

Solar Zenith Angle Dependence of Ionospheric Absorption during Different Epochs of the Solar Cycle

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Cos χ variation of absorption for the period 1972-80 over Udaipur (24°35'N) is presented. The working frequencies are in the range 2-4.1 MHz. The cos χ variation of absorption follows expressions $A = A_1 + B_1 \cos^n \chi$ and $A = B'_1 \cos^n \chi$ for low and high solar activity periods, respectively. The cos χ index values have also been found to be different during the minimum and maximum periods of the solar activity. The results have been discussed.

1 Introduction

The variation of non-derivative absorption (A_{nd}) at a fixed frequency with cos χ as given by Appleton¹ is

$$A_{nd} \propto \cos^{3/2} \chi \quad \dots (1)$$

Best and Ratcliffe² found the cos χ index for total absorption to be 3/2. White and Straker³ have reported the value of cos χ index for total absorption as 1.7.

Appleton¹ himself, using A1-technique, found the value of cos χ index to be 0.8 instead of 3/2. Various other workers⁴⁻¹² have reported the value of cos χ index as varying from 0.5 to 1.5. They have suggested that Eq. (1) can be better represented by

$$A \propto \cos^n \chi \quad \dots (2)$$

where n is the index of cos χ and has a value lower than 3/2.

However, the workers at the National Bureau of Standards¹³ and others¹⁴⁻¹⁸ have shown that Eq. (2) for small values of cos χ takes the form

$$A = A_1 + b_1 \cos^n \chi \quad \dots (3)$$

Rai¹⁵ has further shown that Eq. (3) would hold good for the whole day but the effect of the term A_1 in noon hours is not very prominent. The term A_1 in Eq. (3) is the value of absorption which is not solar controlled and has been taken as the absorption suffered in the lowermost ionospheric region produced by cosmic rays and photodetachment of negative ions. Previous workers¹⁷⁻²⁰ of this laboratory have studied the cos χ variation of absorption and found Eq. (3) to hold good in low solar activity periods. The purpose of this study is to check the validity of Eq. (2) or Eq. (3) at this latitude (i.e. Udaipur) during the moderate and high epochs of the solar activity and to find the value of n for this period and variation, if any, with solar activity.

2 Data analysis and results

In order to check the validity of Eq. (2) or Eq. (3) and to calculate the cos χ index at a certain fixed frequency, the monthly median values of total and D-region absorption were plotted against cos χ on log-log graph paper for each month during the period of investigation. Best-fit lines have been drawn by the method of least squares. Some typical graphs for the variation of absorption with cos χ during moderate and high solar activity periods at the working frequency are shown in Figs. 1 and 2 for total and D-region absorption, respectively. The method adopted for determining the contribution of D- and E-region absorption to the total absorption is the same as described by Vijayvergia and Rai¹⁸. From Figs. 1 and 2 it is observed that these results follow Eq. (2) for both total and D-region absorption. Previous workers of

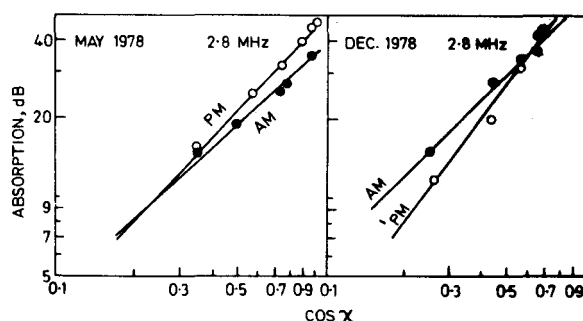


Fig. 1—Variation of total absorption with cos χ

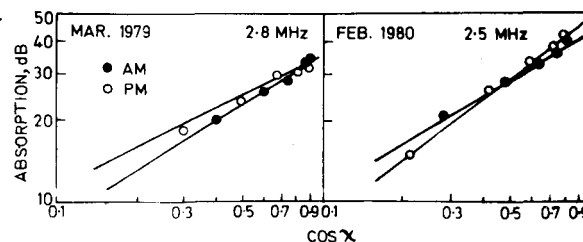


Fig. 2—Variation of D-region absorption with cos χ

this laboratory who have worked during the low solar activity period (1972-76) have obtained the variation of log A versus log $\cos \chi$ graph as represented in Fig. 3A (Ref. 18). Thus it is observed that during the minimum period of solar activity, the diurnal variation of absorption is governed by Eq. (3) and during the maximum period of the solar activity, it is represented

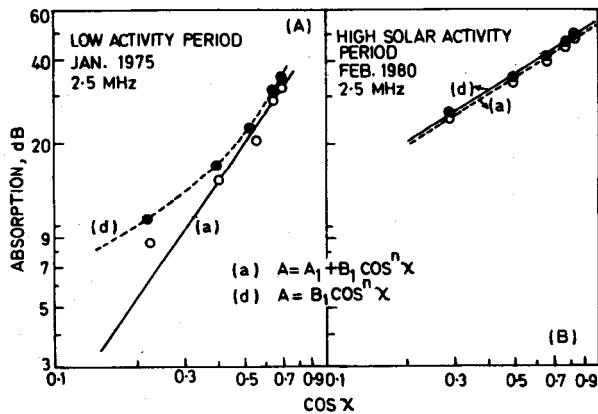


Fig. 3—Variation of total absorption with $\cos \chi$ for: (A) low solar activity period and (B) high solar activity period

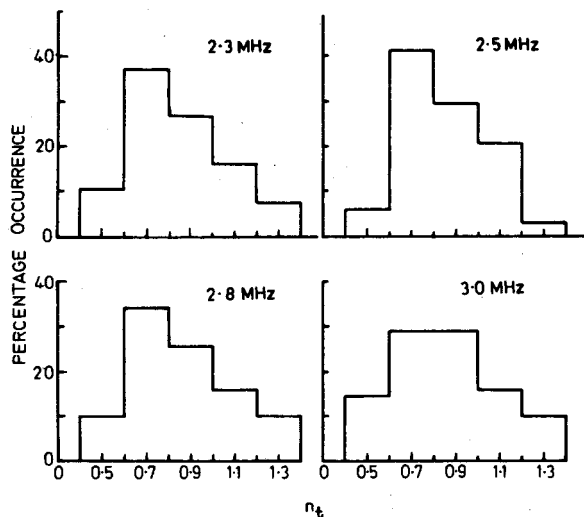


Fig. 4—Histograms of $\cos \chi$ index for total absorption for moderate and high solar activity periods

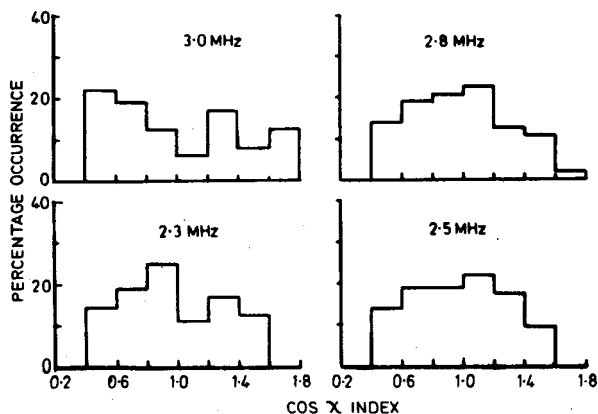


Fig. 5—Same as Fig. 4 but for D-region absorption

by Eq. (2). Rai¹⁵ has suggested that in Eq. (3), A_1 represents the absorption in the lower ionosphere. It is a well known fact that the ionization due to cosmic ray decreases with increase in solar activity. Theoretical calculations have been made for absorption in the lower part of the D-region, i.e. below 70 km for expected electron density distribution during the minimum and maximum periods of the solar activity. The calculated values of absorption are 2.0 and 0.85 dB for low and high solar activity periods, respectively, at

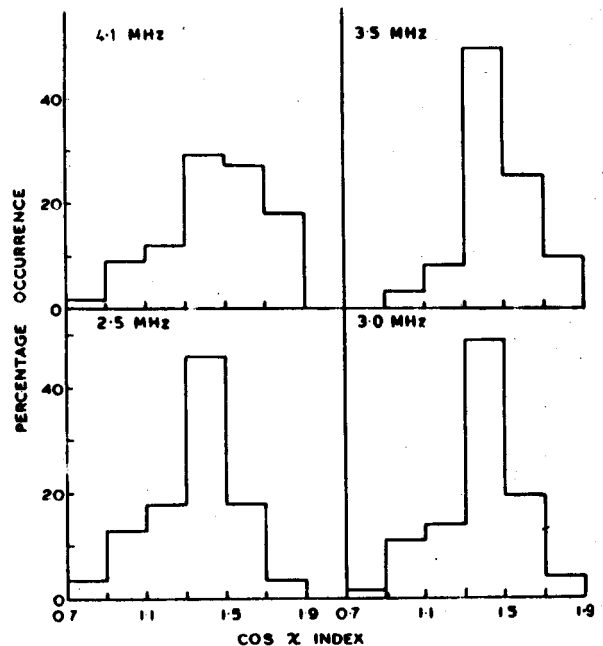


Fig. 6—Histograms of $\cos \chi$ index for total absorption for low solar activity period

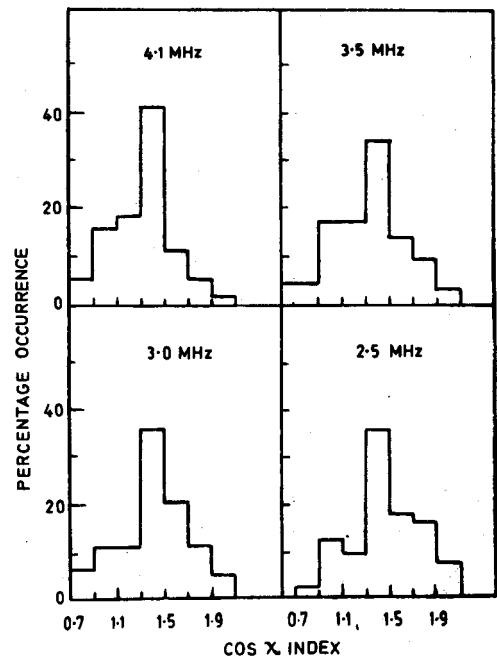


Fig. 7—Same as Fig. 6 but for D-region absorption

2.5 MHz. After subtracting the value of A_1 from observed total absorption at 2.5 MHz during low solar activity period, it is observed that $\log A$ versus $\log \cos \chi$ graph becomes a straight line as shown in Fig. 3A (curve a). Adopting the same procedure for the results obtained for maximum solar activity period at 2.5 MHz, it is observed that there is not much change in the shape and inclination of the graph after deducting the value of A_1 from the total absorption (Fig. 3B), which was already a straight line. There are two reasons for this behaviour during the maximum period of solar activity, viz. (i) the value of A_1 has decreased and (ii) the value of B_1 has increased.

The value of n also seems to be affected due to solar activity. For the estimation of the most probable values of $\cos \chi$ index for total (n_t) and D-region (n_d) absorption, its percentage occurrence in different intervals have been calculated. Histograms for percentage occurrence of n_t and n_d at different frequencies are shown in Figs. 4 and 5 for moderate and high solar activity periods and Figs. 6 and 7 for low solar activity periods¹⁹.

3 Discussion

The mean values of n_t and n_d are 0.90 and 0.97, respectively, for moderate and high solar activity periods (1977-80). The mean values of n_t and n_d are 1.31 and 1.27, respectively, for low solar activity periods (1972-76). On comparison of the values of n_t/n_d obtained for the period of moderate and high solar activity with that obtained for low solar activity, it has been found that n_t and n_d have lower values in moderate and high solar activity periods as compared to low solar activity period. These results may be compared with that of other workers obtained as given in Table 1. From Table 1 it is observed that the values of n_t obtained by Gnanalingam and Ratnasiri²¹ are 1.01 and 0.80 during IQSY and IGY periods, respectively, at 2.6 MHz. The value of n_t obtained by Skinner and Wright⁷ is 0.63 at 2.4 MHz during IGY period. For Ahmedabad, Shirke *et al.*²³ working at 2.5 and 2.6 MHz during IGY period obtained the mean value of n_t as 0.73, whereas Bhonsle and Ramanathan²² for the same period and place obtained the mean value of n_t as 0.97 at 25 MHz. Not many

Table 1—Cos χ Exponent for Absorption Obtained by Different Investigators at Different Places

Investigator	Frequency MHz	Place	Geogr. latitude (N)	Cos χ n_t	Exponent n_d	Remark
Bhonsle & Ramanathan ²²	25	Ahmedabad (1957-58) IGY	23°01'	1.10	—	Summer
				1.00	—	Equinox
				0.80	—	Winter
				0.97	—	Mean
Shirke ²³	2.5 and 2.6	Ahmedabad IGY	23°01'	0.86	—	Summer
				0.74	—	Equinox
				0.69	—	Winter
				0.73	—	Mean
Rao <i>et al.</i> ²⁴	5.0	Delhi (1954-60)	28.6°	1.04	—	Summer
				0.96	—	Equinox
				0.88	—	Winter
				0.96	—	Mean
Sarada & Mitra ²⁵	22.4	Delhi (1957)	28.6°	0.92	0.77	Mean
Ramanamurty & Rao ²⁶	5.65	Waltair (1962)	17.72°	1.26	—	Mean
Skinner & Wright ⁷	2.4	Ibadan (1957-58)	7.4°	0.63	—	Mean
Gnanalingam & Ratnasiri ²¹	2.9	Colombo IGY	6.9°	0.91	—	Mean
	2.6			0.80	—	Mean
	2.6			1.01	—	Mean
Ganguly ¹⁰	1.7-6.5	Calcutta (1966-68)	22.8°	—	1.10	Mean
Yasuda ²⁷	2.4	Kokubunji IGY	35°43'	0.85	—	Summer
				0.79	—	Winter
Setty <i>et al.</i> ²⁸	5.7	Delhi (1969-70)	28.6°	0.93	—	Mean

results are available at the same place and frequency for a complete solar cycle. However, the general trend is as follows.

- (i) The value of n_i/n_d are higher during the low solar activity period.
- (ii) The values of n_i/n_d are also higher at higher frequencies (Shirke *et al.*²³ and Bhonsle & Ramanathan²²). The difference in the value of n_i/n_d during minimum and maximum periods of the solar activity at this latitude, i.e. Udaipur, may be explained as follows.

Rai²⁹ has shown that for the non-isothermal region the value of n_d is given by

$$n_d = n'_d + \beta/2 \quad \dots (4)$$

where n'_d is the value of $\cos \chi$ index expected for isothermal ionospheric region and n_d is the value of $\cos \chi$ index obtained experimentally and $\beta = dH/dh$.

In the main absorbing region, the mean value of β is of the order of -0.06 (CIRA, 1972). In the present investigation the authors have obtained the value of n_d as 0.96 at 2.5 MHz. Using the mean value of n_d and β , Eq. (4) takes the form

$$n'_d = 0.96 + 0.03 = 0.99 \quad \dots (5)$$

Rai²⁹ has further shown that the value of n'_d depends on the magnitude of the terms $1/2(\alpha_c/\alpha_0) \sec \chi$ or $1/2(\alpha_c/\alpha_0)^{1/2} \sec \chi$ and $1/2[(\omega + |\omega_L|)/\nu_0] \sec \chi$. Here α_0 is the value of effective recombination coefficient (α_{eff}) at height h_0 for $\chi = 0$, α_c is the constant value of α_{eff} [$\alpha_c \gg \alpha_0 \exp(-pz)$], z is the reduced height ($h - h_0/H$), p is a constant, h is the true height, H is the scale height, h_0 is the true height of the peak of the layer at $\chi = 0$, ω is the angular wave frequency ($\omega = 2\pi f$), ω_L is the longitudinal component of ω_H and ν_0 is the effective collision frequency for electron at height h_0 . Present day knowledge about α_{eff} shows that the value of α_{eff} is almost constant up to 85 km, i.e. $\alpha_c \gg \alpha_0 \exp(-pz)$ and then starts to decrease exponentially under quiet conditions in the D-region^{30,31}. The experimental results ($\cos \chi$ and frequency index) also suggest that the value of α_{eff} is constant in the main absorbing region^{20,31}. Therefore, the value of n'_d at this latitude depends only on the magnitude of the term $1/2[(\omega + |\omega_L|)/\nu_0] \sec \chi$. Theoretical values of n'_d for different values of $1/2[(\omega + |\omega_L|)/\nu_0] \sec \chi = b$ are given in Table 2 (Ref. 15). It may be seen from Table 2 that the value of $n'_d = 0.99$ corresponds to $b = 1.75$. For overhead Sun position, i.e. $\sec \chi = 1$, we have

$$b = 1/2[(\omega + |\omega_L|)/\nu_0] \\ = [(f + |f_L|)/\nu_0]\pi = 1.75 \quad \dots (6)$$

The effective value of the working frequency ($f + |f_L|$) is 3.15 MHz for the whole period under consideration.

Table 2—Values of n'_d for Different Values of b

b	n'_d
0.30	0.40
0.50	0.60
0.75	0.70
1.00	0.77
1.25	0.88
1.50	0.94
1.75	1.00
2.00	1.05
2.25	1.10
2.50	1.15
2.75	1.20
3.00	1.25
3.50	1.35

The value of ν_0 obtained from Eq. (6) is given by

$$\nu_0 = 5.65 \times 10^6 \text{ collisions/sec} \quad \dots (7)$$

This value of ν_0 corresponds to 75 km height³². This value suggests that the D-region ledge in electron density profile for overhead Sun position is at about 75 km height. It may be added here that the effective collision frequency in moderate and high solar activity periods at all the heights is more as compared to the low solar activity period³³. Due to higher value of effective collision frequency in moderate and high solar activity periods the value of n_d would be lower than that obtained in low solar activity period. The height of the peak electron density for overhead Sun position suggested by Jain¹⁹ and Vijayvergia²⁰ for low solar activity period is $76-78$ km. There may not be variation in the D-region ledge height for the overhead Sun position during maximum and minimum periods of the solar activity. The ledge height obtained is in good agreement with the results obtained by other methods³⁴.

The same explanation holds good for the results of other workers also. The above explanation further suggests that for the same place and time the value of n_i/n_d is higher at higher frequencies. This is supported by the experimental results obtained by various workers in Indian subcontinent during IGY period.

Various workers have studied the latitudinal variation of n_i (Refs. 20 and 35). They have not considered the solar activity and frequency effects on n_i . From the above discussion, it is suggested that the latitudinal variation of n_i/n_d can be studied only when the value of n_i or n_d is available for the same epoch of the solar activity and for the same frequency.

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