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## WATER VAPOR ATTENUATION STUDIES FOR KA AND V BAND FREQUENCIES OVER A TROPICAL REGION

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### ABSTRACT

The recent communication satellite systems tend to employ higher frequency (18-60 GHz) bands to satisfy the growing capacity requirements. Such wide bandwidths are valuable in supporting applications such as high speed data transmission and video distribution. The attenuation of Satellite signals due to water vapor absorption is very essential for high frequency (>10GHz) satellite communication. Using the formulae referred in Recommendations ITU-R, P.676-5, predictions of specific attenuation and path attenuation due to water vapor absorption are calculated and presented and also compared with the water vapor attenuation estimated from Radiosonde data collected from the India Meteorological Department (IMD), for the first time over tropics. The important findings of the current study includes the observation of slant path attenuation value, which is high for frequencies like 20 GHz, 24 GHz, 26 GHz, 47 GHz and () low for frequencies 18 GHz, 16 GHz, 14 GHz, and 12 GHz etc. It is also observed that for low elevation angles the slant path attenuation is maximum and its value decreases with the increase of elevation angle. For the 1200 GMT similar results are obtained indicating that there is significant diurnal change in the observed attenuation.

**Keywords:** Satellite communications, Water Vapor, Attenuation, Communication Satellites, High Frequency bands.

### INTRODUCTION

In the last decade, new and challenging satellite applications evolved, leading to spectral blocking of the conventional frequency bands allocated for satellite services, they are L, S and C bands operated 1/2 GHz, 2/4 GHz, and 4/6 GHz respectively. At present the recent developments in the space technology, intended for production of VSAT/USAT (Very/Ultra Small Aperture Terminals) systems primarily for data applications, the direct-to-home (DTH) services by Direct Broadcast Satellite (DBS) systems and also to non-geo-stationary (NGSO) orbit constellations. These are all belonging to the Fixed Satellite Service (FSS), and gradually tend to employ higher frequency bands to satisfy the increasing capacity requirements. Hence the recent satellite systems are operating at Ku (12/14

GHz), Ka (20/30 GHz) and V (40/50 GHz) band frequencies. The wave spectrum at 12-60 GHz is of increasing interest to both service providers and systems designers due to because of the wide bandwidths available for carrying communications at this frequency range. Such wide bandwidths are highly valuable in high speed data transmission and video distribution. In the absence of rain, cloud and atmospheric gases can play an important role in signal attenuation; hence their effects must be assessed in order to determine their impact on satellite communications (César Amaya, 2002). But, higher frequencies (Beyond 10 GHz) giving rise to signal fading due to physical phenomena related to the propagation of radio waves through the atmosphere (Crane, 2003) and hence the higher frequencies at Ka and V band are more

vulnerable to propagation effects such as oxygen and water vapor absorption for both fixed and mobile satellite communications.

Rain is typically the main cause of attenuation on most propagation paths at frequencies above about 10 GHz and it increases significantly as frequency increases from Ka to the EHF band (30-300 GHz). However, attenuation by clouds and atmospheric gases (oxygen and water vapor) also assumes generally greater significance with increasing frequency, and their persistent effects influence satellite communication systems.

Throughout the globe the slant-path attenuation due to atmosphere gases and water vapor has been investigated (Althuser *et al*, (1978); Asoka Dissanayake *et al*, (2001); César Amaya (2002); Carlos Catalán *et al*, (2002); Kifah Al-Ansari and Awadallah Salama (2005); Mandeep and Hassan (2008)) by using different instruments and methods. Studies on attenuation over tropical region are sparse. Uppalet *al*. (1979) reported water vapor attenuation with passive radiometer operating on 22.235 GHz, Karmakar *et al*. (2001) using dual frequency microwave radiometers operating at 22.235 and 31.4 GHz and Sarkar *et al*.(1998;2005) for a frequency range of 1-350GHz at elevation angles 3 and 10 degrees. The studies reported are very limited especially in tropics. There is a need to take up large number of measurements to validate the existing ITU-R models.

In the present paper an attempt is made to develop a systematic procedure for the estimation of water vapor attenuation and estimate probability of occurrence of attenuation for different elevation angles and for different frequencies over a tropical region. The procedure involved is very accurate line by line estimation of water vapor attenuation using the radiosonde data. Satellite observations were used for validation. The procedure of estimating water vapor attenuation, the results and discussions are presented in following sub sections.

## DATA BASE AND METHODOLOGY

Absorption is a function of temperature, pressure and humidity. Therefore, it is necessary that these meteorological parameters be determined along the propagation path in order to calculate the gaseous attenuation for any geographical location. Radiosonde data, over Chennai, were obtained twice daily (at 0500 and 1700 h IST) from the IMD for 5 years (2000-2004). From these available data we computed the attenuation of Satellite signals due to water vapor absorption, using the formulas referred in Recommendations ITU-R, P.676-5(2001). The detailed procedure is given in Appendix-A.

## RESULTS AND DISCUSSIONS

### Variability in slant path attenuation using radiosonde data

For the present work we analyzed the radiosonde data collected from the India Meteorological Department (IMD), over a period of 5 years (2000-2004). We individually analyzed both the data sets of morning radiosonde ascent starting at 00:00GMT and the evening radiosonde ascent at 12:00 GMT for each day. The maximum altitude considered in this study is 5 km as the water vapor data may not be available after 5 km as the zero degree isotherm is about 5 km over India. The slant path attenuation of water vapor attenuation statistics was calculated for frequencies between 12 GHz to 47 GHz at different elevation angles starting from 5° to 75°. We have analyzed and plotted Cumulative Distributive Frequency (CDF) plots for both morning and evening radiosonde data and found that no significant difference between the morning and the evening water vapor absorption. Hence we combined both the data and presented CDF graphs for various elevation angles and are shown in figures 1 to 8.

The above observations clearly revealed that, slant path attenuation of water vapor is high for the frequencies 24 GHz, 47 GHz, 20 GHz, and 28 GHz etc. The corresponding value is less for the

lower range frequencies like 18 GHz, 16 GHz, 14 GHz, and 12 GHz etc. It is also clear that for low elevation angles like  $5^{\circ}$ ,  $15^{\circ}$  etc, the slant path attenuation is maximum and about 10 dB. Its value decreases with the increase of elevation angle. For higher elevation angles like  $65^{\circ}$ ,  $75^{\circ}$  etc, the slant path attenuation is about 0.1dB.

#### **Comparison of slant path attenuation obtained from radiosonde data and ITU-R reference values:**

The slant path attenuation values of water vapor computed using radiosonde data for different frequency values and for different elevation angles are compared with ITU-R standard reference values. The maximum value, minimum value and also the difference between the maximum and minimum values is also tabulated. They are shown in Tables 1 to 4.

In addition to above comparison we also made comparison for higher frequencies like 28 GHz, 30 GHz and 47 GHz and clearly noticed that; (i) The slant path attenuation values which are calculated by the radiosonde data are in good agreement with the standard ITU-R values, (ii) The slant path attenuation values are decreasing with increase of elevation angles and (iii) With the increase of frequency from 16 GHz to 47 GHz the slant path attenuation value is increased corresponding to each elevation angle. It can also be concluded that the difference value also decreases with the increase of elevation angles. There is a significant difference in the minima and maxima values at low elevation angles which is for serious concern for the operation of VSAT and HAPS.

#### **CONCLUSIONS**

The attenuation of Satellite signals due to water vapor absorption is calculated using the formulas referred in *Recommendations ITU-R, P.676-5(2001)*. Predictions of specific attenuation and path attenuation due to water vapor absorption are also presented and compared with the water vapor attenuation calculated using Radiosonde data collected from the India Meteorological

Department (IMD), Chennai station. The important findings of the present work are summarized as follows.

- (1) The slant path attenuation value is high for frequencies like 20 GHz, 24 GHz, 26 GHz, and 47 GHz. The corresponding value is low for frequencies 18 GHz, 16 GHz, 14 GHz, and 12 GHz etc.
- (2) For low elevation angles like  $5^{\circ}$ ,  $15^{\circ}$  etc, the slant path attenuation is maximum (10dB) for morning radiosonde observations. Its value decreases with the increase of elevation angle and for higher elevation angles like  $65^{\circ}$ ,  $75^{\circ}$  etc, the value is about 0.1dB. For the evening data—~~is~~ also similar results are obtained indicating that there is significant diurnal change in the observed attenuation.
- (3) The estimated slant path attenuation values from radiosonde data are in good agreement with the standard ITU-R reference values except in few cases. It can be due to the fact that the ITU-R values are averaged over a longer time compared to the present data (5 years), and hence the present observed values may be slightly varying from the ITU-R reference values.
- (4) The slant path attenuation value gradually decreases with the increase of elevation angle.—It can also be concluded that the difference value also decreases with the increase of elevation angles. There is a significant difference in the minima and maximum values at low elevation angles which are of serious concern for the operation of VSAT and HAPS (High Altitude Platform Stations).

#### **ACKNOWLEDGEMENTS**

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**APPENDIX-A:** The atmosphere is a layer of gases covering the surface of the earth. There are many gases in the atmosphere. The two that cause almost all of the radio wave attenuation are Oxygen (O<sub>2</sub>) and Water Vapor (H<sub>2</sub>O). The two components (O<sub>2</sub> and H<sub>2</sub>O) should be added together for the total specific attenuation. Hence, the gaseous absorption is calculated as the sum of water vapor absorption and oxygen absorption. Recommendation: ITU-R P.676-5 (2001) can be used to estimate the attenuation by atmospheric gases on terrestrial and slant paths, which are based on curve fitting to the line-by-line calculation. The input parameters required for the calculation include frequency, path elevation angle, and height above mean sea level and water vapor density. The oxygen attenuation is considered a background effect with very little temporal variation; variations in gaseous absorption arise from changes in the amount of water vapor in the atmosphere.

Oxygen absorption is not considered in the present study, as the FSS (Fixed Satellite Services) do not employ the frequencies close to the oxygen absorption band (~60 GHz) at present in India. The water vapor absorption at Ku- and Ka-band satellite communication links is only considered in this study. The attenuation of Satellite signals due to water vapor absorption is calculated using the formulas referred in Recommendations ITU-R, P.676-5(2001). Predictions of specific attenuation and path attenuation due to water vapor absorption are presented in this chapter.

**METHODOLOGY:** As per the Recommendation: ITU-R P.676-5 (2001a) together with the Recommendation: ITU-R P.453-8 (2001b), the water vapor absorption can be calculated.

For water vapor, the specific attenuation,  $\gamma_w$  (dB/km) is given by,

$$\begin{aligned} \gamma_w = & \{ (3.13 \cdot 10^{-2} r_p r_t^2) + (1.76 \cdot 10^{-3} \rho r_t^{8.5}) \\ & + r_t^{2.5} [ (3.84 \xi_{w1} g_{22} \exp(2.23(1-r_t)) / ((f-22.235)^2 + 9.42 \xi^2 w_1) \\ & + (10.48 \xi w_2 \exp(0.7(1-r_t))) / ((f-183.31)^2 + 9.48 \xi^2 w_2) \\ & + (0.078 \xi w_3 \exp(6.4385(1-r_t))) / ((f-321.226)^2 + 6.29 \xi^2 w_3) \\ & + (3.76 \xi w_4 \exp(1.6(1-r_t))) / ((f-325.153)^2 + 9.22 \xi^2 w_4) \\ & + (26.36 \xi w_5 \exp(1.09(1-r_t))) / (f-380)^2 \\ & + (17.87 \xi w_5 \exp(1.46(1-r_t))) / (f-448) \\ & + (883.7 \xi w_5 g_{557} \exp(0.17(1-r_t))) / (f-557)^2 \\ & + (302.6 \xi w_5 g_{752} \exp(0.41(1-r_t))) / (f-752)^2 ] \} f^2 \rho \cdot 10^{-4} \text{-----(1)} \end{aligned}$$

For  $f \leq 350$  GHz

With:

$$\xi_{w1} = 0.9544 r_p r_t^{0.69} + 0.0061 \rho \text{-----(2)}$$

$$\xi_{w2} = 0.95 r_p r_t^{0.64} + 0.0067 \rho \text{-----(3)}$$

$$\xi_{w3} = 0.9561 r_p r_t^{0.67} + 0.0059 \rho \text{-----(4)}$$

$$\xi_{w4} = 0.9543 r_p r_t^{0.68} + 0.0061 \rho \text{-----(5)}$$

$$\xi_{w5} = 0.955 r_p r_t^{0.68} + 0.006 \rho \text{-----(6)}$$

$$g_{22} = 1 + (f-22.235)^2 / (f+22.235)^2 \text{-----(7)}$$

$$g_{557} = 1 + (f-557)^2 / (f+557)^2 \text{-----(8)}$$

$$g_{752} = 1 + (f-752)^2 / (f+752)^2 \text{-----(9)}$$

Where,  $f$ =frequency (GHz)

$$r_p = p/1013 \text{-----(10)}$$

$$r_t = 288 / (273 + t) \text{ -----(11)}$$

p: pressure (hPa)  
 t: temperature ( °C) and  
 ρ: water vapor density (g/m<sup>3</sup>).

Using the Recommendation ITU-R P.453-8 (2001b), we can find the water vapor density “ρ”.

The relationship between water vapor pressure “e” and relative humidity “H” is given by,

$$e = H e_s / 100 \quad \text{hPa} \text{ -----(12)}$$

And

$$e_s = a \exp (bt / (t + c)) \quad \text{hPa} \text{ -----(13)}$$

Where,

H: Relative humidity (%)  
 t: Celsius temperature (°C)  
 e<sub>s</sub>: Saturation vapor pressure (hPa) at the temperature t (°C) and the  
 Co-efficient a, b, c are:

For water:

a = 6.1121  
 b = 17.502  
 c = 240.97

(Valid between -20° to +50°, with an accuracy of ±0.20%)

For ice:

a = 6.1115  
 b = 22.452  
 c = 272.55

(Valid between -50° and 0°, with an accuracy of ±0.20%)

Vapor pressure “e” is obtained from the water vapor density “ρ” using the following equation,

$$e = \rho T / 216.7 \quad \text{hPa} \text{ -----(14)}$$

By re-arranging the above equation, water vapor density “ρ” in g/m<sup>3</sup> can be found,

$$\rho = e * 216.7 / T \text{ in g/m}^3 \text{ -----(15)}$$

**Slant Path Attenuation:** The gaseous attenuation model given in Recommendation: ITU-RP.676-5 (2001), can be used to predict the water vapor absorption for terrestrial and slant paths. It defines a simple algorithm for the calculation of water vapor absorption along the slant paths through the earth’s atmosphere in the frequency range 1-350 GHz. The zenith path water vapor absorption is obtained by multiplying an equivalent height for water vapor “h<sub>w</sub>” with the specific attenuation due to water vapor, γ<sub>w</sub> (dB/km) calculated in the equation (1).

For water vapor, the equivalent height is,

$$h_w = 1.65 \{ 1 + 1.61 / ((f - 22.23)^2 + 2.91) + 3.33 / ((f - 183.3)^2 + 4.58) + 1.90 / ((f - 325.1)^2 + 3.34) \}$$

in km for f ≤ 350 GHz. ----- (16)

The total zenith attenuation is,

$$A = \gamma_w h_w \text{ (dB)} \text{ -----(17)}$$

For an elevation angle “φ” between 5° and 90°, the slant path attenuation (for earth-space paths) is obtained using the cosecant law, as follows,

$$A = \gamma_w h_w \sin\phi \text{ (dB)} \text{----- (18)}$$

Where, “ $\phi$ ” is the elevation angle.

The required input parameters like Temperature, Pressure and Humidity and water vapor density were obtained from radiosonde data and by developing a Matlab Programme, the desired output values are estimated.

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**Table 1: Comparison of slant path attenuation values of water vapor due to radiosonde data for frequency 12 GHz with ITU-R standard values**

ELEVATION ANGLE	Frequency = 12 GHz				
	Comparison		Radiosonde Data		
	ITU – R VALUES (dB)	RS DATA MEAN (dB)	MAXIMUM VALUE (dB)	MINIMUM VALUE (dB)	DIFFERENCE (dB)
5 <sup>0</sup>	0.2161	0.322	0.8747	0.141	0.733
15 <sup>0</sup>	0.0728	0.109	0.294	0.04	0.254
25 <sup>0</sup>	0.0446	0.066	0.18	0.0291	0.1509
35 <sup>0</sup>	0.0328	0.049	0.132	0.0214	0.1106
45 <sup>0</sup>	0.0266	0.04	0.081	0.017	0.0021
55 <sup>0</sup>	0.023	0.034	0.07	0.015	0.0014
65 <sup>0</sup>	0.0208	0.031	0.063	0.0135	0.0153
75 <sup>0</sup>	0.0195	0.029	0.059	0.0127	0.0144

**Table 2: Comparison of slant path attenuation values of water vapor due to radiosonde data for frequency 14 GHz with ITU-R standard values**

ELEVATION ANGLE	Frequency = 14 GHz				
	Comparison		Radiosonde Data		
	ITU – R VALUES (dB)	RS DATA MEAN (dB)	MAXIMUM VALUE (dB)	MINIMUM VALUE (dB)	DIFFERENCE (dB)
5 <sup>0</sup>	0.4941	0.542	1.237	0.228	1.009
15 <sup>0</sup>	0.1664	0.17	0.38	0.07	0.31
25 <sup>0</sup>	0.1019	0.104	0.238	0.047	0.191
35 <sup>0</sup>	0.0751	0.0769	0.175	0.034	0.141
45 <sup>0</sup>	0.0609	0.063	0.1058	0.028	0.067
55 <sup>0</sup>	0.0526	0.054	0.091	0.024	0.03
65 <sup>0</sup>	0.0475	0.049	0.082	0.0219	0.0601
75 <sup>0</sup>	0.0446	0.046	0.077	0.0206	0.0564

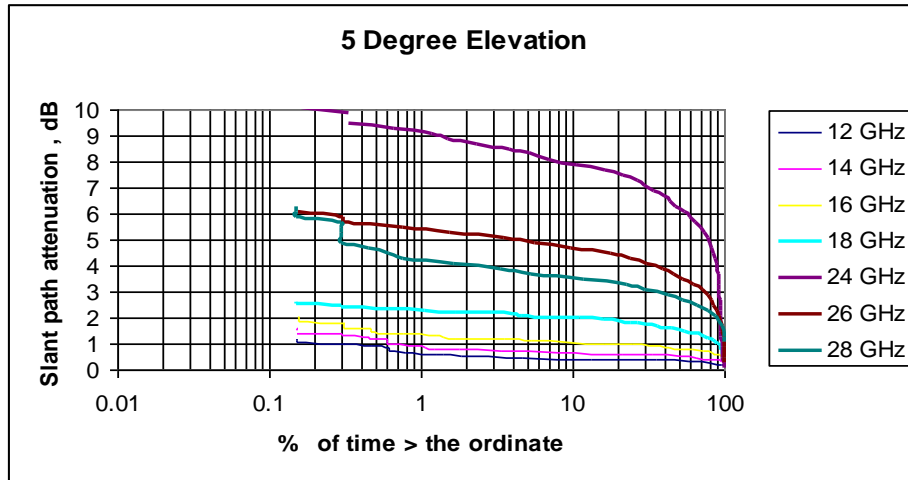
**Table 3: Comparison of slant path attenuation values of water vapor due to radiosonde data for frequency 16 GHz with ITU-R standard values**

ELEVATION ANGLE	Frequency = 16 GHz				
	Comparison		Radiosonde Data		
	ITU – R VALUES (dB)	RS DATA MEAN (dB)	MAXIMUM VALUE (dB)	MINIMUM VALUE (dB)	DIFFERENCE (dB)
5 <sup>0</sup>	0.8353	0.795	1.41	0.315	1.095
15 <sup>0</sup>	0.2813	0.335	1.191	0.131	1.06
25 <sup>0</sup>	0.1723	0.171	0.29	0.08	0.21
35 <sup>0</sup>	0.1269	0.127	0.202	0.059	0.143
45 <sup>0</sup>	0.103	0.103	0.164	0.048	0.055
55 <sup>0</sup>	0.0889	0.089	0.141	0.041	0.116
65 <sup>0</sup>	0.0803	0.078	0.128	0.037	0.091
75 <sup>0</sup>	0.0754	0.075	0.085	0.035	0.085

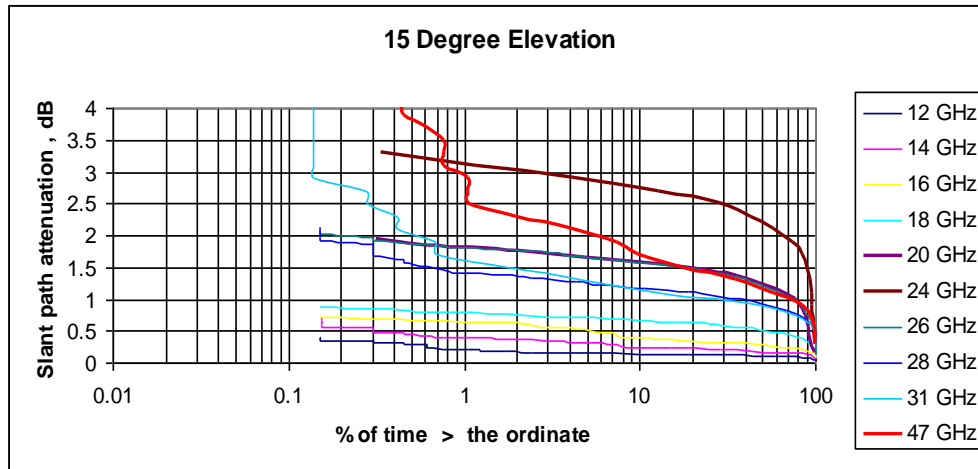
**Table 4: Comparison of slant path attenuation values of water vapor due to radiosonde data for frequency 18 GHz with ITU-R standard values**

ELEVATION ANGLE	Frequency = 18 GHz				
	Comparison		Radiosonde Data		
	ITU – R VALUES (dB)	RS DATA MEAN (dB)	MAXIMUM VALUE (dB)	MINIMUM VALUE (dB)	DIFFERENCE (dB)
5 <sup>0</sup>	1.59	1.52	2.49	0.6	1.89
15 <sup>0</sup>	0.53	0.513	0.841	0.2025	0.638
25 <sup>0</sup>	0.32	0.314	0.515	0.124	0.391
35 <sup>0</sup>	0.24	0.233	0.288	0.091	0.288
45 <sup>0</sup>	0.19	0.189	0.234	0.074	0.234
55 <sup>0</sup>	0.17	0.178	0.479	0.007	0.479
65 <sup>0</sup>	0.15	0.147	0.183	0.057	0.183
75 <sup>0</sup>	0.144	0.138	0.171	0.054	0.171

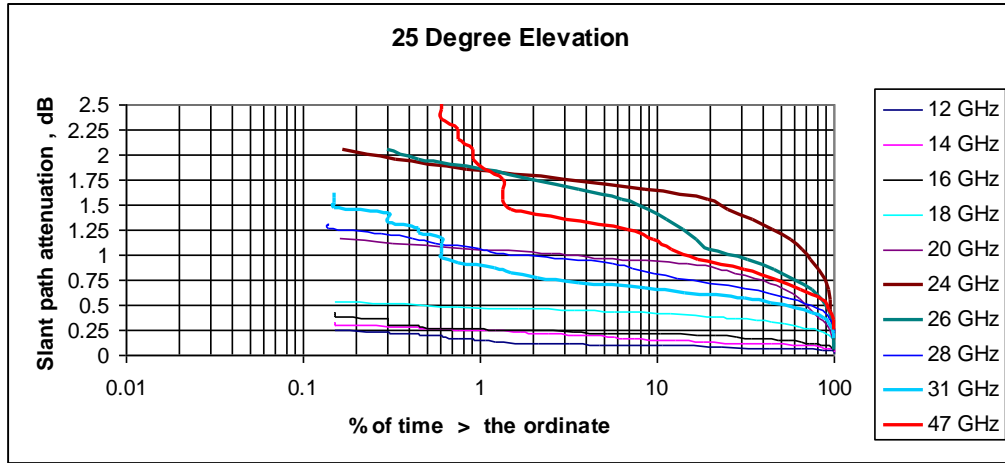
**Figure 1: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 5<sup>0</sup> elevation angle**



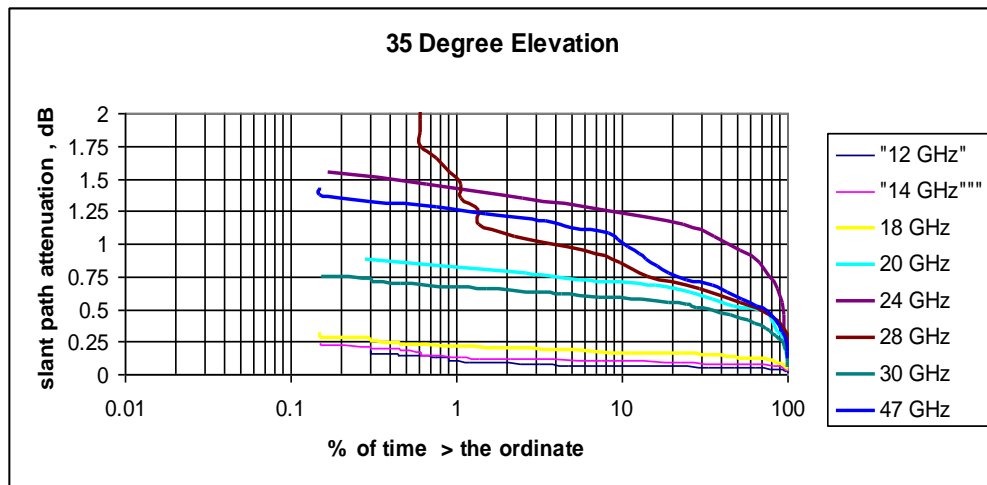
**Figure 2: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 15<sup>0</sup> elevation angle**



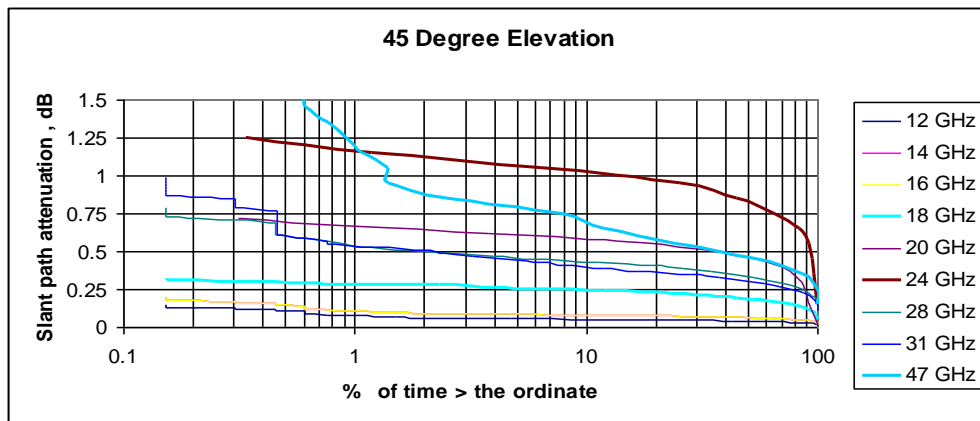
**Figure 3: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 25° elevation angle**



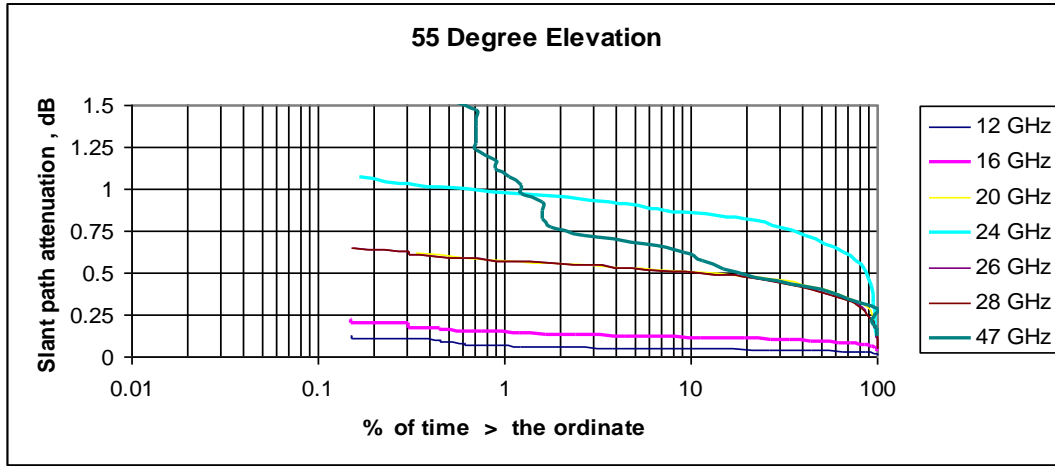
**Figure 4: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 35° elevation angle**



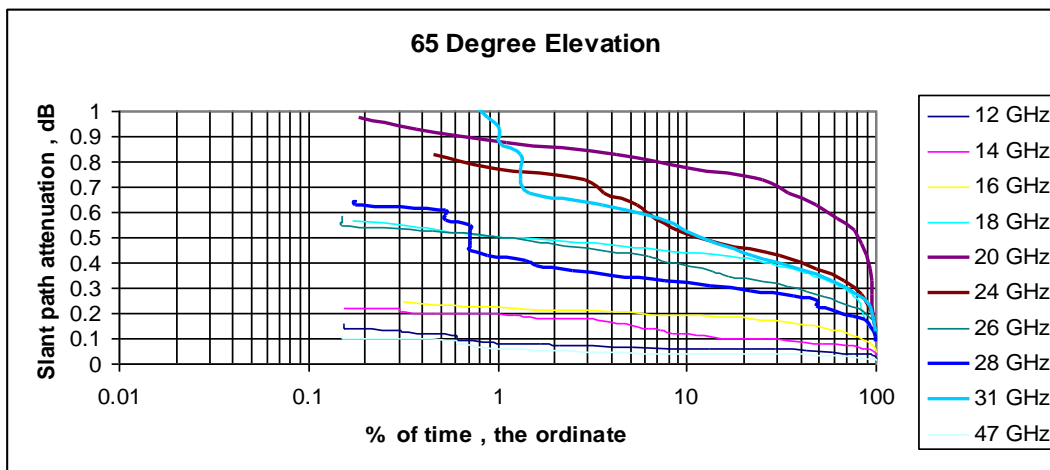
**Figure 5: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 45° elevation angle**



**Figure 6: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 55° elevation angle**



**Figure 7: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 65° elevation angle**



**Figure 8: Yearly variation of Slant path attenuation of water vapor using radiosonde data at 75° elevation angle**

