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AUTUMN COURSE ON GEOMAGNETISM, THE IONOSPHERE AND MAGNETOSPHERE

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LECTURE 1: Characterization of Tropospheric Environment.

LECTURE 2: Special Problems in Tropical Ionospheric Communications.

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CHARACTERISATION OF TROPOSPHERIC ENVIRONMENT

1. Introduction:

Nature has given us a spherical earth and a messenger in the form of electromagnetic radiations which can travel only in straight lines. If the earth were flat and devoid of any atmosphere, with a mere few watts of power total world-wide communication can be achieved. This explains why the ionosphere is being exploited to reflect the radiowaves so that we can get over the curvature of the earth. This is what essentially a communication satellite does too. However, the troposphere where we live is also fortunately endowed with similar qualities to some extent so that with intelligent planning we can achieve fairly large ranges. Now, let us look at the average characteristics of the troposphere that are most relevant to radio communications:

(1) Pressure decreases exponentially with altitude.

(2) Temperature decreases with altitude.

(3) Gas composition is uniform except for water vapour which usually decreases with altitude.

(4) Rain and water vapour absorb radio wave energy at frequencies about 10 GHz.

(5) Super-refraction and ducting result in anomalous propagation conditions.

(6) Scattering due to dust, smoke, fog, hail etc. cause loss of energy.

(7) Depolarisation results due to non-spherical rain drops.

(8) Tropospheric turbulence which is omnipresent helps in long distance troposcatter communications.

(9) Terrain and vegetation are critical in some areas and may dominate all other factors.

(10) MOST IMPORTANT OF ALL a number of above parameters fluctuate by several orders of magnitude in space and time.

2. RRI Profiles:

The entire exercise can be summarised as 'Prediction of both the median and the range of fluctuations of the above parameters in space and time'. The first three points in the above list uniquely determine the Radio Refractive Index (RRI) at a given time and place and the vertical gradient of this RRI along the ray path decides the course of the ray.

Let us look at the RRI equation - or rather the refractivity equation:

$$N = 77.6 \left(\frac{p}{T} + \frac{4810\, e}{T^2} \right)$$

The above equation obviously emphasises the importance of water vapour gradient in controlling the refractivity gradient. The refractivity gradient is important for the following reasons:

(1) It decides the radio horizon distance in LOS Links.

(2) It decides the height of the common volume in troposcatter links.

(3) It decides the errors in tracking, position fixing etc.

(4) The changes in RRI gradient are responsible for several multipath fading phenomena including fadeouts over irregular terrain.

Since it is realised that RRI profile morphology uniquely determines the tropospheric radio propagation, this has been the primary concern for communication users since quite some time. The earliest organised work in this area was done by Bean and others in 1966 by way of a World Atlas of Radio Refractivity. The data used for this Atlas was too sparse, especially in the tropics, and local climatic effects essentially are not reflected. The measurement techniques used for Radio Sonde were also primitive. It would be necessary to bring out detailed documents for different zones using more recent measurements. As an approximation it was assumed that the surface Refractivity N_s has some correlation with the initial refractivity gradient ΔN_1 and designers started using N_s values as a first step. Almost all the information available now on RRI profiles is based on the Radio Sonde Data collected around the world by various countries as part of the programme under WMO. Such observations suffer from a number of serious deficiencies, but they are all we have got on any morphological scale. Figures (1) to (4) show some samples of N_s and ΔN_1 (surface to 250 m) contours over the Indian subcontinent. It is instructive to notice the large seasonal and regional variations in these contours. The lower N_s values occur over the arid zones of Rajasthan and the highest along west coast. They are generally high in summer and monsoon periods. The initial gradients are lowest in Srinagar area and highest in the coastal areas. They are highest in premonsoon and high in winter months. The values are generally low during daytime compared to night.

3. Super Refraction and Ducting:

By differentiating the equation for Refractivity with respect to height we get

$$\frac{dN}{dh} = 77.6 \left[\frac{1}{T} \frac{dp}{dh} - \left(\frac{p}{T^2} + \frac{9620e}{T^3} \right) \frac{dT}{dh} + \frac{4810}{T^2} \frac{de}{dh} \right] m^{-1}$$

$\frac{dp}{dh}$ is always negative; $\frac{de}{dh}$ and dT/dh are usually negative. Normally $\frac{dT}{dh}$ tends to oppose the Refractive index decrease with altitude, but on occasions when $\frac{dT}{dh}$ is positive, all the three terms adds up to produce a large refractivity lapse rate resulting

in super refraction. If the modulus value of the gradient is higher than 157 per km, ducting occurs. As can be seen, ΔN_1 values are very high in coastal areas except during the peak of monsoon. Figs. 5 and 6 show examples of contour diagrams showing duct occurrence frequency over the Indian subcontinent. Ducts can provide communication over very long distances with marginal power; but they also can be a nuisance in a number of ways. Interference from long distance unwanted transmitters and Radar blind holes are the obvious examples.

Just as in dielectric wave guides, for any particular tropospheric duct, there is a maximum wave length λ_m beyond which ducting will not occur. The following approximate relationship can be used to estimate the probability of ducting for any wave length, if the duct dimensions are known:

$$\lambda_m = 8.5\, h^{3/2} \times 10^{-4}$$ where h is duct thickness in metres.

Typical values of cut-off wave lengths are:

m metres	0.01	0.1	1	10
h metres	6	24	120	600

4. Rain and Water Vapour Attenuation:

Rain attenuation is caused by two factors. Firstly, the electric field associated with radio wave induces displacement current in the water drop and because of the high dielectric constant of water compared to air, the currents are heavy especially at higher frequencies. Secondly, such currents induced in the droplets are sources of secondary radiation in all directions and the strength in the direction of interest is weakened. In tropics where heavy rain is characterised by drop sizes as big as 6 or 7 mm, the liquid water content can go up to as high as 10 gm per cubic metre. While the physics of rain attenuation is well understood to enable one to calculate the attenuation per km of path for given rain characteristics, it is the rain morphology, its cumulative distribution statistics, the variability in the rain cell length and drop size distribution which are not available with required accuracy. Here again the problem is that the rain gauges employed by the meteorology departments have integration times too long to be of any use in microwave communications.

Microwave frequencies above 20 GHz also suffer attenuation because of molecular absorption. The energy of the radio wave is used up in heating the gases, in ionising or exciting atoms and molecules etc and molecules pass from a lower energy to a higher energy. Since the energy levels of the atoms and the molecules are discrete, this absorption is resonant or selective in nature. The most important gases in this context are water vapour and oxygen. Figure shows the specific attenuation for a wide frequency range. Since the water vapour contributes for the resonance at the lowest frequencies, the distribution of water vapour is of primary importance in designing tropospheric links especially in the tropics.

In addition, the water vapour profiles as we have seen earlier essentially dominate the radio refractivity variations which are important in microwave and radar communications. With this in view,

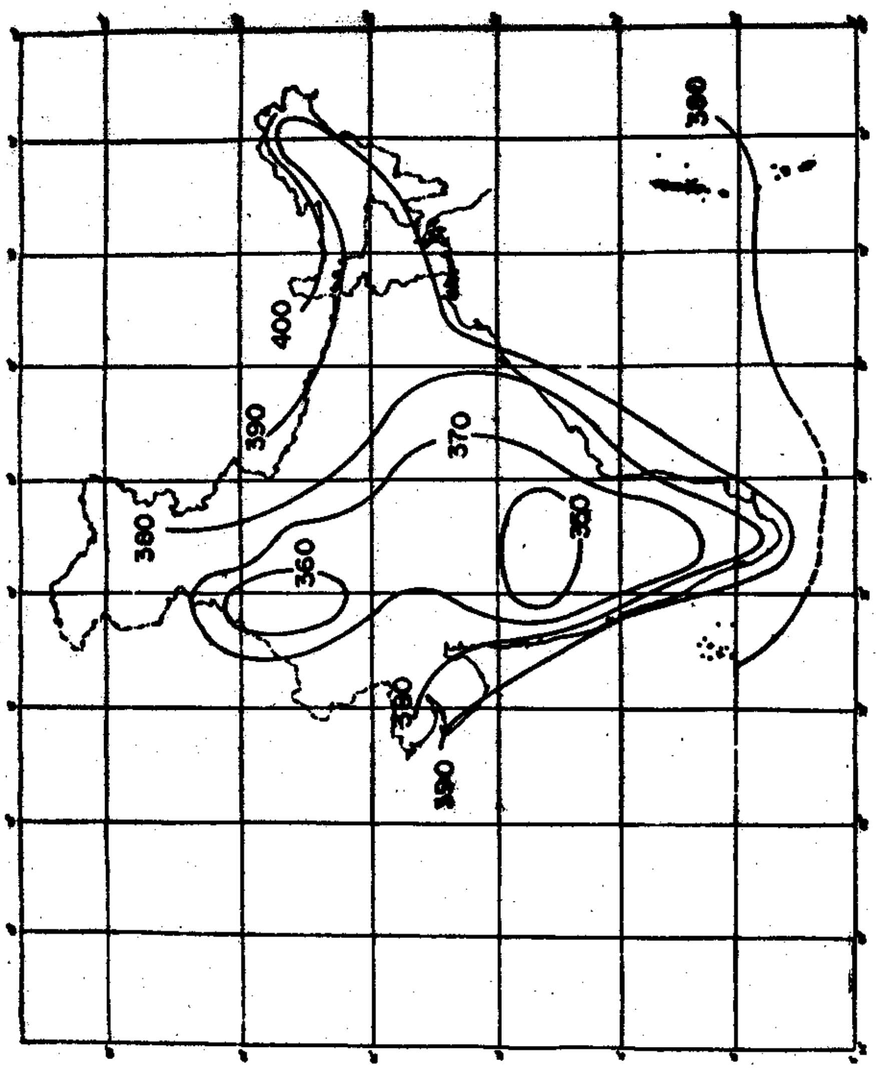
we in India, have brought out recently a water vapour atlas using a comprehensive data base of radiosonde measurements of the Indian Meteorological Department. Figs. 9 to 10 show examples of water vapour contours and distribution. Though the specific attenuation for water vapour is low compared to rain, the rain cells are always limited to a few kms only, while the terrestrial radio links will have to contend with water vapour all through its path. Fig. 11 shows the Refractivity profile over Assam valley at dawn.

5. Troposcatter Parameterisation:

There is always a certain amount of turbulence in the atmosphere, and more so in the boundary layer. While the RRI profiles derived from Radiosonde data are too gross to show this fine structure, the serrations on N (h) curves obtained by a microwave refractometer demonstrate how turbulence modulates the Radio refractivity. Atmospheric turbulence by itself has evolved into a vast discipline and is not within our scope of discussion here. Basically, the laminar flow, when its velocity exceeds a critical value, turns turbulent, cascading of energy from large scale eddies to smaller ones proceeds until the eddies are so small that their energy is dissipated due to the viscosity of the medium. But the eddies where the energy is conserved are known as the inertial region and can be characterised interms of a 3-dimensional structure constant to represent the mean square variations in refractivity. The variance in the logarithm of the amplitude of the received signal is proportional to

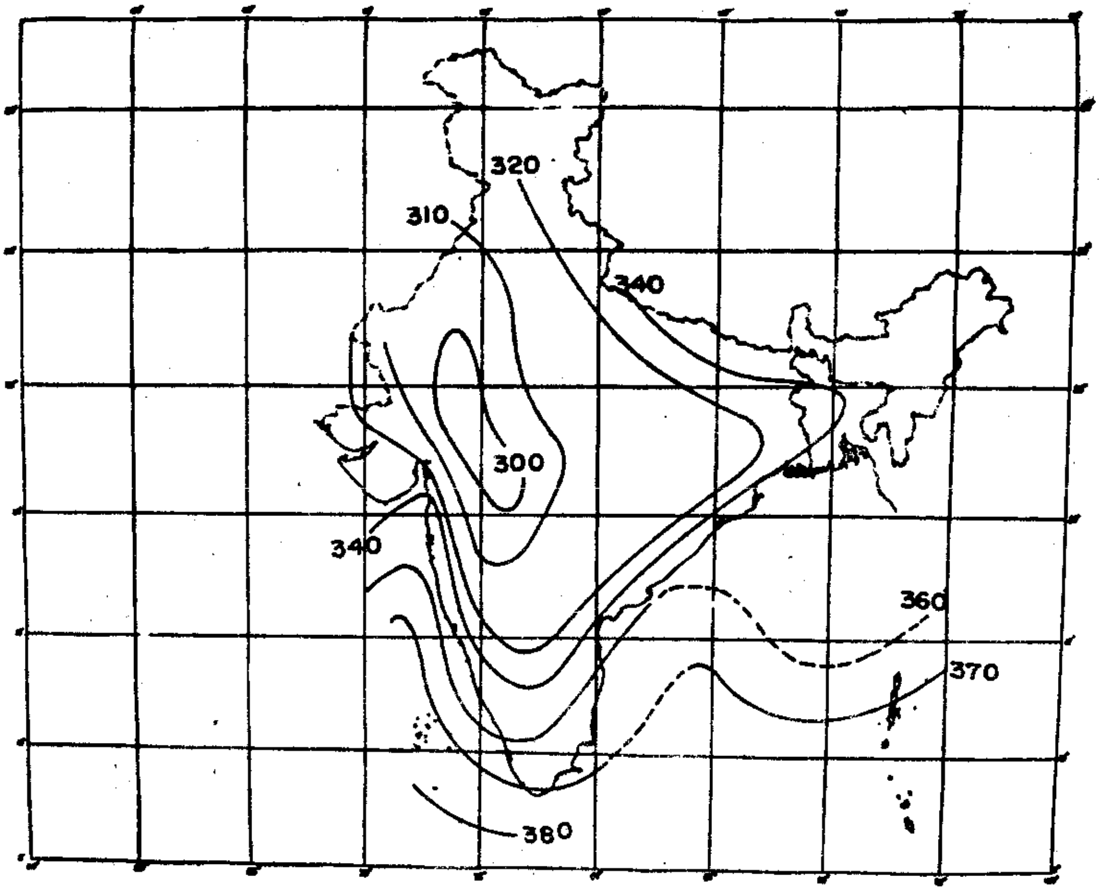
$$\left(\frac{2\pi}{\lambda}\right)^n \quad \Sigma C_n^2$$

This structure constant C_n^2 will decide the scattering capability of the medium and it is necessary to evolve its morphology at any place to design optimum powers for communication. It is also necessary to take this constant into account for optimising the antenna sizes because of aperture-to-medium coupling.



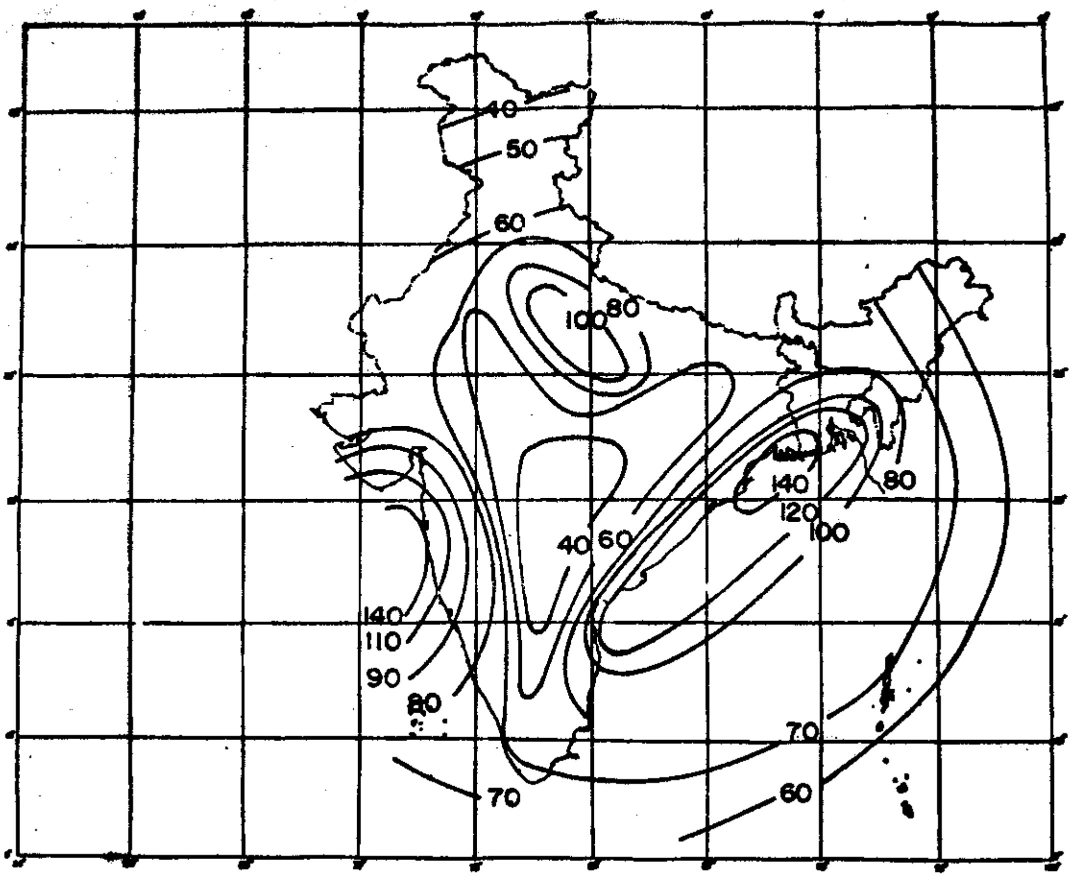
Distribution of surface refractivity in July (0300 [illegible])

FIG 1



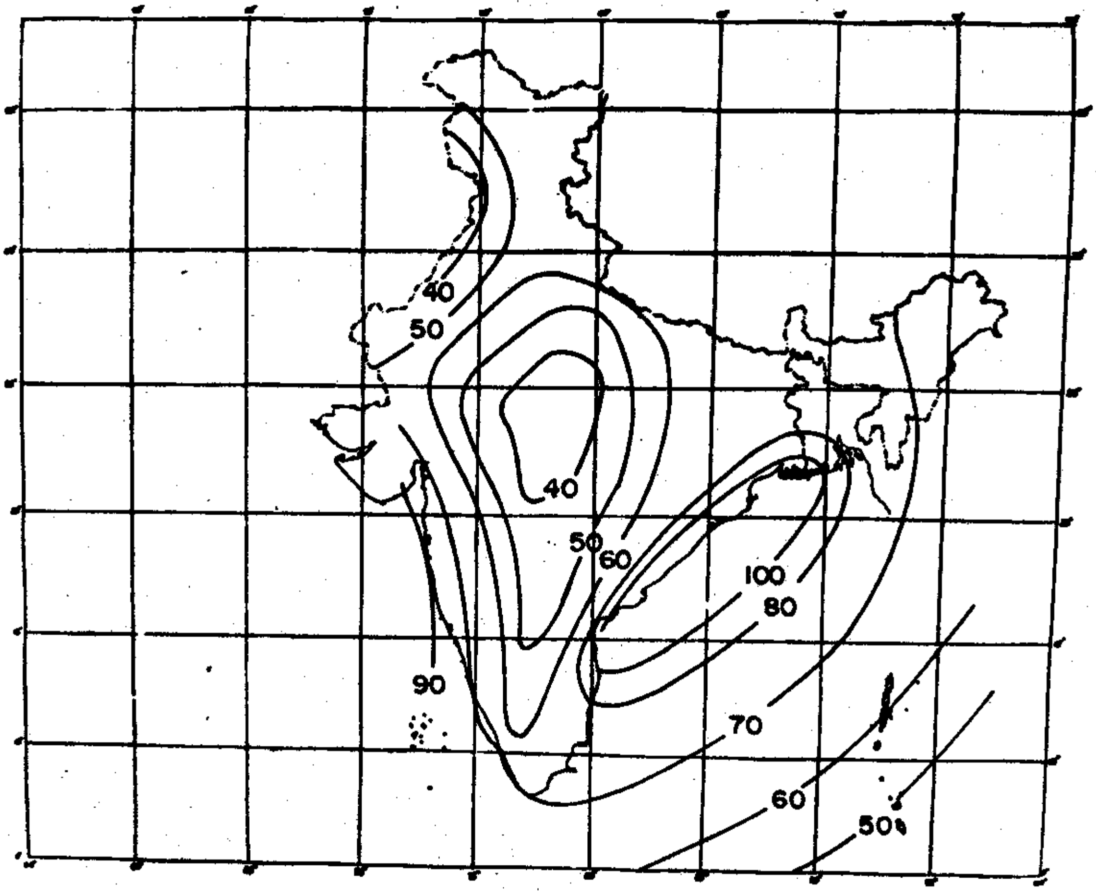
Distribution of surface refractivity in December (0300 GMT)

FIG 2



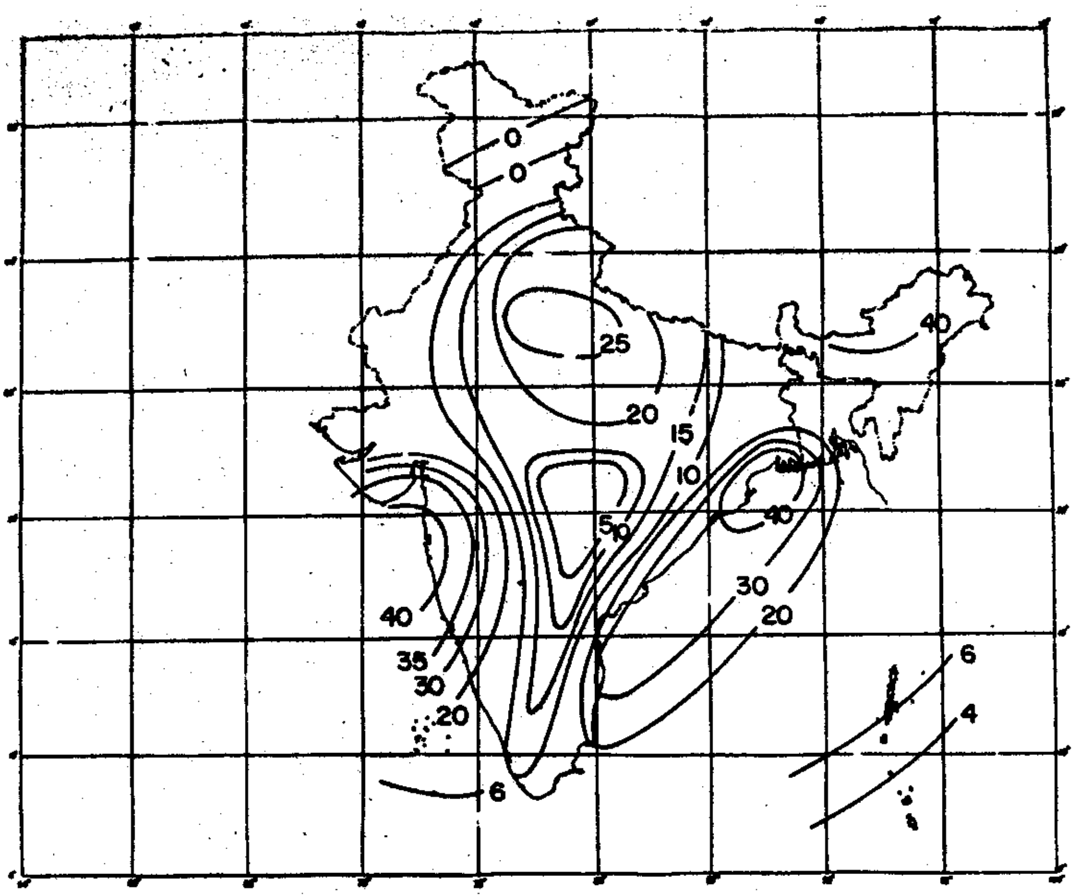
Initial refractivity lapse rate in May (0000 GMT)

FIG 3



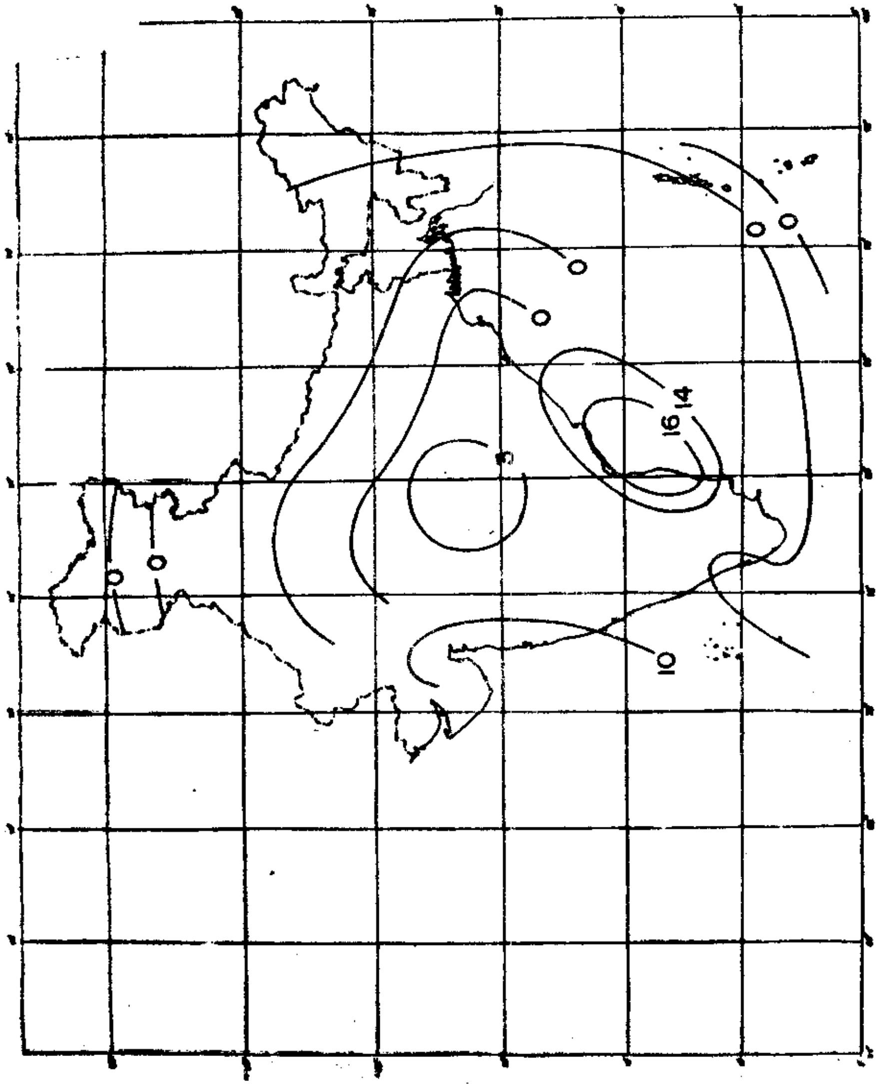
* Initial refractivity lapse rate in August (0000 GMT)

FIG 4



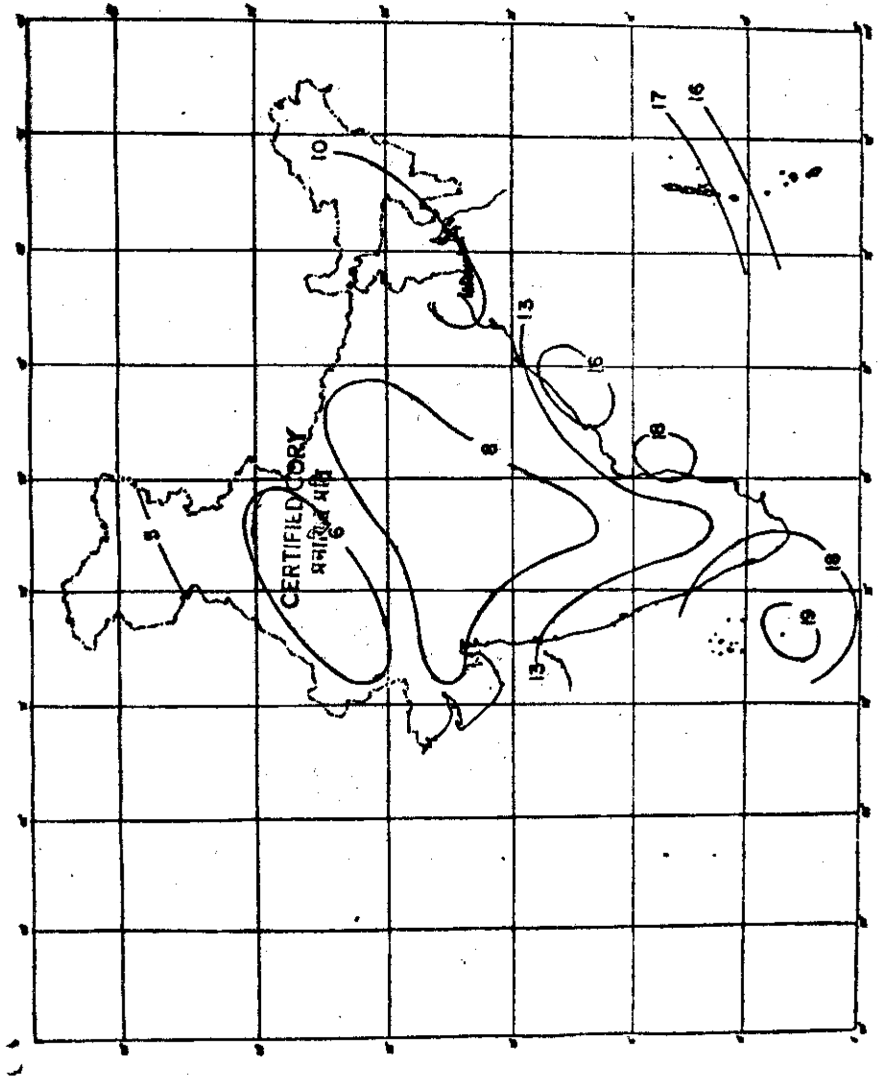
* Surface duct occurence probability in May (0000 GMT)

FIG 5



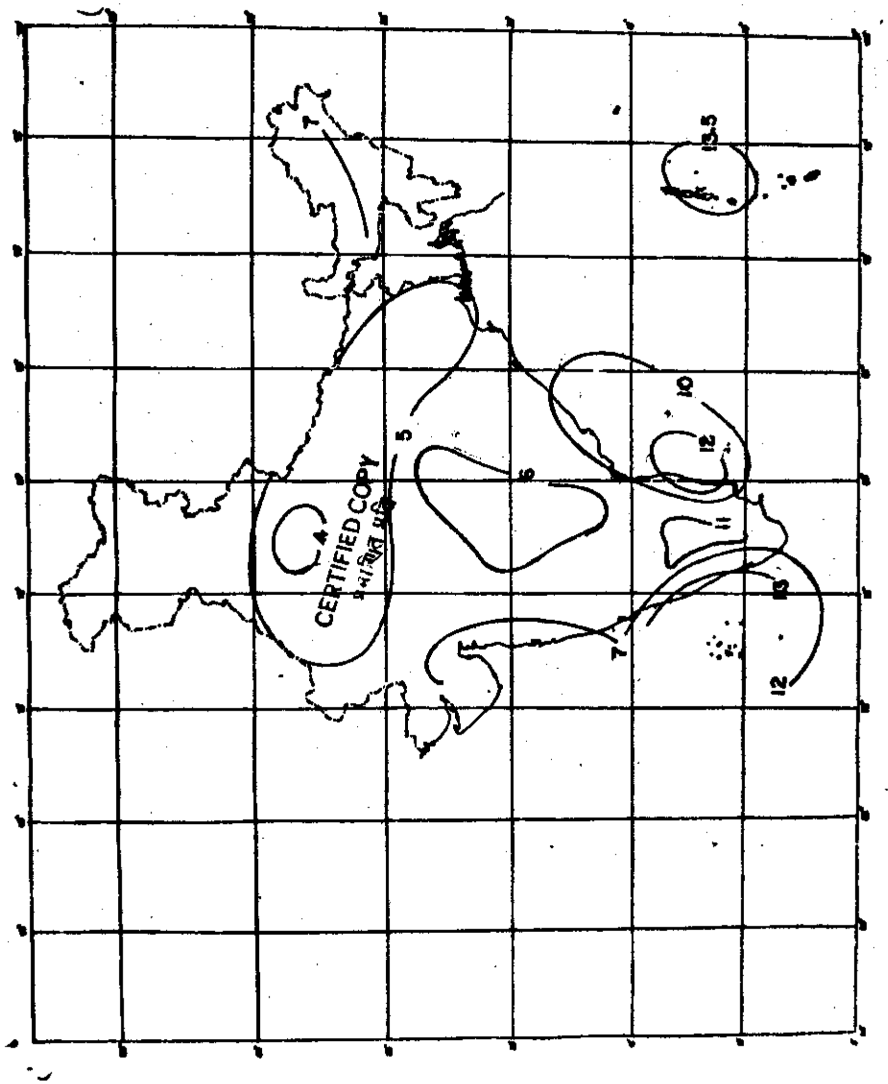
Surface duct occurrence probability in July (0000 GMT).

FIG 6



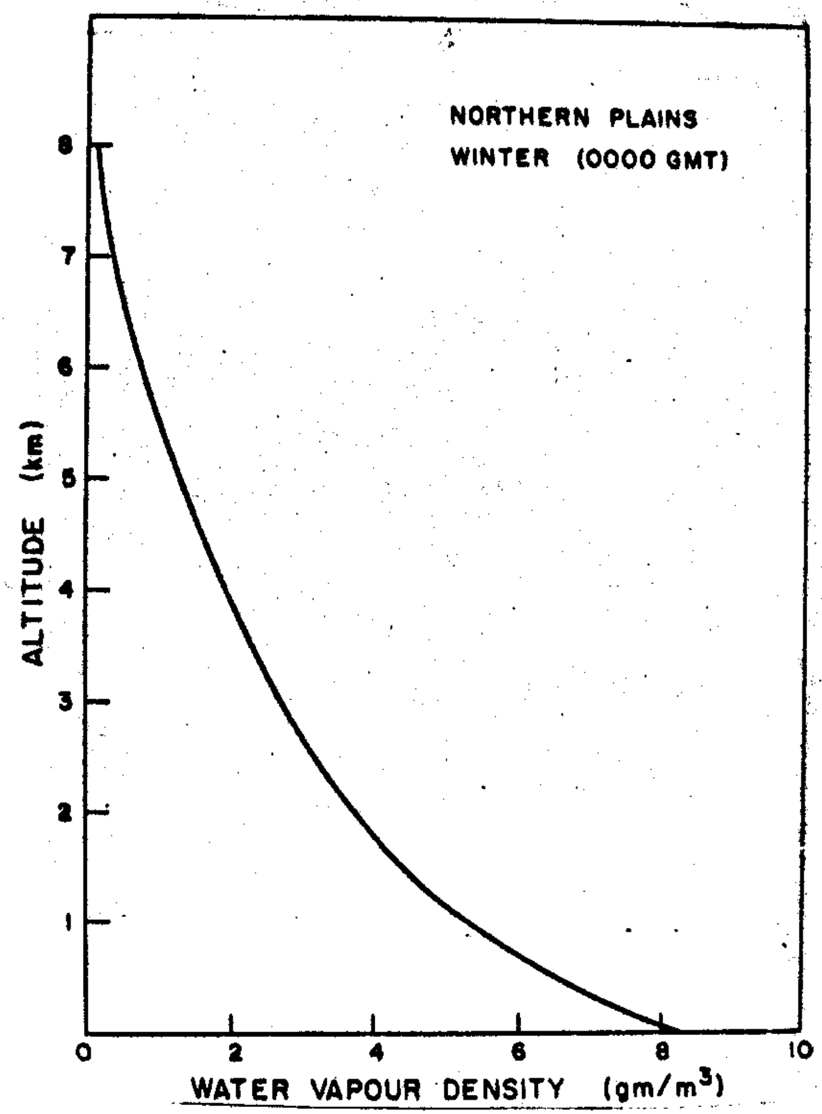
Distribution of water vapour density over surface in December (0000 GMT)

Fig. 7



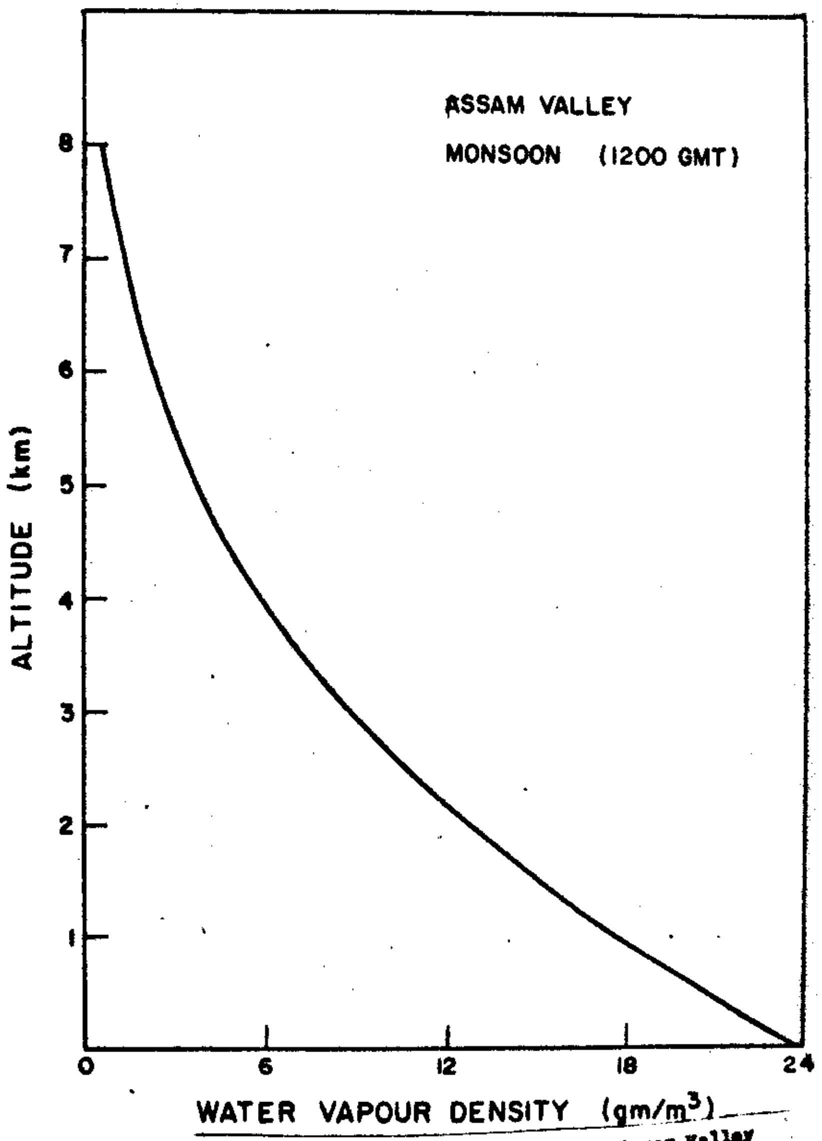
Distribution of water vapour density at 900 mb level in December (0000 GMT)

FIG. 8



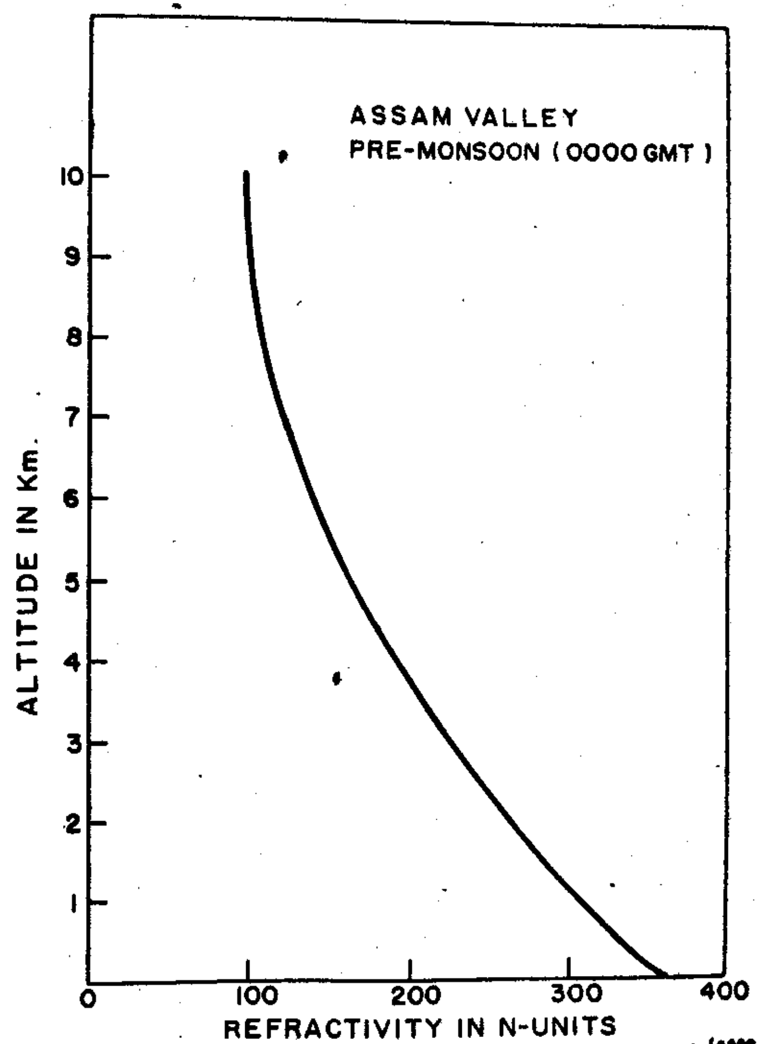
Water vapour density profile over Northern Plains in winter (0000 GMT)

Fig. 9



Water vapour density profile over Assam Valley in monsoon (1200 GMT)

Fig. 10



Refractivity profile over Assam valley in premonsoon (0000 GMT)

FIG. 11

SPECIAL PROBLEMS IN TROPICAL IONOSPHERIC COMMUNICATIONS

B M REDDY

1. INTRODUCTION

Some of the most serious problems in tropics are caused by (a) large local time variations of foF2 critical frequencies especially during sunrise hours and (b) large horizontal latitudinal gradients in the F-region electron densities associated with geomagnetic anomaly. Similar problems may arise with respect to the gradients in the mid-latitude trough region at night; however, no discussion on this aspect is included here since this is restricted to low latitude issues.

2. PROBLEMS ARISING OUT OF STEEP TEMPORAL GRADIENTS PARTICULARLY DURING DAWN

The local time gradients during sunrise hours are known to plague HF communications particularly at low latitudes. This problem is extremely important in countries where the main stay of point-to-point communications continues to be the HF band supported by ionosphere. Specific mention may be made of the following points in this connection.

(a) HF link operators are expected to get their frequencies cleared from the appropriate Governmental Authority well in advance and it is usual practice to fix one frequency for the day-time and another for the nighttime. The use of the night frequency during sunrise will require much more power than is normally permitted while the frequency allocated for the day-time will be higher than the MUF during the transient period.

(b) Point-to-point links normally use inexpensive tuned directional antennas and frequent change of operational frequency is deleterous from the point of view of antenna efficiency.

(c) In case of long distance circuits in the East-West direction involving multi-hop F-region propagation, the problem of the sunrise period will extend to a large number of hours, because the different F-region reflection points will fall in the transient location at different periods.

Fig.1 shows the diurnal variation in foF2 for Kodaikanal and Ahmedabad for winter during low solar activity period. The normalised hourly percentage changes in foF2 are shown in the lower portion of the figure. The significance of the percentage changes is important because even assuming that changes in the link frequency are permitted antenna design considerations restrict such changes. The normalized percentage changes are calculated using the following relation.

$$\text{Normalized percentage change in } (foF2)_{\text{hour } x} = \frac{(foF2)_{\text{hour}(X+1)} - (foF2)_{\text{hour } x}}{(foF2)_{\text{hour } x}} \times 100$$

The most important feature of this diagram is the extremely steep percentage increase in foF2 which is as high as 230 percent at 5 A.M. for Kodaikanal. Of course, the very low nighttime minimum values in foF2 at low latitudes are essentially responsible for these abnormally high percentage increases. It may also be noticed from the figure that the dusk changes are not so spectacular especially when the percentage changes are considered.

Fig.2 shows variation of normalized percentage changes in foF2 at dawn for Kodaikanal and Brisbane during the years 1957 to 1967. The solar activity variations modulated by seasonal variations as the running average sunspot number decreased from about 200 to 10, are very obvious. The magnitude of variations at Brisbane (Geo. Mag. Lat. 35.7°S) during the dawn are only marginal and show very little solar activity dependence. For Kodaikanal (Geo. Mag. Lat. 0.8°N), however, the percentage changes are spectacularly large and the variation with solar activity is very significant. A very interesting feature is that during high solar activity period the percentage values are larger at Brisbane, whereas at Kodaikanal the changes are insignificant. This figure convincingly demonstrates the seriousness of this problem at low latitudes for medium and low solar activities.

3. PROBLEMS DUE TO LARGE SPATIAL GRADIENTS IN THE EQUATORIAL ANOMALY REGION

The equatorial zone of approximately 30° wide centered at the geomagnetic equator exhibits several peculiar ionospheric properties, one of which is the large spatial gradients that affect ionospheric radio propagation in a number of ways. If we consider the anomaly peak in the northern hemisphere to be at 15°N Geo. Mag. Lat. and if a north-south HF circuit is operating such that the reflection point is on either of the sides of the peak and if the frequency of the link is very close to the MUF, a peculiar situation arises. If the point of reflection is equator-ward of this anomaly peak, the radiowaves incident on the ionosphere for the northern circuit will continuously come across increasing level of

electron density on two counts (a) due to the vertical gradient as the radiowave penetrates higher into ionosphere (b) due to the horizontal gradient as the wave progresses in the direction of increasing electron density. On the other hand for the same link in the return direction, the horizontal gradient is reversed. Thus the real MUF values for the two opposite directions in the same circuit can vary by a large margin depending on the angle of incidence and on the magnitude of the horizontal gradient. In fact, rather frequently, especially when the operating frequency is close to the MUF (calculated ignoring horizontal gradients), only one way communication would be possible. This has been one of the unusual complaints in the Indian Sub-continent. To understand the magnitude of this problem we have used the Aoutteee II data (f x F2), so that spatial resolution of the data can be high compared to ground based data. Assuming simple parabolic distribution, vertical electron density profiles are derived in the F2 region and the latitudinal gradients at fixed heights are computed. These horizontal gradients along the ray path are compounded with the vertical gradients to calculate the change in the real MUF for varying magnitudes of horizontal gradients. Fig.3 shows some sample results of the change in MUF for different gradients for three angles of incidence. As expected, the shift in the MUF increases with increasing angles of incidence (at the ionosphere). It has been observed that gradients between 3 to 4 electrons per cubic centimeter per meter are usually prevalent in the equatorial anomaly region. Fig.3 is given only to illustrate the problem and results from more rigorous three dimensional ray tracing methods which only confirm this are beyond the scope of this paper. However, the point to be noted is that even for modest angles of incidence such as 50 and electron density gradients of $3.5/cm^3/m$, the shift in actual MUF is from 15 MHz to 18 MHz while in the opposite direction the effective MUF will fall to 13 MHz. Thus, employing a frequency higher than 13 MHz will result only in one way communication.

4. ATMOSPHERIC RADIONOISE

Because of the predominantly rural nature of the tropical countries, man-made noise is hardly of any consequence except in a few big cities. However, atmospheric radio noise (ARN) is a very serious problem to be contended in the tropics (system noise and cosmic noise are far lesser in LF, MF and HF bands). The predictions of CCIR were found to be gross over-estimates for Indian zone. The Research Department of All India Radio conducted comprehensive observations and Table 1 shows the measured (M) and CCIR-predicted (P) values for three locations in India for different seasons and local time periods.

TABLE - 1

COMPARISON BETWEEN MEASURED AND CCIR PREDICTED MEDIAN VALUES OF ATMOSPHERIC NOISE [dB (μv/m)] AT 155 kHz FOR DELHI, TRIVANDRUM AND GAUHATI FOR 6 kHz B.W.

SEASONS	TIME BLOCK (HOURS) (L.M.T)	DELHI		TRIVANDRUM		GAUHATI	
		M	P	M	P	M	P
WINTER	1200-1600	12	5	12	15	6.5	7
	1600-2000	16	25	13	26	9.5	23
	2000-2400	22	30	16.5	32	14	28
SPRING	1200-1600	-	-	15	29	14	24
	1600-2000	-	-	20	37	28	35
	2000-2400	-	-	29	38	31.5	37
SUMMER	1200-1600	25	40	13	33	11	40
	1600-2000	29	35	25	33	21	36
	2000-2400	31	38	31	34	32	41
AUTUMN	1200-1600	14	28	15	29	-	-
	1600-2000	22	36	22	36	-	-
	2000-2400	24	38	30	38	-	-

5. DAY-TO-DAY VARIABILITY

Long distance HF communication supported by the F-region is essentially controlled by the two parameters, foF2 and $M(3000)F_2$ which together decide the MUF. While prediction of the median values of these parameters for any particular month can be made with some degree of accuracy, it has not been possible to predict their day-to-day changes. These large day-to-day variations, especially manifested in foF_2 variations are apparently unrelated to any specific solar or geomagnetic events and may be termed as F-region geophysical noise. Several studies made at NPL, New Delhi using low latitude data showed little correlation between the daily foF_2 variations and standard solar and geophysical indices.

Rather interestingly, the storm-time variations in MUF during geomagnetic storms are within the daily fluctuations. At tropical latitudes, foF_2 values marginally decrease during storms while $h_p F_2$ increases at all latitudes. In general, whatever the reasons, whenever the changes in both foF_2 and h_pF_2 are in the same sense, the consequent changes in MUF will only be marginal because of this compensating tendency. Figs. 4 and 5 show how the variations can be indexed for a tropical station.

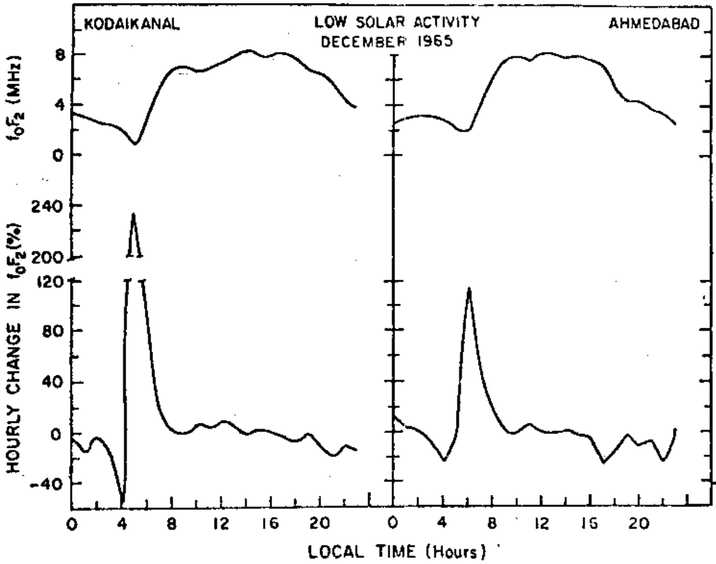


FIGURE 1. DIURNAL VARIATION OF FOF2 AND THE CORRESPONDING NORMALIZED HOURLY PERCENTAGE CHANGES IN FOF2 FOR KODAIKANAL AND AHMEDABAD. REMARKABLY LARGE PERCENTAGE INCREASE OF 230% IN FOF2 FOR KODAIKANAL AT 0500 LT IS AN IMPORTANT FEATURE TO BE NOTICED.

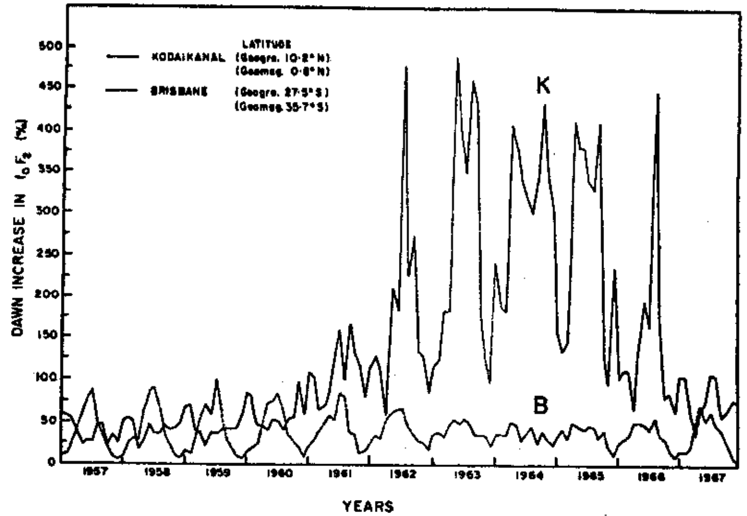


FIGURE 2. SPECTACULARLY LARGE VALUES OF PERCENTAGE INCREASE IN FOF2 FOR KODAIKANAL DURING MEDIUM AND LOW ACTIVITY PERIODS CAN BE NOTICED HERE. THE LATITUDINAL DEPENDENCE OF DAWN TIME FOF2 CHANGES CAN BE APPRECIATED BY COMPARING KODAIKANAL AND BRISBANE.

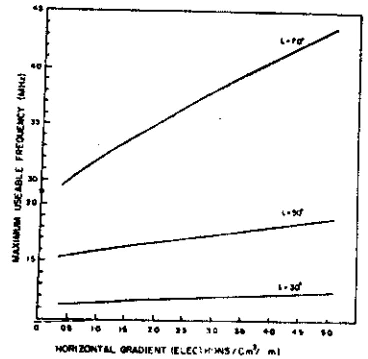


FIGURE 3. THE EFFECT OF HORIZONTAL ELECTRON GRADIENTS ON MAXIMUM USEABLE FREQUENCIES IS SHOWN IN THIS FIGURE. THE CONSEQUENCES CAN BE SERIOUS FOR HIGH ANGLES OF INCIDENCE-THAT IS FOR LONG PATH DISTANCES.