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TROPICAL IONOSPHERIC COMMUNICATIONS WITH SPECIAL EMPHASIS ON ATMOSPHERIC NOISE AND MAGNETIC STORMS

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Tropical Ionospheric communications with special emphasis on Atmospheric Noise and Magnetic storms

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Introduction:

This report does not include a discussion on the fundamentals and basic physics of the ionosphere. An excellent review was presented by Rishbeth at Trieste in February 1989 and is also available as a publication (Rishbeth, 1988). This report will concentrate on Atmospheric Radio Noise in the tropics and on ionospheric storms for reasons explained in the relevant sections.

The ionosphere is produced essentially by the solar EUV and X-rays at all latitudes and to some extent by the solar particles at high latitudes. The F-layer is the most important region for long distance HF communications though E-layer is also used for shorter distances during daytime. The D-region is a nuisance for HF communications as it absorbs radio wave energy during day-lit hours. D-region can also be used for some specialised services in the LF and VLF bands and also in the VHF band through scatter mechanisms; but any further discussion on these topics is beyond the scope of this presentation. It is known for quite some time now that the solar ionising radiations in the EUV and X-ray regions display a distinct 11-year cycle, similar to the sunspot cycle. It should be added here that the total energy in the EUV and X-ray regions is but an insignificant part of the total solar radiant energy; but it is enough to produce and maintain the ionosphere in the tenuous reaches of our upper atmosphere. For the very reason that EUV and X-rays produce the ionosphere, they do not reach the earth and hence cannot be monitored through ground-based experiments. One is thus compelled to look for a surrogate index that correlates with the ionising radiations, but can be monitored from the earth. One such index with a long series of observations is the Sun-Spot Number (SSN). While the sunspot number has proved to be a good index because of a long series of available data, it is not of much use in short term predictions. With the availability of satellite measurements of the actual ionising radiations, it is hoped that a new index will be developed after statistically significant series of such measurements are available. One such preliminary attempt was made recently by the authors using a limeted set of EUV flux measurements during 1977-80 (Lakshmi et al 1988).

Atmospheric Noise:

Atmospheric radio noise (ARN) also called static is caused by the naturally occurring intercloud electrical discharge 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 30 MHz which includes the broadcasting bands. In any radiocommunication system, noise sets a limit for the satisfactory reception of radio signals. Around 1950's, in view of increasing demand for allocation of frequencies for broadcasting and other communication systems, a need was felt to establish a network of noise measuring stations using standardized method of measurement. As per the CCIR Recommendation in 1956, planned measurement of ARN were made at sixteen stations all over the world, including India during the years 1957-61 and a Report on "World Distribution of Characteristics of Atmospheric Radio Noise" was presented by the CCIR in (1963). However, since only a meagre number of sixteen stations over the whole world were involved, the report could not be comprehensive. All India Radio (AIR) measured ARN levels at four stations in India namely Delhi, Gauhati, Vizag and Trivandrum during 1957-1965 and their results were presented in CCIR Document No. 301 (1966). Ghosh et al (1975) have estimated ARN values for Poona and Nagpur from thunderstorm activity by considering that ARN field strength is directly proportional to the thunderstorm activity in that region. Large differences have been observed by many workers between the measured values and those predicted from CCIR report 322 (1963) especially in the tropics including Indian zone (Joglekar, 1971; Gosh, 1972; Gosh and Saksena, 1978).

National Physical Laboratory (NPL), New Delhi has been measuring average levels of ARN since September 1987 at several frequencies using "Anritsu" Model ML 428 B field strength meter, employing vertical rod aerial and a strip chart recorder (Lakshmi et al 1989). The instrument satisfies CISPR and MIL standards. The ARN level recordings have been made for 16 minutes around each hour. Median, upper decile and lower decile values of ARN field strength in dB u v/m at 1 kHz bandwidth have been worked out from these records. Noise power is expressed by a quantity 'Fa' which denotes ARN field strength in terms of noise power from a short, vertical grounded, loss free antenna in dB above kTob. Here k is Boltzmann constant, b is effective receiver bandwidth in Hz and To is reference temperature taken as 288°K.

En (noise field strength in dB uv/m =

Fa - 95.5 + 20 log (MHz) + 10 log b (Hz)

Kotaki et al (1981) have derived maps of global distribution of thunderstorm activity observed with Ionospheric Sounding Satellite (ISS-b), from the data collected during 1978-80. Recently global maps of occurrence of lighning discharge have also been made by Kotaki and Katoh (1983) and based on information on lightning discharges they have further derived global maps on atmospheric radio noise for 2.5, 5, 10 and 20 MHz on hourly basis for autumn season. The radio noise values derived by them were found to be in better agreement with the observations made all over the world when compared to data from CCIR Report 322 (Kotaki, 1984).

Figure 1 shows ARN values measured at NPL, New Delhi during 1987-88 at 2.5, 5 and 10 MHz for summer, autumn and winter seasons along with AIR measurements for Delhi during 1957-61 and corresponding CCIR (1985) predictions. It is obvious from this figure that NPL measurements during 1987-88 continue to be much higher than CCIR predictions and also marginally higher, within 6 dB, than earlier AIR measurements for Delhi. However, the most striking feature as can be noticed from the figure is the comparatively marginal diurnal variation of 5 to 10 dB in the NPL measured values in contrast to more than 30 dB variation seen in CCIR predictions at lower frequencies. The measured values are higher in summer as compared to those in winter and autumn seasons by about 10 dB.

The present study unambiguously reveals some major disparities that exist between the actual measured values of radio noise levels over India in HF bands and thos predicted by CCIR (1989). Prevalence of very high levels of noise during day-time hours and marginal increase in noise levels during transition period (1600-2000 hrs) from their day-time levels are two important aspects of radio noise over the Indian region which have not been characterized truly by CCIR noise maps. Global ARN maps of both CCIR and those orm data underestimate the noise levels for the Indian region during daytime.

CCIR maps as well as estimated values of ARN from thunderstorm activity data show large increase of the order of 20-50 dB during nighttime from their daytime value and thse increases are generally attributed to propagated component of noise from distant thunderstorm. However, ARN measurements over the Indian region do not reveal such large increases and are usually of the order of 5-10 dB. Further, the observed diurnal variation of 5 - 10 dB in the frequency range of 2.5 - 10 MHz also may mean that the noise component due to local thunderstorm activity is overwhelmingly large and dominating the propagated component of noise from distant thunderstorms even during nighttime in 2.5 - 10 MHz range. It was reported by Kotaki and Katoh (1983) that the local component and propagated component become comparable around 20 MHz during nighttime and at lower frequencies the propaged component accounts for more than 90% of the ARN levels.

The large daytime values of ARN and the modest increase from the daytime to nighttime values observed both by AIR and NPL essentially at the lower frequencies needs a closer inspection. The possibility of contamination from man-made noise has been ruled out by conducting special campaigns at remote rural areas which also confirmed the general trend. The obvious suggestion seems to be preponderance of the line of sight component. However, there is no such obvious reason as to why it should be so at Delhi. The possibilities are very large cloud height ~~like~~ which will make the LOS range large enough to make the LOS component overwhelming. A second but less attractive reason is that some kind of scatter due to turbulence, layer, etc. might extend the range of the noise ~~sights~~ propagated through troposphere. The prevalence of such large layers and glints of course is well-known in tropics; but much more data especially the frequency variation of ARN would be required before arriving at any positive conclusion.

It is also necessary to study the ARN levels over tropics vis-a-vis thunderstorm activity to assess the contribution of local as well as distant thunderstorm activity precisely to noise levels at locations in the tropical region.

Magnetic Storm:

Magnetic storms are known to be a consequence of interaction between the terrestrial upper atmosphere and enhanced solar wind. A number of solar phenomena such as solar flares, coronal holes are known to eject large amounts of solar plasma (solar wind) consisting of electron, protons and Helium nuclei. These particles after their passage through inter planetary medium find an entry into the earth's auroral zone through the open field line structure of the magnetosphere. The geomagnetic storms that follow these particle events can cause a variety of terrestrial effects such as disruptions to radio systems operating in a wide range of frequencies.

The normal (or quiescent) solar wind travels twoards earth with a velocity of 350-700 Km/sec and continuously exerts a pressure on the day light side of the magnetosphere. At about 10 earth radii the pressure exerted by the solar wind is balanced by the magnetic pressure of the terrestrial magnetic field and magnetic lines of force extending beyond 10 earth radii are pushed back by the solar wind (Fig.2) thus creating an open field line structure around auroral latitudes. However, on the night-side of the magnetosphere, solar wind does not exert any significant pressure and the geomagnetic field can extend to very long distances.

Sudden Commencement Storm:

The most striking of the transient magnetic disturbances is the magnetic storm of sudden commencement type. Following certain types of solar flares after several hours to a day or so, there is frequently a sudden increase of about 20 to 30 gammas in the horizontal component of the geomagnetic field. This is observed almost simultaneously all over the globe. The increase which occurs within a few minutes is called the "sudden commencement phase" of the magnetic storm; the field strength then starts to drop to its normal levels in the next 2-8 hours called the "initial phase." During the main phase of storm which can last from 12 to 24 hours and more the magnetic field continues to decrease and reaches levels considerably below its pre-storm levels and finally during the "recovery phase" the field returns to its quiescent values in one or two days (Fig.3).

The SC of a storm owes its origin to a cloud of plasma emitted during a solar flare which moves at a velocity of 1000-2000 Km/sec. When this plasma encounters the geomagnetic cavity, about a day after leaving the sun, it produces sudden commencement storm all over the globe. Due to excessively large particle densities as well as their kinetic energy the boundary of the magnetosphere is compressed and this compression moves rapidly as hydrromagnetic waves along the field lines and produces the observed SC increase in the magnetic field, especially in the horizontal component. As the compression relaxes, the field recovers to its original value (initial phase).

During the main phase, the normal ring current (radiation belt) which exists at all times around the earth is enhanced by charged particles emitted during a solar flare and introduced into the magnetosphere. The possible entry points for these particles are the night side tail and the cusps (open field line structure). It is also suggested that the charged particles in the ionosphere are also trapped by the field lines during a storm. Geomagnetic storm is one of the delayed effects of a solar disturbance, the delay being of the order of 1 to 3 days and the ionospheric response to magnetic storms can further be delayed by as much as 12 hours and more. These comparatively longer delay times of magnetic disturbances after the solar event enable their prediction and also their ionospheric effects on near-real-time basis. This essentially means development of models (i) for predicting a geomagnetic storm based on solar observations and another for storm-time departures in ionospheric parameters. While the predictability of the storm-inducing solar event itself remains elusive, it is now possible to predict the storms after seeing the solar events through optical, x-ray and radio observations. Daily forecasts on geomagnetic conditions are being issued by the various Regional Warning Centres (RWC) and Associate Regional Warning Centres (ARWC) operating under International URSIGRAM World Day Service (IUWDS) network and these forecasts can be profitably used to predict their likely terrestrial effects including in the ionosphere.

Ionospheric Storms:

Magnetic storm-time behaviour of ionosphere is highly variable and complex. It is known to be dependent on severity, phase of the storm, occurrence time, latitude, longitude season etc. There have been several studies on these aspects and the results are well documented (Matsushita, 1959; Obayashi, 1964, Maeda and Sato, 1959; Somayajulu, 1963). The most outstanding features are the dramatic decrease of F-region peak densities (N_e) at mid and high latitudes and some modest increase in N_e at low and equatorial latitudes during the main phase of the storm. The F-region peak heights are found to increase at all the latitudes.

These observed ionospheric changes arise due to storm-induced changes in dynamics and neutral composition and temperature. Additional current systems set-up during storms can drastically change electro-magnetic drift patterns (E x B) all over the globe. Further, the increased heat input during storms resulting from both precipitating particles and Joule dissipation of ionospheric electric fields at auroral latitudes can bring about changes in neutral temperature and composition. The energy from these high latitudes heat sources is transported to low latitudes through gravity waves and or by equatorward winds. (Rishbeth, 1975; Prolss, 1981; Blanc, 1980). It is also important to note that no single mechanism can explain all the observed changes, and it is quite likely that several of these mechanisms may simultaneously come into play depending on the latitude and severity of the storm. Molecular rich equatoward winds can bring about compositional changes (increase in N_2/O) at mid latitudes, thus causing electron density depletion due to increased loss rates; while electrodynamical effects become important for the observed positive responses at equatorial and low latitudes.

Ionospheric effects at Equatorial and low latitudes:

There have been several excellent studies on ionospheric responses to magnetic disturbances at low and equatorial stations (Kotadia and Jani, 1967; Rajaram and Rastogi, 1973). The ionosphere in this zone is characterised by a variety of ionospheric phenomena namely, equatorial anomaly in F-region peak electron densities, equatorial electrojet, equatorial spread F, sporadic E and high levels of geophysical noise in F-region parameters: within this zone is also located the focus of sq. current system which is known to influence the electron distribution in the F-region. It has also been observed that the extent of day-to-day variability (Geophysical noise) in F-region parameters is quite large in this zone and is often comparable to storm-time departures (Aggarwal and Reddy 1974, Lakshmi et al 1983). A systematic study was made by Lakshmi et al (1983) to isolate storm-time departures in F-region critical frequencies (foF2) from their day-to-day variability by suitable selection of groups of quite and disturbed days.

Figure 4 shows the range of foF2 values for Kodaikanal for the quiet days chosen for the month of June 1965 alongwith the range of values for the disturbed days of the month. The median foF2 values for these sets of days are also shown separately in the figure. The spread of foF2 values that is seen in the diagram for quiet days is essentially due to geophysical noise in foF2 parameters as the solar and magnetic levels for all the quiet days are nearly same. However, the point to be noted here is that the range of foF2 values for disturbed days of the month is markedly above the quiet day range.

Figure 5 shows range of foF2 values during quiet and disturbed days for a winter month for Ahmedabad. It is evident from the figure that disturbed time values are not distinguishable from quiet time values especially during nighttime. It has also been observed that disturbed time values at Ahmedabad (geomag. lat. 14^{O}N) which is located close to anomaly peak can be both higher and lower when compared to quiet time values depending on season and local time. Figure 6 shows median foF2 value for several stations in the tropics for both quiet and disturbed periods during May 1969. One can easily appreciate the latitudinal dependence of disturbed time variation.

MUF variations during disturbed periods:

Normally HF circuit planning is based on predicted monthly median values of maximum useable frequencies (MUF) and a knowledge of departures expected in MUFs rom their monthly medians during distrubed periods is essential for the operation of any reliable HF link. NPL, New Delhi (Lakshmi et al, 1983) have conducted exhaustive studies using a large volume of data to develop models for prediction of MUF departures in low and equatorial latitudes (Fig.7,8). These departures in MUF are dependent on the simultaneous variations that take place in the F-region critical frequencies (foF2) and peak heights (hmF2) during disturbed periods. Both these parameters are known to respond positively at these latitudes, however these positive responses result in compensating effects on MUF. The increase in foF2 will increase the MUF values while the increase in hmF2 will tend to decrease the values for the circuit. It should be mentioned here that the changes in hmF2 become important for circuit greater than 1000Km and for shorter circuit variations in MUF are essentially decided by variation in foF2. Table 1 gives the details of the effective deviations in MUF for circuits of various path length due to simultaneous changes in foF2 and hmF2.

In the mid and high latitudes the combination of negative responses in foF2 and positive hmF2 responses would result in large negative deviations in MUFs leading to serious disruptions in HF networks.

In comparison the storm-time variations in MUFs at low latitudes are very marginal and normally of positive kind. This is one of the reasons that makes HF communication very attractive at low latitudes.

Disturbed-time models developed at NPL, India (Lakshmi et al, 1983) indicate that the ionospheric responses to magnetic disturbances in Indian Zone varies widely starting from positive responses in 8-20°N geographic latitude belt to predominantly negative response around 30°N, interspersed with a very complex situation of both positive and negative responses at latitudes around the peak of the equatorial anomaly. Table 2 summarises the storm reflections in different latitude zones in India.

Based on these models it is suggested that the following specific remedial measures can be taken by a communicator to improve the reliability of HF circuit operating in India.

i) MUFs for circuits operating with reflections in the region 8-20°N geographic latitude are invariably increased during disturbed periods in all the seasons and this situation can be advantageously used to operate the circuits of path lengths less than 1000 km at higher frequencies and with lower transmitter powers. A higher operational frequency improves the reception partly because of reduced ionospheric losses and partly due to reduced atmospheric radio noise, which is an important parameter at low latitudes.

ii) The circuits operating with reflections in the zone 20-23°N should have the flexibility to alter the terminal parameters (frequencies and transmitter powers) especially when high circuit reliability is desired. Since the zone is manifested by rather unpredictable positive and negative changes during magnetic storms, it is advised that for high reliability circuits, the operating frequencies should be reduced by 15 to 20% with an appropriate increase in power whenever 'magalert' forecasts are issued.

iii) The MUFs for circuits operating with reflections in the region beyond 28° geographic latitude should be reduced by 15 to 30% depending on the severity of predicted magnetic activity in summer and equinoctial months especially when the circuits are operated close to the predicted monthly median values.

Severe magnetic storms:

Ionospheric responses in general at equatorial and low latitudes have been found to be positive and moderate. However, on a number of occasions specially during severe magnetic storms significantly large variations including negative responses have been observed (Kotadia and Ramanathan, 1961) at these latitudes. Fig. 9 shows such large negative responses observed in foF2 at Kodaikanal situated close to geomagnetic equator during the great storm of 13th March 1989. The dramatic collapse in foF2 by about 6MHz that occurred at 00000LT on 14th March 1989 is of special significance to HF communications. The foF2 values were at considerably reduced levels all through the night until sunrise. The decrease in foF2 during 0000-0500 hrs. on 14 March varied from 3-6 MHz from the monthly median values. Interestingly no significant changes in foF2 can be seen during daytime on 14th March 1989.

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Table I - Effect of Simultaneous Deviations in foF2 and hmF2 on MUFs for Circuits of Different Path-lengths

Deviation(%)		Effective deviation (%)			
foF2	hmF2	MUF (3000)F2	MUF (2000)F2	MUF (1500)F2	MUF (1000)F2
+10	+10	+3	+3	+6	+7
+20	+10	+13	+13	+15	+15
+20	+20	+6	+9	+10	+15
-10	+10	-15	-15	-13	-12
-20	+10	-23	-23	-22	-20
-20	+20	-28	-25	-24	-22

FIGURE CAPTIONS

Fig.1 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.

Fig.2 A schematic diagram of solar wind interaction with the geomagnetic field showing the various regions of magnetosphere.

Fig.3 Variations in H-field recorded at Delhi (28.7°N, 77.2°E) during a magnetic storm. The various phases of the storm can be seen in the diagram.

Fig.4 The quiet and disturbed day range of foF values for Kodaikanal for June 1965 (top half) shown along with their median value (bottom half).

Fig.5 The quiet and disturbed day range of foF$_2$ values for Ahmedabad for November 1971 (top half) shown along with their median values (bottom half).

Fig.6 The median foF$_2$ values for quiet and disturbed days for May 1969 for several Indian stations.

Fig.7 Percentage deviations in MUF (4000)F from monthly median values for several disturbed days during summer months for Kodaikanal.

Fig.8 Percentage deviations in MUF (4000) F from monthly median values for several disturbed days during summer months for Delhi.

Fig.9 foF$_2$ values for Kodaikanal during the great magnetic storm of 13 March 1989 alongwith monthly median values.

TABLE 2

NATURE OF EXPECTED DEPARTURES IN MUF (4000) F2 VALUES FROM MONTHLY MEDIANS FOR DISTURBED DAYS ALONG WITH THEIR STANDARD DEVIATION IN PERCENTAGE

Geomagnetic latitude deg. N.	Geographic latitude deg. N.	Local time hrs 0600-2400	Local time hrs 2400-0600	Local time hrs 0600-2400	Local time hrs 2400-0600	Local time hrs 0600-2400	Local time hrs 2400-0600
0-10	8-20	Positive (20%)	Positive and Negative	Positive (18%)	Positive and Negative	Positive (20%)	Positive and Negative
10-14	20-23	Positive and Negative (20%)	Positive and Negative (25%)	Positive and Negative (12%)	Negative (25%)	Positive and Negative (18%)	Positive and Negative (30%)
19	28	Negative (18%)	Positive and Negative (20%)	Negative (15%)	Positive and Negative (20%)	Positive and Negative (15%)	Positive and Negative (25%)

TABLE 2

NATURE OF EXPECTED DEPARTURES IN MUF (4000) F2 VALUES FROM MONTHLY MEDIANS FOR DISTURBED DAY'S ALONG WITH THEIR STANDARD DEVIATION IN PERCENTAGE

Geomagnetic latitude deg. N.	Geographic latitude deg. N.	Local time hrs 0600-2400	Local time hrs 2400-0600	Local time hrs 0600-2400	Local time hrs 2400-0600	Local time hrs 0600-2400	Local time hrs 2400-0600
0-10	8-20	Positive (20%)	Positive and Negative	Positive (18%)	Positive and Negative	Positive (20%)	Positive and Negative
10-14	20-23	Positive and Negative (20%)	Positive and Negative (25%)	Positive and Negative (12%)	Negative (25%)	Positive and Negative (18%)	Positive and Negative (30%)
19	28	Negative (18%)	Positive and Negative (20%)	Negative (15%)	Positive and Negative (20%)	Positive and Negative (15%)	Positive and Negative (25%)

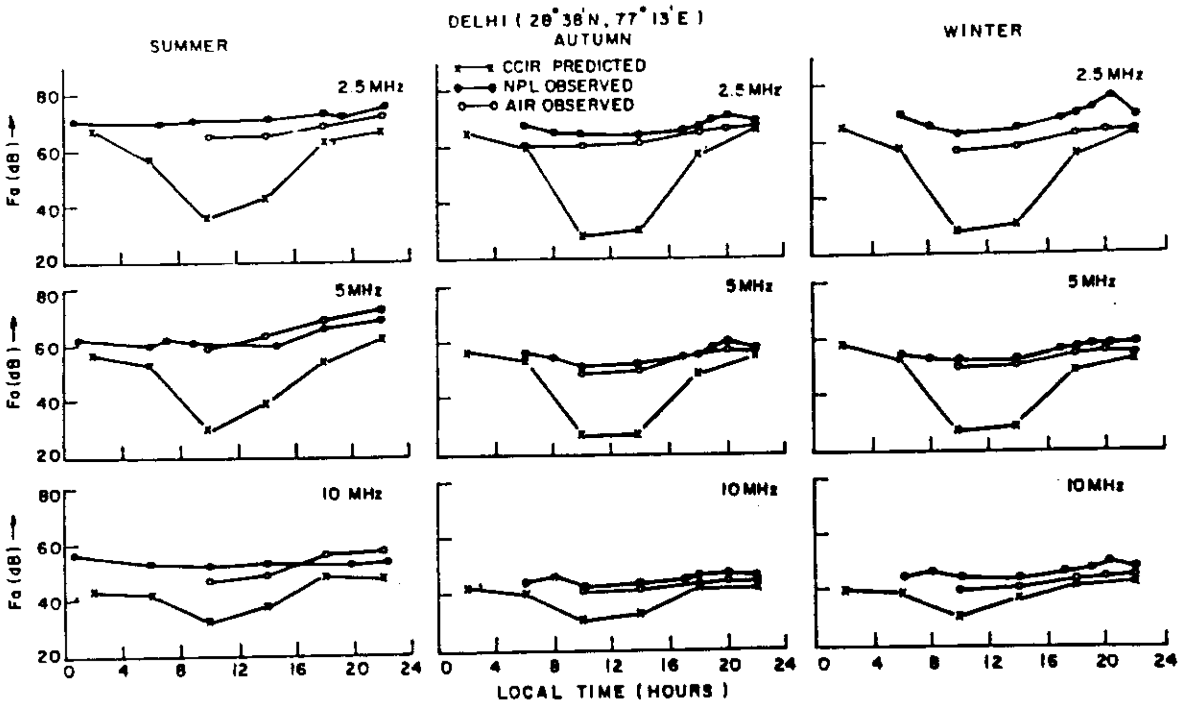

DELHI (28°38'N, 77°13'E)
SUMMER
AUTUMN
WINTER
CCIR PREDICTED
NPL OBSERVED
AIR OBSERVED
2.5 MHz
5 MHz
10 MHz
Fa (dB) ⟶
80
60
40
20
0
4
8
12
16
20
24
LOCAL TIME (HOURS)

Fig 1

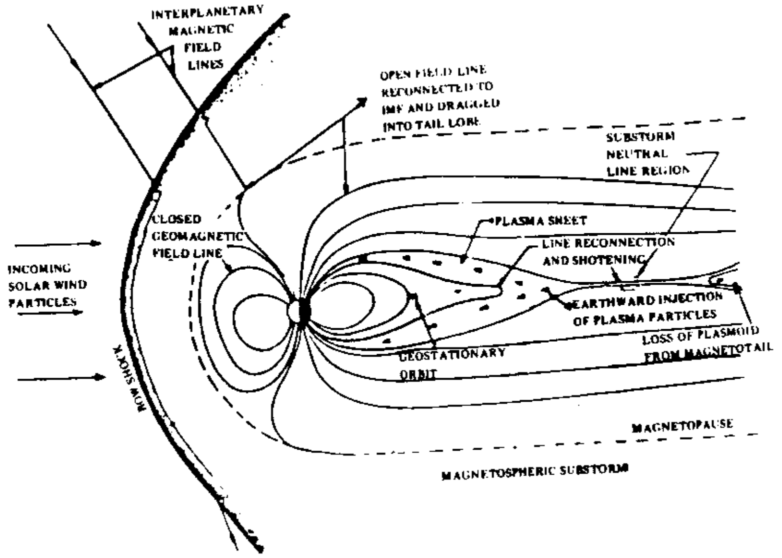
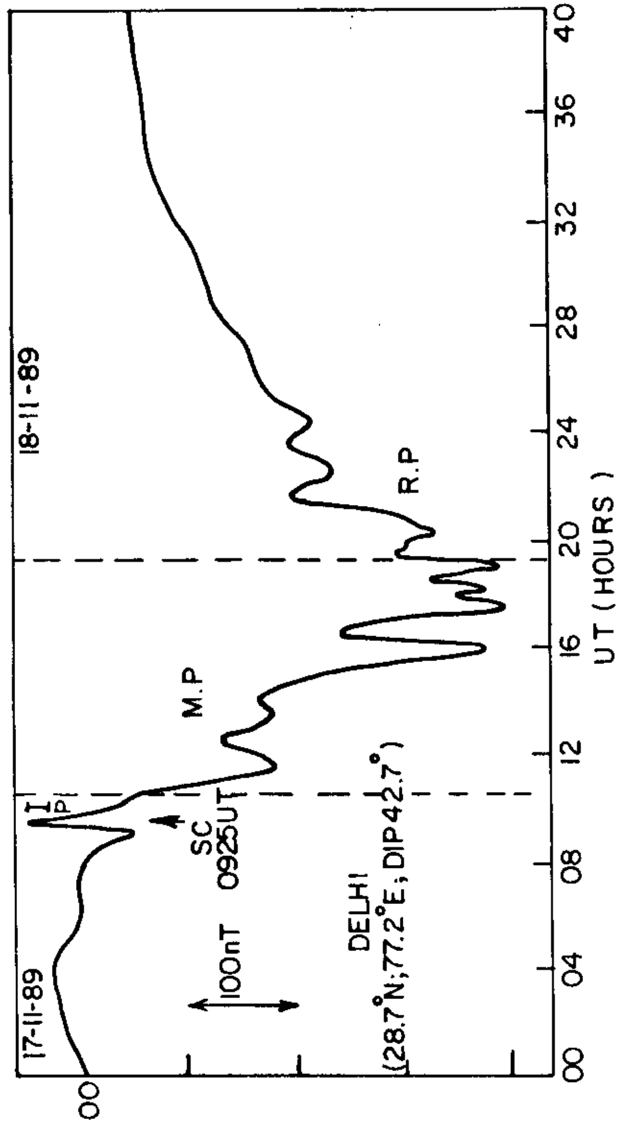

INTERPLANETARY MAGNETIC FIELD LINES
OPEN FIELD LINE RECONNECTED TO IMF AND DRAGGED INTO TAIL LOBE
SUBSTORM NEUTRAL LINE REGION
CLOSED GEOMAGNETIC FIELD LINE
PLASMA SHEET
LINE RECONNECTION AND SHOTENING
INCOMING SOLAR WIND PARTICLES
EARTHWARD INJECTION OF PLASMA PARTICLES
LOSS OF PLASMOID FROM MAGNETOTAIL
GEOSTATIONARY ORBIT
BOW SHOCK
MAGNETOPAUSE
MAGNETOSPHERIC SUBSTORM

Fig 2


17-11-89
18-11-89
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0925UT
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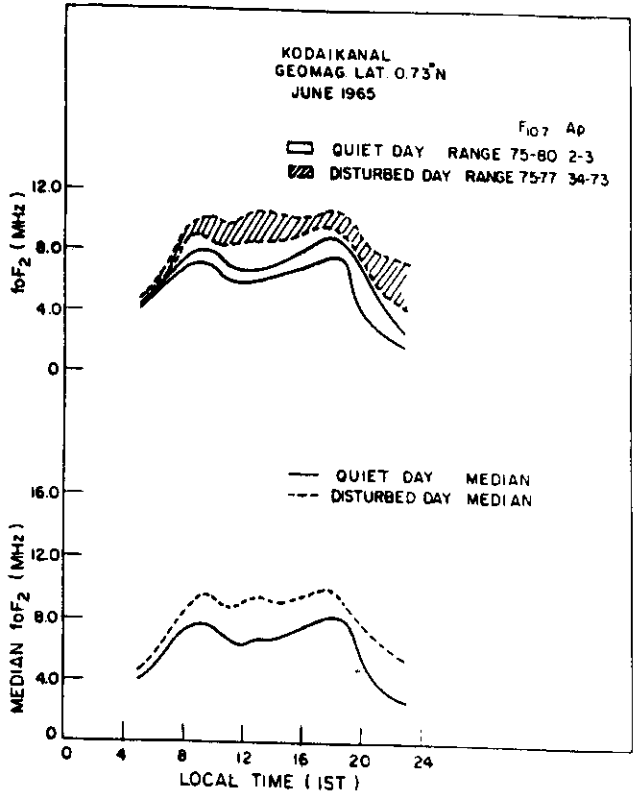
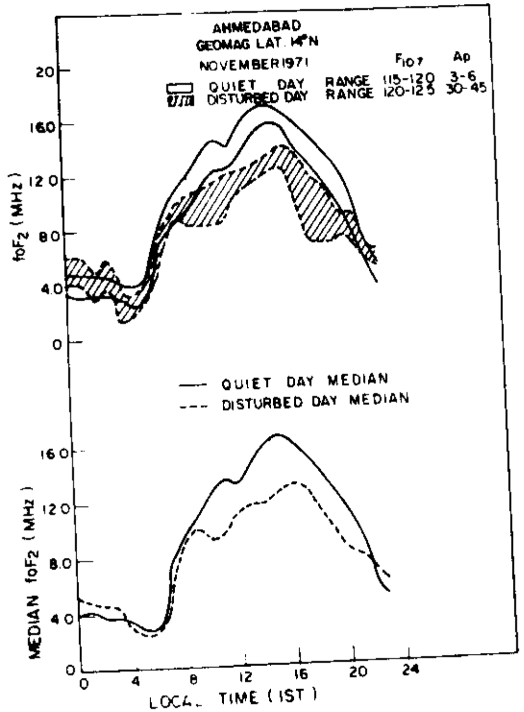
Fig 3


KODAIKANAL
GEOMAG. LAT. 0.73°N
JUNE 1965
F10.7 Ap
☐ QUIET DAY RANGE 75-80 2-3
▨ DISTURBED DAY RANGE 75-77 34-73
foF2 (MHz)
12.0
8.0
4.0
0
— QUIET DAY MEDIAN
--- DISTURBED DAY MEDIAN
16.0
12.0
8.0
4.0
0
MEDIAN foF2 (MHz)
0
4
8
12
16
20
24
LOCAL TIME (IST)


AHMEDABAD
GEOMAG LAT. 14°N
NOVEMBER 1971
F10.7
Ap
QUIET DAY RANGE 115-120 3-6
DISTURBED DAY RANGE 120-125 30-45
foF2 (MHz)
20
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MEDIAN foF2 (MHz)
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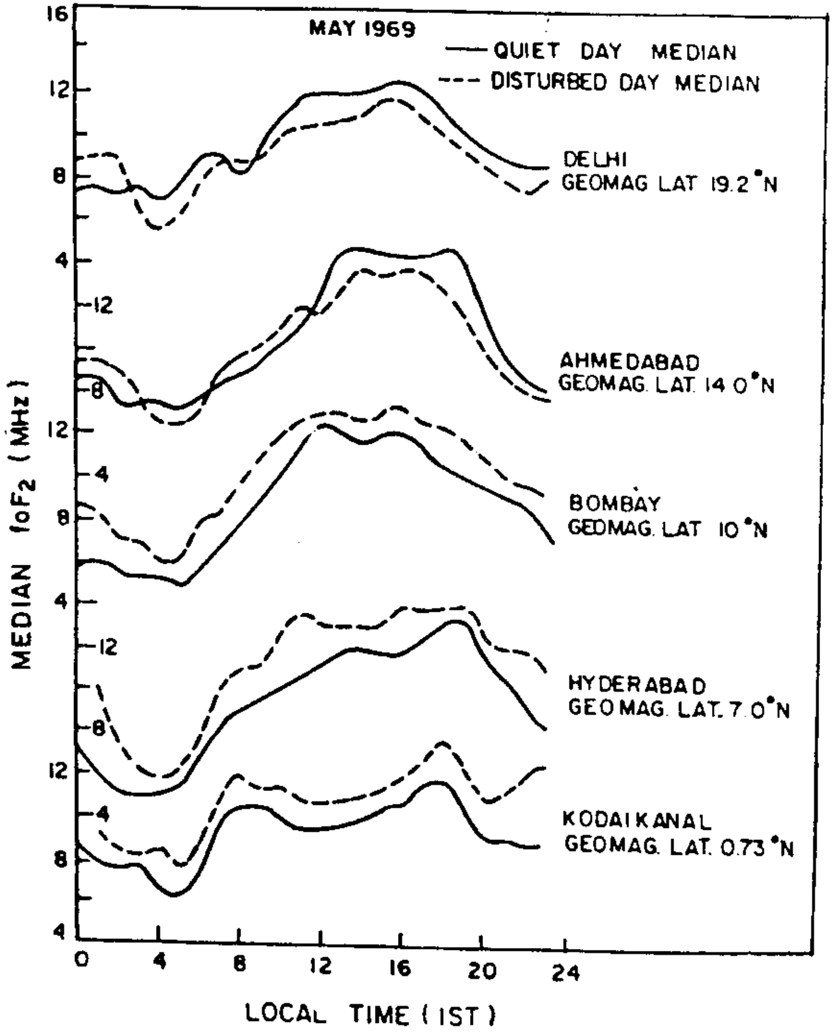
16
20
24
LOCAL TIME (IST)

Fig 11


MAY 1969
— QUIET DAY MEDIAN
--- DISTURBED DAY MEDIAN
16
12
8
4
12
8
4
12
8
4
12
8
4
12
8
4
DELHI
GEOMAG LAT 19.2°N
AHMEDABAD
GEOMAG. LAT. 14.0°N
BOMBAY
GEOMAG. LAT 10°N
HYDERABAD
GEOMAG. LAT. 7.0°N
KODAIKANAL
GEOMAG. LAT. 0.73°N
MEDIAN foF2 (MHz)
0
4
8
12
16
20
24
LOCAL TIME (IST)

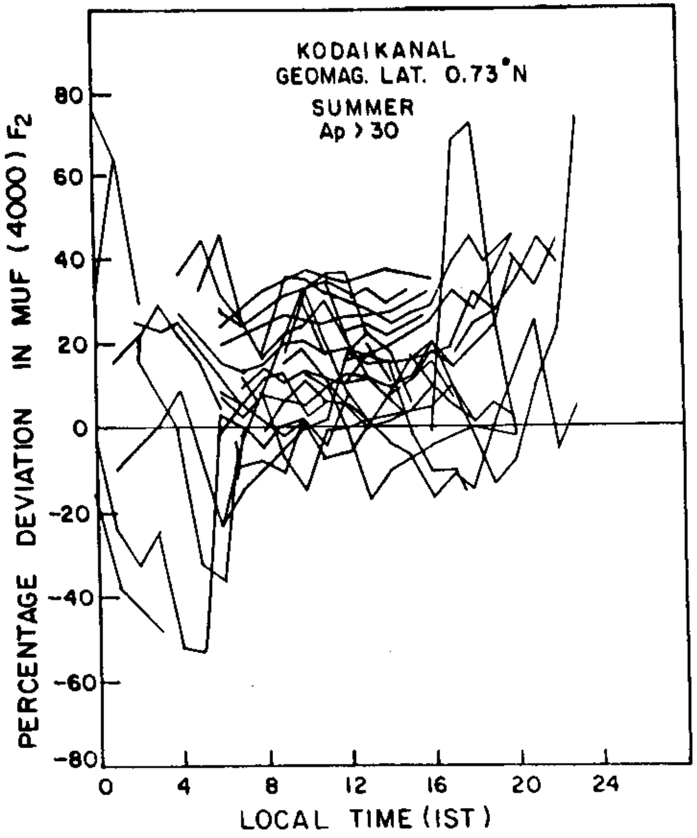

KODAIKANAL
GEOMAG. LAT. 0.73°N
SUMMER
Ap > 30
PERCENTAGE DEVIATION IN MUF (4000) F2
80
60
40
20
0
-20
-40
-60
-80
0
4
8
12
16
20
24
LOCAL TIME (IST)

Fig 7

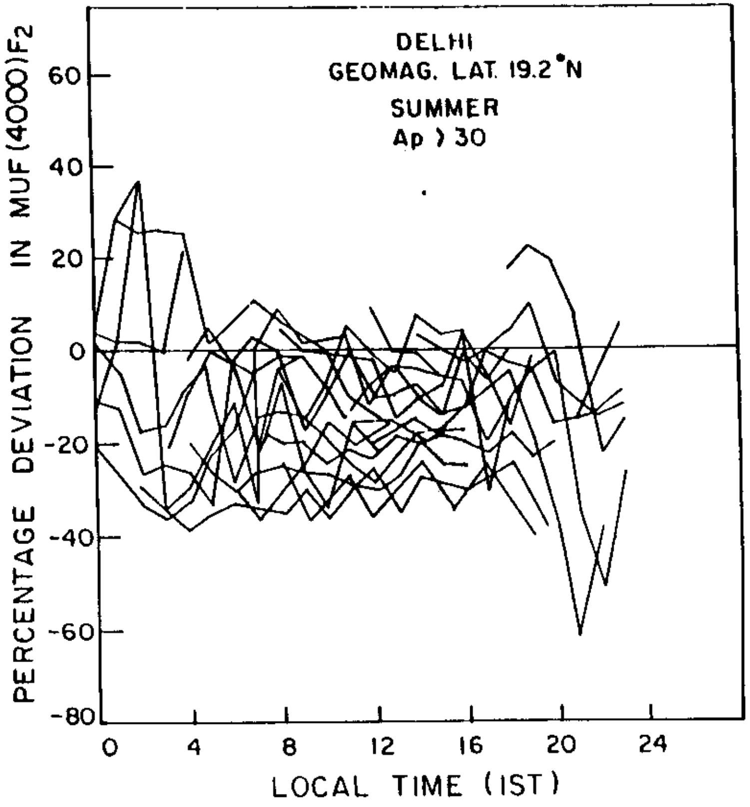

DELHI
GEOMAG. LAT. 19.2°N
SUMMER
Ap > 30
PERCENTAGE DEVIATION IN MUF (4000) F2
60
40
20
0
-20
-40
-60
-80
0
4
8
12
16
20
24
LOCAL TIME (IST)

Fig 8

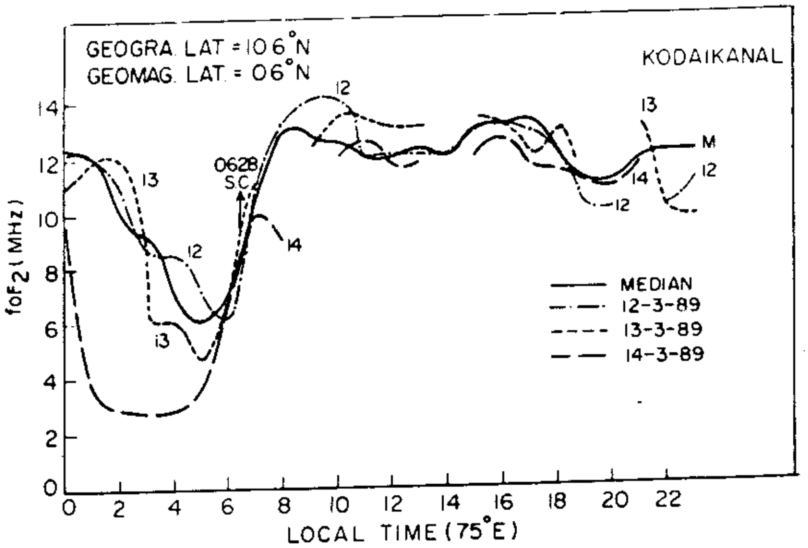

GEOGRA. LAT = 10.6°N
GEOMAG. LAT = 0.6°N
KODAIKANAL
foF2 (MHz)
0
2
4
6
8
10
12
14
LOCAL TIME (75°E)
0
2
4
6
8
10
12
14
16
18
20
22
0628 SC
12
13
14
M
MEDIAN
12-3-89
13-3-89
14-3-89

Fig 9