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Seasonal & Solar Control of Ionospheric Absorption at a Low Latitude Station*

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Results of ionospheric absorption measured by Al-method on internationally accepted standard frequency 2.2 MHz at Ahmedabad (23°N, 72.6°E; mag. dip 34°N) are presented for a period of over seven years (1972-1978) including solar minimum epoch in 1976. The diurnal index (n) of cos χ is found to be in anticorrelation with the time delay (τ) in the diurnal maximum of absorption. The absorption at fixed values of cos χ shows better agreement with the sunspot number as well as $S_{10.7}$ radio flux than its noontime (1200 hrs) value. Absorption at constant solar zenith angle (χ) normalized to minimum solar activity shows two maxima in equinoxes corresponding to the atmospheric pressure maxima at 85-90 km. No significant correlation of n and τ is found with the index of solar activity. These are explained in terms of changes in the intensity of solar ultraviolet ionizing radiation and the atmospheric gas composition in the lower ionosphere with solar activity and the season.

1. Introduction

Multifrequency ionospheric absorption measurements by Al-method at Ahmedabad (23°N, 72.6°E; mag. dip 34°N) were started in early 1972, and some of the important results have already been published[1-4] regarding the absorption (L) measured with Es-reflection, short-term irregular variations in L, electron density and loss coefficient height profiles at different solar zenith angles, its relation with magnetic activity and so on. Such work was done for the first time at a low latitude station like Ahmedabad. Here a longer series of absorption data covering a period of 7 years is used to examine the solar-terrestrial phenomena occurring in the lower ionosphere. It may be stated that our station is located outside the winter anomaly and post-storm enhancement zones of absorption as against those found at midlatitudes. Pronounced day-today fluctuations observed at Ahmedabad are mainly due to the occurrences of blanketing Es and solar X-ray bursts. The measurements of absorption, using an automatic multi-frequency ionospheric absorption measuring equipment, were done regularly and systematically on all days and for all daylight hours, except for conditions not under human control.

2. Index of Diurnal Variation of Absorption for Solar Minimum

If L_0 is absorption at cos $\chi=1$ ($\chi=0$ for the sun at zenith) and n is the exponent of cos χ, then the usual method to find n is to plot L and cos χ on a log-log graph paper and to fit by the least-square method a straight line on these points represented by the equation

$$\log L = \log L_0 + n \log \cos \chi$$

An example of the above plots is shown in Fig. 1 for different months of the year 1976 for the absorption measured on 2.2 MHz. The epoch of minimum solar activity was centered round. June-July and the sunspot number (R_z) during the year varied from 2 to 22, its annual average being 12.6. It is seen that the straight-line fits are quite good excepting in two months during which some scatter is noticed at low values of cos χ when f_0E approaches the observing frequency or the normal E-layer splits up into E_1 and E_2 layers. The value of the slope, i.e. the index n varies from 1.18 to about 0.40 during the course of a year, highest in

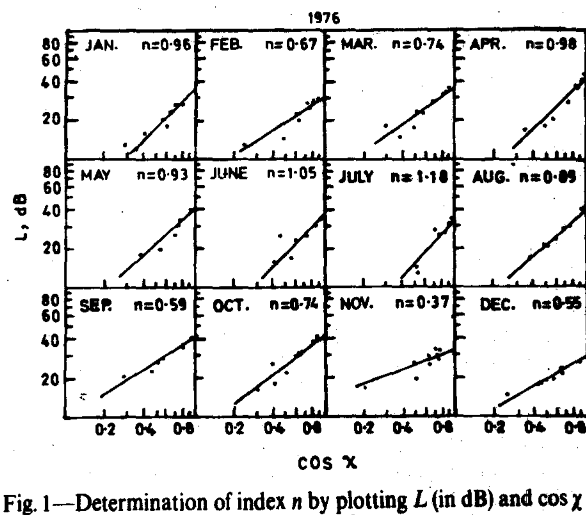

Fig. 1—Determination of index n by plotting L (in dB) and cos χ on log-log scales for diurnal variation of absorption on 2.2 MHz at Ahmedabad during sunspot minimum year 1976

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summer and lowest in winter, although the value in January was exceptionally high. The annual average value of n turns out to be 0.80.

3. Relaxation Time in Absorption

The diurnal variation of absorption shows usually its rapid rate of increase in the forenoon hours in contrast to the slow rate of fall in the afternoon hours. As a result of this non-symmetrical diurnal variation around the noontime (1200 hrs), the afternoon values of absorption are higher than the forenoon values for the same $\cos\chi$ value. To find the time of maximum absorption, time in hours during forenoon and afternoon is noted for 4 or 5 selected values of equal absorption and the mean time of these hours is found for each pair and finally the average is found out for the number of pairs considered. The time so found is compared with the time of maximum $\cos\chi$ and the difference between the two gives the time delay, τ, due to the relaxation effect in the ionized layers. There is another method used by Lustovica[5] for finding out the time-delay which is obtained from the plot of $(L_{max} - L_t)$ versus $(t_{noon} - t)$, where t is any time of the day. We have tried both the above methods and the values of τ so obtained are almost the same. It could be as high as 45 min in winter and as low as -5 min in summer. Negative value of τ means diurnal maximum of absorption occurs before noontime. Fig. 2 shows a comparison of index n and time delay, τ, for 7 yr along with the changes in sunspot number, R_z. The 12-monthly running averages of these quantities are also drawn through their monthly values. It is interesting to note that the time delay is generally less when the rate of diurnal variation of absorption (or n) is more. From about 60 available values of n and τ, the correlation coefficient was found to be about -0.60 with a high degree of confidence or significantly low error. Another thing to notice is that there does not seem to be any correlation between the month-to-month R_z and n or τ. Even the long-term variations shown by the running averages do not indicate any significant effect of solar activity on n and τ which are centred at the mean values of about 0.80 and 18 min, respectively. Table 1 gives a summary of the mean values of L, n, τ and R_z for the years 1972-78.

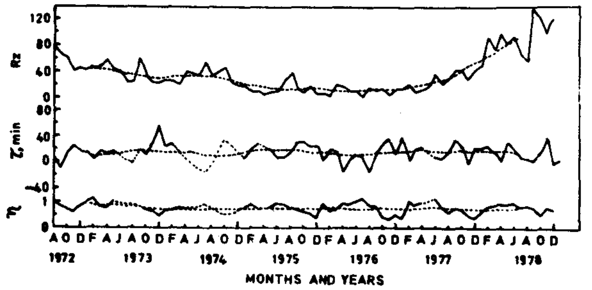

Fig. 2—Variations of diurnal index n, time-delay τ of daytime maximum absorption at Ahmedabad (f = 2.2 MHz) behind apparent solar noon and sunspot number for different months during the years 1972-78 (Dotted lines show 12-monthly running averages through the respective parameters. Continuous curves joined up with dots show interpolation for missing data.)

Table 1—Mean Values of L, n, τ and R_z for the Years 1972-78

Year	L_0 ($\cos\chi = 1$) dB	L ($\cos\chi = 0.6$) dB	n	τ min	R_z
1972	44.82	28.87	0.81	11.3	68.9
1973	40.46	25.87	0.82	18.7	38.2
1974	40.01	27.48	0.71	17.0	34.5
1975	37.29	24.67	0.76	19.3	15.5
1976	37.05	24.40	0.80	11.0	12.6
1977	37.07	23.78	0.76	17.7	27.5
1978	48.82	32.38	0.82	15.9	92.6

4. Solar Activity and Absorption

The index of solar activity used here is either R_z or 10.7 cm solar radio flux ($S_{10.7}$). The yearly running averages of these two indices show a very good linear relation. Fig. 3 shows the relation between $\bar{R}_z$ nad $\bar{S}_{10.7}$ for the solar cycle years 1957-68, maximum to maximum epochs. This plot shows a good straight-line fit represented by the empirical formula

$$S_{10.7} = 57.95 + 0.92\,R_z$$

with a correlation coefficient 0.998 between them. It is brought out that even at $R_z = 0$, there still remains a radiation of about 60 units of $S_{10.7}$ (1 unit $= 10^{-22}$ W/m²Hz). However, the day-to-day or the

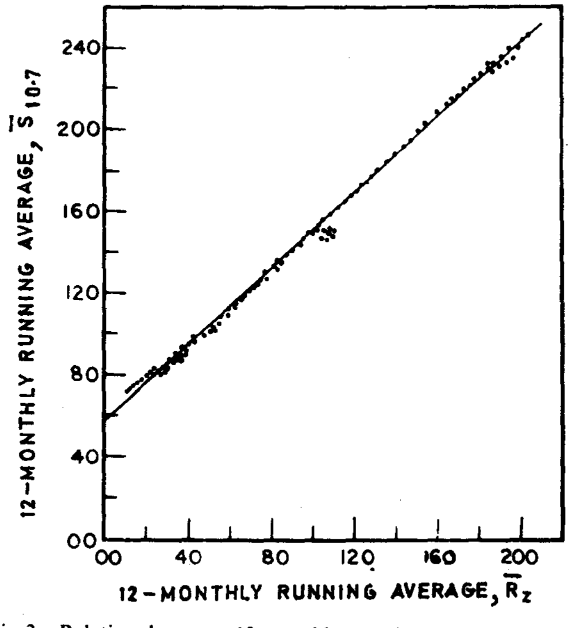

Fig. 3—Relation between 12-monthly running averages of solar activity indices R_z and $S_{10.7}$

instantaneous changes or even monthly mean values of R_z and $S_{10.7}$ may not show such good correlation.

The regression coefficient or the slope of the straight line is also nearly unity. Oshio *et al.*[6] have also reported non-correlation between day-to-day values of $S_{10.7}$ and Lyman-α flux, the latter being mainly responsible for the D-layer ionization. A new index of solar activity has been attempted by Rawer *et al.*[7] in terms of EUV flux observed in satellites for modelling of the neutral atmosphere but with not much success. So far as variation of ionospheric short wave radio absorption with solar activity is concerned, the indices $\bar{R}_z$ and $\bar{S}_{10.7}$ have been ascertained fairly well on the whole. In Fig. 4 are shown plots of monthly median absorption values at noon, at $\cos\chi = 1$ (i.e. L_0) and at $\cos\chi = 0.6$ and compared with the monthly mean values of R_z. It is seen that month-to-month variations in L_{noon} are quite large as compared to those of absorption at constant solar zenith angle (SZA) and R_z. This is understandable because $\cos\chi$ at noon in different months goes on changing from a maximum value of 0.999 in June-July to a minimum value of 0.703 in December-January at Ahmedabad which results in the variation of absorption in addition to that due to the changes in sunspot activity. But the SZA effect is eliminated when absorption at constant $\cos\chi$ and not at the same hour of the day is considered for different months. This is clearly seen from the other two plots of absorption for $\cos\chi = 1.0$ and $\cos\chi = 0.6$. The latter value is chosen because it is available for all the months, around midday in winter and at morning and evening hours in summer. Absorption at constant SZA shown in Fig. 4 is the mean of forenoon and afternoon values read from the straight line of log-log plot of L against $\cos\chi$, and L_0 is the intercept obtained by extending the straight line towards $\cos\chi = 1$ limit. It is seen that not only the month-to-month fluctuations in absorption are reduced, but also they show better correspondence with the sunspot number than what the absorption at noon shows. Prompted by this correspondence analysis, next step was taken to derive a relation between L at constant SZA ($\cos\chi = 1.0$ and $\cos\chi = 0.6$ for all months) and R_z as well as $(S_{10.7} - 60)$ from their mass-plots over a period of more than half sunspot cycle. These are shown in Fig. 5. There is a lot of crowding in the points (Fig. 5) at low solar activity above and below the straight line within the limits of ± 7 dB in L_0 and ± 5 dB in L at $\cos\chi = 0.6$. This scatter is due to the seasonal influence and the broad solar minimum interval. The scatter due to seasonal influence can be reduced or almost eliminated by plotting the 12-monthly running averages of absorption against those of R_z or $S_{10.7}$. An example of this is shown in Fig. 6 which relates $\bar{L}$ with $\bar{R}_z$. But the straight-line fits in the mass-plot of monthly values and yearly morning average value are almost the same.

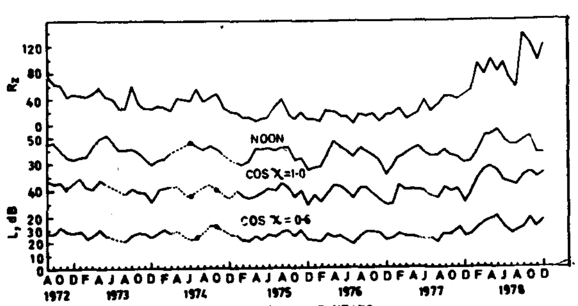

Fig. 4—Variations of monthly median values of ionospheric absorption at Ahmedabad (f = 2.2 MHz) at noon (1200 hrs), for $\cos\chi = 1$ and $\cos\chi = 0.6$ compared with the changes in sunspot number (R_z) (Bigger dots on the curves mean values available but joined up by broken lines to interpolate them for missing values.)

The empirical linear relations so established are as follows.

(i) In case of $\cos\chi = 1$, for absorption with $S_{10.7}$

$$L_0 = 33.81\{1 + 0.0054\,(S_{10.7} - 60)\} \text{ (in dB)}$$

and that with sunspot number

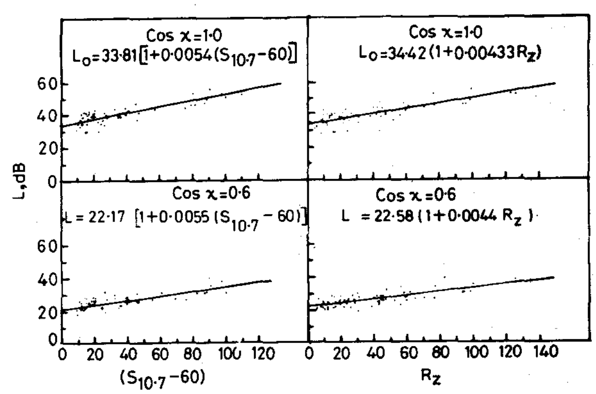

Fig. 5—Mass-plots of L at $\cos\chi = 1$ and $\cos\chi = 0.6$ against R_z and $S_{10.7}$ for all months of the years 1972-78 at Ahmedabad (f = 2.2 MHz)

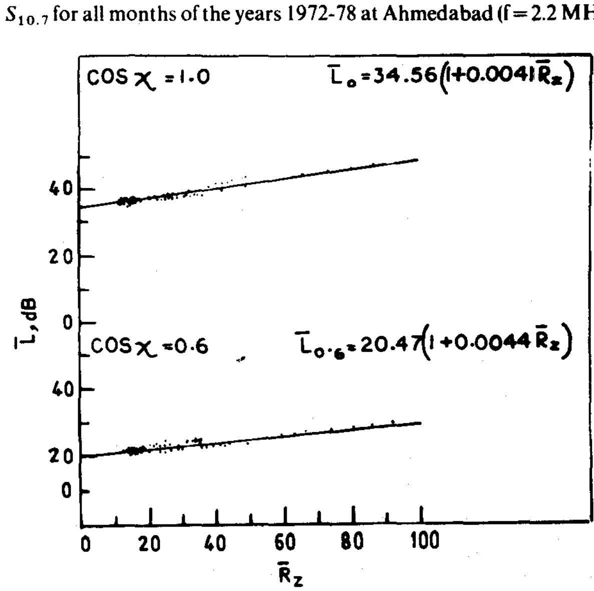

Fig. 6—Plots showing the variation of 12-monthly running averages of L with sunspot number at two fixed solar zenith angles

$L_0 = 34.42(1 + 0.0043\, R_z)$ (in dB) for monthly mean values

and $\bar{L}_0 = 34.56(1 + 0.0041\, \bar{R}_z)$ (in dB) for 12-monthly running averages.

(ii) In case of $\cos\chi = 0.6$, the corresponding relations of absorption with $S_{10.7}$ and R_z are

$\bar{L} = 22.17\{1 + 0.0055(\bar{S}_{10.7} - 60)\}$ (in dB)

$\bar{L} = 22.58(1 + 0.0044\, R_z)$ (in dB) for monthly values and $\bar{L} = 20.47(1 + 0.0044\, \bar{R}_z)$ (in dB) for 12-monthly running averages.

The above relations are of the general form

$$L = a(1 + bR_z) \text{ or } a\{1 + b(S_{10.7} - 60)\} \text{ (in dB)}$$

It is interesting to note that whether one considers absorption at $\cos\chi = 1$ or $\cos\chi = 0.6$, the value of regression coefficient, b, does not differ much, although the slope, ab, of the line in case (i) is definitely higher than that in case (ii). Further, even though the values of a are practically same for either index of solar activity, the value of b is higher for $S_{10.7}$ index than for R_z index, almost by 25%. This is quite logical since in the relation of $S_{10.7}$ with R_z, a coefficient of 0.92 is involved. The percentage increase relative to solar minimum value of absorption with R_z or with $S_{10.7}$ at $\cos\chi = 1$ and $\cos\chi = 0.6$ is same, but the absolute increase in L (in dB) with solar activity is higher in case (i) than in case (ii). Table 2 gives information for ready reference on how the absorption varies with R_z at different latitudes. Though the observing period and radio frequency are not the same for different places, the values of a and b give an indication of their latitudinal and frequency dependence. However, these are mean values for all months taken together.

It has been shown[12] that the value of b for absorption at constant SZA does change with season also. Some of the values of a and b given in Table 2 are derived for noon values of absorption for which the mass-plots show scatter due to change in $\cos\chi$ value with month in addition to that due to purely seasonal influence.

5. Seasonal Variation of Absorption (Free from Solar Control)

To find purely seasonal influence on radio wave absorption, it is necessary to consider absorption at constant solar zenith angle and at fixed index of solar activity. Here, taking the value of b derived from Fig. 5, the values of L at $\cos\chi = 1$ and $\cos\chi = 0.6$ in each month are divided by the factor $1/(1 + bR_z)$, where R_z is the mean sunspot number for the corresponding month. Of course, there is some thaw in this way of normalization of absorption to the condition $R_z = 0$, i.e. a at the respective SZAs since we are assuming the value of b to be the same for all the months. Due to this assumption, there is going to be a slight distortion in the real seasonal variation. Only if a long series of data is available, the value of b can be determined for each month separately, and then the normalized absorption will be more reliable for detecting the seasonal influence in it. Nevertheless, the attempt made here by taking the same b for all the months yielded interestingly significant result. Fig. 7 shows the year-after-year seasonal variation of absorption normalized to $R_z = 0$ at $\cos\chi = 1$ and $\cos\chi = 0.6$.

It is noticed that the seasonal variation has a general trend of maxima in equinoxes and minima in summer and winter. The magnitude of seasonal variation between the upper and lower limits is approximately 15dB for $\cos\chi = 1.0$ and 9dB for $\cos\chi = 0.6$ around the annual mean of about 37 and 24dB, respectively. It is interesting to see that the above type of seasonal

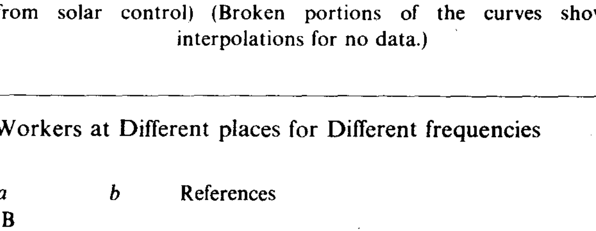

Fig. 7—Curves showing the seasonal variation of absorption (free from solar control) (Broken portions of the curves show interpolations for no data.)

Table 2—Values of a and b as Obtained by Different Workers at Different places for Different frequencies

Place	Frequency MHz	Period yrs	a dB	b	References
Colombo	2.0	1964-68	36.0	0.0053	Gnanalingam[8]
	2.2	1964-68	31.2	0.0055	-do-
Ibadan	2.4	1954-58	42.8	0.0031	-do-
Waltair	2.0	1963-65	—	0.0056	Rao & Rao[9]
Singapore	2.4	1954-58	40.4	0.0048	Gnanalingam[8]
Kokubunji	2.4	1957-59	28.0	0.0041	-do-
Freiburg	1.725	1963-65	28.0	0.0043	Patel & Kotadia[10]
Slough	4.0	1935-52	1.3	0.0095	Appleton & Piggot[11]
Ahmedabad	1.8	1972-78	39.5	0.0043	Kotadia *et al.*[4]
Ahmedabad	2.2	1972-78	34.27	0.0043	Present work

variation in absorption is similar to that of atmospheric pressure at 85-90 km altitude although some discrepancies are seen owing to some other reasons such as that of b discussed above and pitfalls due to missed measurements. The atmospheric models (CIRA 1972) and those proposed from recent satellite observations show equinoxial maxima in O_2 concentration in the lower ionosphere.

6. Discussion and Conclusions

(i) The index n of $\cos \chi$ in the diurnal variation of absorption generally varies from 1.2 to 0.5 during the course of a year and the annual mean values for the 7-yr period reviewed here remain within 0.75 to 0.80. This result is in agreement with those obtained at most of other latitudes and so we can say that the rate of variation of D-region ionization during the day is practically the same over a wide region of the globe.

(ii) The time delay in the diurnal maximum of absorption behind the apparent solar noontime is found to vary in anticorrelation with the index n which decides the rate of diurnal variation of absorption. In general, τ is large in winter (about 45 min) when n is small (about 0.5); in summer, τ is small (about 2 min) when n is large (about 1.2). The negative correlation coefficient for these two parameters is about 0.6. Such inverse relation is also found at midlatitudes except in winter months, when anomalous increase of absorption occurs. The reason for this is common at all places and that is the change in gas composition and recombination coefficient at different heights with season. There is no significant change in the values of n and τ with solar activity. The complex ion chemistry in the D-region may also affect to some extent the anti-correlation between n and τ.

(iii) Ionospheric absorption shows a linear relation with the solar activity represented by the index R_z or $S_{10.7}$. The 10.7 cm solar radio flux remains at about 60 units even at the solar minimum epoch ($R_z = 0$). In recent years,[13-15] attempts have been made to show that the D-layer ionization and hence the radio wave absorption in it varies as square-root of the total solar X-ray flux in the wavelength ranges 1-8 and 1-20 Å This would imply that the indices R_z and $S_{10.7}$ should be related in some way to square root of the 1-20 Å solar X-ray flux in so far as the normal non-flare variation of absorption with solar activity is concerned. The radio wave absorption during abnormal events of large increase in X-ray flux and Lyman-α radiation as that emitted during solar flares needs a follow up study for their respective contribution to the D-layer ionization, since the normal absorption increases by a factor of about 1.7 from solar minimum to solar maximum. In fact absorption data serve as a tool for defining another index of solar activity in terms of X-ray flux.

(iv) The remnant radio wave absorption left after removing the effects of the sun's position with respect to the earth and of the solar activity shows a seasonal variation with maxima in equinoxes and minima in summer and winter, i.e. almost reverse to the seasonal variation of absorption of midlatitudes. At a low latitude, the seasonal variation of absorption is found to follow, in some way, with the atmospheric pressure and hence the collision frequency of electrons essentially with the neutrals in the lower ionosphere. This also involves change in the gas composition indicated by [NO/O_2] and [O/O_2]. The causes for summer and winter maxima and equinoctial minima of absorption at midlatitudes are probably different from those responsible at low latitudes.

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