347-50

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Tropospheric water vapour modelling over a tropical location by radiometric study

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Below 30 GHz, the thermal emission line of water vapour in the atmosphere occurs at 22.235 GHz. An estimate of attenuation and hence of water vapour scale height has been made at this frequency. The results show that both these attain a maximum value in the month of August and a minimum in the month of December over Calcutta. With the help of attenuation data and corresponding water vapour scale height data, the vertical distribution of water vapour density has been made over the same place.

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1 Introduction

Measurement of water vapour in the atmosphere is extremely useful in understanding the tropospheric-stratospheric exchange, global hydrogen budget, sun-weather and geosphere-biosphere relationship[1]. Moreover, measurements of vertical and horizontal distributions of water vapour as well as that of its temporal variation are essential for probing deeper into the mysteries of several anomalous effects on the water vapour distribution related to meteorological events, particularly over the tropical locations like Calcutta in India.

The conventional technique for vertical profiling of water vapour in the tropospheric region was based on radiosonde measurements. However, due to the sluggishness and limited accuracy of the radiosonde measurements, we have to look for the faster response and more accurate techniques of measurement based on radiometry.

Ground-based radiometry techniques also have the advantage that a continuous round the clock measurements are possible over the same vertical path[2]. At the same time, the radiometric data can be used to infer the height profile of water vapour density by the use of the statistical inversion technique. The choice of frequency for radiometric measurements depends on two important factors: (a) the radiometric temperature at which selected frequency should be strongly sensitive to water vapour and very weakly sensitive (mostly insensitive) to other atmospheric variables such as temperature profile, and (b) the water vapour weighting function at the selected frequency should have height profiles sufficiently different from those at neighbouring frequencies[3]. Each of these factors can be achieved conceptually by choosing the frequency at the water vapour resonance line occurring at 22.235 GHz. Hence, for the water vapour profiling in the troposphere, radiometric study at 22.235 GHz has been undertaken at the Institute of Radio Physics and Electronics, University of Calcutta, in collaboration with the Space Applications Centre, Ahmedabad, under the IMAP (Indian Middle Atmospheric Programme)/IMAP-C Project.

This report describes the observations made by 22.235 GHz radiometer over Calcutta (lat. 22°68'N; long. 88°32'E) and presents preliminary retrievals of tropospheric water vapour abundance and distribution.

2 Instrument

The 22.235 GHz radiometer is, in fact, a prototype of that flown in Bhaskara I and II satellites for remote sensing studies. The characteristics of the radiometer are given below:

Antenna	Corrugated horn lens having a beam width of 22°
RF bandwidth	200 MHz
Time constant	1 s
Sensitivity	1 K

Calibration of the radiometer was made regularly by receiving the thermal emission from ecosorb absorbers immersed in liquid nitrogen contained in a flask. The recorded level increased linearly with antenna temperature which was equal to emission noise temperature of the atmosphere. The radiometer was placed in a temperature controlled room, with the axis of the antenna beam horizontal. A plane reflector placed outside the room at an angle of 45° to the antenna beam, enabled zenith sky temperature to be measured. The temperature of the comparison load was also recorded simultaneously by incorporating a thermal sensor attached to the load. This enabled us to correct any changes of the temperature of the comparison load in between two calibrations.

3 Theoretical background

The absorption of water vapour molecule at 22.235 GHz is given by[4]

$$\gamma_{1.35}=3.24\times10^{-4}\frac{P\rho\exp(-644/T)\gamma^2}{T^{3.125}}$$

$$\times\left(1+0.0147\frac{\rho T}{P}\right)\times\left[\frac{1}{(\gamma-22.235)^2+(\Delta\gamma)^2}\right.$$

$$\left.+\frac{1}{(\gamma+22.235)^2+(\Delta\gamma)^2}\right]+2.55\times10^{-8}$$

$$\times\frac{\rho\gamma^2\Delta\gamma}{T^{3/2}}\,\text{cm}^{-1}\qquad\ldots(1)$$

where

γ Resonance frequency in GHz

T Kinetic temperature in K

P Total atmospheric pressure in mm Hg

ρ Water vapour density in g/m^3

$\Delta\gamma$ Pressure broadened half width parameter and is given by

$$\Delta\gamma=2.58\times10^{-3}\left(1+0.0147\frac{\rho T}{P}\right)\frac{P}{(T/318)^{0.625}}\,\text{GHz}\qquad\ldots(2)$$

From (1) and (2), after simplification, we get

$$\gamma_{1.35}=17.92\frac{\rho\exp(-644/T)}{PT^{1.875}}\left(1+0.0147\frac{\rho T}{P}\right)^{-1}$$

$$+11.91\times10^{-7}\left(1+0.0147\frac{\rho T}{P}\right)\frac{P}{T^{2.125}}\text{cm}^{-1}\qquad\ldots(3)$$

But the contribution of second term in Eq. (3) is of the order of 1% of the first term and hence neglecting the second term, we are left with

$$\gamma_{1.35}=17.92\frac{\rho\exp(-644/T)}{PT^{1.875}}$$

$$\times\left(1+0.0147\frac{\rho T}{P}\right)^{-1}\text{cm}^{-1}\qquad\ldots(4)$$

Now considering the typical surface parameters for Calcutta

$P_0=1000$ mbar, $T_0=300$ K, $\rho_0=25$ g/m^3,

we find that $0.0147(\rho T/P)$ is much less than one and hence neglected. Converting Eq. (4) into dB, we get

$$\gamma_{1.35}=1.0114\int_0^\infty\frac{\rho T^{0.5269}}{P}\,\text{dB}\qquad\ldots(5)$$

According to Hess[5] and Brunt David[6], the atmosphere is assumed to be of constant lapse rate. With this assumption the relation between atmospheric temperature T and pressure P is given by Poisson's equation as

$$T=T_0\left[\frac{P}{P_0}\right]^{R\beta/g}\qquad\ldots(6)$$

$$P=P_0\exp\left[-\frac{h}{H_P}\right]\qquad\ldots(7)$$

$$\rho=\rho_0\exp\left[-\frac{h}{H_\rho}\right]\qquad\ldots(8)$$

where

β Average adiabatic lapse rate = 0.7509 K/100 m (data taken from Civil Aviation Department, Calcutta Airport, for 1.5 km to 7 km)

h Atmospheric height in km

R Gas constant (= 2.9 units)

g Acceleration due to gravity

H_p Pressure scale height (= 8 km)

H_ρ Water vapour scale height to be determined.

Using Eqs (6), (7) and (8) into Eq. (5) and after some simplifications, the water vapour scale height comes to

$$H_\rho=\frac{P_0\gamma}{1.0114\,T_0^{0.5269}\rho_0+P_0\gamma\times0.1103\,\gamma}\,\text{km}\qquad\ldots(9)$$

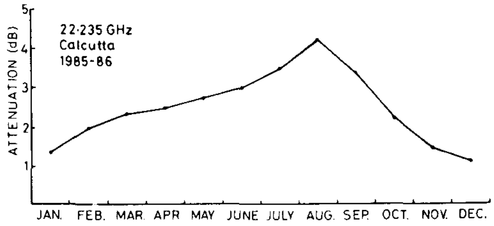

Fig. 1—Monthly variation of attenuation (dB) estimated from 22.235 GHz radiometric data

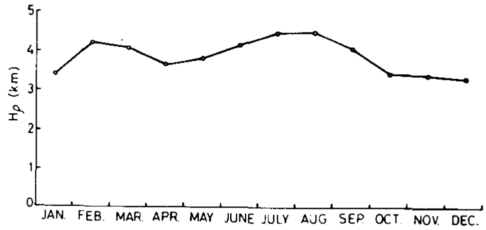

Fig. 2—Monthly variation of water vapour scale height H_p estimated from 22.235 GHz radiometric data

Now, according to Allnutt[7], the zenith attenuation γ can be found out by using

$$\gamma = 10 \log_{10} \frac{T_m}{T_m - T_a} \text{ dB} \qquad \ldots (10)$$

where T_m is the mean atmospheric temperature and is assumed to be 290 K for fair weather conditions and T_a is the antenna temperature to be measured. It is to be noted here that the value of T_m may increase due to rain scatter[8]. But, in our study the rain scatter has not been considered.

Now, with the knowledge of γ from the measurement of T_a from radiometric study at 22.235 GHz [using Eq. (10)] and by the substitution of γ in Eq. (9), the water vapour scale height H_p can be found out.

4 Observations and results

The 22.235 GHz radiometer became operational in late 1984 for the trial run, and the useful data were obtained during 1985-87. This report considers the clear air observations made within the period July 1985 through June 1986.

Round the clock observations were made by the radiometer, and the radiometric antenna temperature data were analysed on a monthly basis from which monthly variation of attenuation (dB) values were found out (Fig. 1). The use of monthly average values of surface meteorological parameters along with the attenuation data produce monthly variation of water vapour scale height H_p [using Eq. (9)]. The variation of H_p is shown in Fig. 2. From the figure it appears that the average value of H_p is 3.887 with a maximum $4.514 \approx 4.5$ km in the month of August and a minimum 3.3 km in the month of December. The monthly variation of H_p described so far is in agreement with the monthly variation of attenuation as shown in Fig. 1, which is in conformity with the discussions made by Sen and Karmakar[9].

But, contrary to this, Sen *et al.*[10] in another report based on radiosonde measurements arrived at a conclusion that the scale height would occur at around 2 km height. This lack of agreement might be due to the fact that the radiometer is running on a round the clock basis encompassing annual variation of water vapour, while the radiosonde data were taken for the monsoon months only covering non-rainy periods, four times a day. In the radiometric study, the presence of excess water vapour at cloud heights (2-5 km) as well as the residual water vapour at the heights encompassing the rain in the post rain periods may give rise to the higher water vapour scale height. During post rain periods the integrated water vapour content may, in fact, be influenced noticeably by high level increase of water vapour density injected by the rain drops into the atmosphere. This suggests that the lifting condensation level, which is defined as the level to which a parcel of moist air is lifted adiabatically before it becomes saturated with respect to a plane surface of water, is taking place somewhat at higher levels than those obtained by radiosonde measurements[11].

Finally, with the help of scale height data obtained by radiometric study and surface water vapour density collected from the India Meteorological Department, Government of India, for Calcutta, the water vapour density profiles for different seasons, viz. winter (Dec.-Feb.), pre-monsoon (Mar.-May), monsoon (June-Sep.) and post-monsoon (Oct.-Nov.) were found (Fig. 3). From Fig. 3 it is evident that radiometric study of water vapour distribution always attains a maximum typically 20-25 g/m^3 in the monsoon month which is in well agreement with the observations made by the India Meteorological Department (IMD), Government of India.

5 Discussions

In our present study, we have limited our discussions to 22.235 GHz radiometric study. But the criteria that are cited in Sec. 1 of this report can also be fulfilled by choosing the other relatively strong water vapour absorption line occurring at 183.3 GHz. For, at or near the peak of water vapour line the absorption coefficient is dominated by water vapour component. This is certainly true for the strong 183.3 GHz line and also true for relatively weak 22.235 GHz line, except in dry climates. Because, in dry climates the total absorption coefficient is not

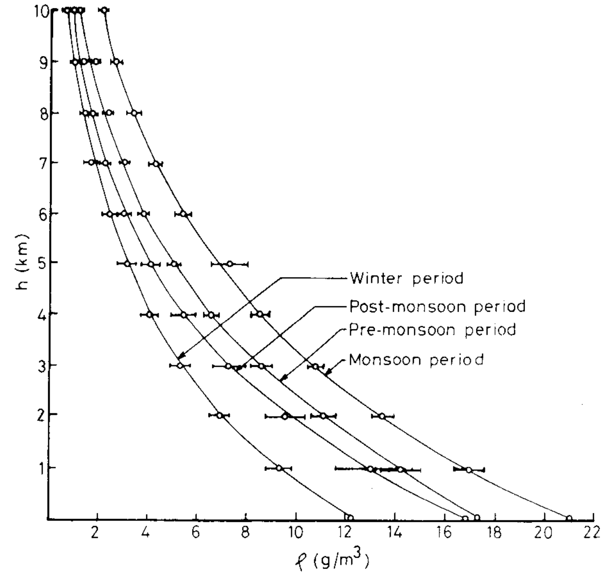

Fig. 3—Height distribution of water vapour density for different seasons in a year over Calcutta, based on radiometric measurements. Standard deviations of the data for different seasons are shown in the curves

strongly dominated by water vapour at 22.235 GHz (Ref. 3). But, we have limited ourselves to the fact that the total absorption coefficient is approximately equal to the only water vapour absorption coefficient at 22.235 GHz, i.e. the explicit dependence of water vapour weighting function on water vapour density profile disappears.

Moreover, due to the weakness of 22.235 GHz line relative to other resonance lines, the weighting function does not vary rapidly with height. Consequently, the radiometric study at 22.235 GHz may not produce water vapour profiles with good vertical resolution. So, under the circumstances it is suggested that 31.65 GHz and 21.0 GHz frequency should be used rather than the line centre frequency 22.235 GHz for the retrieval of water vapour profile in the troposphere. It may give similar results both in shape and in terms of their variations but with somewhat better agreement in magnitude[3].

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