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SOME PROBLEMS IN IONOSPHERIC COMMUNICATIONS IN THE TROPICS

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Some problems in Ionospheric Communications in the Tropics

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1. Introduction: The radio propagation characteristics in the tropical environment are significantly different from those at mid and high latitudes. With the increasing sophistication and reliability of electronics hardware of radio systems, it is important to assess the advantages offered and the constraints imposed by local propagation media to design optimal communication systems. The tropical ionosphere is protected by the terrestrial magnetic field from the invasion of the storm-time solar wind particle effects that disrupt HF communications for long periods at high latitudes. The effects of the consequent ionospheric storms that drastically deplete the electron population at mid and high latitudes are also marginal in the tropics. The only flare-induced deleterious effect on communications in the tropics is the short-wave fadeout which may last upto 20 to 30 minutes for intense flares. Also the tropical ionosphere is densely populated with charged particles (because of low solar-zenith angles) and thus can support communications at relatively higher frequencies resulting in better utilisation of the HF spectrum.

However, there are several special problems too. Most obvious are the large day-to-day variability, intense atmospheric radio noise, large spatial and temporal gradients and intense spread F. We will discuss some of these problems in detail.

2. Day-to-Day Variability in F Region Parameters

The state of art allows credible predictions as far as the median MUF parameter is concerned. Such median predictions by definition hold good only 50% of the time. The F region is subject to a large day-to-day variability which is apparently unrelated to any specific solar or magnetic event. It will be necessary to scale down the working frequencies below the predicted MUF by various degrees to attain increased reliability levels. The extent of this variability is dependent on geographical location, local time, season and solar activity; to optimize the frequency usage, it is

imperative to know the morphology of this day-to-day variability. Rush et al. (1974) have studied the day-to-day variability of f_oF2 and h_mF2 at mid-latitudes and have concluded that f_oF2 variations are more important than h_mF2 variations in affecting HF communications. Some studies (Aggarwal et al, 1979 and Aggarwal, 1985) were reported from India in recent years using the long series of Indian ionospheric data. Fig.1 shows the coefficient of variation in f_oF2 for Kodaikanal for the low solar activity year of 1975. Coefficient of variation is defined as ratio of standard deviation to its average value in per cent. The effect of this large day-to-day variability is two-folw:since all the users have to choose frequencies much lesser than predicted MUF values, the available frequency spectrum is reduced; at frequencies far less than the MUF values, the power requirements steeply go up resulting in expensive equipment and in avoidable pollution. Thus the necessity for accurate evaluation of the day-to-day variability cannot be over-emphasized.

3. HF Communication Problems due to Large Spatial and Temporal Electron Density Gradients

The rapid variations of F region critical frequencies during sunrise hours and the large horizontal latitudinal gradients in the F region electron densities associated with geomagnetic anomaly cause serious problems to HF communications at low latitudes (Lakshmi et al., 1979). Fig.2 shows the percentage change in electron density compared to the previous hour for winter during the low solar activity period of 1965. As can be expected, the changes are spectacularly large at Kodaikanal and become modest as the latitude increases. The problems posed due to such rapid dawn transition are multi-faceted. Typically HF link operators employ one daytime frequency and one nighttime frequency. The use of nighttime frequency during sunrise will require much larger power than is normally permitted while the frequency allocated for the daytime will not be supported during such transition by the ionosphere. Also, point-to-point links normally use inexpensive tuned directional antennas and frequent change of operational frequency is not possible. The obvious remedy of course is to have a third frequency allocated for the transition period. This third frequency has to be judiciously selected from a study of long series of observations during transition periods. The problems posed by large spatial gradients are particularly serious in the equatorial zone though similar problems do exist in the mid-latitude trough region. For example, if we consider the equatorial anomaly peak in the northern hemisphere to be at 15^{o} north geomagnetic latitude and if the north-south HF circuit is operating such that the reflection point is on either side of the peak, a peculiar situation arises. If the point of reflection is equatorward of this anomaly peak , the radiowave incident on the ionosphere for the northern circuit will continuously come across increasing levels of electron density on two counts, namely, the one due to the vertical gradient as the radiowave penetrates higher into the ionosphere and the other due to horizontal gradient as the wave progress towards the direction of increasing electron density. On the other hand for the same link in the north-to-south direction the horizontal gradient is reversed while the vertical gradient still continue to be positive. Fig.3 shows how the maximum usable frequency changes as the horizontal gradient transcends from negative to positive values for three different angles of incidence at the ionosphere. It was observed from actual observations from top-side sounder satellite that horizontal gradients of three electrons per cc per metre do exist in the equatorial ionosphere which may yield MUF values ranging between 20 MHz and 39 MHz for a predicted MUF of 28 MHz. Thus HF communication in one direction only is possible if a frequency predicted assuming zero gradient is used.

4. Magnetic Storm Effects on HF Communication

Magnetic storms are known to be a consequence of interaction between the terrestrial upper atmosphere and enhanced solar wind. While the ionospheric storm behaviour (Matsushita, 1950; Maeda and Sato, 1959 and Reddy et al., 1967) is complex and defies a unique description, the following simplified picture is useful in modelling HF communications. During the main phase, the electron densities are depressed at mid and high latitudes while they increase to a lesser extent at low latitudes. The F region height however, increases at all latitudes. The increased height and enhanced f_oF2 at low latitudes partly compensate for each other and the MUF values undergo but marginal changes compared to the predicted values. This is one reason that continues to retain HF communications at low latitudes as attractive. While the predictability of the storm-inducing solar event itself remains elusive, it is now possible to predict the storms

after seeing the solar event through optical and radio observations. Predictions of ionospheric departures are best done from statistical patterns developed from mass plots of percentage deviations in MUFs from their respective monthly medians. Figure 4 shows the typical behaviour of predominantly positive deviations in MUFs for an equatorial station Kodaikanal (Geomag.Lat. 0.7^{o}N). It is only appropriate to mention here the services available through the chain of Regional and Associated Regional Warning Centres (RWC and ARWC) of International Union of World Day Service (IUWDS). Daily messages regarding nascent solar and magnetic conditions that are received at these centres on near-real-time from observatories around the world are interpreted in terms of disturbances to communications and appropriate warnings are issued to aid radio communicators.

5. F-region Variability during Quiet Periods

Studies conducted on F-region variability (Lakshmi et al, 1986) have revealed that critical frequencies can be considerably lower than their monthly medians during certain groups of magnetically quiet days especially around equatorial and low latitudes. These negative deviations are particularly large during certain local time intervals viz. 0400–0600 hrs and 0800–1000 hrs. These situations also considerably reduce the available radio spectrum and may also require an additional frequency for the link during these periods. Figure 5 shows these negative deviations in foF2 for several groups of quiet days for Kodaikanal (Geomag. Lat. 0.7^{o}N). The local time, seasonal and solar activity dependence of these negative departures can be appreciated from the figure.

6. Problems in Ionospheric Predictions due to the Saturation Effect

The long series of observations available on sunspots makes it an ideal solar index for predictions using statistical techniques. The smooth monthly mean sunspot number (R_{12}) is known to display good correlation with monthly median values of ionospheric parameters. However, with increasing solar activity levels the variation in f_oF2 exhibits saturation, introducing difficulties in predictions and this effect is more pronounced at low latitudes. It is not yet certain if the mean ionizing radiations namely solar EUV and X-rays show good correlation with the surrogate index sunspot number even at high solar activity levels. An attempt was made at the National Physical Laboratory (Lakshmi et al.,1988) to use satellite measurements of EUV flux (170-190 A) during the years 1977-80 to study the dependence of noon f_oF2 at 3 low latitude sations. The results are shown in Fig.5. The right half of the diagram demonstrates the well known saturation effect when sunspot number is used. The left half shows a marked improvement with the EUV flux. While several other indices such as index and the IF_2 have shown slightly improved correlation with ionospheric parameters, EUV - based index will have to be ultimately used after statistically significant data has been collected.

7. Atmospheric Radio Noise levels in Tropics

The performance of any radio system can be severely compromised by the atmospheric radio noise levels prevailing at the receiver antenna. Atmospheric radio noise (ARN) is caused by the naturally occurring inter-cloud electrical discharges in thunderstorms accompanying electric flashes in the earth's atmosphere. They are spread over a wide range of radio spectrum and their intensity bears an inverse ratio to the frequency. Their effects are significant upto 20 MHz. An apriori knowledge of prevailing atmospheric radio noise levels is essential for proper planning of radio system.

As per CCIR recommendations in 1956, planned measurements of ARN levels were made all over the world and based on these measurements global maps for predicting radio noise levels were presented in CCIR Report NO.322 (1963). Large differences have been observed by many workers between the measured values and those predicted from CCIR maps especially in the tropics (Joglekar, 1971, Ghosh, 1972 and Ghosh and Saksena, 1978).

ARN measurements in India were made at different frequencies by All India Radio at several locations on seasonal basis during 1957-1965 and recently in 1987 National Physical Laboratory has started ARN measurements at New Delhi. Figure 6 shows a comparison of AIR observed and NPL observed ARN levels at 2.5, 5 and 10 MHz at Delhi with values predicted from noise maps of CCIR-322-2 (1985). The figure unambiguously reveals that actual measured levels of ARN at Delhi during daytime hours are considerably

higher than CCIR predictions and also the observed diurnal variation in noise levels is much less than CCIR prediction. Similar observations have been also made in regard to other locations in the Indian zone (Lakshmi et al.,1989).

8 Interference due to Anomalous Ionospheric Propagation

There are a number of modes of propagation where the lower parts of VHF band can be supported by the ionosphere; but some of them are beyond the scope of this lecture. The three major possibilities are the following:

(a) The tropical F_2 layer during high solar activity period can have electron densities that are high enough to support single hop propagation of frequencies in Television Band I (47-68 MHz) over distances of 3000-4000 km. The percentage probability can be as high as 10 to 20% on groups of days. Similarly, there are instances when European TV was received in USA during winter (when the winter anomaly in mid latitudes is very pronounced).

(b) Equatorial sporadic E can be intense during daytime, especially in summer. During certain times, the foEs values can exceed 10 to 12 MHz for as high as 5 to 10% time supporting channels 2 and 3 of Band I Television broadcasting, because of the high obliquity factor for propagation via Es layer (due to its low altitude compared to F_2 layer).

(c) The F-layer of the ionosphere can be artificially modified by powerful commercial broadcast transmitter operating close to the plasma frequency and thus generating intense irregularities caused by local heating. These irregular and intense blades of ionisation can reflect frequencies of the order of 40 to 70 MHz.

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Figure Captions

Fig.1 Monthly and diurnal variation of coefficient of variation (V) for foF2 for Kodaikanal during the low solar activity year 1975.

Fig.2 Diurnal plots of percentage changes in electron densities (N_e) for three stations in India for a low solar activity winter month (January 1965).

Fig.3 The changes in MUFs caused by varying values of horizontal gradients for different angles of incidence.

Fig.4 Percentage deviations in MUF(4000)F2 values from their monthly medians for several disturbed days during equinoxes for Kodaikanal.

Fig.5 Percentage deviations in foF2 from their monthly medians for several groups of quiet days for Kodaikanal.

Fig.6 Plots of monthly median noon foF2 values Vs. EUV flux (170-190Å) in arbitrary units and R_{12} for three low latitude stations for equinoxes.

Fig.7 A comparison of observed ARN levels (Fa(dB)) at Delhi by NPL during 1987-1988 with earlier AIR observations (1957-1967) and CCIR predictions for summer, autumn and winter seasons at 2.5, 5.0 and 10.0 MHz.

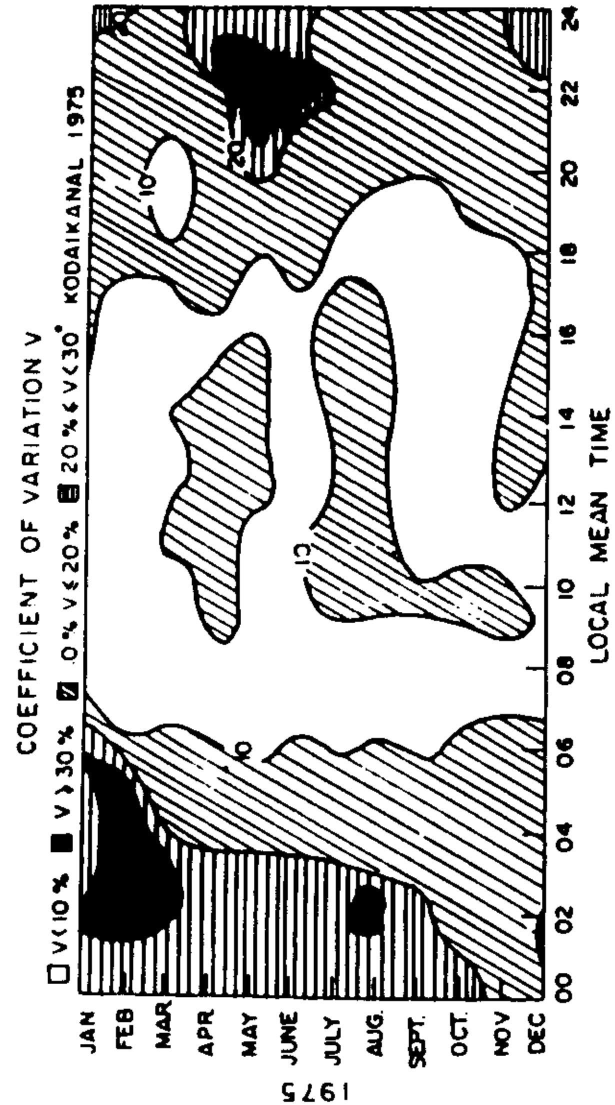


Fig.1

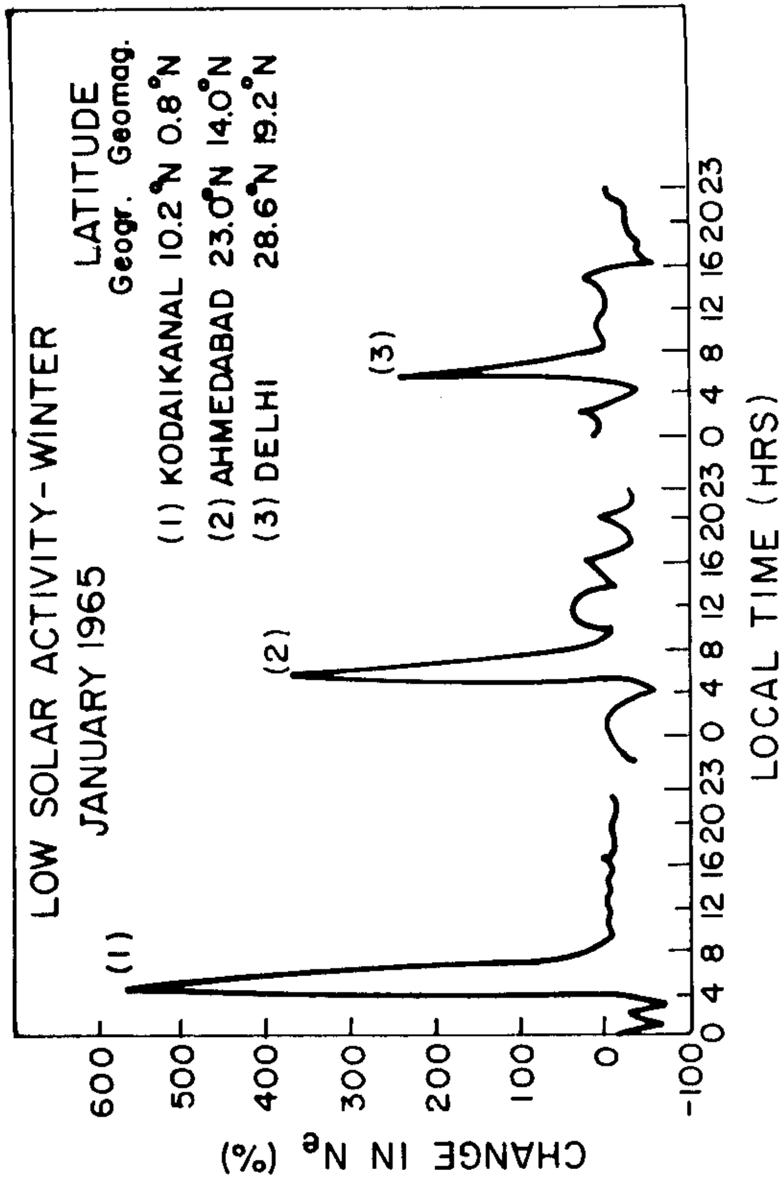

LOW SOLAR ACTIVITY - WINTER
JANUARY 1965
LATITUDE
Geogr. Geomag.
(1) KODAIKANAL 10.2°N 0.8°N
(2) AHMEDABAD 23.0°N 14.0°N
(3) DELHI 28.6°N 19.2°N
(1)
(2)
(3)
600 500 400 300 200 100 0 -100
CHANGE IN N_e (%)
0 4 8 12 16 20 23 0 4 8 12 16 20 23 0 4 8 12 16 20 23
LOCAL TIME (HRS)

Fig.2

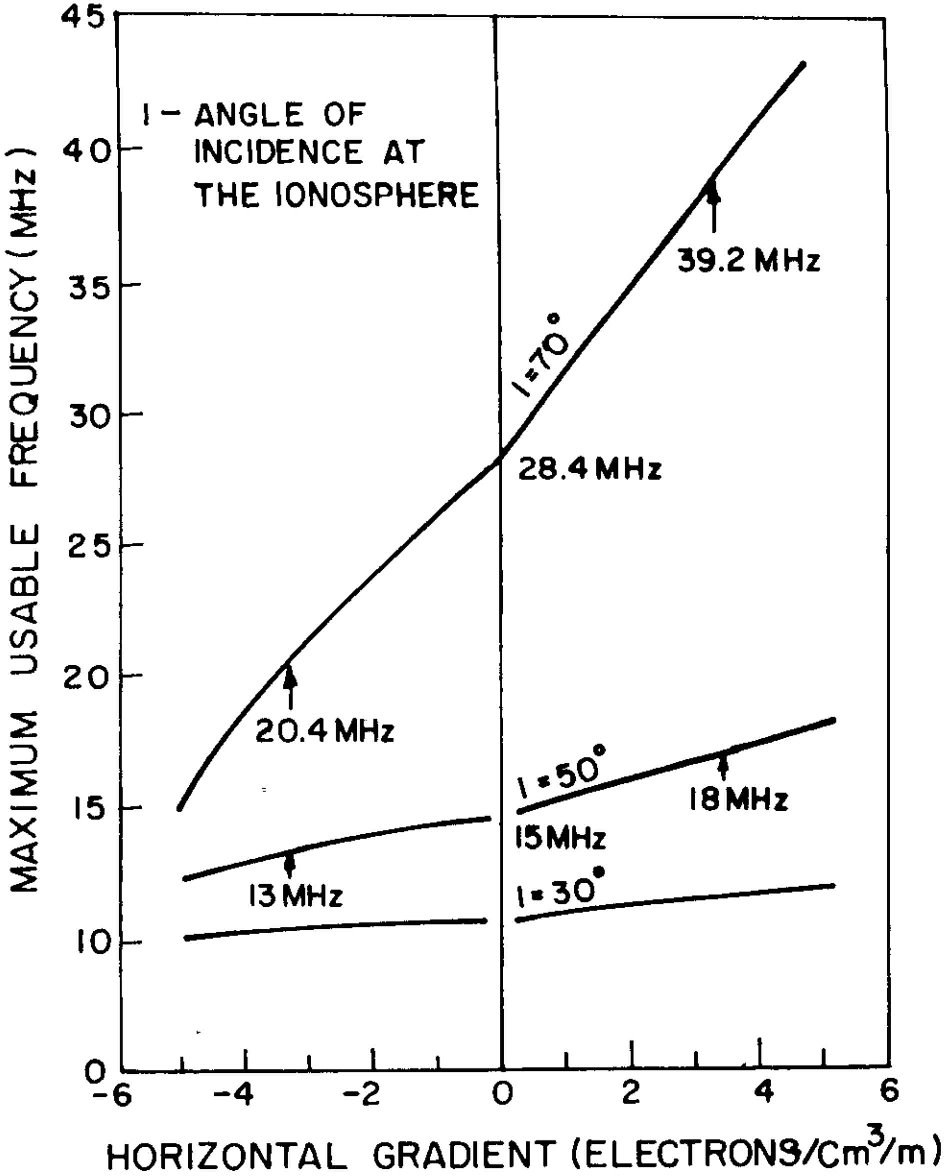

I - ANGLE OF
INCIDENCE AT
THE IONOSPHERE
39.2 MHz
I=70°
28.4 MHz
20.4 MHz
I=50°
18 MHz
15 MHz
13 MHz
I=30°
45 40 35 30 25 20 15 10 0
MAXIMUM USABLE FREQUENCY (MHz)
-6 -4 -2 0 2 4 6
HORIZONTAL GRADIENT (ELECTRONS/Cm^3/m)

Fig.3

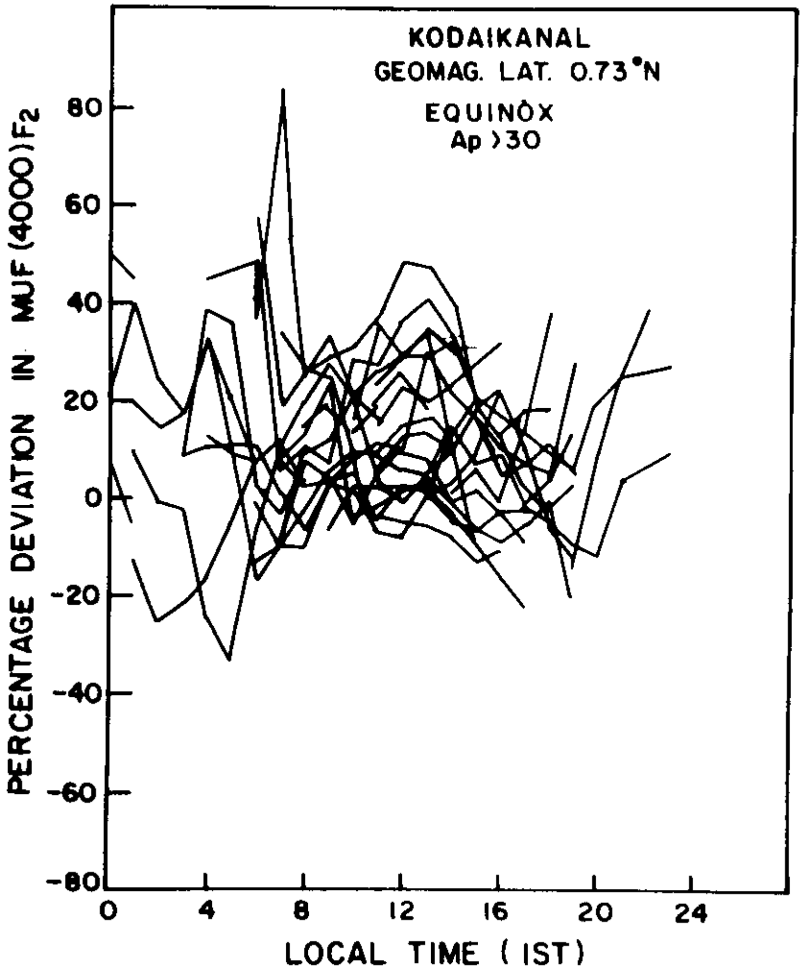

KODAIKANAL
GEOMAG. LAT. 0.73°N
EQUINOX
Ap >30
PERCENTAGE DEVIATION IN MUF (4000) F2
80
60
40
20
0
-20
-40
-60
-80
0
4
8
12
16
20
24
LOCAL TIME (IST)

Fig.4

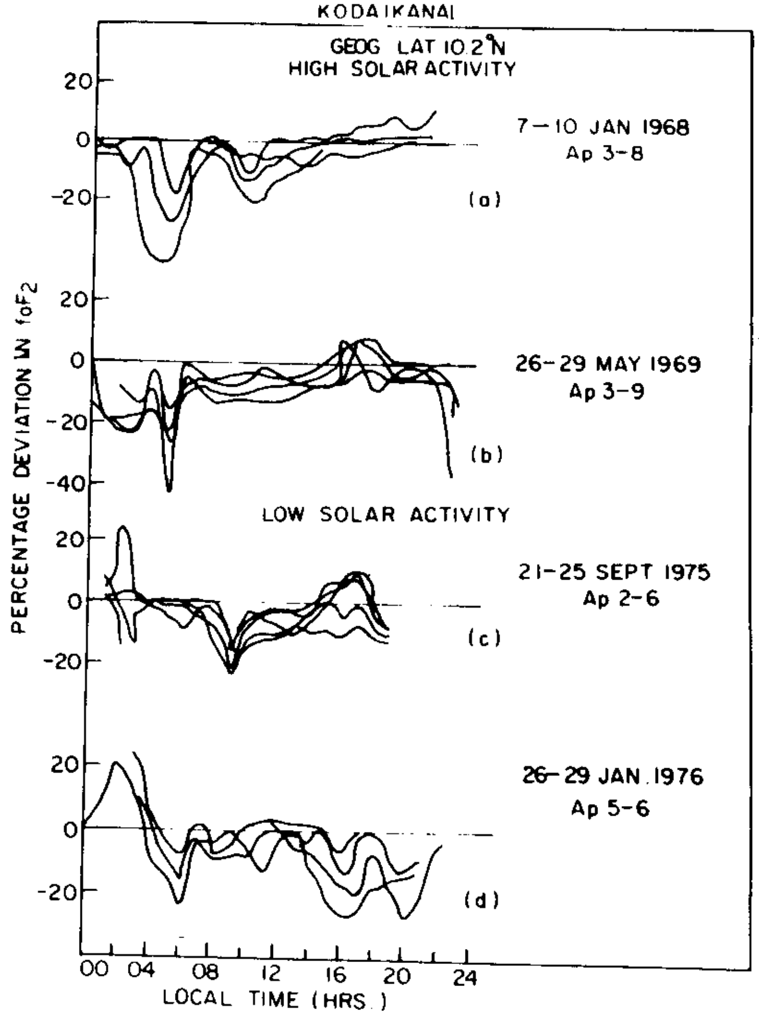

KODAIKANAL
GEOG LAT 10.2°N
HIGH SOLAR ACTIVITY
7–10 JAN 1968
Ap 3–8
(a)
26–29 MAY 1969
Ap 3–9
(b)
LOW SOLAR ACTIVITY
21–25 SEPT 1975
Ap 2–6
(c)
26–29 JAN 1976
Ap 5–6
(d)
PERCENTAGE DEVIATION IN foF2
20
0
-20
-40
00
04
08
12
16
20
24
LOCAL TIME (HRS.)

Fig 5

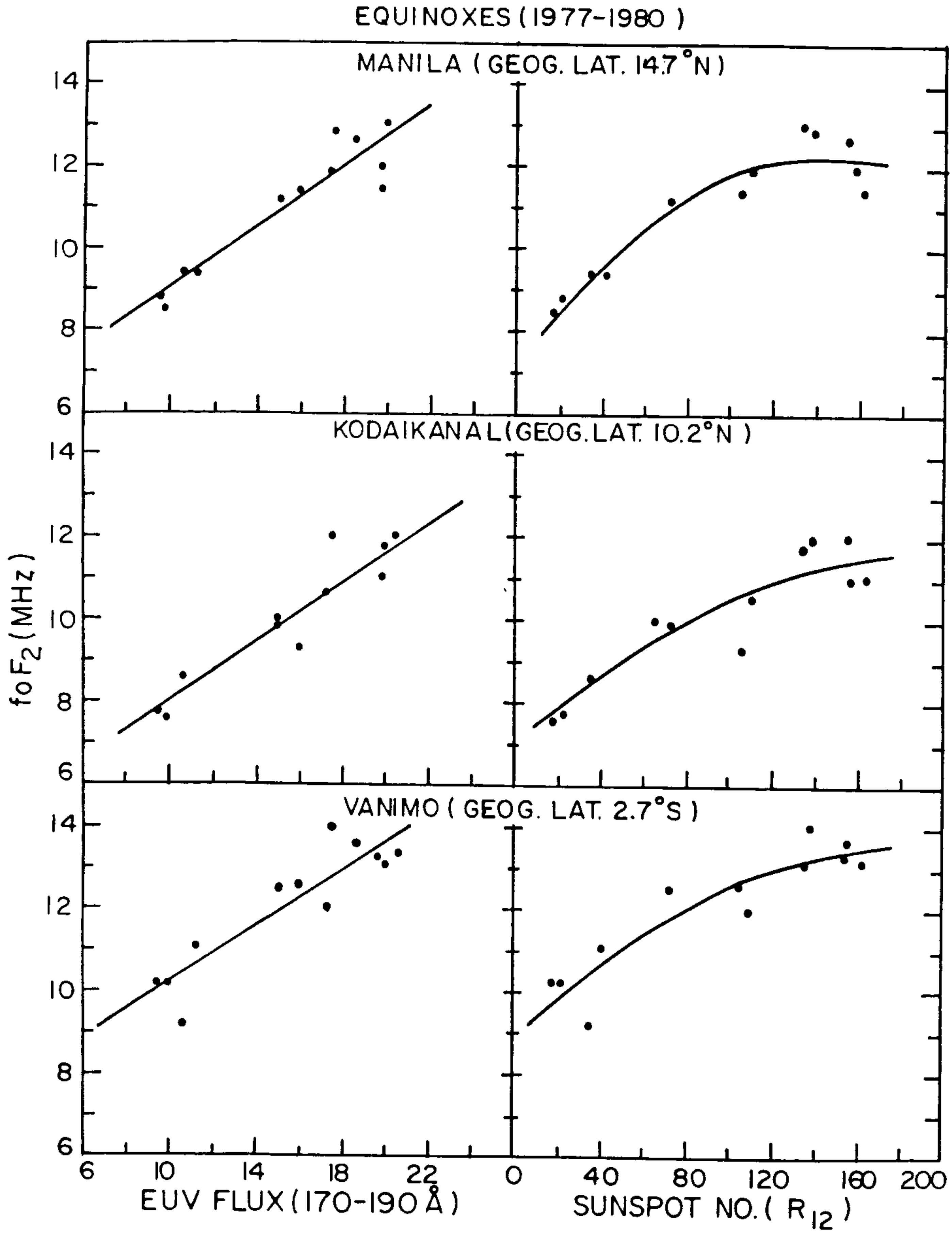
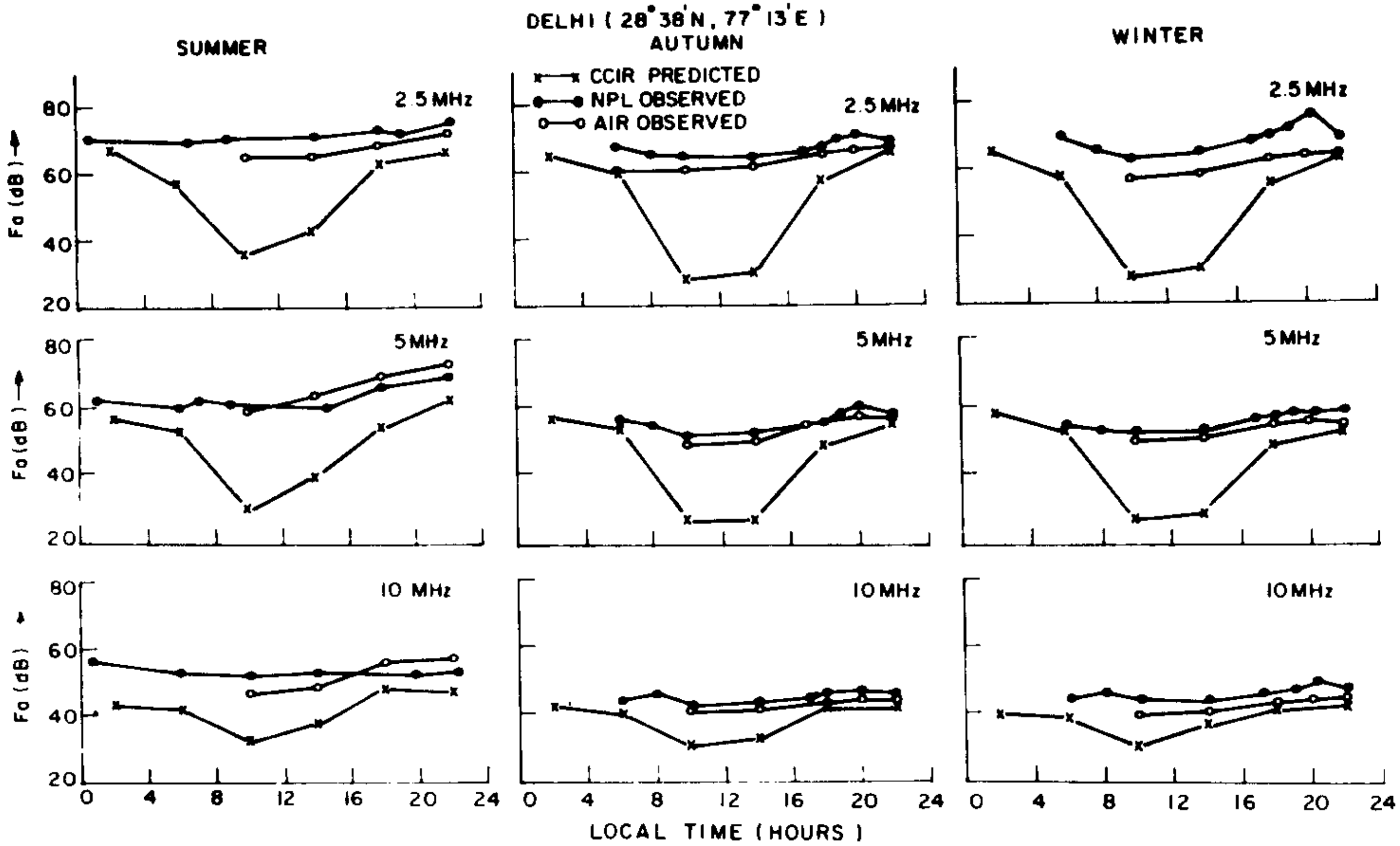

EQUINOXES (1977-1980)
MANILA (GEOG. LAT. 14.7°N)
KODAIKANAL (GEOG. LAT. 10.2°N)
VANIMO (GEOG. LAT. 2.7°S)
foF2 (MHz)
14
12
10
8
6
6
10
14
18
22
0
40
80
120
160
200
EUV FLUX (170-190 Å)
SUNSPOT NO. (R12)

Fig 6



DELHI (28°38'N, 77° 13'E)
SUMMER
AUTUMN
WINTER
CCIR PREDICTED
NPL OBSERVED
AIR OBSERVED
2.5 MHz
5 MHz
10 MHz
Fa (dB)
LOCAL TIME (HOURS)

Fig 7