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Complete List of Authors:	Karmakar, Pranab; Institute of Radiophysics and Electronics, Centre for Research and Training in Microwave and Millimeterwaves Calheiros, Alan James; National Institute for Space Research (INPE), Center for Weather Forecast and Climate Studies (CPTEC) Angelis, Carlos; National Institute for Space Research (INPE), Center for Weather Forecast and Climate Studies Machado, Luiz Augusto; National Institute for Space Research, Center for Weather Forecast and Climate Studies Costa, Simone; National Institute for Space Research (INPE), Center for Weather Forecast and Climate Studies (CPTEC)
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RADIOMETRIC STUDIES OF WATER VAPOUR AT 22.234 GHz OVER BRAZIL

Pranab K. Karmakar[1], Alan James P. Calheiros[2], Carlos Frederico Angelis[2], Luiz Augusto Toledo Machado[2], Simone Sievert da Costa[2]

1 – Institute of Radiophysics and Electronics,
Centre for Research and Training in Microwave and Millimeterwaves
University of Calcutta, West Bengal
92, A.P.C Road, Kolkata – 700 009, India
(karmakar_p_k@yahoo.com)

2 – Instituto Nacional de Pesquisas Espaciais - INPE
Centro de Previsão de Tempo e Estudos Climáticos - CPTEC
Road. Dutra, km 40, Cachoeira Paulista – SP 12630000 – Brazil
(alan.calheiros; carlos.angelis; luiz.machado; simone.sievert)@cptec.inpe.br

Abstract

The integrated water vapour content is measured by ground based radiometer at 22.234 GHz at INPE- Brazil. The whole data set have been categorized in two sets: one for no cloud and the other for cloudy conditions. The attenuation (dB) under no cloud condition were always found to be varying within 1.0-1.5 dB except at around 14 through 18 hrs and it reaches a value more than 1.5 dB with a maxima at 17 hrs. This is in conformity with the theoretically calculated values of water vapour density over the same place. It was also revealed that over Brazil there always exists a threshold value of water vapour content irrespective of clear and cloudy sky. This value is around 40 kg/ m^2 during the month of January which is the rainy season over Brazil.

I. Introduction

It is well known that water vapour and liquid water present in cloud play an important role in controlling the atmospheric energy budget. Ground based remote sensing in microwave band has been known as feasible means for the measurement of precipitable water vapour (Wei and Lu, 1994)[1]. In fact, at microwave frequencies there exists an interaction between the electromagnetic radiation and suspended molecules in the atmosphere, in particular with oxygen and water vapour. This interaction may be manifested in two ways in terms of complex refractivity. The imaginary part is generally expressed as attenuation and real part is dealt with propagation delay. Keeping these in view we have installed a multichannel ground based microwave radiometer to retrieve the water vapour and temperature profiles at the Instituto Nacional de Pesquisas Espaciais (INPE, Brazil : 22.5 deg South).

This work aims at estimating the atmospheric water vapour by using the radiometric brightness temperature. For this purpose, initially zenith looking radiometer at the weak water vapour resonance line is used. The word "weak" here refers to less attenuation of radiation in comparison to the other line occurring at 183.311 GHz. (Elgered, 1993)[2]. Subsequently, the derived water vapour content from the radiometric measurements has been compared with the radiosonde data. Besides these, we have the facility of launching the balloon flight to get the radiosonde data, few meters away from the site where the radiometer is located.

II. Instrumentation

Radiometer has been designed for ease of use, accuracy, reliability, portability etc. As in this case the radiometer has the passive technology, it does not emit radiation detectable by any normal means. The antenna system has a clear view of the sky from horizon to horizon, at least in one vertical plane. However in our case, the antenna is pointed towards zenith. The radiometer is controlled by Radiometrics proprietary software. Calibration is made by using liquid nitrogen and displayed in graphical format. There are three options in the main menu of the soft ware. First the level 0 files (raw sensor data in volts), level 1 file (brightness temperatures) and level 2 files (profile retrievals). Here, in our study we have used only the level 1 file. Table 1 shows the instrument specifications, more detail about it can be found at www.radiometrics.com.

Instrument specifications	
Calibration brightness temperature accuracy	0.5 K
Long term stability	<1K/year
Integration time	0.2 sec.
Resolution	2 K
Antenna system optical resolution	4.9-6.3(-24 dB)
RF bandwidth	300 MHz.

TABLE 1

Radiometer Main Characterization

III. Selection of frequency

It known that water vapour is a well mixed constituent in the atmosphere and varies according to site, season and local meteorological conditions. Hence this variation will affect both the vertical and horizontal distribution of water vapour both in space and time. Calculation of atmospheric emission up to 26 GHz has been done using the radiosonde data during the month of January, 2009, which is eventually the rainiest month over Brazil. Assuming a constant relative humidity of 80% up to a height of 0-1 km (RH=80% for 0<H, 1000m) and 96% for the height from 1-4 km (96% for 1000m <H <4000m), the high altitude profile of brightness temperature shows a sharper line than the low altitude profile. In this case the surface temperature was assumed to be $30^{o.}$C. These assumptions are based on the nature of variability of radiosonde data. The high altitude profile of water vapour shows a sharper line than the low altitude profile although the delay was the same in both the cases. This prompted us to conclude that if one wishes to maximize the signal from a given amount of water vapour, the observation should be carried out at 22.234 GHz and it was also revealed that near the half power point of the line profile would provide the most accurate estimate (Karmakar et al, 1999)[3].

IV. Analyses and Results

A. Attenuation due to water vapour

The radiometer outputs were in the form of sky brightness temperature (T_b). These data were then converted to attenuation (dB) by using the following relationship (Aunutt, 1976)[4].

$$\text{Attenuation, } A = 10\log\frac{T_m - T_{\cos}}{T_m - T_b} \quad (1)$$

where Tm is the mean atmospheric temperature which depends on ground temperature. It should be emphasized that Tm is found to be dependent on frequency (Mitra et al 2000)[5] and maintains a relationship.

$$T_m = CT_g \quad (2)$$

where, T_g is the ground temperature and C is a constant at a particular frequency and found to be C= 0.95 at 22.234 GHz. However, for all practical purposes, we have assumed Tm = 275 K. In relation (1), Tcos is the temperature due to cosmic background noise and the accepted value is Tcos = 2.75 K , in the microwave band (ulaby,1986)[6]. Hence, by using different radiometric output as brightness temperatures T_b, the attenuation A (dB) values were calculated with the help of equation (1). The variation of attenuation with time (hrs) at 22.234 GHz has been pictorially presented in Fig (1). It is to be mentioned that the radiometer has the provision to measure the height of the cloud base which is being identified as 0 for no cloud and 1 for cloudy conditions in the zenith direction. Taking this advantage we have categorized the whole data set in two groups: one for cloudless sky and the other one for cloudy sky irrespective of cloud thickness. This procedure is because we do not have any other facility to measure the cloud thickness. However, the inbuilt infrared measurement of cloud base temperature and the retrieved temperature profile can be used to estimate cloud base height. For cloudless condition, Fig. 1 shows that the attenuation remains always within 1.0-1.5 dB except at around 14 hrs through 18 hrs, when the attenuation reaches a value more than one 1.5 dB. This is might be due to the fact that in the afternoon the water vapour concentration goes to a maximum. Usually after this span of time rain starts provided the saturation occurs. But we have deliberately avoided the raining times. However the water vapour goes to a maximum without saturation for which we have taken the radiometric data for our analyses.

As discussed in section 3, the signal to noise ratio is considered to be the largest at 22.234 GHz provided the pressure and temperature are constant and can provide a good measure of water vapour amount. But, in practice water vapour pressure distribution with height is always changing and it causes the pressure broadening of the absorption line at 22.234 GHz. So, keeping these in view, we have examined the variation of water vapour pressure in a water vapour column with time and also that of water vapour density. The estimates of water vapour pressure, e, and also water vapour density, ρ, were found by using the following relations (Sen et. al 1989)[7].

$$\rho(g/m^3) = \frac{e \times 1800}{8.31 \times T_D} \tag{3}$$

where, e is given by(Karmakar et al,2001)[8].

$$e(mb) = 6.105\exp\{25.22[1-273/T_d(h)] - 5.31\log_e[T_d(h)-273]\} \tag{4}$$

and T_d is the dew point temperature (K).

The time variations of water vapour pressure and water vapour density are shown respectively in Figures 2 and 3. Radiosonde analyses in deriving water vapour density at INPE, Brazil, reveal that from 15 hrs through 18 hrs, during no cloud condition, it attains a value of about 38 g/m^3 and subsequently water vapour pressure also shows the similar trend of achieving of about 55 mb pressure. Besides this, it is interesting to note that the atmosphere contains maximum water vapour density although no cloud is present overhead. These results are in conformity with Fig (1) where the water vapour attenuation at 22.234 GHz exhibits a maximum at 17 hrs.

B. Water vapour scale height

It is revealed from the radiosonde data analysis available from BADC (British Atmospheric Data Centre,U. K.) that during the month of January and February 2009, the water vapour density attains the maximum value, over Brazil. From these results we were prompted to get the balloon flight data at our Institute during the month of January along with radiometric data in the form of corresponding brightness temperature. But as the radiosonde data are sluggish and cannot run on a continuous manner we believe to get the continuous monitoring of brightness temperature due to water vapour by deploying the microwave radiometer. Radiosonde data analysis at our place, during the whole month of January, 2009, provides us the height distribution of water vapour density. We then attempted to fit all these data with the exponential equation,

$$\rho = \rho_0 \exp\left(-\frac{h}{H_\rho}\right) \tag{5}$$

where, Hρ is the scale height. Analytically, this water vapour scale height is defined as the height at which water vapour density becomes 1/e times the surface value. So if we can measure the water vapour scale height from radiometric measurement it would then be convenient to get the vertical profile of water vapour. For this purpose, we take help of the algorithm developed by Karmakar, et al, (1999)[3] applicable for single frequency 22.235 GHz, wherein the water vapour scale height, Hρ, was found to be.

$$H_\rho(km) = \frac{P_0 A}{1.0114 \times T_0^{0.52699} \times \rho_0 + P_0 \times 0.1103 A} \tag{6}$$

where, A is the 22.235 GHz attenuation in dB and suffix zero in different parameter stand for surface values. Now, substituting the surface values of pressure, temperature, water vapour density and corresponding derived radiometric attenuation (see Fig 1) in the equation (5), we get time variation of ρ during the month of January over INPE, Brazil (Fig. 4) As is expected from the foregoing discussions that it should attain a minimum around 17 hrs of the day with no cloud overhead. However, the presence of cloud shows a major deviation in this pattern (Fig. 4).

Hence, it is clear that the water vapour measurement has already been influenced by the presence of cloud liquid water. Besides these, the oxygen contribution to the radiometric measurement of brightness temperature is also a parameter to be considered. This dry part attenuation is, however, a very slowly varying component depending on ambient pressure and temperature. The radiosonde analysis of dry attenuation during the month of January at INPE is, on an average, found to be 0.06 dB. Hence from Fig 1, we again see that within 1.5 dB total attenuation, 0.06 dB is only due to oxygen.

C. Water vapour content

Now, remembering equation (5), we write water vapour content.

$$W = H_{\rho} \times \rho_0 \times 10^3 \, g/m^2 \tag{7}$$

The surface water vapour $\rho_0 (g/m^3)$ available from radiosonde data were compared from those obtainable from the radiometric measurement by using equation (5). It is observed from Fig (3) that with clear sky condition the measured water vapour density takes a value of maximum 35 g/m^3 around evening hrs and minimum of about 15 g/m^3 in the early morning.

Moreover, from Fig (4), it is observed that the water scale height, on an average, during the whole day is 2 km. In an another paper one of the present authors (Sen et al;1989)[7] found that for a time resolution between 12 and 24 hrs, the correlation between the variation pattern of integrated water vapour content W(g/m^2), and water vapour density of 2 km height, is very good. Hence it is concluded that any transportation of water vapour from the surface to the altitude 2 km must have been negligible effect within this time scale. If the time scale is increased to 48 hrs, the integrated water vapour content is poorly correlated with that around 2 km height. The difference in behavior in this type of variation for a short (12-24 hrs) and a long time of 48 hrs scale suggests that the transportation of water vapour to high attitudes occurred within a time scale greater then 24 hrs.

However, using equation (7) we have attempted to present derived water vapour content from the radiometric measurement variation with the directly obtained brightness temperature from our radiometer at 22.235 GHz during clear (8) and cloudy (9) sky conditions. This is presented in Fig (5). Regression analysis of the scatter plot shows the best linear equations over INPE, Brazil is (22^0S),

$$W(clear\ sky) = 478.451T_b + 9574.36 \quad (8)$$

$$W(cloudy\ sky) = 532.970T_b + 6558.36 \quad (9)$$

Comparing the estimated regression equation (10) over Calcutta (22^0N) we found as (Karmakar, 1989) [9],

$$W(cloudy\ sky) = 612.0T_b + 16400 \quad (10)$$

and the estimated regression equation (11) over Delhi (28.38^0 N) [Bhattacharya,1985] [10],

$$W(cloudy\ sky) = 588.23T_b - 2110 \quad (11)$$

To provide a more clarity of Fig (5), we have redrawn the curve in larger scale of brightness temperature which is presented in Fig (6). It shows that 60 K in both the curves i.e., one for clear sky and the other for cloudy sky, meet at 40 kg/m^2 water vapour content value, in the vertical axis. However, this 60 K corresponds to 1.06 dB in which only 0.06 dB is due to oxygen, as mentioned earlier. Linear regression of water vapour content in g/m^2 versus brightness temperature in K at 22.234 GHz by radiometry at INPE, Brazil is shown in Fig. 6. So, it is presumably considered that over Brazil there always a threshold value of water vapour content irrespective of clear and cloudy sky. This value is around 40 kg/m^2 during the month of January which is the rainy season over Brazil.

Now to get a comparative study between the calculated (using the radiosonde data available from balloon flight at a nearby station which is 100 mts away from the site of the radiometer), y (12), and measured (using the radiometer) water vapour content, x, we have presented it pictorially (Fig 7). This shows the relationship that exists between the two is:

$$y = 0.4218x + 31.31 \tag{12}$$

The measured values of precipitable vapour content always assume a larger value than those of calculated values. The r.m.s difference between these two types of studies is 0.49. This difference might be due to spatial and temporal baseline and sensor accuracy specially while calculating the absolute humidity profile using radiosonde data.

V. Discussions

In the present case, the integrated water vapour content has been measured by deploying 22.234 GHz. radiometer. We have assumed that there is no such appreciable variation of pressure and temperature, but that is not the case. In principle, when pressure and temperature change as occurs with height in the troposphere, operation at the line centre is not optimal (Hogg et al, 1983) [11]. The frequency is to be selected a little away from the resonance line which could primarily sense the vapour. This frequency should be independent of particular distribution of water with height.

The derived or estimated vapour content during cloudy sky may not give a result of good precision because liquid water content in the cloud contaminate the vapour measurement while radiometer is operative at 22.234 GHz. It should be mentioned here that we already have undertaken the work in separating vapour and liquid by multi-frequency ground based microwave radiometry. The result would be published in due course of time.

As this type of research has been done for the first time in Brazil, there is no previous study with which the results can be compared. The strong and sufficient/significant similarity between the calculated and measured values of water vapour content suggests that the radiometer can be used for continuous monitoring of water vapour. However, the radiometric measurements of precipitable water vapour have also played an important role in the evaluation of radiosonde accuracy (Westwater; 2003)[12]. Both radiosonde and remotely sensed water vapour also have significant applications in climate research and in the calibration and validation of remote sensing instruments (Turner et al 2003) [13]. For these studies, comparison between different radiosonde types and different manufacturers as well as various types of remote sensors are quite useful in evaluating accuracies and in finding possible inconsistencies in the instruments (Westwater, 2007)[14].

VI. Acknowledgement

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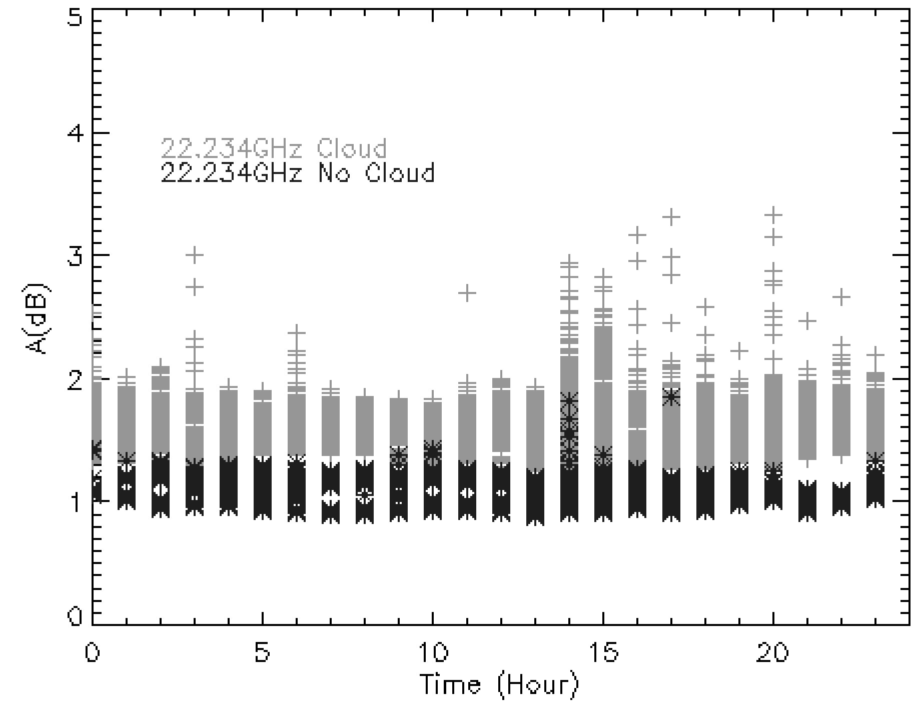


Fig 1. Radiometric attenuation at 22.234 GHz at INPE, Brazil, during January 2009.

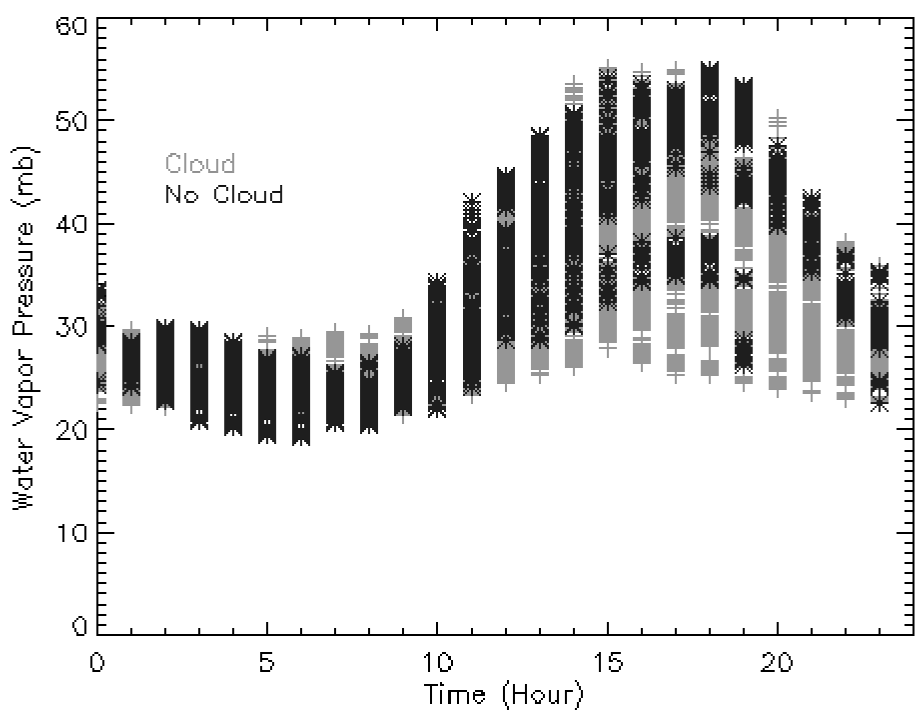


Fig 2. Water vapour pressure in mb versus time in hrs by radiometry at INPE, Brazil (January 2009).

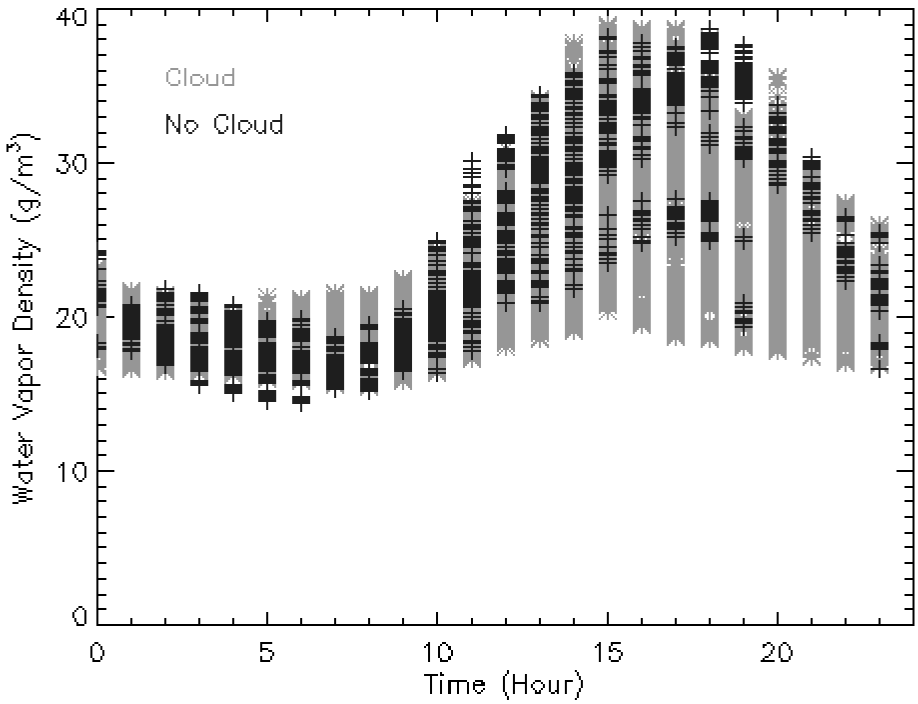


Fig 3. Water vapour density in g/m versus time in hrs by radiometry at INPE, Brazil (Jan 2009).

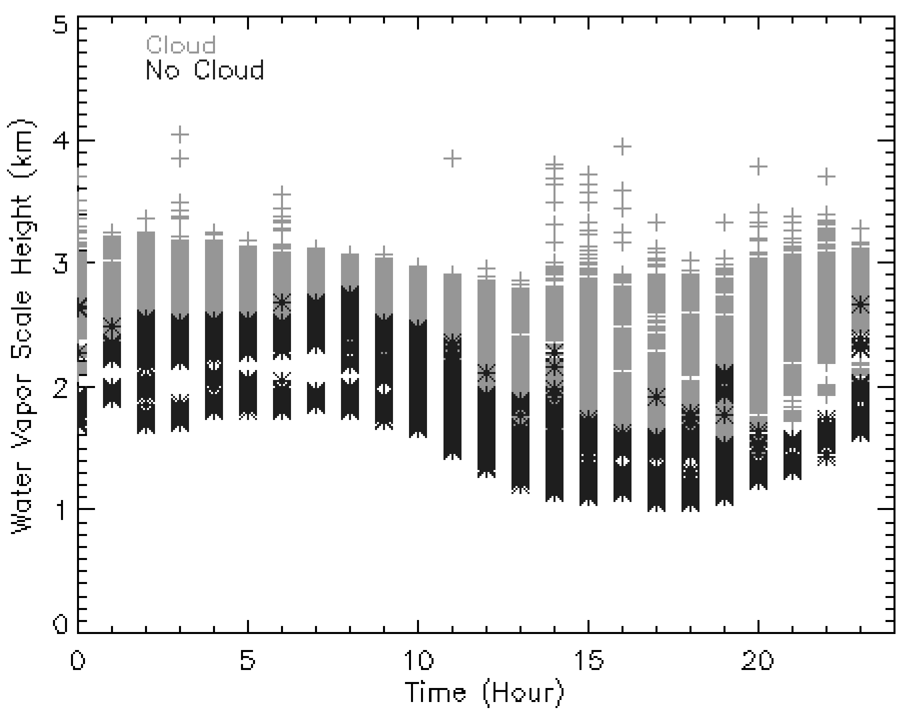


Fig 4. Water vapour scale height in km versus time in hrs by radiometry at INPE, Brazil (January, 2009).

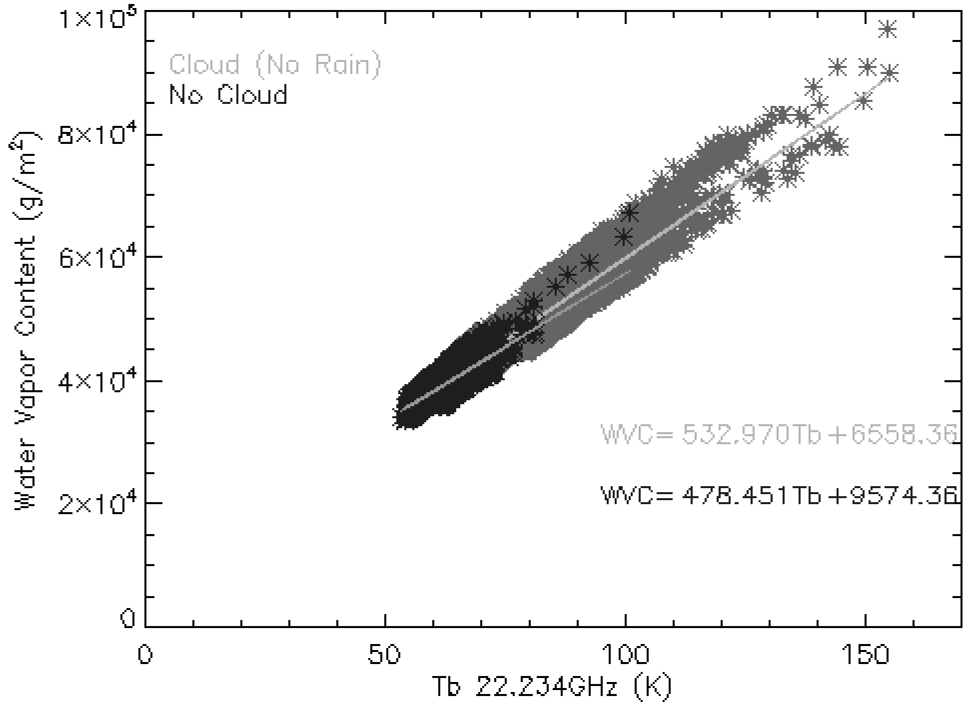


Fig 5. Water vapour content (g/m^2) versus brightness temperature in Kelvin at 22.234 GHz by radiometry at INPE, Brazil (Jan 2009).

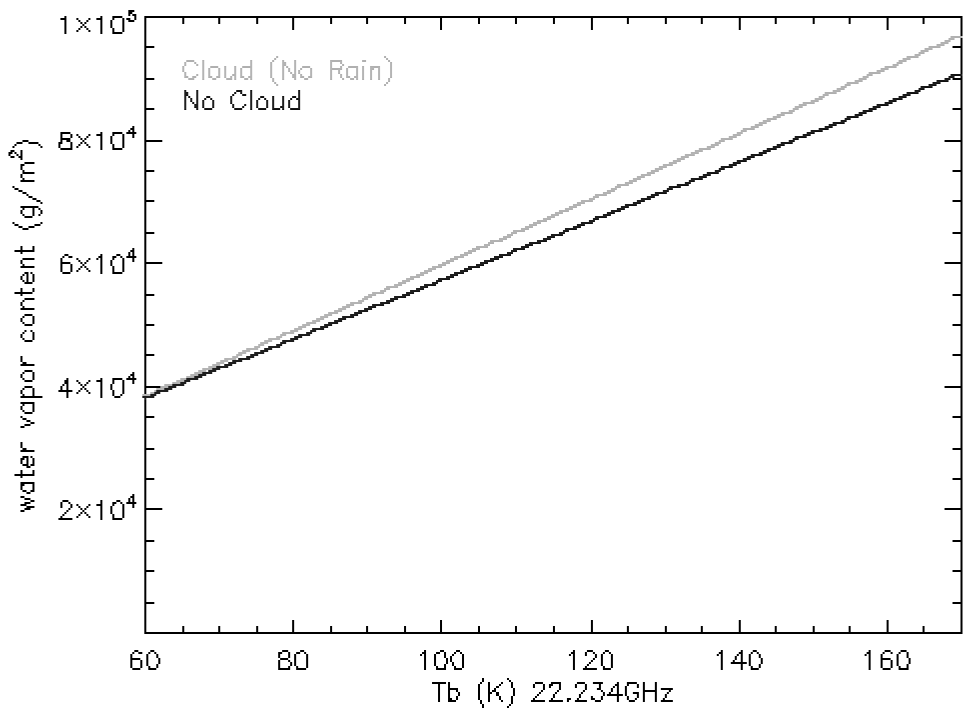


Fig. 6 Redrawn curve of figure 5.

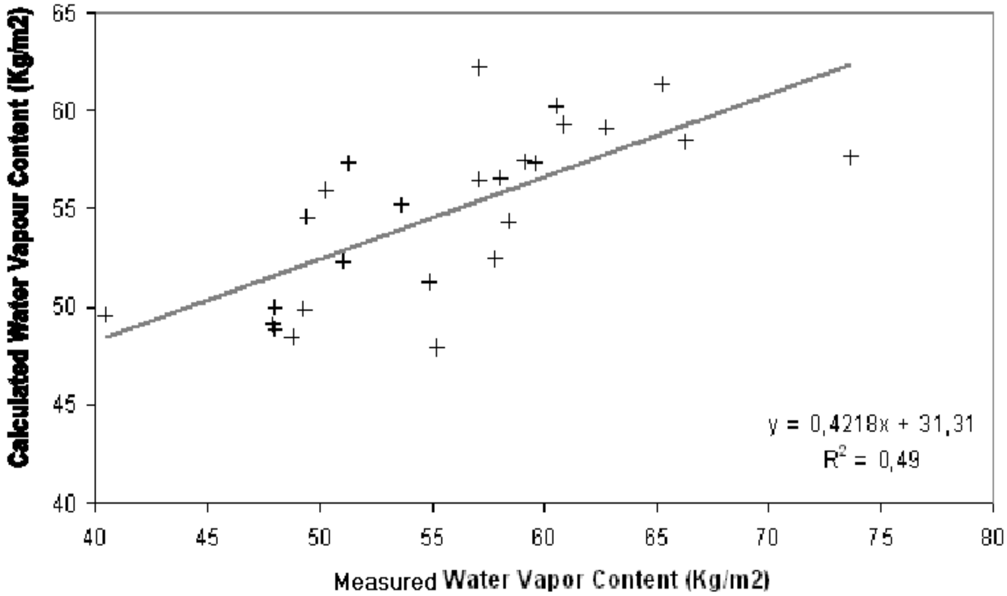
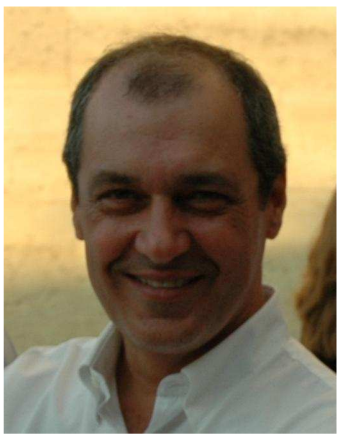


Fig 7. Calculated vapour content using radiosonde data versus measured vapour content using 22.234 GHz radiometer.

P. K. Karmakar obtained his Ph.D (Tech) degree from Calcutta University in 1990. He is working in the department of Radiophysics and Electronics, Calcutta University since 1988. He has more than 40 number of publications in national and international Journal of repute along with 30 numbers of conferences articles. He has been awarded the Young Scientist Award of URSI in the tear 1990. He had been to Remote sensing Laboratory, University of Kansas, USA as a visiting scientist. He has also been awarded the South-South Fellowship of TWAS to act as a visiting scientist at the Center for Space Sciences, China in the year 1997.He also acted as visiting scientist at INPE, Brazil during February- March, 2009. His current are of research include Microwave/Millimeterwave Propagation and Remote Sensing, Modeling of Atmosphere and Microwave Communication etc.

Alan James P. Calheiros is PhD Student at National Institute for Space Research. In 2008, he received his Master degree in Meteorology from the National Institute for Space Research. In 2006, he received is degree in Meteorology from Federal University of Alagoas. His research focuses on the remote sensing of precipitation

Carlos Frederico Angelis is Ph.D. by University of Birmingham, England (2003). His area of research is on estimative of precipitation based on Remote Sensing tools. He works at Center of Weather Forecast and Climate Studies, and he is the head of the satellite division that belongs to CPTEC.



Luiz Augusto Toledo Machado is Ph.D. by Université Pierre et Marie Curie, France (1992) and Postdoctorate at Centre National de la Recherche Scientifique, France (1997). His area of interest is Meteorology, emphasizing Remote Sensing of the Atmosphere. He works in the National Institute for Space and Research where the head of Center for Weather Forecast and Climate Studies.

Simone Sievert da Costa received degrees in physics (1998) from Federal University of Paraná, Brazil. In 2001, she received her MS. degree in Atmospheric Science from Sao Paulo State University, Brazil. In 2006, she received her Ph.D. degree from The University of Reading, UK. In March 2007, she joined the Center for Weather and Climate Study of the National Institute for Space Research, Brazil. Her research focuses on the remote sensing of atmosphere, mainly on the inference of temperature and moisture profiles through satellite sensors.