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ATLAS

OF

IONOSPHERIC COMMUNICATION PARAMETERS

OVER TROPICS

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National Physical Laboratory
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ATLAS OF IONOSPHERIC COMMUNICATION PARAMETERS OVER THE INDIAN SUBCONTINENT

S.Aggarwal, S.K.S.Shastri and B.M.Reddy

1. INTRODUCTION

For more than fifty years now ionosphere reflected communication using HF band continues to be the backbone of long distance broadcasing and communications. With the advent of high reliability techniques such as LOS microwave system, tropo-systems and geostationary satellite based systems it seemed HF system will become outdated one day. But the last one or two decades have shown, indisputably, that these systems of communications remain as important even today. In almost all the countries HF band is getting overcrowded. There are several reasons for this superimacy of ionospheric communications especially at low latitudes. The low latitude ionosphere is protected by the Earth's magnetic field from invasion of solar charged particles and hence disturbances due to particle effects are minimised. Because of low solar zenith angles the charged particle population is relatively higher resulting in a wide band of available HF spectrum. HF system is best suited when the reliability criteria are less stringent as the operational costs are minimal. HF also is used as a back-up service by most of the high profile users. The CCIR Report 340 thus contains a class of ionospheric characteristics that can be used for frequency prediction of specific link for predicted level of solar activity.

However the present Atlas has several advantages that should dramatically improve the prediction capability for India for reasons described in the following paragraphs.

The charged particle population in the ionosphere naturally depends upon the neutral atmosphere which presents the ionizable constituents and on the ionizing radiations from the sun (particle effects are also important at high latitudes). While all radiations including visible and infrared may be responsible for the neutral atmospheric profile, the ionizing radiations are essentially the EUV and X-ray radiations which undergo large variations with the solar epoch. The ideal solution of course would be to measure these ionizing radiations and then predict their level for future years. These measurements are impossible on a routine basis. One alternative, therefore, is to monitor the sun using those radiations (like the VHF and SHF radio waves) which reach the ground based sensors unhindered by the intervening terrestrial atmosphere and correlate these measurements with ionosphere-producing radiations. However, because of the availability of long series of observations, the sunspot number has been found to be most suitable for statistical prediction techniques.

The solar activity study, which was started two hundred years ago out of scientific curiosity, had assumed great importance by the second quarter of this century because of ionospheric communications. Since

recent years, the interest in this study has sky-rocketed because of its potential applications in a wide variety of areas of human interest, such as environmental effects and biological aspects, sun-weather relationship, satellite lifetimes and manned space flights. Though the ionospheric prediction techniques used at NPL is not very different from other techniques, the wealth of data that has gone into the system and the continuous updating, as the new data pours in, has instilled a certain measure of confidence among the users in the east zone and especially in India where HF communications still remain as the backbone of long distance communications. This brings in enormous pressure in conserving the HF spectrum and consequently the assignments of frequencies to users is rather involved and time-consuming. This is one reason why short-term forecasting was not very much in demand until recently. We are presently giving short-term forecasting also.

2. IONOSPHERIC PROOAGATION PREDICTIONS

The presence of free electrons in the ionosphere produces the reflecting regions important for radio-wave propagation. In the principal regions, between the approximate heights of 75km and 500km, the electrons are produced by the ionizing effect of ultraviolet and soft x-rays from the sun. Ionosphere affects the propagation of radiowaves in two ways: advantageously by enabling communication(e.g. reflection) and adversely by scattering, absorbing, producing multipath etc. that interfere with optimum traffic requirements. For convenience in studies of radiowave propagation, the ionosphere is divided into three regions defined according to height and ion distribution: the D,E, and F regions. Each region is subdivided into layers called the D,E, E_s,F1, and F2 layers, also according to height and ion distribution. At HF, all the regions are important and must be considered in predicting the operational parameters of radio communication circuits. From the view point of propagation, the E and F layers act principally as radiowave reflectors and permit long range propagation between terrestrial terminals. E region can support frequencies for communications upto distances of the order of 2000 kms. whereas F region can support communications upto a distance of 4000 kms in one single reflection. The D region acts principally as an absorber causing signal attenuation in the HF range (3-30 MHz). Basic atmospheric density and ionisation data for these main layers is thus required for prediction of propagation parameters.

2.1 F2-REGION IONIZATION AND PREDICTION

The ionization density of the F2 region is very unstable and exhibits marked variations with geographic latitude and longitude, local time, season of the year, and solar activity. The characteristics of the F2 region in terms of the vertical incidence critical frequency (foF2) and the M (3000) F2 factor as determined from vertical ionosonde records, are used for predictions.

Solar activity changes are incorporated by correlating observed F2 layer parameters with corresponding smoothed sunspot numbers. Monthly median foF2 and M(3000)F2 data for different stations is correlated to twelve month running average sunspot numbers (R_{12}) for the same month, for each of the local time hours from 00 to 23 hours. Maximum usable frequencies for a distance of 4000 kms. is obtained by using the following relation.

$$MUF\,(4000)F2 = foF2 \times M(3000)F2 \times 1.1 \quad (1)$$

Values for intermediate distances can be read from nomogram in Fig.1 and the procedure is described in section 4. Contour maps,(Appendix A)for five levels of solar activity corresponding to R =0,50,100,150 and 200, of foF2 and MUF(4000)F2 have been drawn in local time vs. latitude frame covering latitude range from 0 to 40°N. The values of the parameters at fixed R_{12} have been obtained from the statistical relationship:

$$foF2 = A + B \times R_{12} + C \times R_{12}^2 \quad (2)$$

and

$$M(3000)F2 = D + E \times R_{12} + F \times R_{12}^2 \quad (3)$$

These have been derived on a main frame computer VAX-11/780 at NPL for all the stations shown in Table 1 and the amount of data used is the largest per station as of now. The coefficients A,B,C,D,E,F are also included in the ATLAS for each station (Appendix C) for each month and for each hour of the day. Normalised percentage errors of fitting a second degree relation with solar activity are also included in tabular form in Appendix D. The database in table 1 shows that two Russian stations have been used in the north and Singapore from the east to complete the latitude range of 0 to 40 degrees north over the Indian Subcontinent. All the figures A1, A2.............,A60 take care of diurnal, seasonal latitudinal and solar activity variations of the F2 region and should be used for planning HF frequencies for any circuits within the Indian Subcontinent. The Procedure to use this atlas is given in section 4. A few examples are also worked out.

2.2 F1-REGION IONISATION AND PREDICTION

A F1-layer prediction system has been developed for the range 2000 to 3400 kms. (DuCharme et.al 1973). The value of foF1 can be determined for any value R fom the following expressions:

$$foF1 = f_s \cos^n(\chi) \quad (4)$$

Where

$$f_s = f_{so} + 0.01\,(f_{s100} - f_{so}) \times R_{12} \quad (5)$$

$$f_{so} = 4.35 + 0.0058\,\lambda - 0.000120\,\lambda^2 \quad (6)$$

$$f_{s100} = 5.35 + 0.0110\,\lambda - 0.000230\,\lambda^2 \quad (7)$$

and $$n = 0.093 + 0.00461\,\lambda - 0.0000540\,\lambda^2 + 0.00031 R_{12} \quad (8)$$

where λ represents geomagnetic latitude in degrees.

The maximum solar zenith angle at which the F1 layer is present is given by the following expressions:

$$\chi_m = \chi_o + 0.01\,(\chi_{100} - \chi_o)\, R_{12} \text{(degrees)} \quad (9)$$

where

$$\chi_o = 50.0 + 0.348\,\lambda \quad (10)$$

$$\chi_{100} = 38.7 + 0.509\,\lambda \quad (11)$$

The M factor for calculating the basic MUF's have been derived and can be determined from the following numerical expressions for R_{12} between 0 to 150:

$$M \text{ factor} = Jo - 0.01\,(Jo - J_{100})\, R_{12} \quad (12)$$

Where $$Jo = 0.16 + 2.64 \times 10^{-3}\, D - 0.40 \times 10^{-6}\, D^2 \quad (13)$$

$$J_{100} = 0.52 + 2.69 \times 10^{-3}\, D - 0.39 \times 10^{-6}\, D^2 \quad (14)$$

and where D represents the great circle distance in kilometers in the range 2000-3400 km.

2.3 E-LAYER IONIZATION AND PREDICTION

For distances less than2000 kms E-layer acts as a reflector for HF radiowaves. Based on all published data for some 55 ionospheric stations following expressions have been obtained and can be used to derive foE at the point of reflection (Muggleton, 1975) and the basic MUF for propagation purposes. With foE expressed in MHz

$$(foE)^4 = A.B.C.D \quad (15)$$

Where A is a solar activity factor, given as (16)

$$A = 1 + 0.0091\, R$$

R is the predicted sunspot number

B is a season factor, given as (17)

$$B = \cos^m(\chi noon)$$

Where:

χ noon is the value of the solar zenith angle at noon for the point of reflection (can be read from Fig.'s B1 to B4) for the month in question

and $$m = -1.93 + 1.92 \cos\lambda \text{ for } |\lambda| < 32^\circ \quad (18)$$

$$m = 0.11 - 0.49 \cos\lambda \text{ for } |\lambda| \geq 32^\circ \quad (19)$$

C is the main latitude factor, given as

$$C = X + Y \cos \lambda \quad (20)$$

Where

$$X = 23,\ Y = 116 \text{ for } |\lambda| < 32^{o} \quad (21)$$

$$X = 92,\ Y = 35 \text{ for } |\lambda| \geqslant 32^{o} \quad (22)$$

D is the time of the day factor given as

1st case: $\chi \leqslant 73^{o}$

$$D = \text{Cos}^{p} \chi \quad (23)$$

Where χ is the solar zenith angle in degrees. For $|\lambda| \leqslant 12^{o}$ $p = 1.31$; for $|\lambda| > 12^{o}$, $p = 1.20$

2nd Case $73^{o} < \chi < 90^{o}$

$$D = \text{Cos}^{p} (\chi - \delta\chi) \quad (24)$$

Where $\delta\chi = 6.27 \times 10^{-13} (\chi - 50)^{8}$ (25)

and p is as in the first case

3rd case: $\chi \geqslant 90^{o}$

The night time value of D, for $\chi \geqslant 90^{o}$, is taken as the greater of those given by:

$$D = (0.072)^{p} \exp(-1.4h) \quad (26)$$

and $D = (0.072)^{p} \exp(25.2 - 0.28\chi)$ (27)

where h is the number of hours after sunset ($\chi = 90^{o}$)

The minimum value of foE, based on Wakai (1971) is given by:

$$(foE)^{4}_{minimum} = 0.017 (1+0.0098R)^{2} \quad (28)$$

The MUF of a particular mode may be determined as the product of the mid-path value of foE and M factor for a transmission distance set equal to that of a single hop.

Figure 2 gives the M factor based on ray-path calculations for a parabolic model E-layer with $h_m E = 110$ km, $y_m E$ = 20 km, when effects of the Earth's magnetic field are neglected. The curve may be approximated by the equation:

$$\text{M factor} = 3.94 + 2.80\, x - 1.70\, x^{2} - 0.60\, x^{3} + 0.96\, x^{4} \quad (29)$$

$$\text{with } x = (d - 1150) / 1150 \quad (30)$$

Where d represents the transmission distance in kilometers.

3. SOLAR ACTIVITY PREDICTIONS

Using observed sunspot number data since 1749 smoothed sunspot number is predicted at NPL and supplied to different user organisations, six months in advance. A complete solar cycle prediction is also supplied for very long-term planning of HF circuits. Table 2 shows a sample of predictions prepared every month. Fig. 3 shows the complete cycle prediction for solar cycle number twenty-two since 1749 which started in September 1986.

4. USE OF THE ATLAS FOR FREQUENCY CALCULATIONS

The procedure is explained here step wise in two different parts. Part 1 explains the use of the atlas to calculate frequencies with the help of diagrams and nomograms whereas Part2 is meant for use on a computer.

4.1 MANUAL METHOD FOR FREQUENCY CALCULATIONS

Step 1. Get the coordinates of the end points of circuit (X_1, Y_1), (X_2, Y_2) where X denotes latitude Y denotes the longitude of the locations involved.

Step 2. Calculate the great circle distance between the two locations using the following relation:

$$\cos d = \sin X_1 \times \sin X_2 + \cos X_1 \cos X_2 \cos (Y_1 - Y_2) \tag{31}$$

where d is in radians and the great circle distance D = Rxd, R being Earth's radius = 6370 kms.

Step 3. Calculate latitude o the mid-point of the path as

$$X_{mid} = (X_1 + X_2)/2 \tag{32}$$

Step 4. Get predicted value of running average sun-spot numbers (R_{12}) for the month under consideration.

Step 5. Check in which of the following intervals intervals does this value lies: 0 - 50, 50 - 100, 100 - 150, 150 - 200.

Step 6. Choose contour maps (appendix A) for the two boundary values of the interval in which R_{12} lies e.g. if R_{12}=121 , choose contour maps for R_{12}=100 and R_{12}=150 for the month under consideration, for both foF2 and MUF(4000)F2.

Step 7. Read the values of foF2 and MUF(4000)F2 at X_{mid}, for all the twenty four hours 00,01............,23 and for two levels of solar activity.

Step 8. Make linear interpolation for R between values read at two levels of solar activity for each of the local time hours. This gives foF2 and MUF(4000)F2 for predicted R_{12}.

Step 9. To get the values for the distance D(calculated in step 2) enter the nomogram at Fig.1 with foF2 and MUF(4000)F2 separately for every hour 00,01,02,........and 23 and read the value of MUF for distance D. This gives MUF(D) values for all the 24 hours for the given circuit that are available for support by the ionosphere for fifty percent of the days for the month under consideration. To obtain frequencies available for ninety percent of the days scale down these values by a factor of 0.85. These scaled down frequencies are known as frequencies of optimum transmission (FOT) i.e. FOT = 0.85 x MUF. Out of these twenty four frequencies, two frequencies are selected one for the day and one for the night so that all the twenty four hours are covered atleast ninety percent of the days by these two frequencies.

Step 10. For point to point communication angle of elevation is also important. If β is the angle of elevation or the takeoff angle it can be derived as follows:

$$\tan\beta = \{\cos(d/2) - (R/(R+h))\} / \sin(d/2) \tag{33}$$

where h can be approximated from:

$$h = (1490/ M(3000)F2) - 176 \tag{34}$$

$$\text{where } M(3000)F2 = MUF(4000)F2/(foF2 \times 1.1) \tag{35}$$

an appropriate takeoff angle can be chosen to meet the antenna requirements and circuit planned finally.*

EXAMPLE : DELHI - MADRAS FOR THE MONTH OF JANUARY 1991

JANUARY 1991 PREDICTED SUNSPOT NUMBER 121

DELHI	TO	MADRAS
(28.6 N 77.2 E)		(13.0 N 80.3 E)

In case of difficult tarrain at either of the terminals if elevation angles are too low change to double hop propagation. Take two points of reflection at a distance D/4 from both the terminals. Follow step 1 through 9 to calculate frequencies (MUF's) for distance D/2 at each of the points of reflection. At each hour of the day take the lower of the two MUFs and convert to FOT's. The angles of (Eqn. 33) of elevation in this case will be calculated using coordinates of the terminals and the mid-point of the circuit. The antenna will have to be adjusted to accomodate these angles on both the sides if reliable communication link has to be established.

GREAT CIRCLE DISTANCE = 1750 kms.

LATITUDE X_{mid} = (28.6 + 13.0)/2 = 20.6 OR 21 DEG. N

Step 1. Since predicted SSN lies in the interval 100-150 select Figures A3 and A4.

Step 2. Read values of foF2 for SSN 100 and 150 (Cols.2 and 3 of Table 3) and MUF(4000)F2 for SSN = 100 and 150 (Cols. 5 and 6 of Table 3).

Step 3. At each of the hours interpolate for SSN = 121 as follows:

$$P(121) = P(100) + (121-100)\ \ P(150)-P(100)\ \ /(150-100)$$

where P is the value of eigher of the two parameters viz. foF2 or MUF(4000)F2 for a given hour. Cols. 4 and 7 of the Table 3 give interpolated values for foF2 and MUF (4000)F2 respectively.

Step 4. Col.8 gives the values of MUF(1750)F2 read from Fig.1. The value of FOT calculated using relation FOT = 0.85 x MUF are shown in Col.9.

4.2 COMPUTER BASED FREQUENCY CALCULATION

Following paragraphs explain the calculations of traffic frequencies using a computer. The computer-based frequency calculation for any specific circuit in the Indian subcontinent require the following input parameters

1. Co-ordinates of the terminal-points.
2. Predicted smoothed sunspot-numbers for the month for which the prediction is required.

4.2.1 Data Base :- The data base comprises of the following

The co-efficients A, B, C, D, E, F the values of which are given in Appendix C for every month separately. Each of the tables (C1 to C12) gives values of the co-efficients for every station listed in table 1 and each hour of the day.

Procedure - After obtaining the above mentioned input parameters the following steps will lead to the predicted values of optimum working frequency at each hour.

Step 1 - Let x_1, y_1 ....coordinates of transmitting location

x_2, y_2 ....coordinates of receiving location

Determine the co-ordinates of the reflection point (x,y) from the following relation

$$x = \frac{x_1 + x_2}{2} \quad ; \quad y = \frac{y_1 + y_2}{2}$$

Step 2 - Determine the great circle distance (D) between the terminal points as explained in section 4.1.

Step 3 - Read the predicted sunspot-number (R) from fig.3 for the required month for which prediction is needed.

Step 4 - Choose the two stations from Table 1 such that in their latitudinal range, the latitude of the reflection point (x) lies. e.g. if the latitude of the reflection point is 20.8°N as in example in section 4.1 then the stations Ahmedabad (23°N) and Bombay (19°N) are chosen.

Step 5 - Read the values of the coefficients A, B, C, D, E, F from Appendix C for the required month for the two chosen stations (in Step 4) at a particular hour say 00 hour. Let A1, B1, C1, D1, E1, F1 be the values of the coefficients for station A say Ahmedabad and let A2, B2, C2, D2, E2, F2 be the corresponding values of the coefficients for station B say Bombay. While reading the values of the coefficients in Appendix C, one may come across the label "DATA INSUFFICIENT". It simply means that the available number of data points is less than seven for that particular station and hour and hence the values of the co-efficients could not be evaluated. In such a situation, interpolate between the neighbouring stations to evaluate the missing value.

Step 6 - Calculate predicted values of foF2 and M(3000)F2 at 00 hours for station A (i.e. Ahmedabad in the present case) using the following relations:

$$foF2_{(A)} = A1 + B1 * R + C1 * R^2$$

$$M(3000)F2\ (A) = D1 + E1 * R + F1 * R^2$$

Step 7 - Calculate predicted values of foF2 and M(3000)F2 at 00 hours for station B (i.e. Bombay in the present case) using the following relations:

$$foF2_{(B)} = A2 + B2 * R + C2 * R^2$$

$$M(3000)F2_{(B)} = D2 + E2 * R + F2 * R^2$$

Step 8 - Calculate foF2 and M(3000)F2 at the reflection point (Lat = x as calculated in Step 1)

$$foF2 = \frac{foF2\ (B) - foF2\ (A)}{(x_2 - x_1)} * \frac{(x - x_1)}{1} + foF2\ (A)$$

$$M(3000)F2 = \frac{M(3000)F2(B) - M(3000)F2(A)}{(x_2 - x_1)} * \frac{(x - x_1)}{1} + M(3000)F2\ (A)$$

The percentage errors from the Appendix D for the point of reflection define the precision of these predicted values.

Step 9 - Convert the M-factor for a distance of 3000 kms i.e. M(3000)F2 to the M-factor fora required distance D(calculated in Step 2) i.e. M(D)F2 by using the factor distance table (Table 4).

Step 10 - Calculate the maximum usable frequency for the distance D i.e. MUF(D)F2 using the following relation

MUF(D)F2 = foF2* M(D)F2

Step 11 - Repeat Step 5 to Step 10 so as to calculate values of MUF(D)F2 at each hour of the day. Table 5 shows the computer output (using first version of the computer software) (Lakshmi et al.,) for a point-to-point circuit "Delhi--Madras" for the month of January 1991.

Step 12 - Calculate FOTs i.e. frequency of optimum transmission at each hour separately using the relation

FOT = 0.85 * MUF(D)F2

Step 13 - Plot values of MUF(D)F2 and FOT at each of the 24 hours (calculated in Step II and Step 12) as shown in Fig.4 and suggest one frequency for the day time and one frequency for the night time.

5. SAMLE ILLUSTRATION FOR DESPATCH TO THE OPERATOR

For operator in the field the planners have to give information in the form of fig.5 for different points of reflections say 5°N, 10°N,...or 35°N. In the diagram FOT values for different distances are shown for January 1991 at a point of reflection close to 20°N. Depending upon the great circle distance and point of reflection the operator can have an idea of the frequencies that will go through and choose one if he has the provision for changing the frequencies or wait for the time when the frequency (fixed) assigned to him will go through.

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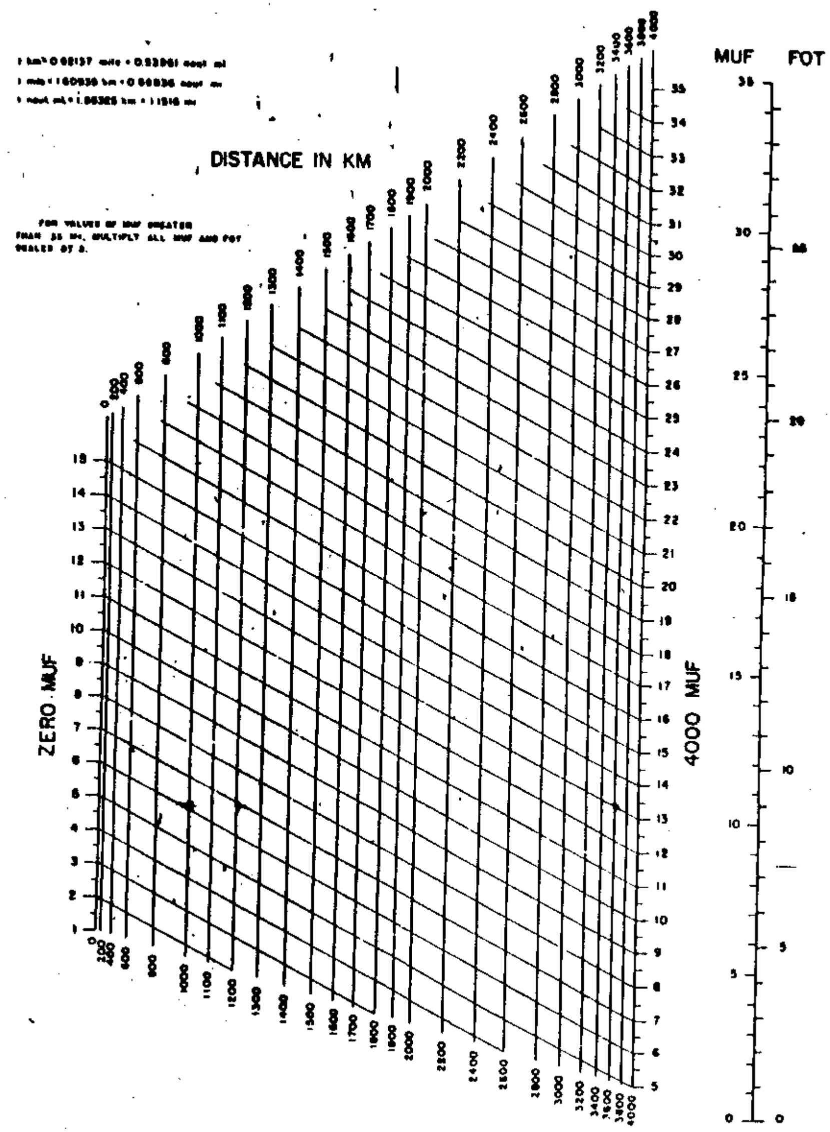


Fig.1 NOMOGRAM FOR TRANSFORMING F_2-ZERO-MUF AND F_2-4000-MUF TO EQUIVALENT MAXIMUM USABLE FREQUENCIES AT INTERMEDIATE TRANSMISSION DISTANCES; CONVERSION SCALE FOR OBTAINING OPTIMUM TRAFFIC FREQUENCY (FOT).

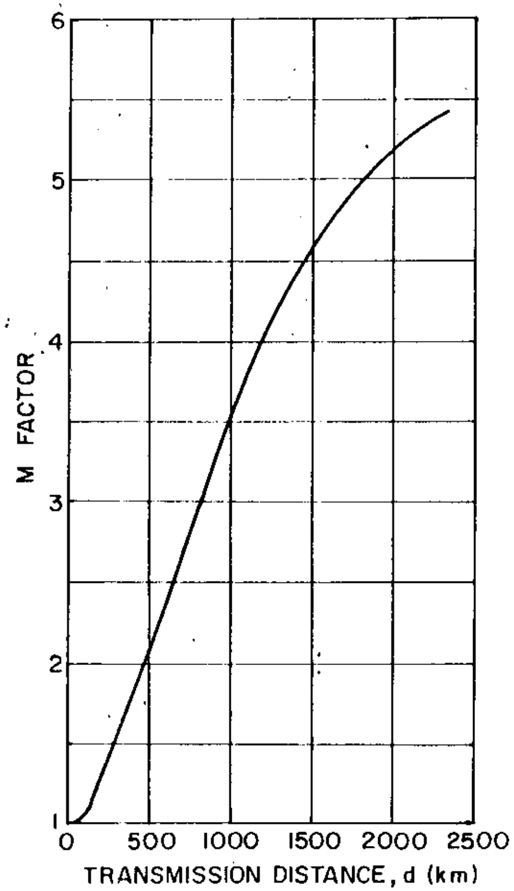


Fig. 2 DISTANCE FACTOR CURVE FOR E LAYER

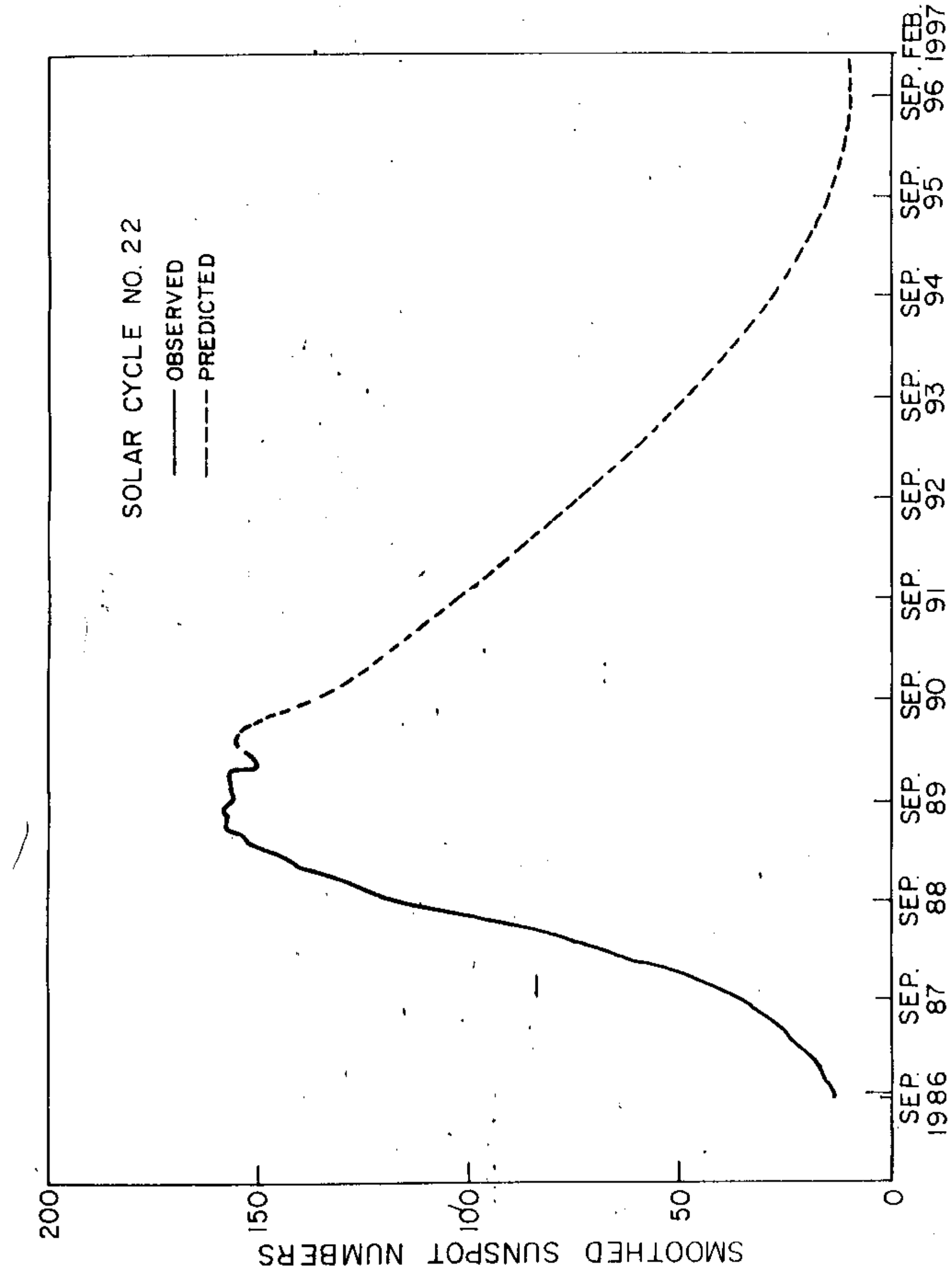
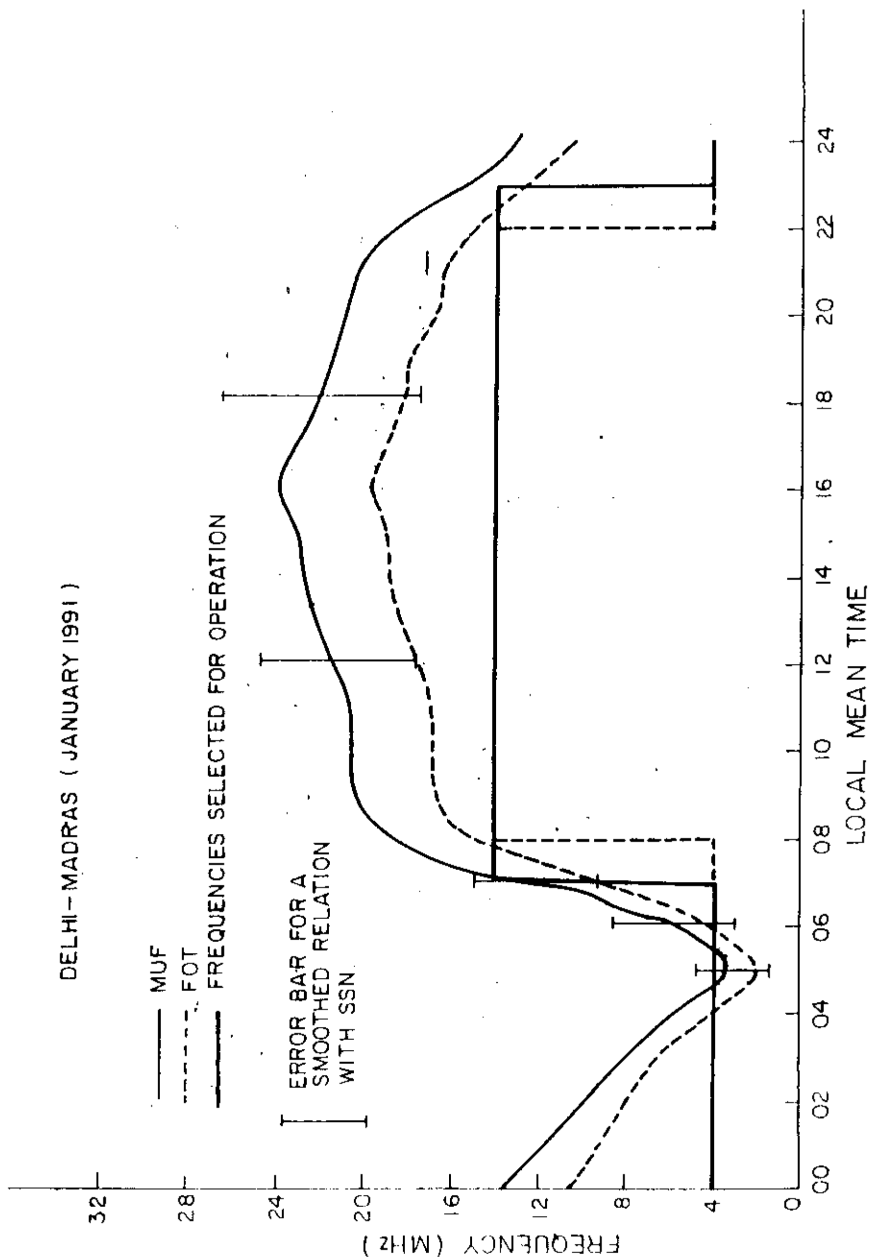
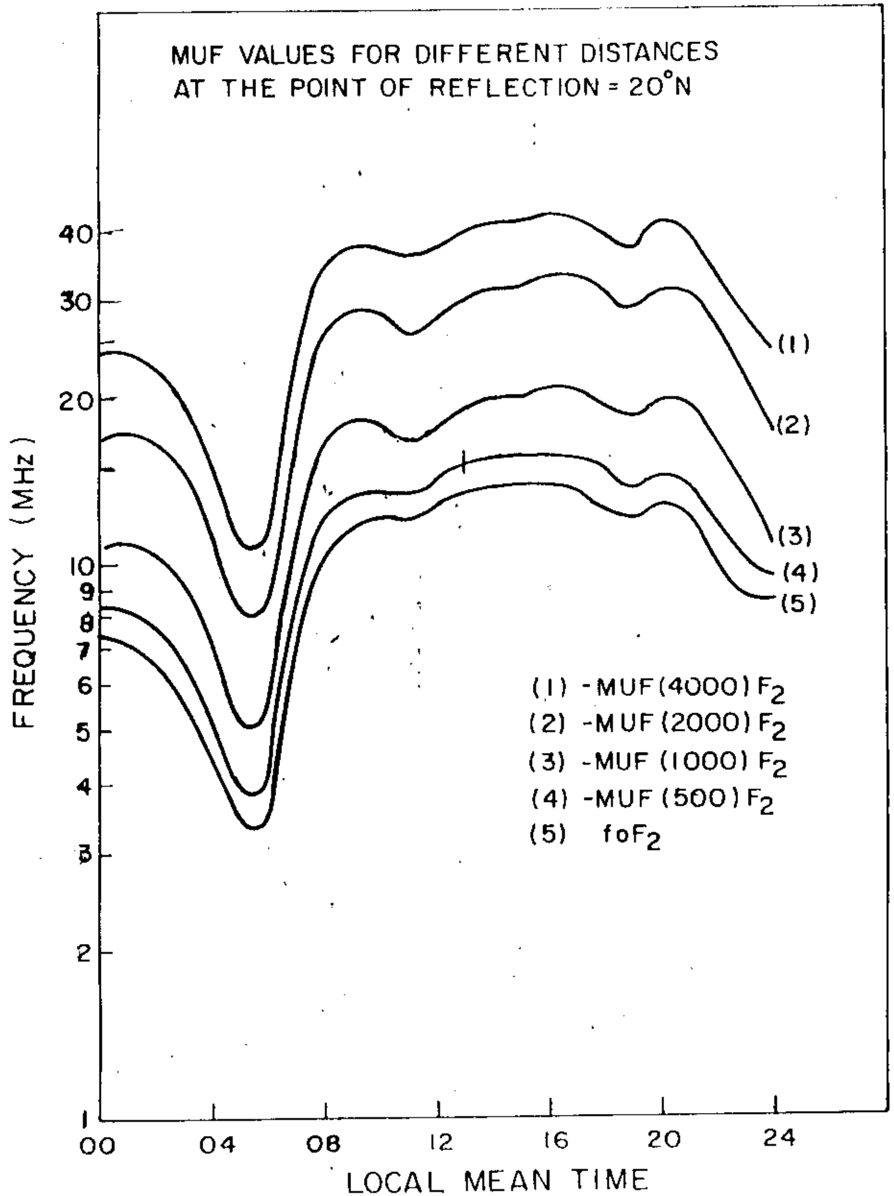


Fig. 3



DELHI-MADRAS (JANUARY 1991)
MUF
FOT
FREQUENCIES SELECTED FOR OPERATION
ERROR BAR FOR A SMOOTHED RELATION WITH SSN
FREQUENCY (MHz)
LOCAL MEAN TIME

Fig:4



MUF VALUES FOR DIFFERENT DISTANCES
AT THE POINT OF REFLECTION = 20°N
FREQUENCY (MHz)
(1) -MUF(4000) F2
(2) -MUF(2000) F2
(3) -MUF (1000) F2
(4) -MUF (500) F2
(5) foF2
LOCAL MEAN TIME

Fig. 5

TABLE 1

LIST OF STATIONS AND THE DATA BASE FOR THE ATLAS

STATION	LAT.	LONG.	YEARS OF DATA
ALMA ATA	43.3°N	76.9°E	≃ 40 yrs
ASHKHABAD	37.9°N	58.3°E	≃ 40 yrs
DELHI	28.6°N	77.2°E	≃ 35 yrs
AHMEDABAD	23.0°N	72.6°E	≃ 33 yrs
HARINGHATA CALCUTTA	22.9°N	88.6°E	≃ 30 yrs
BOMBAY	19.0°N	72.8°E	≃ 35 yrs
HYDERABAD	17.4°N	78.5°E	≃ 10 } 42 yrs
MANILA	14.7°N	121.1°E	≃ 20 } 42 yrs
BAGUIO	16.4°N	120.6°E	≃ 12 } 42 yrs
MADRAS	13.0°N	80.3°E	≃ 17 yrs
TIRUCHIRAPALLI	10.8°N	78.7°E	≃ 30 yrs
KODAIKANAL	10.2°N	77.5°E	≃ 43 yrs
THUMBA TRIVANDRUM	8.6°N	76.9°E	≃ 20 yrs
SINGAPORE	1.3°N	141.3°E	≃ 26 yrs

TABLE 2

Predicted values of 12 months running average Sunspot-Numbers

(Based on observed sunspot numbers upto August 1990)

Month	$\bar{R}$	Month	$\bar{R}$
April 1990	156	October	132
May	154	November	129
June	152	December	126
July	147	January 1991	123
August	142	February	121
September	136	March	120

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10th August 1990.

TABLE - 3

DELHI - MADRAS (28.6) (13.0) JANUARY 1991 Great circle distance 1750 kms

TIME/SSN→	foF2			MUF(4000)F2			MUF(1750)F2	FOT(1750)
	100	150	121	100	150	121	121	121
00	6.9	9.5	8.0	23.0	30.0	25.9	17.0	14.4
01	6.2	8.9	7.3	20.0	28.0	23.4	15.3	13.0
02	5.8	8.0	6.7	18.0	26.0	21.4	14.0	11.9
03	4.9	6.8	5.7	16.5	22.0	18.8	12.2	10.4
04	3.9	5.4	4.5	13.0	17.0	14.7	9.5	8.1
05	3.0	4.2	3.5	8.0	13.5	10.3	7.0	5.9
06	4.5	5.0	4.7	14.0	15.0	14.4	9.5	8.1
07	6.5	7.5	6.9	24.0	26.0	24.8	15.9	13.5
08	10.1	11.1	10.5	32.5	37.5	34.6	22.5	19.1
09	10.6	12.0	11.2	35.5	39.0	37.0	24.0	20.4
10	11.2	12.8	11.9	36.0	38.0	36.8	24.2	20.6
11	12.0	13.2	12.5	36.5	37.5	36.9	24.4	20.7
12	12.5	13.5	12.9	37.5	37.5	37.5	25.0	21.2
13	13.2	13.9	13.5	39.0	38.0	39.0	26.0	22.1
14	13.3	14.1	13.6	40.0	38.0	40.0	26.8	22.8
15	13.2	14.1	13.6	40.0	38.0	40.0	26.8	22.8
16	13.0	14.0	13.4	42.0	38.0	42.0	27.8	23.6
17	12.9	13.5	13.1	41.0	38.0	41.0	27.0	22.9
18	12.9	13.2	13.0	39.0	38.0	39.0	26.0	22.1
19	11.7	13.2	12.3	38.0	38.5	38.2	25.6	21.8
20	11.2	13.1	12.0	37.0	38.0	37.4	24.4	20.7
21	10.5	12.5	11.3	35.0	38.0	36.3	24.0	20.4
22	9.1	11.6	10.1	32.0	38.0	34.5	22.2	18.9
23	8.0	10.5	9.0	26.0	34.0	29.4	19.0	16.1
24	6.9	9.5	8.0	23.0	30.0	25.9	17.0	14.4

TABLE 4

FACTOR-DISTANCE TABLE

DISTANCE (KMS.)	M-FACTOR VALUES (EACH FIGURE TO BE DEVIDED BY 100) (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0	100	100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	101	101	101	101	101	102	102	103	103	104
200	100	100	101	102	102	102	103	103	104	105	106	107	108
300	100	100	102	103	104	104	105	106	109	110	112	114	118
400	100	101	103	105	106	107	108	110	113	115	118	122	129
500	101	102	105	108	110	111	113	117	121	125	131	139	144
600	102	104	107	112	114	115	119	124	130	135	145	156	160
700	103	106	110	115	119	122	127	134	142	149	160	173	177
800	105	109	114	119	124	129	135	144	154	162	175	190	195
900	107	112	118	123	130	136	143	155	165	174	190	205	212
1000	109	115	122	123	136	143	152	166	176	187	205	220	230
1100	111	113	126	133	142	151	162	177	187	199	219	234	246
1200	114	122	130	139	148	159	172	189	199	212	233	249	262
1300	117	125	135	145	154	167	181	199	210	224	246	262	276
1400	121	129	141	151	161	175	191	209	222	237	259	276	290
1500	124	133	146	153	163	184	200	213	231	243	270	288	303
1600	127	137	152	165	175	193	209	[illegible]	241	259	281	300	316
1700	130	142	157	171	182	200	217	236	259	268	291	311	327
1800	134	147	163	177	190	203	226	245	259	278	302	322	339
1900	137	152	168	183	197	215	233	252	268	287	312	332	349
2000	141	157	174	190	205	223	241	260	277	297	322	343	359
2100	145	152	179	196	211	229	249	267	285	305	330	351	368
2200	149	167	164	202	219	236	255	275	293	313	339	360	378
2300	153	172	189	207	224	242	261	282	300	320	345	367	385
2400	157	177	195	213	231	243	267	289	307	323	352	374	393
2500	161	181	199	217	236	254	273	295	313	334	357	379	399
2600	165	185	204	222	242	260	279	301	320	340	363	385	405
2700	169	189	208	226	246	265	284	306	325	345	368	389	409
2800	173	193	212	231	251	270	290	311	331	351	373	394	414
2900	176	196	216	235	255	275	295	315	335	355	376	397	417
3000	180	200	220	240	260	280	300	320	340	360	380	400	420
3100	182	202	222	242	262	282	302	322	342	362	382	402	0
3200	185	205	225	245	265	285	305	325	345	365	335	405	0
3300	188	208	223	248	268	288	308	323	348	368	398	0	0
3400	191	211	231	251	271	291	311	331	351	371	391	0	0
3500	194	214	234	254	274	294	314	334	354	374	0	0	0
3600	196	216	236	256	276	296	314	336	356	0	0	0	0
3700	199	219	239	259	279	299	319	339	359	0	0	0	0
3800	202	222	242	262	332	302	322	342	0	0	0	0	0
3900	205	225	245	265	265	305	325	345	0	0	0	0	0
4000	208	226	248	268	288	308	328	0	0	0	0	0	0

FROM THE 13 VERTICAL COLUMNS TWO ADJACENT COLUMNS ARE CHOSEN SUCH THAT THE PREDICTED M(3000)F2 VALUE OBTAINED IN STEP , LIES BETWEEN THEM; E.G. IF THE PREDICTED M(3000)F2 VALUE IS 2.92 THE COLUMNS (6) AND (7) ARE CHOSEN. ALONG THESE VERTICAL COLUMNS THE M(FACTOR) VALUES ARE READ FOR THE GIVEN DISTANCE.

TABLE-5

MONTH= 1	YEAR= 1991 --DELHI-MADRAS																							
PATH DISTANCE= 0.1731E+04																								
FIRST MODE ONE HOP																								
L. TIME	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	[illegible]	19	20	21	[illegible]	[illegible]
UD FMUF	205	211	199	183	133	96	102	219	334	361	360	319	333	340	354	[illegible]	380	384	361	338	352	348	[illegible]	255
MED FMUF	157	156	150	138	100	74	76	162	242	258	261	236	256	272	285	[illegible]	299	300	282	266	265	278	[illegible]	201
LD FMUF	113	114	108	100	74	54	56	115	167	170	177	167	[illegible]	204	[illegible]	217	227	231	217	205	[illegible]	[illegible]	[illegible]	149
EMUF	[illegible]	[illegible]	0	0	0	0	0	106	144	167	182	170	143	191	184	172	151	117	87	64	[illegible]	41	[illegible]	[illegible]
LUF	0	0	0	0	0	0	0	56	80	91	98	101	[illegible]	102	[illegible]	[illegible]	84	68	[illegible]	0	0	0	0	[illegible]
ANGLE(F)	[illegible]	[illegible]	156	146	154	172	169	155	152	165	173	147	140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	159	165	158
ANGLE(E)	32	32	32	32	32	32	[illegible]	32	32	32	32	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32	[illegible]	32
L. TIME	0	1	2	3	4	5	6	7	8	9	10	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Each figure in the Table should be devided by 10 to yield frequency in MH_z and angle in degrees.

L. TIME: Local time in hours
UD FMUF: Upper decile values of maximum-useable frequencies for F-region
MED FMUF: Median values of maximum-useable frequencies for F-region
LD FMUF: Lower decile values of maximum useable frequencies for F-region
EMUF: Median values of maximum-useable frequencies for E-region
MUF: Lowest useable frequencies
ANGLE (F): Angles in degrees for F-region-reflection
ANGLE (E): Angles in degrees for E-region-reflection
L. TIME: Local time in hours

APPENDIX A
MAPS OF F2 LAYER COMMUNICATION PARAMETERS

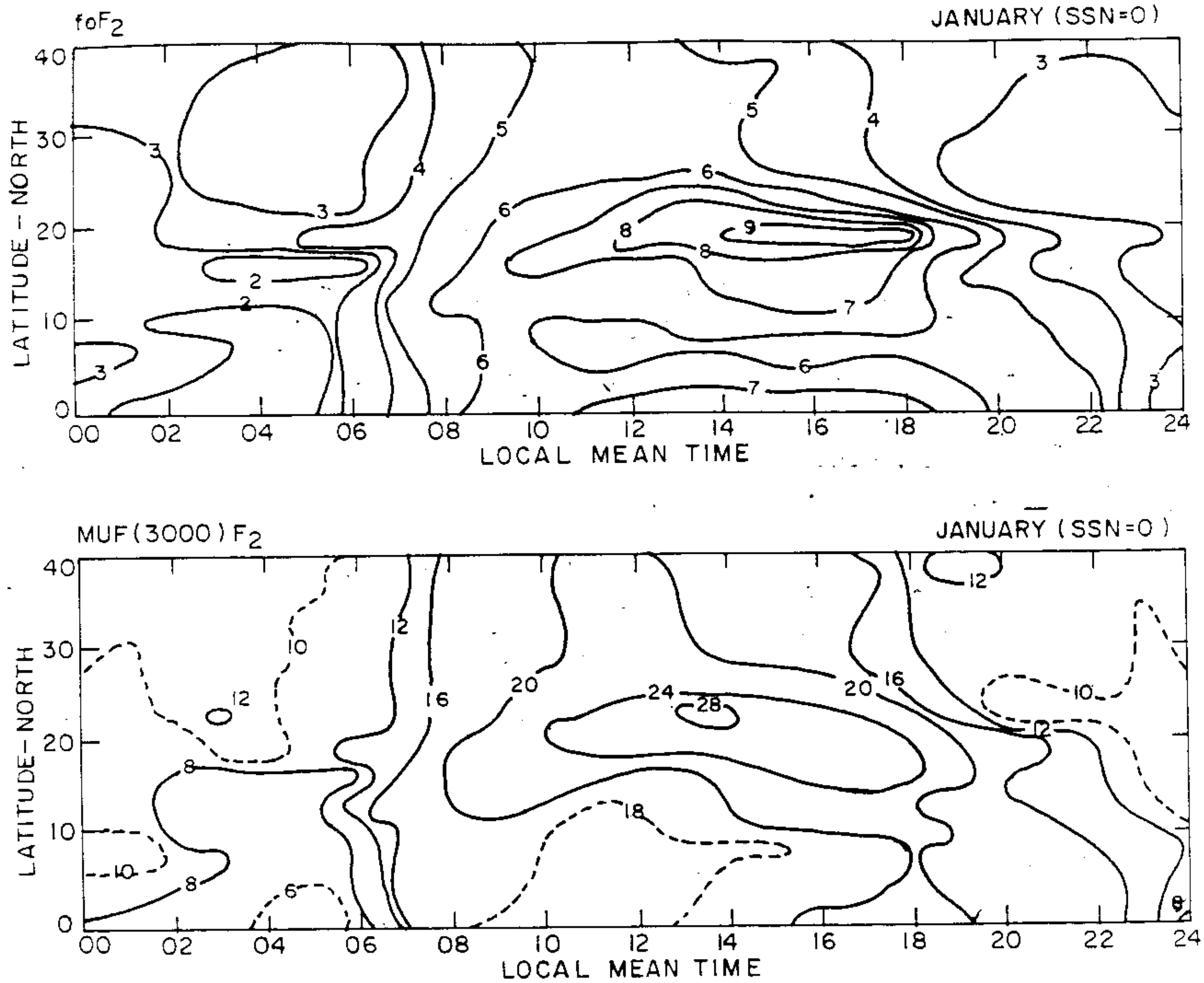

Fig.A1 .CONTOUR MAPS OF foF_2 AND MUF(4000) F_2 FOR JANUARY (SSN = 0)

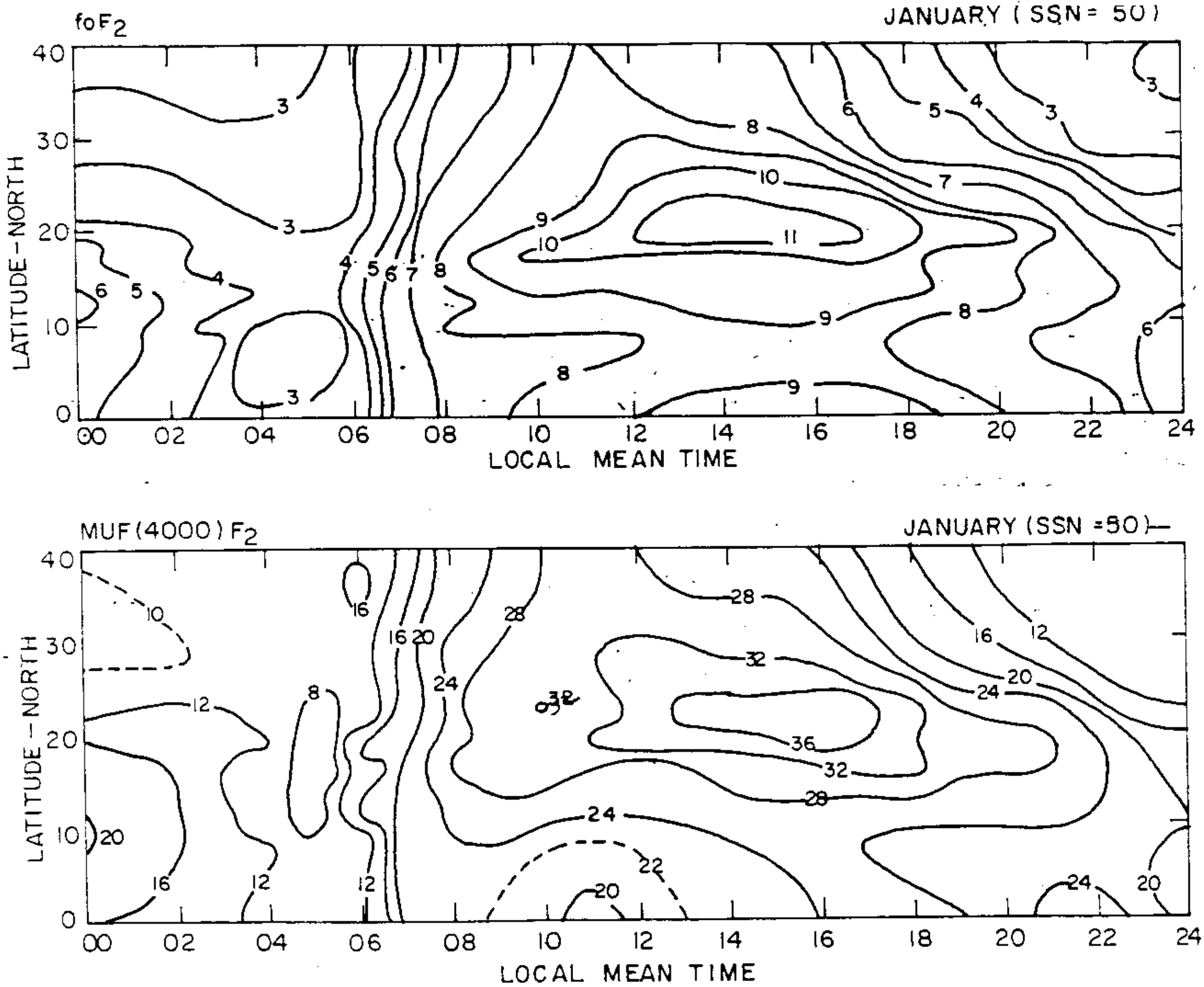

Fig.A2 CONTOUR MAPS OF foF_2 AND MUF(4000) F_2 FOR JANUARY (SSN=50)

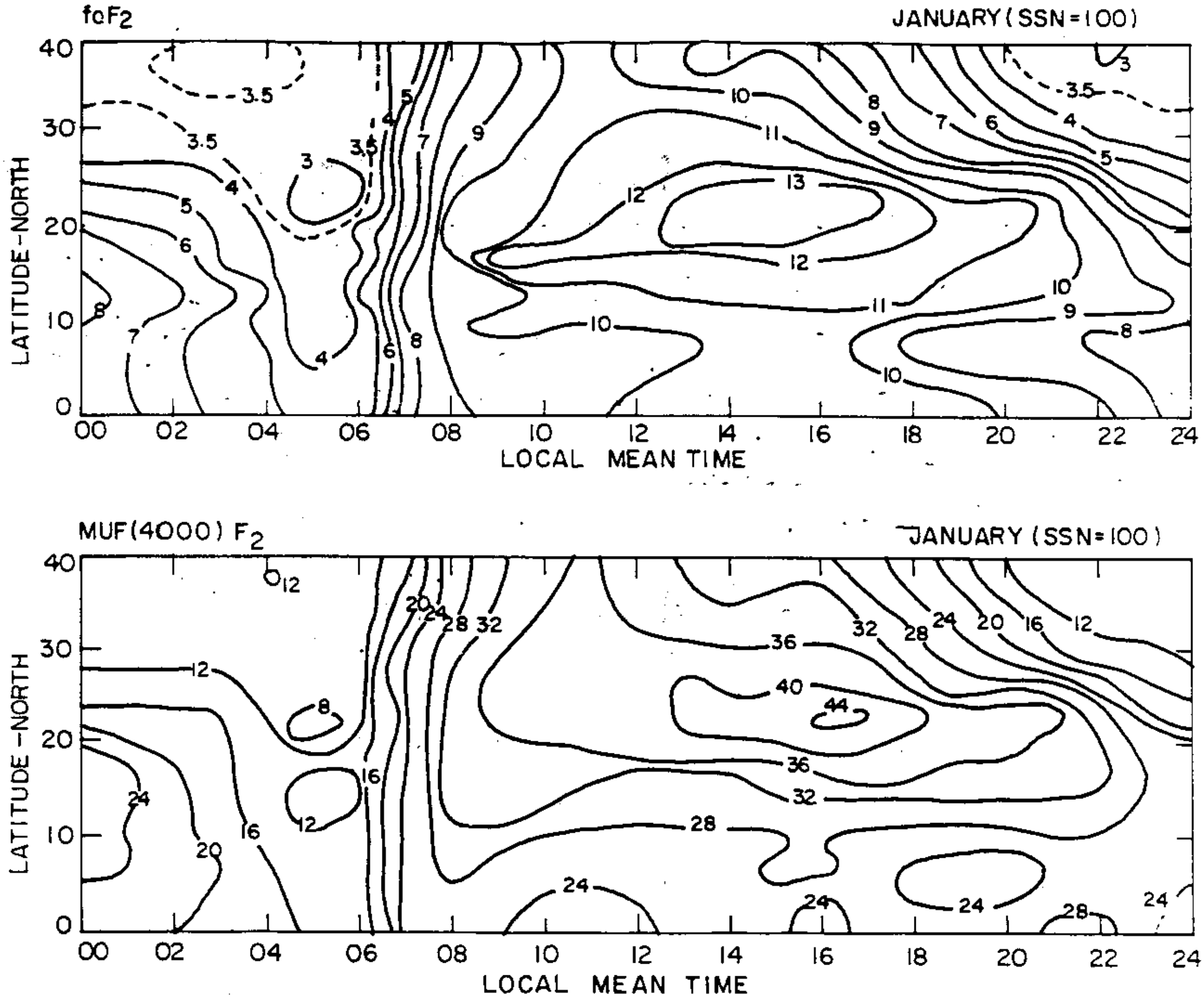

Fig.A3 CONTOUR MAPS OF foF_2 AND MUF(4000) F_2 FOR JANUARY (SSN=100)

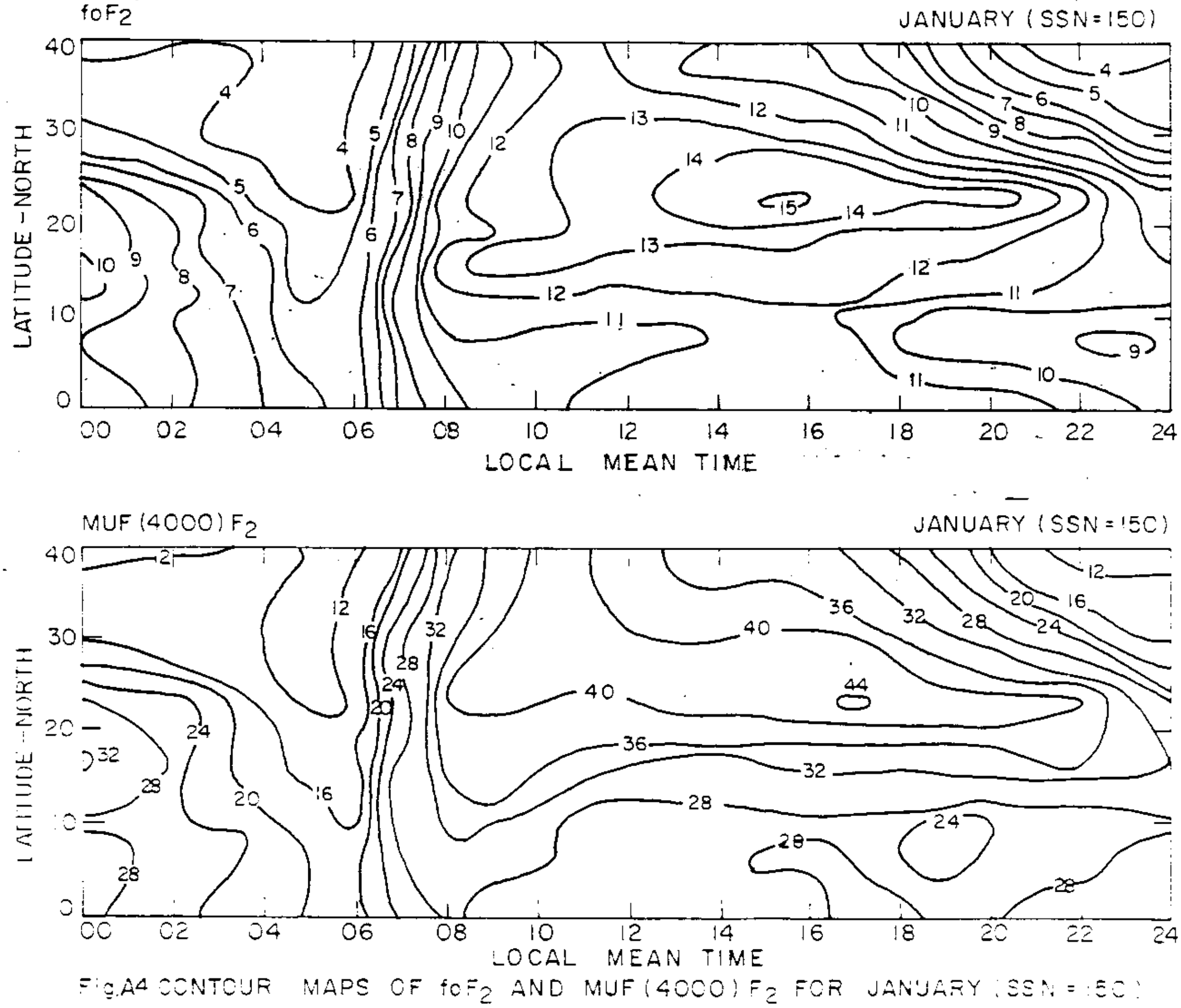

Fig.A4 CONTOUR MAPS OF foF_2 AND MUF(4000) F_2 FOR JANUARY (SSN=150)

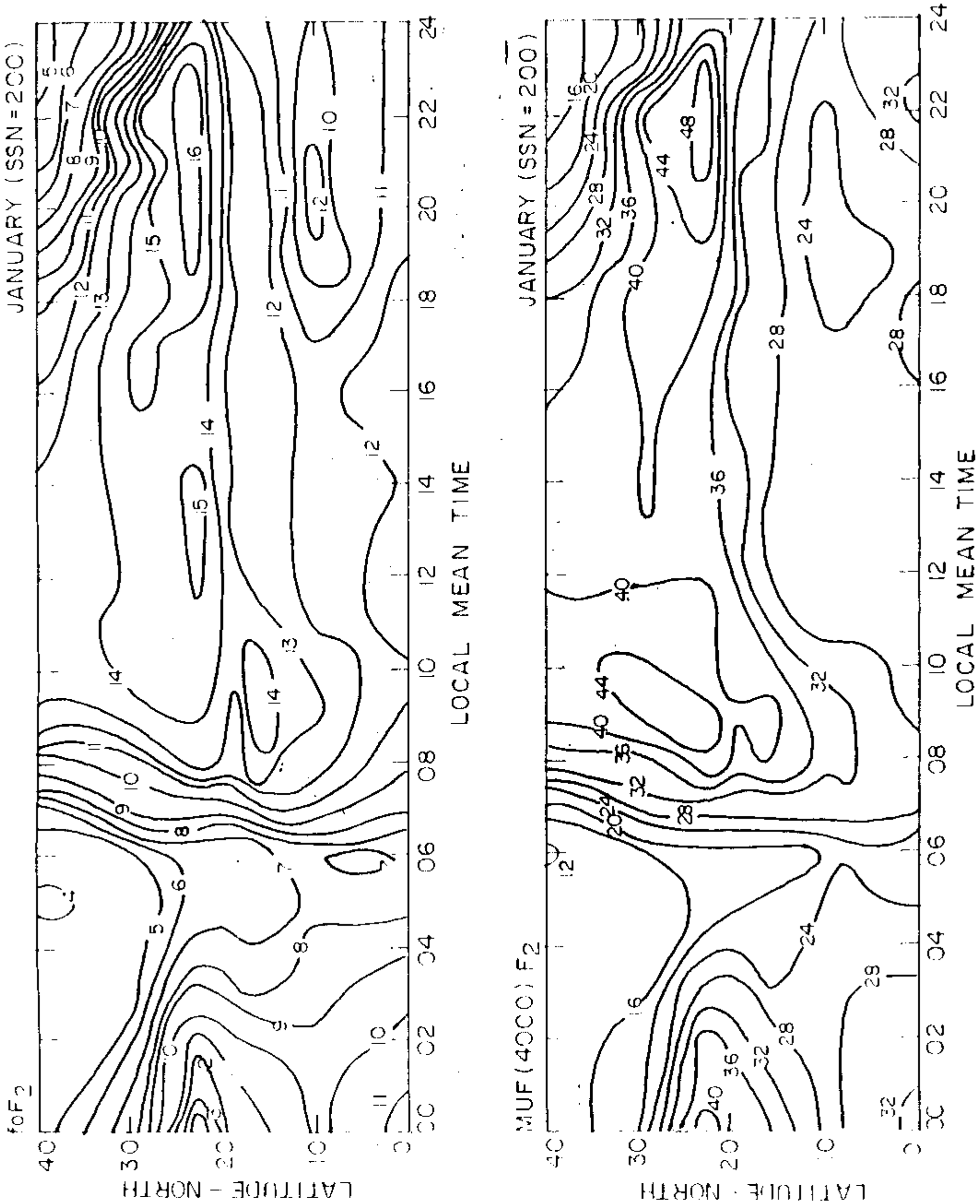

Fig.A5 CONTOUR MAPS OF foF_2 AND MUF(4000) F_2 FOR JANUARY (SSN=200)

APPENDIX B

THE SUN'S ZENITH ANGLE OVER INDIAN SUBCONTINENT

B.1 THE SUN'S ZENITH ANGLE FOR JANUARY, FEBRUARY AND MARCH.
B.2 THE SUN'S ZENITH ANGLE FOR APRIL, MAY AND JUNE.
B.3 THE SUN'S ZENITH ANGLE FOR JULY, AUGUST AND SEPTEMBER.
B.4 THE SUN'S ZENITH ANGLE FOR OCTOBER, NOVEMBER AND DECEMBER.

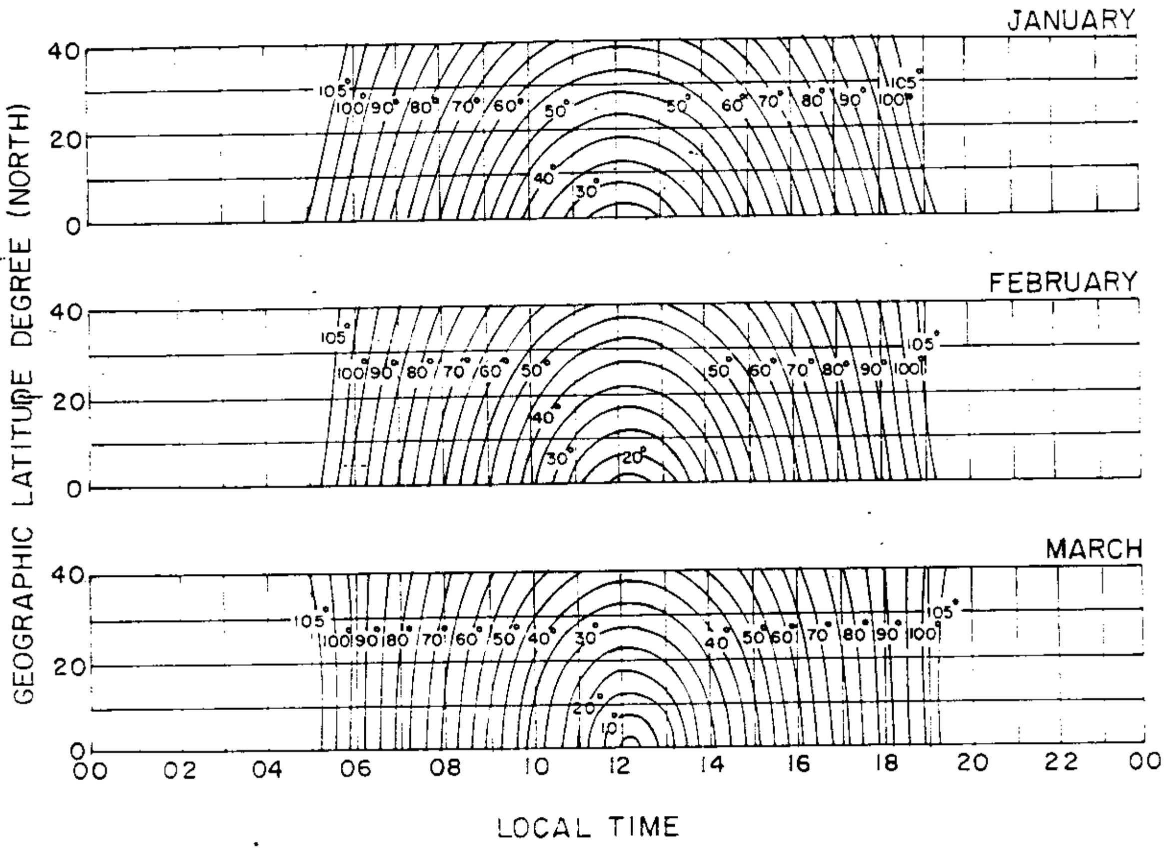

Fig. B.1 SUN'S ZENITH ANGLE- JANUARY, FEBRUARY AND MARCH

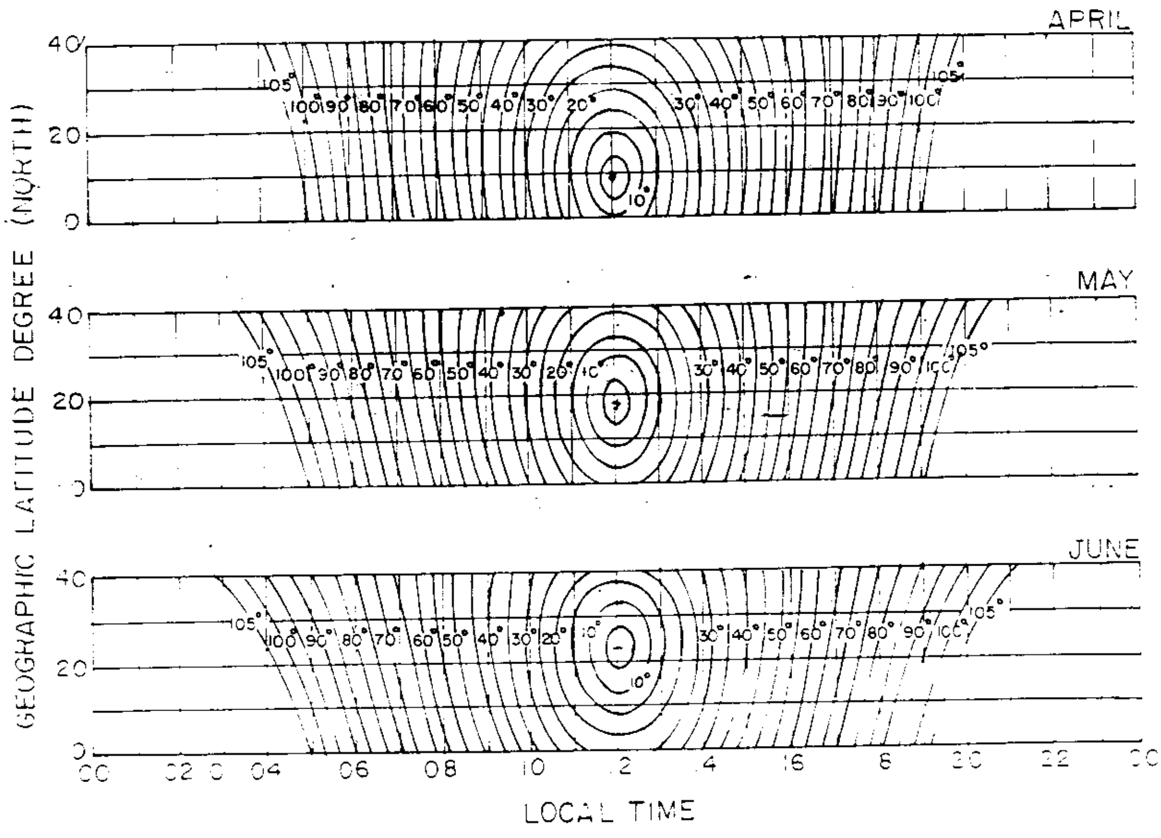

Fig. B.2 SUN'S ZENITH ANGLE - APRIL, MAY AND JUNE

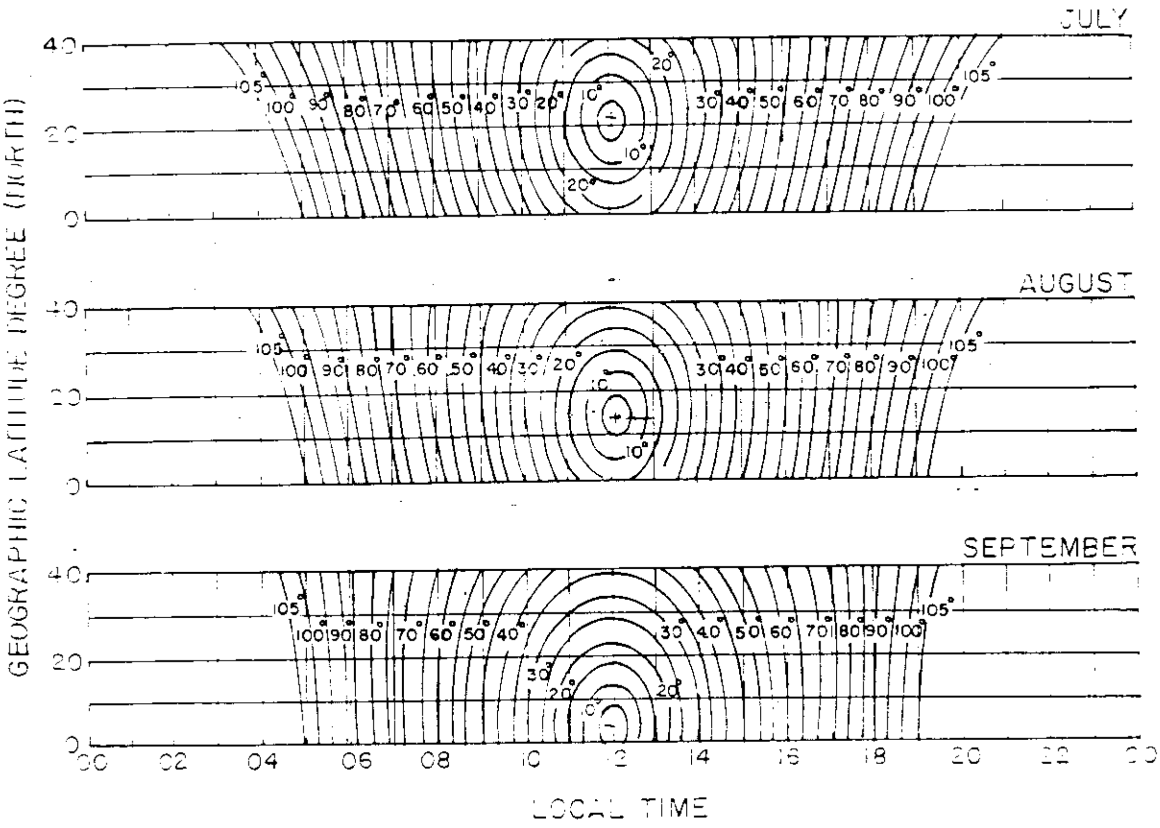

Fig. B.3 SUN'S ZENITH ANGLE--JULY, AUGUST AND SEPTEMBER

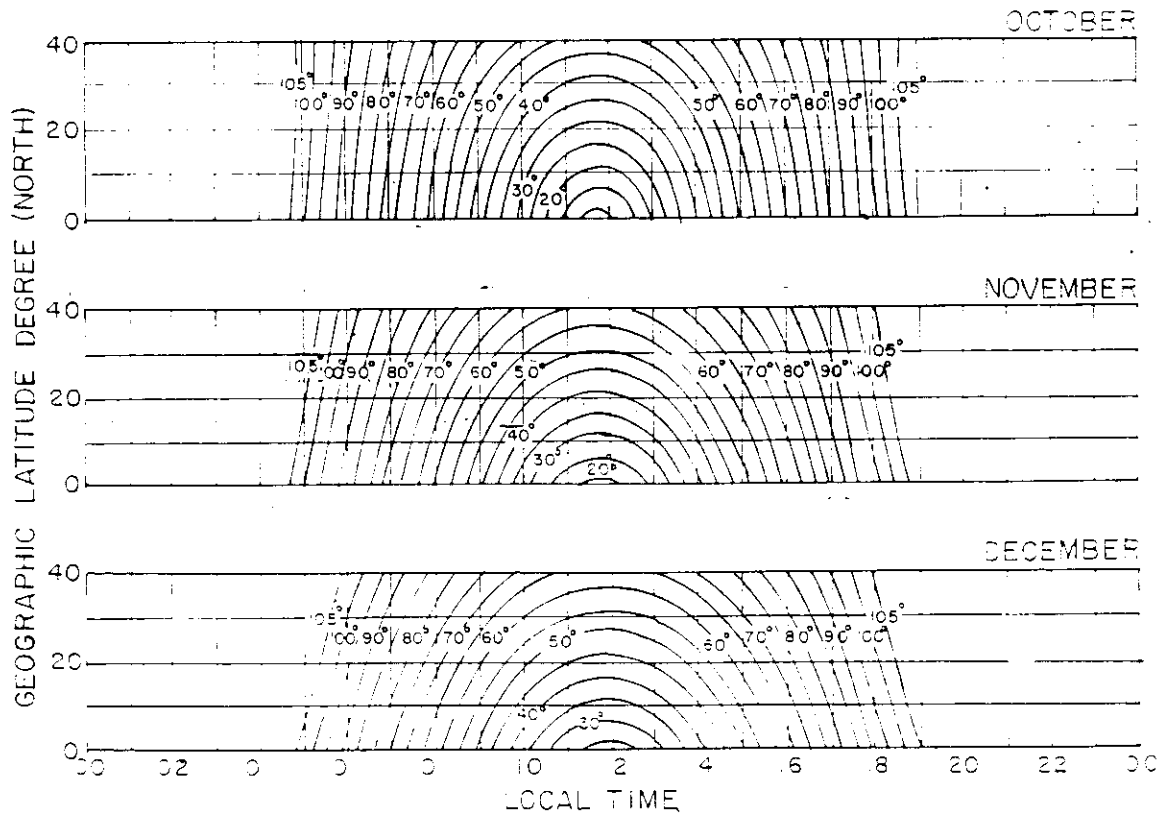

Fig. B.4 SUN'S ZENITH ANGLE—OCTOBER, NOVEMBER AND DECEMBER

APPENDIX C

TABLES COTAINING SECOND DEGREE COEFFICIENTS:A,B,C,D,E AND F.

TABLE C1 SECOND DEGREE CO-EFFICIENTS A,B,C,D,E,F FOR JANUARY

****
JANUARY
****

ALMATA (43.2)

HOUR	A	B	C	D	E	F
1*	[illegible]	-0.102E-01	0.932E-04	0.305E+01	-0.269E-02	-0.144E-05
2*	0.334E+01	-0.747E-02	0.696E-04	0.306E+01	-0.294E-02	-0.752E-06
3*	0.331E+01	-0.635E-02	0.631E-04	0.306E+01	-0.281E-02	0.101E-05
4*	0.332E+01	-0.485E-02	0.525E-04	0.308E+01	-0.258E-02	-0.227E-05
5*	0.323E+01	-0.166E-02	0.403E-04	0.309E+01	-0.223E-02	-0.214E-05
6*	0.323E+01	-0.248E-02	0.407E-04	0.323E+01	-0.158E-02	-0.626E-05
7*	0.290E+01	0.167E-02	0.174E-04	0.324E+01	-0.216E-02	-0.488E-05
8*	0.308E+01	0.757E-02	0.314E-04	0.326E+01	-0.201E-02	-0.288E-05
9*	0.436E+01	0.251E-01	0.176E-04	0.352E+01	-0.135E-02	-0.848E-05
10*	0.490E+01	0.405E-01	0.494E-05	0.345E+01	-0.205E-02	-0.199E-05
11*	0.521E+01	0.494E-01	-0.171E-04	0.346E+01	-0.242E-02	-0.221E-05
12*	0.527E+01	0.561E-01	-0.618E-04	0.346E+01	-0.122E-02	-0.104E-04
13*	0.510E+01	0.497E-01	-0.382E-04	0.348E+01	-0.145E-02	-0.117E-04
14*	0.495E+01	0.442E-01	-0.199E-04	0.347E+01	-0.312E-02	-0.457E-05
15*	0.493E+01	0.447E-01	-0.237E-04	0.343E+01	-0.137E-02	-0.136E-04
16*	0.471E+01	0.422E-01	-0.163E-04	0.349E+01	-0.947E-03	-0.171E-04
17*	0.427E+01	0.300E-01	0.413E-04	0.353E+01	-0.103E-02	-0.171E-04
18*	0.355E+01	0.280E-01	0.564E-04	0.332E+01	0.531E-03	-0.186E-04
19*	0.318E+01	0.209E-01	0.735E-04	0.317E+01	0.250E-02	-0.219E-04
20*	0.334E+01	-0.303E-02	0.146E-03	0.324E+01	0.319E-02	-0.267E-04
21*	0.322E+01	-0.168E-01	0.163E-03	0.323E+01	0.329E-03	-0.114E-04
22*	0.308E+01	-0.125E-01	0.116E-03	0.310E+01	-0.165E-02	-0.363E-05
23*	0.322E+01	-0.120E-01	0.100E-03	0.306E+01	-0.267E-02	0.138E-05
24*	0.326E+01	-0.968E-02	0.809E-04	0.303E+01	-0.313E-02	0.259E-05

ASHKABAD (37.9)

HOUR	A	B	C	D	E	F
1*	0.315E+01	-0.471E-02	0.696E-04	0.306E+01	-0.262E-02	0.135E-05
2*	0.310E+01	-0.267E-02	0.590E-04	0.308E+01	-0.313E-02	0.573E-05
3*	0.310E+01	0.950E-03	0.384E-04	0.311E+01	-0.322E-02	0.689E-05
4*	0.299E+01	0.576E-02	0.121E-04	0.319E+01	-0.362E-02	0.723E-05
5*	0.287E+01	0.862E-02	-0.520E-05	0.322E+01	-0.256E-02	-0.774E-07
6*	0.277E+01	0.564E-02	0.989E-05	0.332E+01	-0.435E-02	0.778E-05
7*	0.257E+01	0.614E-02	0.344E-05	0.325E+01	-0.250E-02	0.209E-05
8*	0.286E+01	0.123E-01	0.133E-04	0.330E+01	-0.241E-02	-0.416E-06
9*	0.439E+01	0.260E-01	0.813E-05	0.362E+01	-0.128E-02	-0.686E-05
10*	0.470E+01	0.352E-01	0.230E-04	0.365E+01	-0.380E-02	0.433E-05
11*	0.502E+01	0.512E-01	-0.386E-04	0.349E+01	-0.157E-02	-0.663E-05
12*	0.552E+01	0.568E-01	-0.607E-04	0.346E+01	-0.534E-03	-0.132E-04
13*	0.532E+01	0.459E-01	-0.350E-04	0.353E+01	-0.192E-02	-0.119E-04
14*	0.510E+01	0.334E-01	0.532E-05	0.353E+01	-0.320E-02	-0.618E-05
15*	0.488E+01	0.400E-01	0.547E-05	0.347E+01	-0.236E-02	-0.100E-04
16*	0.509E+01	0.395E-01	0.634E-06	0.351E+01	-0.220E-02	-0.985E-05
17*	0.475E+01	0.383E-01	-0.469E-06	0.361E+01	-0.152E-02	-0.159E-04
18*	0.418E+01	0.242E-01	0.598E-04	0.351E+01	[illegible]	-0.178E-04
19*	0.329E+01	0.200E-01	0.929E-04	0.327E+01	0.167E-02	-0.196E-04
20*	0.302E+01	0.546E-02	0.120E-03	0.337E+01	0.758E-03	-0.143E-04
21*	0.323E+01	-0.139E-01	0.175E-03	0.335E+01	-0.281E-03	-0.122E-04
22*	0.303E+01	-0.155E-01	0.151E-03	0.324E+01	-0.412E-02	0.928E-05
23*	0.298E+01	-0.102E-01	0.113E-03	0.304E+01	-0.316E-02	0.646E-05
24*	0.304E+01	-0.411E-02	0.700E-04	0.301E+01	-0.259E-02	0.378E-05

TABLE C1 (CONTD.)

DELHI ([illegible])

HOUR	A	B	C	D	E	F
1*	0.290E+01	-0.121E-01	[illegible]	0.316E+01	-0.284E-02	0.523E-05
2*	0.262E+01	[illegible]	0.145E-03	0.315E+01	-0.186E-02	0.194E-05
3*	0.296E+01	-0.963E-02	0.132E-03	0.328E+01	-0.323E-02	0.404E-05
4*	0.232E+01	-0.136E-02	0.590E-04	0.339E+01	-0.121E-02	-0.376E-05
5*	0.274E+01	-0.575E-03	0.429E-04	0.363E+01	-0.777E-02	0.172E-04
6*	0.249E+01	0.314E-02	0.265E-04	0.342E+01	-0.636E-02	0.159E-04
7*	0.267E+01	0.291E-02	0.422E-04	0.326E+01	-0.208E-02	-0.453E-06
8*	0.371E+01	[illegible]	-0.147E-04	0.347E+01	0.106E-02	-0.163E-04
9*	0.466E+01	0.471E-01	-0.959E-04	0.359E+01	-0.169E-02	-0.485E-05
10*	0.496E+01	0.504E-01	-0.295E-04	0.343E+01	0.176E-02	-0.205E-04
11*	0.518E+01	0.620E-01	-0.254E-04	0.333E+01	0.240E-02	-0.246E-04
12*	0.573E+01	0.631E-01	-0.945E-04	0.329E+01	0.158E-02	-0.220E-04
13*	0.561E+01	0.777E-01	-0.172E-03	0.345E+01	-0.189E-02	-0.151E-04
14*	0.544E+01	0.605E-01	-0.173E-03	0.337E+01	0.394E-03	-0.243E-04
15*	0.522E+01	0.755E-01	-0.138E-03	0.344E+01	-0.375E-02	-0.447E-05
16*	0.475E+01	0.794E-01	-0.143E-03	0.336E+01	0.244E-02	-0.353E-04
17*	0.459E+01	0.700E-01	-0.875E-04	0.344E+01	0.133E-02	-0.309E-04
18*	0.410E+01	0.549E-01	0.197E-07	0.347E+01	0.330E-02	-0.374E-04
19*	0.329E+01	0.391E-01	0.899E-04	0.340E+01	0.320E-02	-0.346E-04
20*	0.263E+01	0.352E-01	0.106E-03	0.327E+01	0.387E-02	-0.376E-04
21*	0.303E+01	0.119E-01	0.222E-03	0.340E+01	0.127E-02	-0.259E-04
22*	0.275E+01	0.174E-02	0.237E-03	0.336E+01	0.559E-03	-0.193E-04
23*	0.372E+01	-0.514E-01	0.547E-03	0.317E+01	-0.911E-03	-0.723E-05
24*	0.273E+01	-0.741E-02	0.196E-03	0.317E+01	-0.115E-02	-0.690E-05

AHMEDABAD ([illegible])

HOUR	A	B	C	D	E	F
1*	0.236E+01	-0.479E-04	0.285E-03	0.291E+01	-0.360E-03	-0.272E-05
2*	0.258E+01	0.444E-02	0.220E-03	0.298E+01	0.509E-03	-0.832E-05
3*	0.297E+01	0.240E-02	0.203E-03	0.321E+01	-0.186E-02	0.297E-05
4*	0.325E+01	-0.131E-02	0.157E-03	0.340E+01	-0.989E-03	-0.497E-05
5*	0.270E+01	-0.102E-01	0.162E-03	0.348E+01	-0.284E-02	-0.269E-05
6*	0.242E+01	-0.179E-01	0.126E-03	0.331E+01	-0.745E-02	0.213E-04
7*	0.236E+01	-0.158E-01	0.179E-03	0.306E+01	-0.323E-02	0.959E-05
8*	0.395E+01	0.117E-01	[illegible]	0.343E+01	-0.426E-02	0.920E-05
9*	0.501E+01	0.460E-01	-0.735E-04	0.341E+01	-0.112E-02	-0.464E-05
10*	[illegible]	0.635E-01	-0.973E-04	0.335E+01	-0.161E-02	-0.320E-05
11*	[illegible]	0.475E-01	-0.436E-04	0.337E+01	-0.144E-02	-0.111E-04
12*	[illegible]	0.519E-01	-0.470E-04	0.329E+01	-0.449E-02	0.238E-05
13*	0.744E+01	[illegible]	-0.941E-04	0.316E+01	-0.386E-02	0.393E-06
14*	0.817E+01	[illegible]	-0.169E-03	0.320E+01	-0.291E-02	-0.732E-05
15*	0.706E+01	[illegible]	-0.217E-03	0.326E+01	-0.300E-02	-0.108E-04
16*	[illegible]	[illegible]	-0.295E-03	0.333E+01	-0.495E-02	-0.188E-05
17*	0.651E+01	0.124E-01	-0.313E-03	0.338E+01	-0.399E-02	-0.684E-05
18*	0.592E+01	[illegible]	[illegible]	0.353E+01	-0.454E-02	-0.607E-05
19*	[illegible]	[illegible]	[illegible]	0.363E+01	-0.470E-02	-0.653E-05
20*	[illegible]	[illegible]	[illegible]	0.332E+01	-0.205E-02	-0.130E-04
21*	[illegible]	[illegible]	[illegible]	0.308E+01	0.184E-02	-0.227E-04
22*	[illegible]	[illegible]	[illegible]	0.326E+01	0.712E-03	-0.171E-04
23*	[illegible]	[illegible]	[illegible]	0.330E+01	-0.219E-02	-0.207E-05
24*	[illegible]	[illegible]	[illegible]	0.307E+01	-0.172E-02	0.100E-05

TABLE C1 (CONTD.)

BOMBAY ([illegible])

HOUR	A	B	C	D	E	F
1*	0.296E+01	0.497E-01	-0.372E-04	0.266E+01	0.109E-01	-0.681E-04
2*	0.272E+01	0.409E-01	0.513E-05	DATA INSUFFICIENT		
3*	0.300E+01	0.257E-01	0.533E-04	DATA INSUFFICIENT		
4*	0.314E+01	0.905E-02	0.923E-04	0.299E+01	0.520E-02	-0.289E-04
5*	0.336E+01	-0.124E-01	0.150E-03	0.326E+01	-0.144E-02	-0.121E-05
6*	0.554E+01	-0.471E-01	0.266E-03	DATA INSUFFICIENT		
7*	0.539E+01	-0.220E-01	0.128E-03	0.335E+01	0.139E-03	-0.132E-04
8*	0.432E+01	0.352E-01	-0.821E-04	0.315E+01	-0.204E-02	0.720E-05
9*	0.580E+01	0.443E-01	-0.520E-04	0.324E+01	-0.837E-03	-0.827E-05
10*	0.656E+01	0.512E-01	-0.106E-03	0.299E+01	-0.182E-02	0.691E-05
11*	0.696E+01	0.582E-01	-0.138E-03	0.300E+01	-0.125E-02	-0.382E-05
12*	0.770E+01	0.592E-01	-0.156E-03	0.296E+01	-0.244E-02	0.143E-05
13*	0.824E+01	0.599E-01	-0.168E-03	0.277E+01	0.168E-02	-0.210E-04
14*	0.868E+01	0.873E-01	-0.366E-03	DATA INSUFFICIENT		
15*	0.912E+01	0.658E-01	-0.228E-03	0.277E+01	-0.258E-02	0.549E-06
16*	0.942E+01	0.562E-01	-0.195E-03	0.266E+01	0.230E-02	-0.219E-04
17*	0.947E+01	0.529E-01	-0.189E-03	0.264E+01	0.912E-02	-0.723E-04
18*	0.856E+01	0.655E-01	-0.242E-03	0.273E+01	0.629E-02	-0.556E-04
19*	0.808E+01	0.558E-01	-0.154E-03	0.285E+01	0.541E-03	-0.147E-04
20*	0.645E+01	0.675E-01	-0.182E-03	0.287E+01	0.430E-02	-0.410E-04
21*	0.555E+01	0.879E-01	-0.267E-03	0.298E+01	0.347E-02	-0.394E-04
22*	0.477E+01	0.793E-01	-0.210E-03	0.312E+01	0.732E-03	-0.210E-04
23*	0.375E+01	0.696E-01	-0.134E-03	0.317E+01	0.385E-02	-0.445E-04
24*	0.341E+01	0.599E-01	-0.741E-04	DATA INSUFFICIENT		

HYD/BAGIO/MANNILA (17.4)

HOUR	A	B	C	D	E	F
1*	0.236E+01	0.604E-01	-0.645E-04	0.325E+01	0.443E-03	-0.146E-04
2*	0.230E+01	0.530E-01	-0.539E-04	0.334E+01	0.689E-04	-0.133E-04
3*	0.204E+01	0.477E-01	-0.534E-04	0.341E+01	-0.286E-04	-0.136E-04
4*	0.173E+01	0.261E-01	0.213E-04	0.340E+01	-0.230E-03	-0.147E-04
5*	0.151E+01	0.167E-01	0.535E-04	0.335E+01	-0.230E-02	-0.366E-05
6*	0.170E+01	0.593E-02	0.887E-04	0.318E+01	0.471E-03	-0.123E-04
7*	0.175E+01	0.137E-01	0.385E-04	0.312E+01	-0.293E-02	0.563E-05
8*	0.443E+01	0.316E-01	-0.109E-04	0.341E+01	-0.145E-02	-0.106E-04
9*	0.551E+01	0.574E-01	[illegible]	0.324E+01	-0.364E-03	-0.111E-04
10*	0.689E+01	0.644E-01	-0.119E-03	0.318E+01	0.239E-03	-0.155E-04
11*	0.727E+01	0.628E-01	-0.137E-03	0.306E+01	-0.184E-02	-0.334E-05
12*	0.688E+01	0.649E-01	-0.149E-03	0.281E+01	-0.271E-02	-0.320E-05
13*	0.673E+01	0.649E-01	-0.173E-03	0.269E+01	-0.159E-02	-0.688E-05
14*	[illegible]	0.645E-01	-0.153E-03	0.273E+01	-0.188E-02	-0.850E-05
15*	[illegible]	0.551E-01	-0.139E-03	0.291E+01	-0.341E-02	-0.545E-05
16*	[illegible]	[illegible]	-0.170E-03	0.307E+01	-0.438E-02	-0.428E-05
17*	[illegible]	[illegible]	-0.195E-03	0.326E+01	-0.544E-02	-0.288E-05
18*	[illegible]	[illegible]	-0.211E-03	0.342E+01	-0.577E-02	-0.315E-05
19*	[illegible]	[illegible]	-0.145E-03	0.356E+01	-0.738E-02	0.396E-05
20*	[illegible]	0.764E-01	-0.212E-03	0.349E+01	-0.627E-02	-0.333E-05
21*	[illegible]	[illegible]	-0.251E-03	0.332E+01	-0.255E-02	-0.149E-04
22*	[illegible]	[illegible]	[illegible]	0.331E+01	0.271E-04	-0.231E-04
23*	[illegible]	[illegible]	[illegible]	0.348E+01	-0.351E-03	-0.177E-04
24*	0.232E+01	0.721E-01	[illegible]	0.371E+01	-0.113E-03	-0.160E-04

TABLE C1 (CONTD.)

MADRAS (13.0)

HOUR	A	B	C	D	E	F
1*	0.247E+01	[illegible]	[illegible]	DATA INSUFFICIENT		
2*	0.234E+01	0.641E-01	-0.126E-03	DATA INSUFFICIENT		
3*	0.235E+01	0.592E-01	-0.124E-03	DATA INSUFFICIENT		
4*	0.207E+01	0.524E-01	-0.951E-04	DATA INSUFFICIENT		
5*	0.263E+01	0.267E-01	-0.132E-04	DATA INSUFFICIENT		
	DATA INSUFFICIENT			DATA INSUFFICIENT		
7*	0.412E+01	0.161E-01	0.143E-04	0.351E+01	-0.598E-02	0.155E-04
8*	0.543E+01	0.223E-01	0.365E-04	0.308E+01	-0.150E-03	-0.497E-05
9*	0.640E+01	0.311E-01	0.292E-04	0.292E+01	-0.850E-03	-0.193E-05
10*	0.678E+01	0.425E-01	-0.277E-04	0.278E+01	0.948E-03	-0.163E-04
11*	0.657E+01	0.499E-01	-0.730E-04	0.267E+01	0.285E-02	-0.305E-04
12*	0.612E+01	0.611E-01	-0.148E-03	0.265E+01	0.732E-03	-0.197E-04
13*	0.651E+01	0.615E-01	-0.163E-03	0.261E+01	0.123E-02	-0.214E-04
14*	0.661E+01	0.565E-01	-0.159E-03	0.250E+01	0.796E-03	-0.167E-04
15*	0.711E+01	0.548E-01	-0.149E-03	0.265E+01	0.148E-02	-0.243E-04
16*	0.718E+01	0.562E-01	-0.153E-03	0.266E+01	0.199E-02	-0.281E-04
17*	0.728E+01	0.573E-01	-0.152E-03	0.274E+01	-0.260E-02	-0.350E-05
18*	0.705E+01	0.607E-01	-0.179E-03	0.275E+01	-0.277E-02	-0.266E-05
19*	0.646E+01	0.684E-01	-0.223E-03	0.288E+01	-0.107E-02	-0.171E-04
20*	0.571E+01	0.758E-01	-0.257E-03	0.300E+01	-0.484E-02	-0.365E-05
21*	0.534E+01	0.628E-01	-0.182E-03	0.305E+01	-0.228E-02	-0.170E-04
22*	0.447E+01	0.806E-01	-0.249E-03	DATA INSUFFICIENT		
23*	0.398E+01	0.794E-01	-0.224E-03	DATA INSUFFICIENT		
24*	0.296E+01	0.929E-01	-0.278E-03	DATA INSUFFICIENT		

TABLE C1 (CONTD.)

KODAIKANAL (10.2)

HOUR	A	B	C	D	E	F
1*	[illegible]	0.706E-01	-0.182E-03	0.343E+01	-0.523E-02	0.127E-05
2*	[illegible]	0.544E-01	-0.973E-04	0.346E+01	-0.443E-02	-0.283E-06
3*	0.171E+01	0.544E-01	-0.912E-04	0.342E+01	-0.304E-02	-0.532E-05
4*	0.151E+01	0.365E-01	-0.679E-05	0.347E+01	-0.422E-02	0.193E-05
5*	0.177E+01	0.162E-01	0.914E-04	0.343E+01	-0.238E-02	-0.334E-05
6*	0.154E+01	0.267E-02	0.131E-03	0.332E+01	0.398E-03	-0.121E-04
7*	0.244E+01	0.653E-02	0.749E-04	0.325E+01	-0.369E-02	0.517E-05
8*	0.457E+01	0.443E-01	-0.793E-04	0.333E+01	-0.375E-02	0.789E-06
9*	0.554E+01	0.533E-01	-0.983E-04	0.310E+01	-0.346E-02	0.182E-05
10*	0.621E+01	0.474E-01	-0.659E-04	0.289E+01	-0.421E-02	0.554E-05
11*	[illegible]	0.516E-01	-0.804E-04	0.272E+01	-0.271E-02	-0.265E-05
12*	0.562E+01	0.530E-01	-0.115E-03	0.269E+01	-0.300E-02	-0.281E-05
13*	0.584E+01	0.575E-01	-0.148E-03	0.269E+01	-0.315E-02	-0.284E-05
14*	0.627E+01	0.551E-01	-0.148E-03	0.271E+01	-0.379E-02	-0.111E-05
15*	0.644E+01	0.574E-01	-0.172E-03	0.274E+01	-0.394E-02	-0.747E-06
16*	0.657E+01	0.590E-01	-0.178E-03	0.277E+01	-0.390E-02	-0.101E-05
17*	0.661E+01	0.571E-01	-0.174E-03	0.283E+01	-0.416E-02	-0.367E-06
18*	0.656E+01	0.491E-01	-0.134E-03	0.290E+01	-0.482E-02	0.132E-05
19*	0.659E+01	0.448E-01	-0.126E-03	0.300E+01	-0.595E-02	0.609E-05
20*	0.566E+01	0.466E-01	-0.150E-03	0.303E+01	-0.520E-02	0.519E-06
21*	0.533E+01	0.571E-01	-0.208E-03	0.316E+01	-0.601E-02	0.225E-05
22*	0.463E+01	0.631E-01	-0.219E-03	0.321E+01	-0.258E-02	-0.868E-05
23*	0.436E+01	0.634E-01	-0.185E-03	0.337E+01	-0.434E-02	-0.503E-05
24*	0.338E+01	0.662E-01	-0.178E-03	0.339E+01	-0.400E-02	-0.494E-05

TIRUCHIRAPALLI (10.8)

HOUR	A	B	C	D	E	F
1*	0.466E+01	0.155E-01	0.964E-04	DATA INSUFFICIENT		
2*	0.395E+01	0.157E-01	0.110E-03	DATA INSUFFICIENT		
3*	0.354E+01	0.192E-01	0.503E-04	DATA INSUFFICIENT		
4*	0.316E+01	0.145E-01	0.770E-04	DATA INSUFFICIENT		
5*	0.213E+01	0.236E-01	0.322E-04	DATA INSUFFICIENT		
6*	0.271E+01	0.128E-01	0.259E-04	DATA INSUFFICIENT		
7*	0.375E+01	0.174E-01	-0.383E-05	0.304E+01	0.285E-02	-0.161E-04
8*	0.509E+01	0.272E-01	0.335E-05	0.312E+01	-0.622E-02	0.262E-04
9*	0.582E+01	0.371E-01	-0.233E-04	0.286E+01	-0.478E-02	0.169E-04
10*	0.610E+01	0.422E-01	-0.513E-04	0.283E+01	-0.665E-02	0.201E-04
11*	0.659E+01	0.415E-01	-0.653E-04	0.268E+01	-0.450E-02	0.855E-05
12*	0.647E+01	0.434E-01	-0.745E-04	0.279E+01	-0.750E-02	0.202E-04
13*	0.637E+01	0.162E-01	0.147E-04	0.265E+01	-0.517E-02	0.111E-04
14*	0.675E+01	0.477E-01	-0.109E-03	0.248E+01	0.988E-03	-0.159E-04
15*	0.662E+01	0.196E-01	-0.301E-05	0.258E+01	-0.469E-02	0.104E-04
16*	0.715E+01	0.404E-01	-0.662E-04	0.268E+01	-0.760E-02	0.236E-04
17*	0.717E+01	[illegible]	-0.551E-04	0.270E+01	-0.525E-02	0.662E-05
18*	0.694E+01	[illegible]	-0.446E-04	0.283E+01	-0.960E-02	0.241E-04
19*	0.664E+01	0.362E-01	-0.673E-04	0.287E+01	-0.122E-01	0.413E-04
20*	0.639E+01	0.334E-01	-0.561E-04	0.291E+01	-0.617E-02	0.109E-04
21*	0.579E+01	0.464E-01	[illegible]	0.269E+01	-0.125E-02	-0.143E-04
22*	0.561E+01	0.715E-01	-0.252E-04	DATA INSUFFICIENT		
23*	[illegible]	[illegible]	0.379E-04	DATA INSUFFICIENT		
24*	[illegible]	0.150E-01	0.106E-03	DATA INSUFFICIENT		

THUMBA (8.5)

HOUR	A	B	C	D	E	F
1*	0.509E+01	0.530E-01	-0.896E-04	0.325E+01	0.106E-02	-0.223E-04
2*	0.305E+01	0.477E-01	-0.656E-04	0.334E+01	-0.300E-04	-0.187E-04
3*	0.256E+01	0.449E-01	-0.513E-04	0.339E+01	-0.162E-02	-0.666E-05
4*	0.226E+01	0.362E-01	-0.128E-04	0.334E+01	0.101E-02	-0.191E-04
5*	0.178E+01	0.316E-01	0.838E-05	0.341E+01	-0.508E-03	-0.779E-05
6*	0.163E+01	0.125E-01	0.848E-04	0.337E+01	0.696E-03	-0.102E-04
7*	0.259E+01	0.558E-02	0.931E-04	0.324E+01	-0.146E-02	-0.260E-05
8*	0.497E+01	0.290E-01	-0.153E-04	0.312E+01	0.186E-02	-0.175E-04
9*	0.565E+01	0.395E-01	-0.444E-04	0.293E+01	-0.683E-03	-0.641E-05
10*	0.653E+01	0.321E-01	-0.159E-06	0.283E+01	-0.164E-02	-0.532E-05
11*	0.611E+01	0.295E-01	0.160E-04	0.265E+01	-0.465E-03	-0.967E-05
12*	0.571E+01	0.421E-01	-0.640E-04	0.259E+01	0.570E-03	-0.161E-04
13*	0.564E+01	0.461E-01	-0.909E-04	0.265E+01	-0.107E-02	-0.913E-05
14*	0.635E+01	0.501E-01	-0.120E-03	0.269E+01	-0.232E-02	-0.434E-05
15*	0.603E+01	0.535E-01	-0.128E-03	0.264E+01	-0.915E-03	-0.121E-04
16*	0.594E+01	0.625E-01	-0.164E-03	0.274E+01	-0.292E-02	-0.463E-05
17*	0.563E+01	0.608E-01	-0.152E-03	0.281E+01	-0.334E-02	-0.248E-05
18*	0.561E+01	0.526E-01	-0.115E-03	0.294E+01	-0.606E-02	0.824E-05
19*	0.599E+01	0.344E-01	-0.551E-04	0.313E+01	-0.906E-02	0.160E-04
20*	0.555E+01	0.401E-01	-0.914E-04	0.309E+01	-0.102E-01	0.240E-04
21*	0.567E+01	0.274E-01	-0.244E-04	0.309E+01	-0.783E-02	0.187E-04
22*	0.558E+01	0.280E-01	-0.201E-04	0.324E+01	-0.614E-02	0.766E-05
23*	0.473E+01	0.355E-01	-0.479E-04	0.323E+01	-0.262E-02	-0.933E-05
24*	0.392E+01	0.442E-01	-0.664E-04	0.305E+01	0.280E-02	-0.266E-04

TABLE C1 (CONTD.)

GENERATORS (1.7)

HOUR	A		C	D	E	F
1*	[illegible]	[illegible]	[illegible]	0.324E+01	-0.722E-02	0.224E-04
2*	0.205E+01	[illegible]	[illegible]	0.305E+01	-0.869E-03	-0.655E-05
3*	[illegible]	[illegible]	-0.359E-04	0.313E+01	-0.256E-02	0.303E-05
4*	[illegible]	0.374E-01	0.572E-05	0.313E+01	-0.206E-02	-0.130E-05
5*	0.163E+01	[illegible]	0.164E-04	0.316E+01	-0.232E-02	0.284E-05
6*	0.151E+01	[illegible]	-0.436E-05	0.316E+01	0.358E-03	-0.126E-04
7*	[illegible]	[illegible]	-0.145E-05	0.320E+01	-0.457E-02	0.828E-05
8*	0.403E+01	[illegible]	-0.455E-04	0.325E+01	-0.255E-02	0.377E-06
9*	0.557E+01	0.384E-01	[illegible]	0.298E+01	-0.266E-02	0.569E-05
10*	0.629E+01	0.353E-01	-0.632E-04	0.257E+01	-0.127E-02	-0.191E-05
11*	0.669E+01	0.314E-01	-0.321E-04	0.241E+01	-0.371E-02	0.957E-05
12*	0.679E+01	0.314E-01	-0.191E-04	0.229E+01	-0.390E-02	0.114E-04
13*	0.716E+01	0.361E-01	-0.490E-04	0.221E+01	-0.116E-02	-0.438E-06
14*	0.717E+01	0.428E-01	-0.901E-04	0.227E+01	-0.698E-03	-0.674E-05
15*	0.737E+01	0.391E-01	-0.744E-04	0.236E+01	-0.290E-02	0.712E-05
16*	0.737E+01	0.414E-01	-0.890E-04	0.242E+01	-0.414E-02	0.976E-05
17*	0.742E+01	0.450E-01	-0.973E-04	0.252E+01	-0.370E-02	0.661E-05
18*	0.746E+01	0.415E-01	-0.890E-04	0.260E+01	-0.257E-02	0.203E-05
19*	0.722E+01	0.438E-01	-0.957E-04	0.273E+01	-0.437E-02	0.641E-05
20*	0.649E+01	0.430E-01	-0.105E-03	0.289E+01	-0.692E-02	0.115E-04
21*	0.537E+01	0.592E-01	-0.141E-03	0.286E+01	-0.530E-02	0.768E-05
22*	0.514E+01	0.624E-01	-0.150E-03	0.303E+01	-0.383E-02	-0.923E-06
23*	0.539E+01	0.315E-01	-0.101E-03	0.343E+01	-0.740E-02	0.154E-04
24*	0.363E+01	[illegible]	-0.699E-04	0.355E+01	-0.926E-02	0.207E-04

APPENDIX D

NORMALISED ERRORS OF FITTING SECOND DEGREE CURVES TO SSN

D. 1 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR JANUARY.
D. 2 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR FEBRUARY
D. 3 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR MARCH.
D. 4 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR APRIL.
D. 5 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR MAY.
D. 6 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR JUNE
D. 7 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR JULY.
D. 8 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR AUGUST.
D. 9 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR SEPTEMBER.
D.10 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR OCTOBER.
D.11 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR NOVEMBER.
D.12 NORMALISED DEVIATIONS IN % FOR foF2 AND MUF(4000)F2 FOR DECEMBER.

TABLE D1

NORMALISED DEVIATION 'IN %   MONTH=JANUARY

foF2

HR/LAT	00	05	10	15	20	25	30	35	40
1*	12.8	9.2	9.5	17.2	18.8	11.6	7.6	5.1	5.9
2*	13.4	8.3	11.3	17.2	17.8	10.1	7.8	4.4	6.4
3*	14.5	12.3	10.5	16.1	14.9	8.7	7.8	3.7	5.5
4*	15.4	13.2	15.0	16.2	16.1	21.1	10.7	3.7	6.1
5*	13.[illegible]	15.8	18.9	17.0	12.6	13.7	8.0	4.3	5.2
6*	13.6	13.8	22.3	16.1	16.0	17.8	14.2	5.8	5.5
7*	8.9	12.1	7.9	12.9	22.7	26.7	14.8	5.8	8.6
8*	4.7	3.7	12.9	6.5	10.7	9.1	9.4	5.9	8.7
9*	3.6	5.3	11.1	5.2	9.8	5.5	13.9	5.6	5.4
10*	3.1	4.8	6.6	3.9	10.0	6.2	8.3	8.5	7.6
11*	3.1	5.2	6.4	4.8	8.7	7.6	8.5	8.0	7.1
12*	4.4	5.0	5.4	6.5	9.0	9.6	7.7	5.7	6.5
13*	3.9	5.0	4.7	7.5	8.2	11.[illegible]	8.2	4.6	6.0
14*	4.0	5.1	4.7	8.9	6.9	9.0	7.7	5.5	5.7
15*	4.0	6.5	5.7	7.9	7.2	8.7	8.9	7.1	6.0
16*	4.0	6.5	5.7	7.4	9.5	7.5	8.8	5.4	5.9
17*	3.9	7.6	7.1	7.0	10.5	7.1	10.6	6.2	7.7
18*	4.2	8.8	8.1	6.7	10.8	10.5	11.4	7.4	8.7
19*	4.3	6.6	8.8	6.8	11.9	10.3	10.6	8.2	7.7
20*	4.6	8.1	8.1	8.9	15.4	12.9	14.3	5.5	8.0
21*	5.8	7.5	9.2	8.7	16.0	15.6	13.2	7.7	9.9
22*	5.5	6.2	7.5	9.0	17.1	13.0	12.0	9.9	10.1
23*	7.5	7.7	8.3	12.1	19.2	21.8	16.8	6.8	7.5
24*	12.0	9.2	9.9	14.8	18.3	15.7	9.6	5.1	6.0

MUF(4000)I 2

HR/LAT	00	05	10	15	20	25	30	35	40
1*	16.5	10.7	15.9	20.1	24.8	15.4	13.7	8.0	9.2
2*	16.7	9.9	17.9	20.0	****	14.0	10.5	7.7	9.0
3*	18.6	14.0	17.2	18.5	****	12.2	11.9	7.6	8.0
4*	19.2	14.4	21.5	19.2	20.2	24.3	15.1	7.8	9.0
5*	17.0	17.8	26.0	20.6	20.4	17.9	16.3	8.7	7.9
6*	17.6	16.0	30.2	21.4	****	23.0	17.6	9.2	8.9
7*	11.3	16.4	13.4	17.0	29.9	31.2	20.2	9.3	12.4
8*	7.6	5.6	19.8	9.0	16.9	12.9	13.0	10.4	12.9
9*	6.1	8.0	17.7	8.5	15.9	8.1	20.3	8.9	10.1
10*	6.1	6.7	11.7	8.3	15.9	11.8	12.3	11.5	11.3
11*	7.0	6.9	11.9	10.9	16.5	10.7	12.1	11.4	10.7
12*	9.6	6.9	10.5	12.2	16.6	12.7	12.2	8.4	9.9
13*	6.0	7.0	9.9	12.6	14.1	14.9	14.7	8.0	9.8
14*	6.2	7.2	10.1	14.2	****	13.1	12.1	8.5	9.5
15*	6.7	9.3	11.5	12.9	13.3	13.4	15.5	10.2	9.6
16*	6.6	9.6	12.0	12.7	15.9	10.6	12.6	8.7	9.1
17*	7.3	11.5	12.4	11.9	15.8	10.6	17.1	9.2	11.3
18*	7.0	12.1	12.5	10.4	16.3	14.1	15.4	10.6	11.9
19*	9.2	10.9	14.3	9.7	17.2	12.8	13.8	11.5	11.3
20*	8.8	12.1	21.1	12.2	19.1	16.6	18.0	8.5	11.8
21*	8.8	13.2	21.0	12.7	20.4	19.5	19.2	11.2	14.3
22*	9.3	11.9	17.1	12.5	18.2	16.5	16.1	15.3	14.3
23*	11.1	14.0	13.9	15.0	24.4	24.9	20.6	9.9	10.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	****	20.8	14.1	8.6	9.5