Combination of the Equatorial Atmosphere Radar – Radio Acoustic Sounding System (EAR-RASS) in Determining a Fine Structure of Total Precipitable Water (TPW) over Kototabang, West Sumatera, Indonesia

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Abstract. This study is mainly concerned an application the combined of the Equatorial Atmosphere Radar (EAR) and Radio Acoustic Sounding System (RASS) in determining a fine structure of Total Precipitable Water (TPW) in the lower troposphere at Kototabang, West Sumatera (0.20^0 S; 100.32^0 E) during the CPEA I Campaign started from April 10 to May 9, 2004. It looks possible, since EAR-RASS is designed specially to detect the wind at three dimensional direction and virtual temperature with good time and spatial height resolution. By applying the Weisner technique (1970), we found a fine structure of TPW vertically during the above period. While, by applying the Cross-Correlation Function (CCF), we found an a goog agreement between TPW and Optical Rain Gauge (ORG). In the same time, we analyzed the Boundary Layer Radar (BLR) to investigate the updraft and downdraft air mass activities from surface up to 5 km. We found the consistency of BLR, RASS and radiometer data when we investigated the vertical profile of TPW. Futhermore, we found the time variation of TPW, especially on April 24 and May 5, 2005 are about 0.43 and 0.35, respectively. Detailed results of this study are discussed in this paper.

1. Introduction

These major part of the solar radiation reaches the Earth's surface without absorption by the atmosphere. The troposphere is heated by infrared radiation from the Earth's surface, and convection transfers thermal and kinetic energy upward. Especially in the atmospheric boundary layer where the atmosphere undergoes direct infrared heating, active convections often appear and sometimes reach up to the tropopause under low-stability conditions. These deep convections are thought to transport minor constituents such as carbon dioxide between the troposphere and the stratosphere [1]. RASS (Radio Acoustic Sounding System) is a ground based remote sensing technique for measuring a height-profile of atmospheric virtual temperature in the tropoposhere and lower stratosphere with time and height resolution of a few minutes and 150-300 m, respectively.

Acoustic wave emitted from a high-power transmitter on the ground produce sinusoidal variations of atmospheric density, resulting in the radio refractive index perturbations. A radar tracks the acoustic wave fronts to receive strong scattering of radio waves (RASS echo). However, there are two necessary conditions to detect RASS echoes; the wave number vector of incident radiowave must be perpendicular to the acoustic wave fronts, and the acoustic wavelength must be half of the radar wavelength for optimum Bragg resonance.

As one of an MST (mesosphere, stratosphere and troposphere) radar, the EAR (Equatorial Atmosphere Radar) can be used to determine wind velocity fluctuations with good time and spatial height resolution. This is similar to the MU (Middle and Upper atmosphere) radar observation [2].

The construction EAR-RASS capable of detecting fine structure in the vertical profiles of virtual temperature, T_v. From this virtual temperature data, we can obtain a fine structure of Brunt Väisälä frequency squared, N^2 as one of the most important parameters needed to explain the Turbulence Energy Dissipation Rate (TEDR), ε and Vertical Eddy Diffusivity (VED), K [3]. This paper is mainly concerned to describe a brief review of the basic concept of RASS technique, especially on determining a fine structure of Total Precipitable Water (TPW) that represented as W profiles with a good time a spatial height resolution.

2. Materials and Methods

2.1 TPW

TPW is defined as the amount of moisture content in an air vertical column if all the moisture in the column undergoes a precipitated condensation as well as decreased as rain [4], in mm or inches, although no natural process can change the entire moisture content the layer becomes rain. Furthermore, the amount of water that can be converted to rain within an air blob at adequate altitude is calculated by adding pressure or pressure from the surface and observing the temperature, humidity and air pressure above it. The formula that is often used to calculate W in millimeters is:

$$\mathbf{W} = \sum_{i=1}^{N} q\,\Delta p$$

With pressure pa in millibar and q in grams per kilogram, is the average value of specific moisture (moisture mass per moist air mass), in the top and bottom layers of each layer. Specific moisture can be expressed in the formula:

$$\mathbf{q} = 622\frac{e}{p-0.37\,e} \approx 622\frac{e}{p}$$

To estimate the value of this TPW using the formula:

$$W = \int_{z=z_i}^{z=z_i+dz} \rho_v\,dz = \int_{z=z_i}^{z=z_i+dz} q\rho\,dz = -\frac{1}{g}\int_{p=p(z_i)}^{p=p(z_i+dz)} q\,dp$$

where:

W = *Total Precipitable Water* (cm)
z_i = height in (m)
p_{zi} = pressure in (hPa)
ρ = air density in (kg/m3)

q = specific humidity between two layers p(z) and p(z_i+ dz) in (g/kg)

To process RASS data, because the available data in the form of q, Tv and z $_i$ used the formula:

$$P = \frac{1}{g} \int_{z=p_z}^{z=p_z-dp} q\, dp$$

To complete the above integration by using the technique of integral average value, obtained:

$$\mathbf{W} = \sum_{i=1}^{N} q_i \, \Delta p_i$$

where q_i is the mean value of q between two pressure layer p_z and (p_z - dz)

According to [4] TPW is calculated each isobaric surface height. To determine the height of the isobaric surface for each of the atmospheric layers based on the Geopotential height with the hypsometric equation:

$$z_2 - z_1 = dz = \frac{R_d}{g_0} \overline{T}_v \ln \frac{P_1}{P_2}$$

$$p_n = p_0 \; \exp\left[(z_2 - z_1) \times \frac{g_0}{R_d \overline{T}_v} \right]$$

where:

T_v = T (1 + 0.608 r) R_d = 287 J/Kg/^{0}K

g_0 = 9.806 m/s^2

$\overline{T}_v$ = The mean value of Virtual Temperature between two layers

While to estimate TPW by using data from Radiometer in accordance with the availability of parameters in the form ρ_v , then using the formula:

$$W = \int_{z=0}^{Z_{top}} \rho_v dz :$$

As well as RASS data, to complete the above integration using the technique of integral integral values, so is obtained:

$$w = \sum_{i=1}^{N} \overline{\rho}_i \, \Delta z_i$$

2.2 Specification of EAR

The EAR has a circular antenna array of approximately 110 m in diameter, which consist of 560 three-element Yagis as presented in Figure 1.

Figure 1. The antenna field of EAR at Kototabang, West Sumatera

It is an active phased array system with each Yagi driven by a solid-state transceiver module. This system configuration makes it possible to direct the antenna beam by electronic control up to 5000 times per second. The EAR transmits an intense radio wave of 47 MHz to the sky, and receives extremely weak echoes scattered back by atmospheric turbulence. It can observe winds and turbulence in the altitude range from 1.5 km to 20 km (troposphere and lower stratosphere). It can also observe echoes from ionospheric irregularities at heights more than 90 km. The explanations more detail is presented at Table 1 which are based on research by [2].

Tabel 1. EAR specification

Location	100.32^{o} E ; 0.20^{o} S ; ± 865 m MSL
Frequency	47 MHz
Output power	100 kW (peak envelope)
Antenna system	Quasi-circular active phased array (110m-diamter, 560 three-element Yagis)
Beam width	3.4^{o} (-3dB, One-way)
Beam direction	Anywhere (within 30^{o} zenith angles)
Observation range	1.5 – 20 km (Atmospheric turbulence) > 90 km (Ionospheric irregularity)

2.3 Radar Equation for RASS Echo

The radar equation for the RASS echo given by [5]. Radiowave echo model of turbulence scattering to the RASS echo was applied by assuming the following conditions :

- The atmospheric temperature is relatively constant over the entire height and the background wind is negligible.
- The radar beamwidth (θ_r) is sufficiently smaller than the acoustic beamwidth.
- The effects of any distortions of the of the acoustic wave fronts caused by turbulence are negligible.

With normal wind profiler radar, successive profiles of three components of the wind velocity, echo power, and the spectral width with certain time and height resolution can be observed. In addition, by applying RASS, we can simultaneously monitor temperature profiles [6,7]. The basic principle and the observational procedure of RASS is shown in Figure. 2.

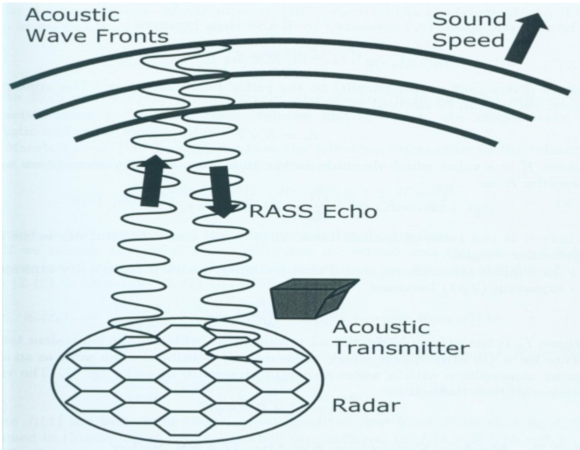

Figure 2. Basic principle of RASS

The basic principle of RASS depends on a relation that sound speed is proportional to the square-root of atmospheric temperature. In a RASS observation, transmitted acoustic pulses from the ground produce refractive-index fluctuations. We can detect the Doppler shift between the transmitted signal and received echoes scattered by acoustic wave-fronts and determine their propagation speed. In the actual atmosphere, the apparent acoustic speed, C_s is the summation of the true acoustic speed, C_a and the background wind velocity, V_r.

$$C_a = C_s + V_r$$

The acoustic speed, C_s measured by RASS then becomes

$$C_s = C_a \cdot n + V_r \cdot n,$$

where n is unit vector parallel to the radar beam direction. The atmosphere temperature can be derived as

$$C_a = K \sqrt{\ } T$$

where K is a value which depends on the humidity. In a dry atmosphere we can describe K as

$$K = K_d = \sqrt{\ } \{\gamma R / M_r\}$$

where γ is the ratio of specific heat, R is a gas constant, and M_d is the mean molecular weight. In a moist atmosphere, sound moves slightly faster than in a dry atmosphere. So, the equation of T_v become

$$T_v = \sqrt{\ } \{C_a / K_d\}$$

where T_v is the atmospheric virtual temperature which is equivalent temperature for a dry atmosphere whose pressure and volume are the same as an actual moist atmosphere with a water vapor mixing ratio of q (kg kg^{-1}). The virtual temperature is defined as

$$T_v = (1 + 0.608\ q)\ T$$

Briefly reviewed here is an application of the MU-RASS technique in monitoring a T_v profile and turbulence echoes from 1.5 to the near tropoppause with an accuracy of T_v within 0.5 K [7, 8, 9, 10, 11].

Three types of acoustic transmitters have been used for the MU-RASS : a pneumatic transducer with a hyperbolic horn, an electro-dynamic loudspeaker with a standard enclosure, and an electro-dynamic loudspeaker with a hyperbolic horn. The pneumatic transducer which can produce transmitted acoustic wave as strong as 147 dB, allowing RASS echoes to be detected up to 22 km was developed some time ago [8].

Ray-tracing results indicated that an acoustic transmitter should be placed windward of the radar antenna. Under disturbed meteorological conditions, the wind velocity tends to fluctuate greatly causing considerable changes in the best position for the acoustic source. To enable continuous observation even under disturbed condition, several acoustic sources composed of loudspeaker until and an amplifier were located around the radar antenna. The output power of a pair of these loudspeaker unit was 132 dB. Because of the lower acoustic power, though, the observation height was limited to below about 8 km.

2.4 Design of Acoustic Transmitter for RASS Measurements with EAR

Since EAR-RASS technique is being constructed now, application of the RASS technique to EAR, in particular a design of a high-power acoustic transmitter are reviewed in this paper.

Figure 3. The hyperbolic horn speaker system at Kototabang. The speaker is mounted on a wooden frame with casters.

Detailed description of these instruments are as follow :

- PC (8 outputs), 1 set :
  - Pentium III (800 MHz), memory 256 MB, H/D 10 GB
  - Digital mixing board : Yamaha DS-2416
  - D/A converter : Yamaha AX-44 (2 sets)
- Acoustic pre-amplifier (4 inputs and 4 outputs), 2 sets :

  - Unbalanced input and balanced output
  - 4 channels
  - UBC-159 (imagenics)
- Power amplifier (2 inputs and 2 outputs), 4 sets :
  - Output power 800 W/channel, 2 channels, total power 1600 W
  - Input terminal should be equiped with a balanced connector
  - Micro-Tech 2401 (Amcron Co.)
  - MPA 750 (JBL)
- Loudspeakers, 16 sets :
  - Electro-voice DL-15 X (diameter :38 cm/15 inch)
  - Nominal impedance : 8 Ohm
  - Maximum continuous input : 400 W
  - Sensitivity : 98 dB at 100 Hz
  - Maximum sound pressure level : 130 dB ((.6 W/m^2)
  - Lower cut-off : 75 Hz
- Acoustic transmitter with a wooden horn with dimension of H850 cm x W1580cm x L2200 cm, 8 sets as shown in F**igure. 3.**

Detailed description of major parameters of RASS-EAR can be shown in **Table 2.**

Table 2. Major parameter of RASS-EAR

	Items
Radar wavelength (EAR)	6.38 m (Freq = 47.0 MHz)
Acoustic power	800 W maximum
Acoust frequency	80 – 120 Hz
Number of speakers	8
Observable height	Up to tropopause
Measurement accuracy	0.5 K (empirical, virtual temperature)
Power amplifier	Yorkville AP 4040
Pre-amplifier	Mackie 1402-VLZ
Speaker box	Wooden buffer box, folded horn (1 m H x 1.5 m W x 2.5 m L)
Speaker	JBL 2226/H
Audio source	Digital mix board and A/D converter controlled with a PC

The example the comparison between RASS and radiosonde in determining the vertical virtual temperature profile at Kototabang on 6 November 2001 are presented in Figure 4.

The thick and thin line indicates radiosonde and RASS data measurement should be noted. The data was taken on 6 November 2001 at 12:57:47 LT from the vertical beam direction. By looking this figure a good agreement between both data below 6 km and between 8-13 km can be detected.

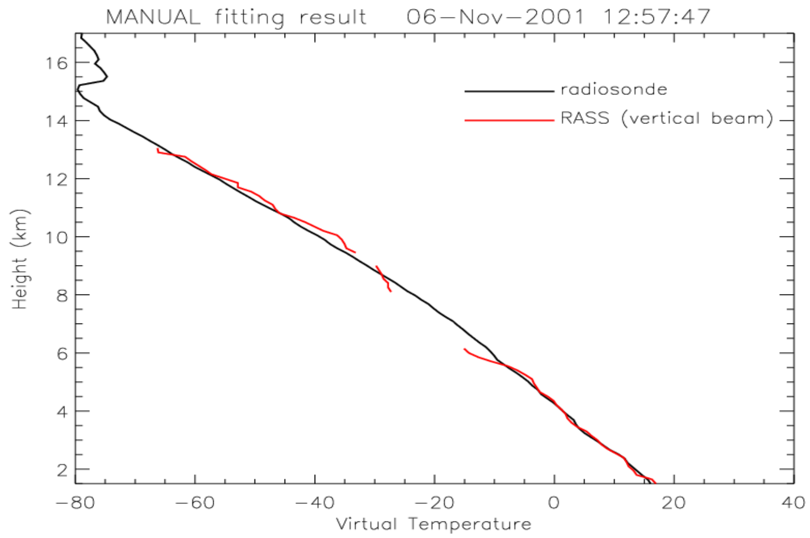

Figure 4. The vertical virtual temperature at Kototabang measured by RASS and radiosonde at 6 November 2001

3. Results and Discussion

The comparison between radiosonde and EAR-RASS techniqusue in determining a fine structure of relative humidity profiles presented in **Figure 5**.

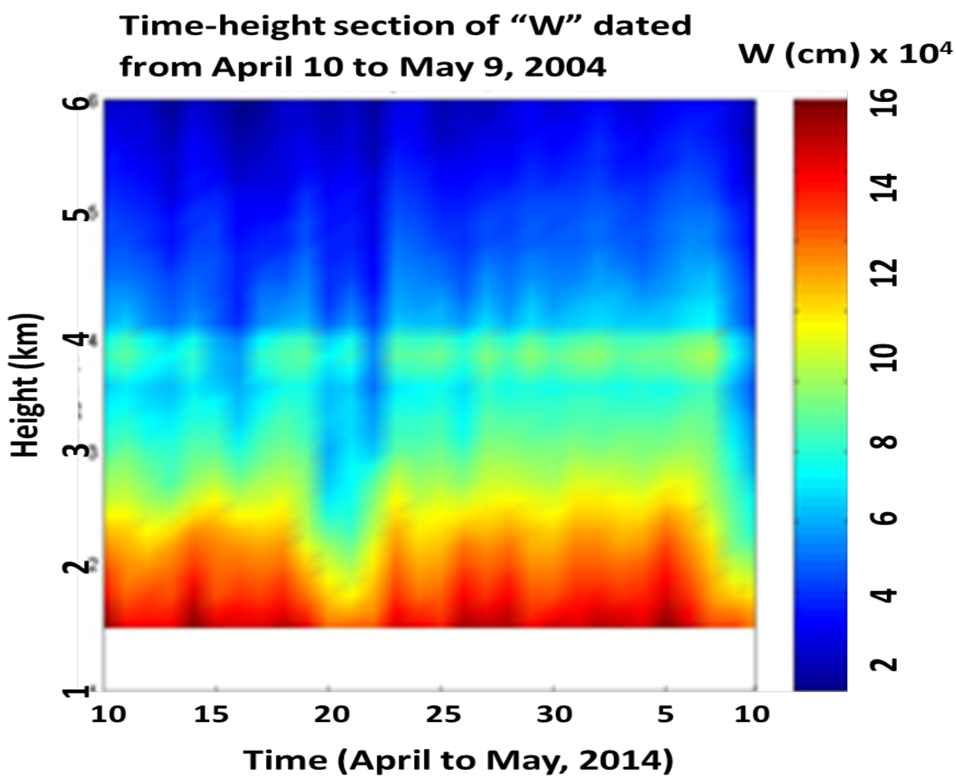

Figure 5. Time-height section of Total Precipitable Water (represented by W) profiles derived from RASS observation from April 10 to May 9, 2004 at Kototabang, West Sumatera.

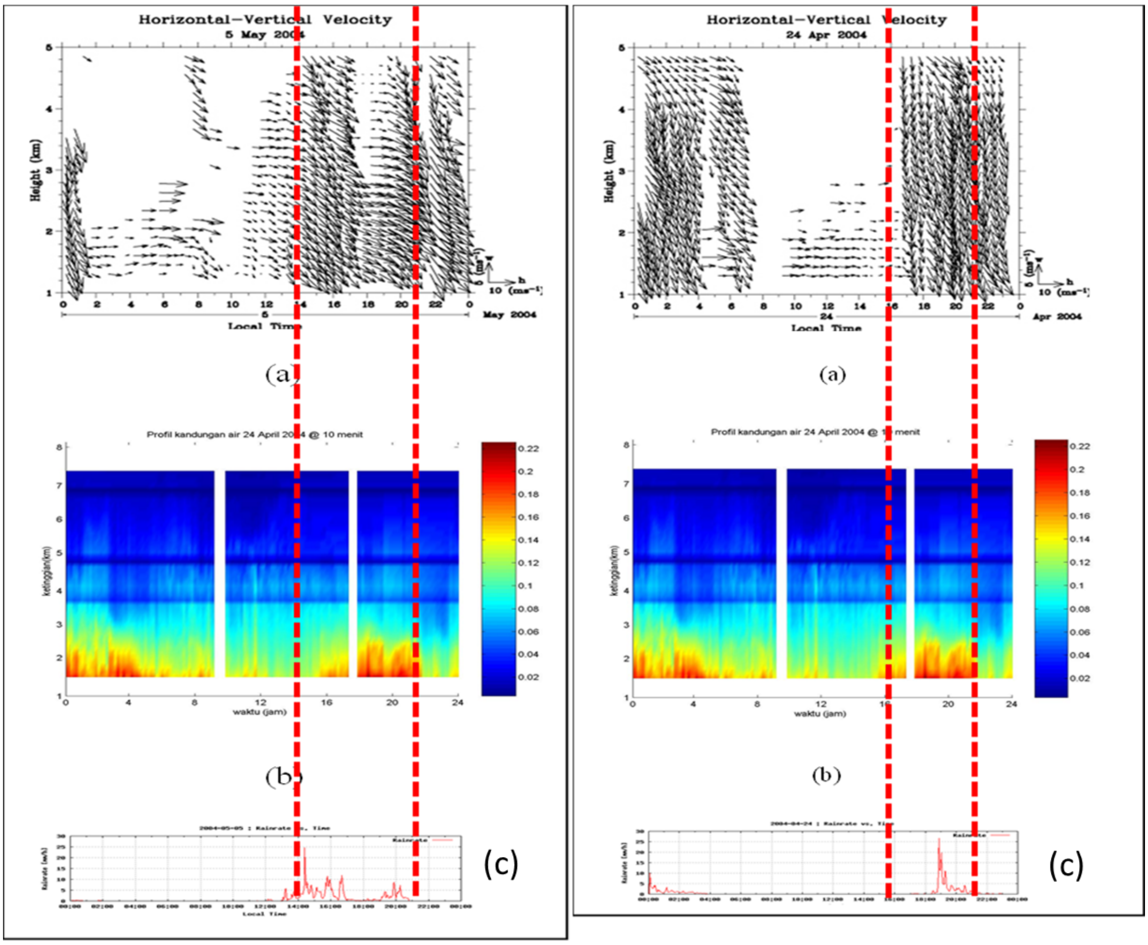

Figure 6. Profile of atmospheric conditions during the events of the Rain on 24 April 2004 and 5 May 2004. (a) Wind profile (b) water content profile (c) rain intensity

From the calculation results obtained TPW values do not determine rain condition. Small TPW value may result in rain occurence, meanwhile large TPW value doesn't guarantee rainy season as well. Contrarily, several also shows large TPW value were followed with high-intensity rainfall.

Shown in **Figure 5**, on April 20-22 there was a decrease in the water content, meanwhile in the 23-24 th there is an increase in water content. Furthermore from **Figure 3** on 21 and 22 there was no record of rainfall intensity and rain fell again on 23 and 24 April. So even when viewed from the data of the wind down in **Figure 6** that on April 24 the activity of the air intake decrease quite intensely at 0-4 and at 17-24. then seen the data contain water content information that at 5-16 there was a decrease in water content and the value rose again after 16 o'clock, other than that from the rainfall data is known at 0-4 and at 17-24 shows there are events of rain.

As on May 5, 2004 when there was an increase in water content of ORG data recorded a large rainfall compared to other days in the period April 10 - May 9, 2004 where the incident rain lasted from 12 to 21 o'clock local time (**Figure 10**). In addition, when the incident rain at that time from the calculation seen the pattern of increase in water content from 12 then the amount of water content is dropped back at 21 o'clock after the rain stopped. As if seen from the BLR data seen intensive air degradation activity at that time.

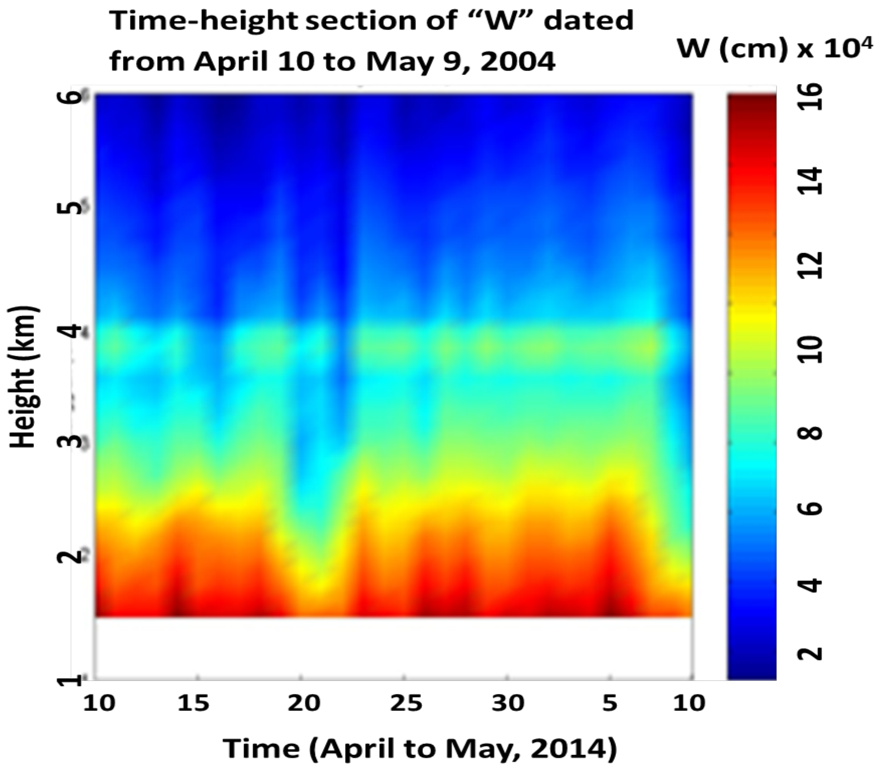

Figure 7. Time-height section of Total Precipitable Water (represented by W) profiles derived from Radiometer observation from April 10 to May 9, 2004 at Kototabang, West Sumatera

This illustrates that the presence of water vapor in the atmosphere is directly proportional to the intensity of rain on the surface and the mass air activity supports the spread of rain. As at 12-16 when the content of water vapor in the column shows a decreasing trend whereas in the ORG data shows a large rainfall event, it could have happened the mass of water vapor formed from the mass air removal from other columns fell in vertical columns Kototabang other than it is apparent that the horizontal winds at 12-21 local time are more dominant than the downdraft winds, this may indicate that at 12-16 hours there is a decreasing vapor mass in the vertical column derived from the removal of air masses from other regions. This result identical with another instrument presented in **Figure 7**.

4. Concluding Remarks

The EAR-RASS offers a great advantage in that it enables user to monitor successive temperature profiles over the entire troposphere into the lower stratosphere with a high time and height resolution. In this paper, the basic principle of RASS especially on design of an acoustic transmitter for RASS measurements with EAR were briefly reviewed. Since the full RASS data campaign at Kototabang has not been obtained. The results of this study indicated the consistency of pattern between BLR, RASS and radiometer data in assessing vertical profile of water vapor content as well as the variation of TPW result from RASS and radiometer data analysis, especially on April 24 and May 5, 2004, 0.43 and 0.35 respectively, besides the mass air degradation activity resulted from BLR data analysis as well as the variation of water content to be an indication of rain.

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5. References

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