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Microwave Communication Parameters Estimated from Radiosonde Observations over the Indian Subcontinent

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Emission and absorption of microwaves in atmospheric gases often limit the useful sensitivity of receiving systems in earth-space links. At frequencies below 30 GHz the emission and absorption due to water vapour content in the atmosphere dominate. A main water vapour line occurs at 22.235 GHz where the attenuation and emission noise attain a maximum. An estimate of attenuation, noise, and group delay made at this frequency, therefore, provides an upper limit of water vapour effects at microwave frequencies below 30 GHz. The study is based on the results of water vapour and radio refractivity distribution over the Indian subcontinent presented in two atlases, namely, *Atlas of Tropospheric Water Vapour over the Indian Subcontinent*, and *Atlas of Tropospheric Radio Propagation Parameters over the Indian Subcontinent*, published by the National Physical Laboratory, New Delhi; these atlases are based on radiosonde observations made by the India Meteorological Department, Govt. of India.

1 Introduction

The advent of satellite communication and the growth of line-of-sight and troposcatter links, in recent years, have apparently initiated a renewed interest in the propagation of microwaves and millimetre waves in earth-space links. The most important region of the atmosphere affecting the performance of such links is its lowermost region—the troposphere extending up to a height of about 10 km. The water vapour content beyond 10 km is negligible in comparison to that below 10 km. This is also borne out by the theoretical estimates of absorption at different altitudes for a standard atmosphere for vertical propagation[1].

The three basic parameters of significance to radio propagation are thermal emission, absorption, and group delay of the atmosphere, all of which are mainly controlled by water vapour content in the atmosphere. Therefore an estimate made at 22.235 GHz provides an upper limit of water vapour effects at frequencies below 30 GHz. But the group delay, introduced by the troposphere for radio signal in the VHF, UHF, and in microwave bands, may be comparable to and even greater than the ionospheric delay. For, the refractive index of air, unlike that of the ionospheric plasma, is practically independent of frequency. In fact, the polarization of water vapour molecules of the atmosphere presumably plays the main role[2]. Also, the fact that the dispersive effect of water vapour is insignificant at microwaves below 30 GHz is duly considered[3]. The refractive index may, therefore, be considered as independent of frequency. However, all these parameters exhibit a similar seasonal dependence originating presumably from the seasonal dependence of water vapour content, which will be discussed in the following sections.

2 Theoretical Background

2.1 Absorption Equation

The attenuation rate in dB/km due to absorption in the atmosphere is given by[4]

$$\alpha = \frac{1.05}{10^{28}} \frac{N_1 \nu^2 \exp(-644/T)}{T^{5/2}} \times \left[\frac{\Delta\nu_p}{(\nu-\nu_0)^2+\Delta\nu_p^2} + \frac{\Delta\nu_p}{(\nu+\nu_0)^2+\Delta\nu_p^2} \right] + \frac{1.52}{10^{52}} \frac{N_1 \nu^2 \Delta\nu_p}{T^{3/2}} \quad \ldots(1)$$

where

N_1	No. of molecules per cm^3
ν	Resonance frequency in Hz
ν_0	Off-resonance frequency in Hz
T	Kinetic temperature in K
$\Delta\nu_p$	Pressure broadened line half-width parameter and is given by

$$\Delta\nu_p = 2.62\times10^9 \frac{\frac{P}{760}}{\left(\frac{T}{318}\right)^{0.625}}(1+0.0046\rho)\,s^{-1} \quad \ldots(2)$$

where

P Total atmospheric pressure in mm Hg

ρ Density of water vapour in g/m^3

2.2 Emission Equation

According to Raina *et al.*[5], the relation between the emission noise temperature T_a and the integrated water vapour content W for vertical propagation at 22.235 GHz is given by

$$T_a = 1.34\times10^{-3}W + 3.5 \quad \ldots(3)$$

where 3.5 serves as an additive constant to T_a as a galactic source noise. This relation can be utilized to estimate T_a directly from the integrated water vapour content calculated from radiosonde data. The estimate of T_a can, in turn, be employed to deduce specific attenuation α from the relation[6]

$$\alpha = \log_{10}\frac{T_m}{T_m - T_a}\ \text{dB/km} \quad \ldots(4)$$

where T_m is the mean atmospheric temperature and is assumed to be 275 K. It is also clear from Eq. (4) that α increases with increase in T_a, as is expected, since good radiators are also good absorbers[7]. As a result, the presence of water vapour degrades the signal-to-noise ratio in the receiving system due to both absorption and emission processes.

It may be mentioned here that the attenuation and noise due to water vapour is significantly greater for slant paths compared to that for vertical propagation, due to the greater length of the path involved. For slant paths, the length of the path l_ϕ for an elevation ϕ of the ray path is given by

$$l_\phi = -R\sin\phi + \sqrt{R^2\sin^2\phi + 2HR + H^2} \quad \ldots(5)$$

where H is the width of the water vapour layer[8].

Moreover, to take into account the curvature of the ray path due to spherical nature of the water vapour layer it is assumed that

$$R = \frac{4}{3}\ \text{earth's radius} = 8500\,\text{km}$$

Now with the knowledge of l_ϕ, the total attenuation A_ϕ at a slant path is given by

$$A_\phi = \alpha\, l_\phi \quad \ldots(6)$$

2.3 Group Delay

According to Sen *et al.*[7], excess group delay τ_T due to the troposphere is given by

$$\tau_T = \frac{10^{-6}}{c}\int_0^h N\,dh \quad \ldots(7)$$

where N is the modified refractivity unit, c the velocity of light, and h the height in the tropospheric region (0-10 km) up to which integration has been carried out.

To find out W (total water vapour content of a cylinder of height 0-10 km and of base 1 m^2), *Atlas of Tropospheric Water Vapour over the Indian Subcontinent* (Ref. 9) has been used; compilation of this atlas involved the use of radiosonde data collected by the India Meteorological Department on a routine basis over sixteen stations during four years (1968-71), using the fixed pressure level data from 1000 mbar to 50 mbar level. Radiosonde flights were taken twice daily, one at 0000 hrs GMT and the other at 1200 hrs GMT, i.e. at 0530 hrs IST and 1730 hrs IST, respectively. Accuracies of relative humidity, temperature, and pressure obtained from radiosonde measurements are within 5 per cent, 0.25°C, and 2 mbar respectively.

To estimate $\int N dh$, *Atlas of Tropospheric Radio Propagation Parameters over the Indian Subcontinent* (Ref. 10) has been used. Compilation of this atlas involved the use of tropospheric radio refractivity data obtained from radiosonde data collected over 32 stations for a period of five years (1975-79) using fixed pressure level data at intervals of 50 mbar from 1000 mbar to 50 mbar levels. Refractivity over the sea area has been calculated from MONEX-79 (Monsoon Experiment-79) data.

3 Estimation of Water Vapour Emission and Absorption

To have estimates of water vapour emission and absorption, water vapour profiles $w(h)$ in different regions of India for different seasons were integrated to obtain

$$\int_0^h w(h)\,dh = W$$

A value of $h = 10$ km was assumed for this purpose. The different subcontinents were then subdivided in two parts; one included (i) northern plane, (ii) central plane, (iii) western plane, (iv) southern plane, (v) desert area, and (vi) Assam valley; and the other included (i) Indian Island, (ii) south east coast, (iii) south west coast, (iv) east coast, and (v) west coast.

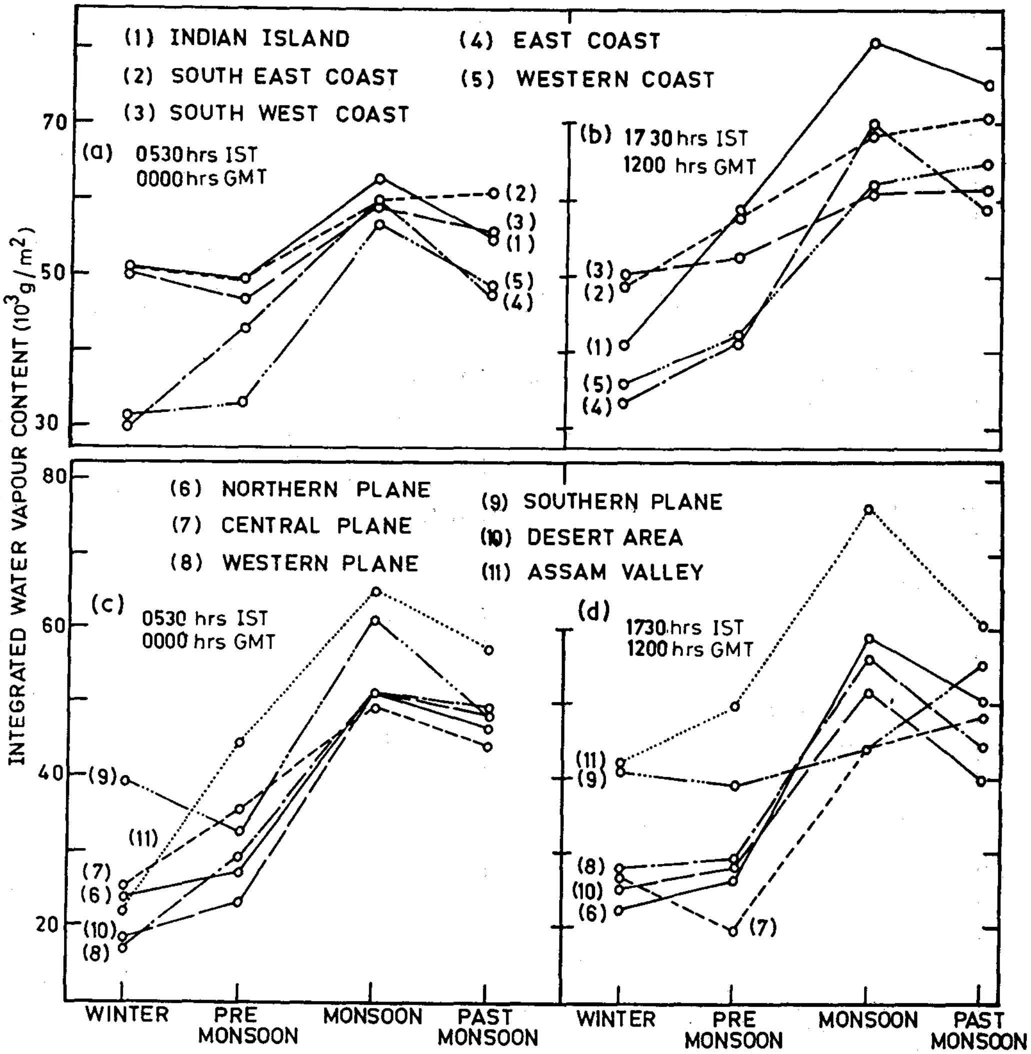

Fig. 1—Seasonal variation of integrated water vapour content over Indian subcontinent [(a) and (b), coastal regions; (c) and (d), plane regions]

Seasonal variation of the integrated water vapour content at 0530 and 1730 hrs IST over Indian subcontinent is shown in Fig. 1.

Seasonal variation of the estimated antenna temperature T_a at 22.235 GHz [using Eq. (3)] at 0530 and 1730 hrs IST is shown in Fig. 2. It is evident from Fig. 2 that T_a is, in general, highest in the monsoon months all over India, as is expected from the highest tropospheric water vapour content at such times. It is also evident that T_a is higher in the coastal regions than over the planes, the Indian Island being the region of highest noise temperature. Amongst the planes, the Assam valley is the region of highest noise temperature while the desert area exhibits the lowest value of noise temperature, particularly at 0530 hrs IST. At 1730 hrs IST, however, the lowest noise temperature amongst the planes is exhibited by the central planes.

Seasonal variation of the attenuation coefficient at 22.235 GHz [using Eq. (4)] exhibits similar trends as shown by T_a (Fig. 3).

Figs 2 and 3 also reveal that the values of T_a and α are lower in winter and pre-monsoon months than in monsoon and post-monsoon months.

The effect of atmosphere on the incoming signal in (i) attenuating it and (ii) adding thermal emission noise to it has already been discussed. Each of these factors tends to reduce the signal-to-noise ratio. Moreover, a significant parameter which takes these two factors into account is $1/\alpha T_a$. This is, in fact, an index of figure of merit of an ideal earth station having an antenna of some standard gain. Seasonal variation of this index over Indian subcontinent is shown in Fig. 4. It is evident from Fig. 4 that highest index is exhibited in the winter season than in the monsoon season. Con-

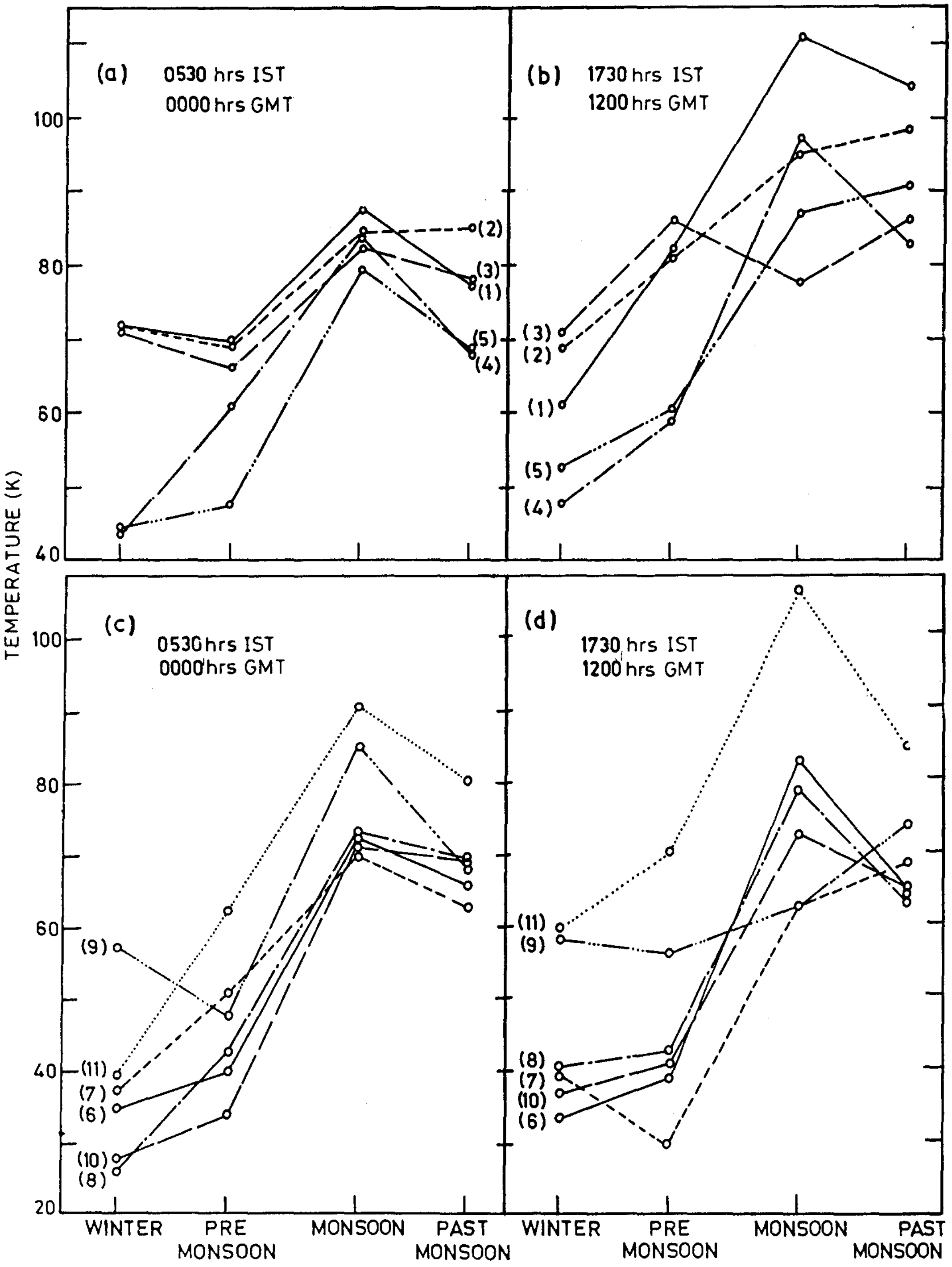

Fig. 2—Seasonal variation of antenna temperature over Indian subcontinent (Designations of curves same as in Fig. 1)

sidering the regional differences of the index, it is noted that at 0530 hrs IST the desert area exhibits the highest index while at 1730 hrs IST the central plane is the region of highest index. These two areas are then considered to be the best regions for earth stations.

The results presented so far are for vertical propagation with zenith angle 90°. For slant paths with elevations of 5°, 10° and 30°, the effective path lengths through the troposphere calculated using Eq. (5) are found to be 107, 57 and 20 km, respectively for a width of 10 km of the troposphere, assuming an effective earth's radius $R = 8500$ km.

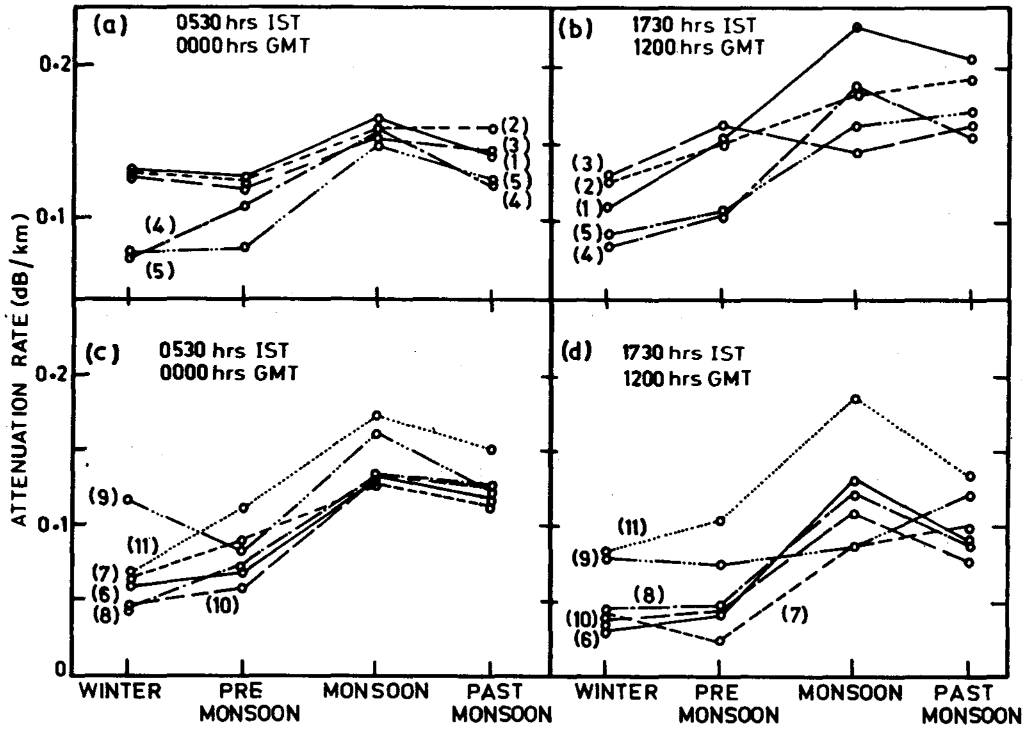

Fig. 3—Seasonal variation of attenuation coefficient over Indian subcontinent (Designations of curves same as in Fig. 1)

4 Estimation of Group Delay

To get an estimate of group delay, the refractivity profiles for different seasons over the Indian subcontinent were integrated for the height range 0-10 km, and subsequently by using Eq. (7) the excess group delay was found out.

Seasonal variation of group delay for different regions of Indian subcontinent is shown in Fig. 5. It is evident from Fig. 5 that the delay time attains a maximum over the Assam valley and minimum over the desert area both at 0530 and 1730 hrs IST, particularly in monsoon months. It may be mentioned here that a minimum value of group delay is attained by the northern plane at 0530 hrs IST and by the south east coast at 1730 hrs IST in the pre-monsoon months.

However, as group delay is considered to be mainly controlled by water vapour, it appears that the variation of delay in different regions would follow the variation of water vapour content and hence that of antenna temperature T_a.

Figs 1, 2 and 5 clearly show that the variations of communication parameters α, T_a and τ_T show a similar trend, exhibiting a maximum in the monsoon months over Assam valley and a minimum in winter over desert area.

5 Effect of Stratospheric Water Vapour on the Estimates

In the foregoing estimates of α and T_a we have neglected the contribution of water vapour content above 10 km altitudes. However, if frequency of operation be coincident with water vapour line on 22.235 GHz and the communication bandwidth is as narrow as a few MHz, serious errors may creep in the presence of even minute traces of water vapour at stratospheric heights. The absence of collision broadening at such heights may lead to a sharp peak of the water vapour spectral line at 22.235 GHz. Under realistic situations of stratospheric water vapour content, the noise temperature at 22.235 GHz may vary from about 50 K to 100 K (Ref. 4). However, at frequencies away from 22.235 GHz, such as those at 20.6 and 24 GHz, the stratospheric water vapour content will be without any effect (Ref. 11). Accordingly, if the estimates of T_a and α presented are extrapolated to frequencies beyond the range 20.6-24 GHz, where the practical microwave earth-space links operate, the stratospheric water vapour content will be without any effect. However, the water vapour profile, from which T_a was deduced, was limited to tropospheric heights and is therefore free from any stratospheric content of water vapour, and as such the extrapolated value will be free from the effect of any stratospheric water vapour contents.

The results obtained at 22.235 GHz band can be summarized as: (1) α and T_a are highest in the monsoon months, over the Assam valley as well as over the Indian Island, where $1/\alpha T_a$, an index of figure of merit

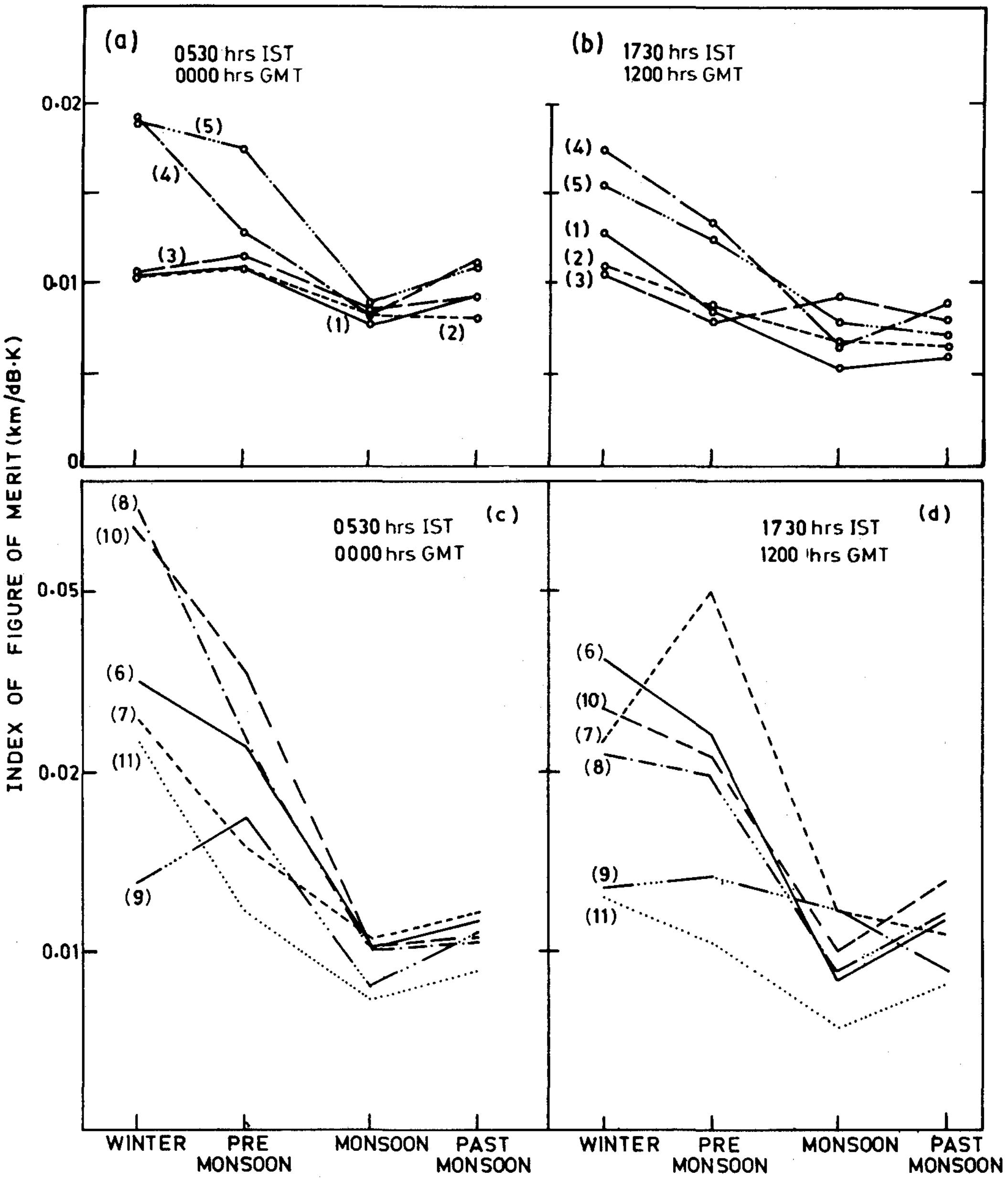

Fig. 4—Seasonal variation of index of figure of merit over Indian subcontinent (Designations of curves same as in Fig. 1)

of an ideal earth station, is lowest; (2) α and T_a are lowest in the winter months over the desert areas and central plane, where the index of figure of merit, $1/\alpha T_a$ is highest; and (3) α, T_a and τ_T are higher at 1730 hrs IST than at 0530 hrs IST.

6 Discussion

The low values of the radio-propagational parameters T_a, α and τ_T over the desert area suggest that it should be an ideal location for an earth station in space communication, and the situation should reverse over the Assam valley. To get a better insight of the variations of radio-propagational parameters, which have been studied twice daily, a vertical water vapour distribution for various averaging time and a continuous monitoring of the water vapour content are needed. The vertical distribution of water vapour may be done by using radiosonde data for 6, 12, 24 and 48 hourly averaging time. On the other hand, continuous monitoring may be done by a radiometer for the assessment and prediction of the effect of water vapour in the troposphere in different meteorological conditions. Such a continuous monitoring has been undertaken at the Institute of Radio Physics and Elec-

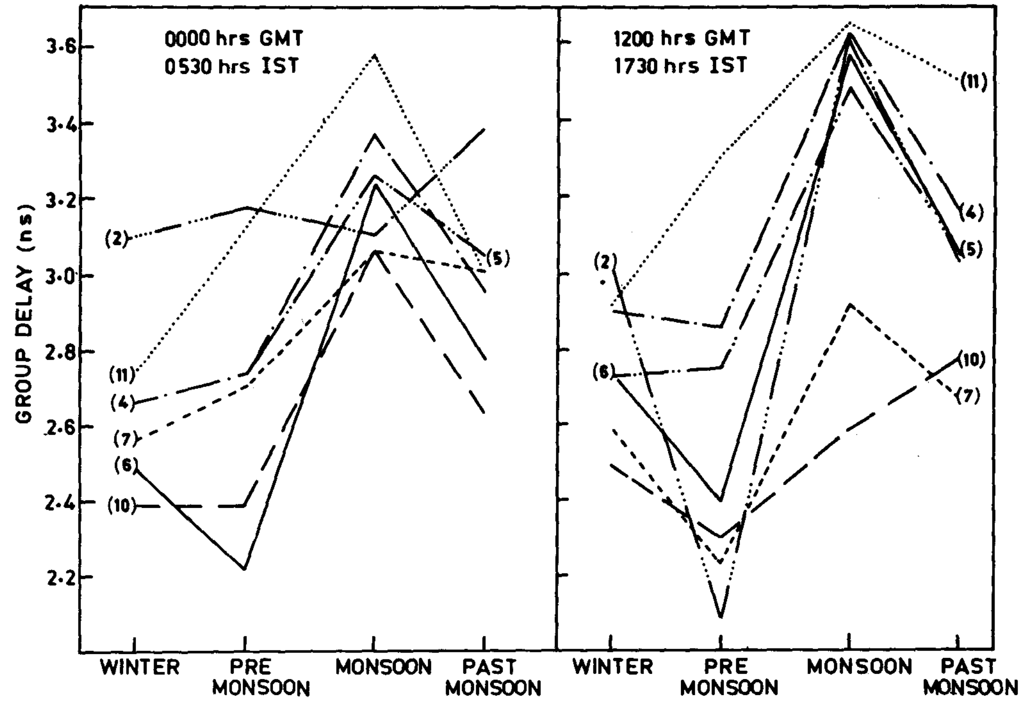

Fig. 5—Seasonal variation of group delay over Indian subcontinent (Due to non-availability of data over Indian Island, south west coast, western plane and southern plane, group delay over these regions are not included.) (Designations of curves same as in Fig. 1)

tronics, Calcutta University, Calcutta, using a radiometer at 22.235 GHz, which is the water vapour resonance line below 30 GHz.

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