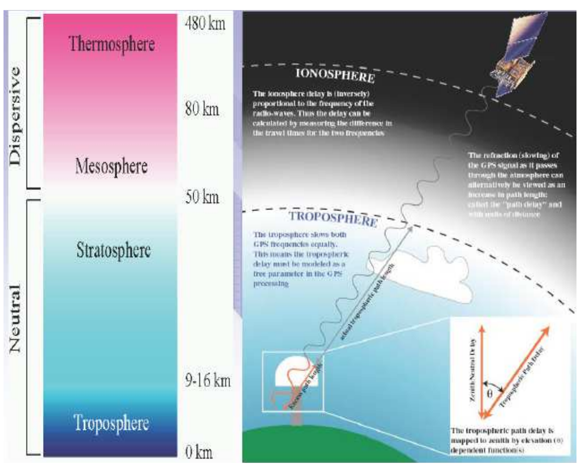

Figure.1. Effect of atmosphere on GPS signals (Kursinski et al, 2004)

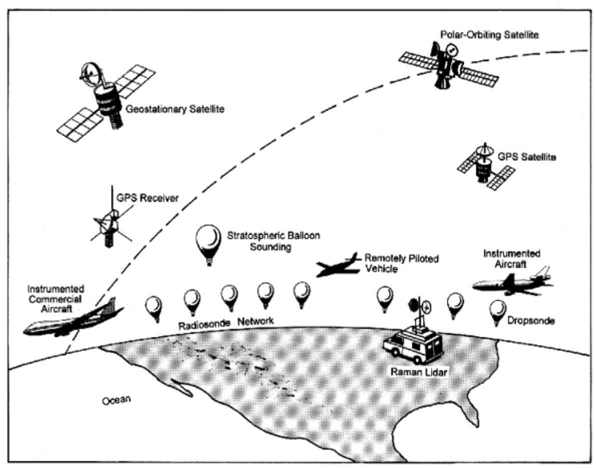

Figure.2.The techniques of water vapour measurements (Carter, 1997)

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. While the hydrostatic delay or Zenith Hydrostatic Delay (ZHD) can be calculated from the surface or the antenna pressure (millibars). ZHD is used as a deduction from the results 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 calculated from ground-based GPS measurements can provide water vapor information, which is consistent with the radiosonde observations. Suitability observations between GPS and radiosonde PWV has also been confirmed in various locations, in Japan, Yoshihira et al (2000) and in Indonesia, Hadi et al. (2010). In addition to the ZWD, from ground-based GPS is also obtained Slant Wet Delay (SWD) to provide information on the amount of water vapor along the ray path from satellites to the GPS receiver, known as

Slant Water Vapour/ SVW, Ware et al.(1996). The absence of data SWD also allows the implementation of high-resolution tomography techniques for imaging the distribution of 3D water vapor in the atmosphere (Lubomir and Jarlemark (2004) and Foelsche et al.(2001).

Besides of ground-based GPS, the observations of atmospheric water vapor content is also done with the space-based GPS radio occultation technique (GPS-RO), 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).With the application of GPS techniques, both ground-based and space-based, can complement the weaknesses and limitations in some conventional techniques of water vapor observations. The use of GPS to provide continuity of data, the cost of installation and its operation is relatively low cost budget, as well as the level of measurement accuracy up to a few millimeters, similar to the radiosonde measurements and water vapor radiometer (Gutman, 2004), and is able to provide 3D profile of water vapor vertical and lateral (slant delay) can use GPS observational data (Foelsche and Kirchengast, 2001; Lubomir and Jarlemark, 2004).

Abidin et al. (2010), the ground-based GPS network was installed in Indonesia by BAKOSURTANAL (Indonesian Coordinating for Surveys and Mapping Agency), but its application to monitoring the water vapor is still not optimal in use. Therefore, it is necessary to study the utilization of those GPS data, mainly in the low level troposphere related to the process of convective activity.

2. RESEARCH PROBLEM

The research question in this proposal is how is the variations of spasio temporal water vapour in the lower troposphere and it's transport based on GPS in relation to the formation and growth of convective activity and the evolution's process? With the aim of developing PWV data from ground-based GPS and GPS-RO to get the spasio temporal variations in the low level troposphere, and to identify the type of local convective convergence zone using PWV from GPS as the precursor of the formation and the growth of convective activity, and for applying tomography techniques for imaging the 3D distribution of water vapor using GPS data, and reconstructing water vapor in the evolution of convective processes. This study only focused on the study of water vapor, especially in the lower troposphere (from surface to near of the planetary boundary layer) with a ground-based GPS data in the network based IPGSN (Indonesian Permanent GPS Stations Network) owned BAKOSURTANAL (Indonesian Coordinating for Surveys and Mapping Agency). Also GPS RO of FORMOSAT-3 (Taiwan's Formosa Satellite Mission) and COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate), which is the mission of a research collaboration between Amerika - Taiwan. The area of research is part of West Java.

3. ANALYSIS OF WATER VAPOR ON LOW LEVEL TROPOSPHERE

3.1 Detection of Water Vapor on The Lower Troposphere Layers

To identify the amount of water vapor in the lower troposphere is done by combining PWV from ground-based observations GPS and GPS RO. PWV with ground-based GPS is produced by processing ZTD, then find the value of ZHD, which can be calculated by the local surface pressure by the following formula:

$$ZHD = (2.779 \pm 0.0024)\frac{P_s}{f(\lambda, H)} \qquad (3.1)$$

where Ps is the surface pressure in millibars and f (λ, H) is a factor that accounted for the variation of gravitational acceleration with latitude and high pressure on the antenna (mb).ZHD is used as a deduction from the results of the ZTD for ZWD (Gutman, 2004).

$$ZWD = ZTD - ZHD \qquad (3.2)$$

ZWD is used to calculate the PWV by considering the average temperature (Tm). where Tm = 70.2 + 0.72Ts (Ts = surface temperature). And the consideration of factors that Π depends on the GPS receiver location, local weather conditions and seasons and the amount varies up to 10% (Bevis et al.,1994).

$$PWV = \Pi(Tm) * ZWD \qquad (3.3)$$

PWV resulting from ZWD represent the bulk of total column water vapor from the troposphere. Furthermore, PWV was calculated based on data from space-based GPS RO by standard methods which can be used formulation WMO,Nakamura et al,(2004):

$$PWV = \frac{1}{g}\int_{pt}^{ps} q\,dp \qquad (3.4)$$

where q is the specific humidity in g / kg, g the acceleration of gravity in m/s2, ps and pt are respectively the atmospheric pressure at the surface and at a reference height where moisture can be considered zero in millibar. To calculate the specific humidity used Causius-Clapeyron equation :

$$q = k_1 \frac{e}{(p - k_2 e)} * 1000 \quad (3.5)$$

where the value of k_1 = 0,622 dan k_2 = 0.378. Specific humidity in g / kg (q value equal to the mixing ratio).

The amount of water vapor in the lower troposphere (PWV_{LL}) obtained by combining PWV generated from ground-based (PWVground) and space-based GPS (PWVspace).

3.2 Movement of Water Vapor and Identification of Convective Type on The Low Troposphere Layers

Water vapor in the lower troposphere (PWV_{LL}) at some point of observation sequences are then plotted as time series. Then do the spatial interpolation methods IDW or Cokriging. The movement of the horizontal transport of water vapor in the lower troposphere are analyzed for the region of West Java to produce a temporal and spatial distribution patterns of diurnal variation. Next of patterns and temporal variations spasio water vapor, will be identified the water vapor convergence zones for the type of convective in the western part of Java, by classifying it into five categories, which are *suppressed convergence (SCn), suppressed convection (SCv), single convection (CS), enhanced convection (CE), and island convection (CI)* (Hadi, 2007).

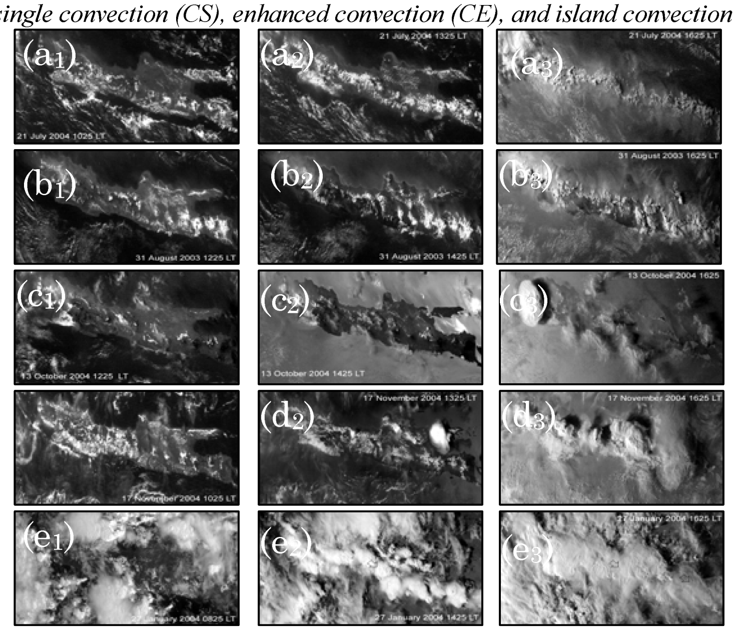

Figure.3.Convectice type based on GMS : suppressed convergence (a_i),suppressed convection (b_i), single convection (c_i), enhanced convection (d_i), and island convection, (e_i) (Hadi, 2007)

Identify the types of convective GPS PWV is done by dividing the observation in the morning, afternoon and evening, which occurs predominantly convective activity. Then calculated statistically, the distribution of the occurence of the type of convective within the observation period.

3.3 Reconstruction of 3D Water Vapor

GPS data is used in the tomographic technique is SWD, which is defined as the integration of refractivity atmosphere because water vapor (N_w) along the signal/ ray path (d_z) from the GPS satellite transmission to the receiver antenna on the GPS receiver. SWD can of ZWD is calculated by the following equation.

$$ZWD = 10^{-6} \int N_w d_z \quad (3.6)$$

SWD can be calculated using the following formula (Chen et al., 1997; Fadil et al. 2009).

$$SWD = Mw(\theta)(ZWD) + M_w(\theta)\cot(\theta)\left[G_N \cos(\varphi) + G_E \sin(\varphi)\right] \quad (3.7)$$

where θ is the elevation angle of the satellite, Mw is the wet mapping function, φ is the satellite azimuth, GN and GE gradient direction North South (NS) and East West (EW).SWD is used to measure water vapor Slant Water Vapour (SWV), where the relationship similar to the relationship ZWD to PWV, which can be calculated

$$SWV = \Pi(Tm) * SWD \quad (3.8)$$

Then to estimate the water vapor profiles in the lower troposphere, the value of SWD in Equation 3.7 is used as input to generate a 3D model of water vapor tomography. Scheme approach is dividing the atmosphere in some voxel, is then calculated refraktifity along ray paths of GPS signals.Linear approach to solve tomography are :

$$A.x = d \quad (3.9)$$

where :

A =data matrix ray segment length.
x = solution vector of an unknown number.
d = vektor data

Hirahara (1996), the GPS tomography, use the following equation:

$$L.N = d_{GPS} \qquad (3.10)$$

for water vapor tomography in the troposphere, the equation becomes:

$$L.N = d_{trop} \Rightarrow \sum N_i ds_i = SWD \qquad (3.11)$$

where :
L = length of the segment of data matrices.
N = index of refraction which is the solution vector to be searched.
D_{trops} = GPS data in the troposphere (SWD).

To reconstruct the 3D vertical in understanding the convergence of water vapor in the lower troposphere layer and convective evolution process tomography techniques based on value of SWD that has been processed, then selected the 3D distribution schemes estimation method water vapor. Seko et al, (2000) calculating the tropospheric delay along the ray path are converted into water vapor, the atmosphere is divided into several grid box, assuming uniform water vapor (*xi jk*), with a value of nilai (*i*, *j* and *k* is the location of the box in the direction of *x, y* and *z*), and then calculated the length of the path in each box and each layernya.

3.4 Building Block of Research

It can be seen in the block diagram below.

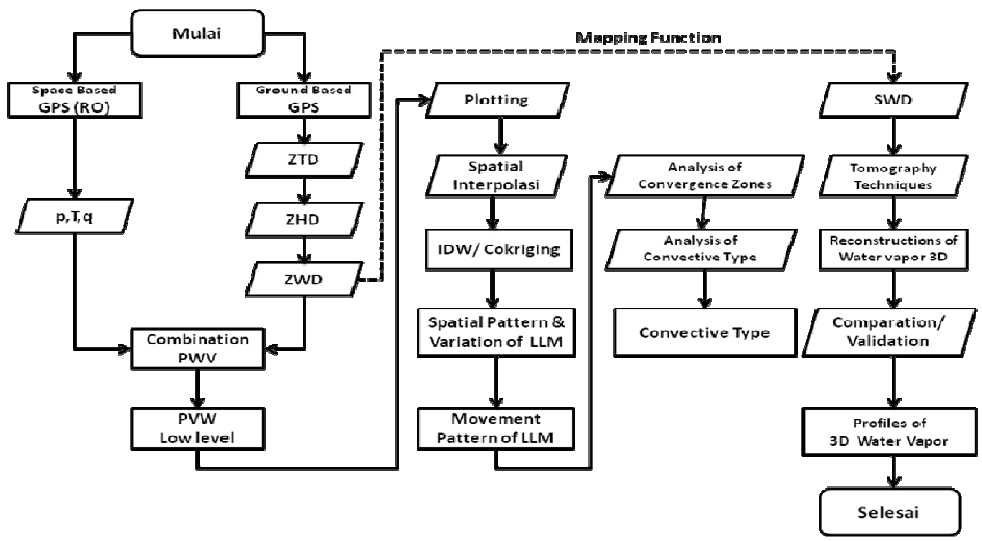

Figure.4. Building Block of Research

3.5 SUMMARY

In this research is expected the results to be obtained namely, spasio temporal patterns and variation of water vapor on low level troposphere using the combination of PWV based on ground and space GPS in region of West Java, and convective type of water vapor convergence zones on low tropospheric layer in the growth of convective cloud formation, and evolution of 3D profile of water vapor by GPS data tomographic techniques related to convective processes.

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