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A Comparative Study of Some Aspects of Low & Middle Latitude Ionospheric Absorption*

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Results of a study of A1 method ionospheric absorption on 2.3 MHz at a midlatitude station, De Bilt (52.1°N, 5.2°E), for the years 1975-80 to find the seasonal and solar cycle variations of the index n of $\cos\chi$ for diurnal variation of absorption (L_{db}), delay time (τ) in its daily maximum, and absorption at constant solar zenith angle (SZA, χ) are presented. These are compared with the results of such variations obtained at a low latitude station, Ahmedabad (23°N, 72.6°E), which is well outside the winter anomaly zone. It is found that there is, in general, an agreement in the seasonal variation of n at the two places, but not so in the case of τ. The time-delay at Ahmedabad is generally larger in winter than in summer varying almost in opposition to n while it has a sharp peak in winter and a shallow trough in summer at De Bilt, thus having no definite relation with n. But reasonably good anticorrelation between n and τ at midlatitude is also obtained if the values of these parameters for winter months are not taken into account. The range of seasonal changes in n and τ seems to decrease with increase in solar activity and the yearly smoothed values of τ rather than n also indicate a fall at the midlatitude. The absorption at constant SZA taken together for all months varies according to a linear relation with solar activity at Ahmedabad and at De Bilt; however, the linearity at the latter place is masked by the anomalous increase of absorption in winter. A curious feature noticed was that the absorption during Apr.-Oct. 1979 fell below that observed during the same months in 1978 although the solar activity in 1979 continued to rise. The above results have been discussed at appropriate contexts in the light of the ionizing radiations, changes in gas composition and the loss rate of ionization.

1 Introduction

The measurement of ionospheric absorption, L_{db}, by A1 method done regularly at all daytime hours and on all days of a month over a long period at a low latitude station like Ahmedabad (23°N, 72.6°E; mag. dip 34°N) helped to study the general and special variations of absorption and to compare them with those found at a midlatitude station like De Bilt (52.1°N, 5.2°E; mag. dip 67.2°N). The observing radio frequencies at Ahmedabad are 1.8, 2.2 and 2.5 MHz and L_{db} data on 2.2 MHz at Ahmedabad are used for the comparative study with those on 2.3 MHz at De Bilt. Earlier, Kotadia and Gupta[1] studied f_{min} data of De bilt in relation to L_{db} on 1.95 and 2.6 MHz frequencies over a period of six years (1968-73) and they pointed out certain limitations in the use of f_{min} as an index of L_{db}. The diurnal, seasonal, solar cycle and some special variations of absorption on 2.2 MHz at Ahmedabad have also been reported by Kotadia *et al.*[2,3] and these will be referred to in our present study. However, stress is laid on the typical differences found in some characteristic variations of absorption at the two places.

2 Index n of $\cos\chi$ for Diurnal Variation of Absorption

The relation for finding the index n is

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

where L_0 is absorption at solar zenith angle (SZA) $\chi = 0$. By plotting L against $\cos\chi$ on log-log graph, values of L_0 and n can be found. The index n given by the slope of the straight line fit would be seen to go through a minimum in midwinter months. These plots (not shown) include absorption values at $\cos\chi$ from 0.20 to 0.60 during October-March while from 0.40 to 0.85 during April-September since L_{db} values for 08 to 17 hrs are only considered. However, L_{db} values for $\cos\chi = 0.24$ are available for all the months and values of L_0 at $\cos\chi = 1$ are obtained by extrapolating the straight line towards the ordinate axis. The values of n so obtained for the solar minimum year 1976 and solar maximum year 1979 at De Bilt are given in Table 1 and compared with those obtained at Ahmedabad for the same years. It would be noticed that there is a similarity in the trend of seasonal and solar cycle variations of n at the two places which fact implies that the factors governing the rates of increase and decrease of absorption in its diurnal variation are common at low and middle latitudes. These factors are the changes in the height distribution of gas constituents, electron-ion densities and effective loss rate in different months.

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Table 1—Values of Index *n* Obtained from the Relation $L = L_0 \cos^n \chi$ for Diurnal Variation of Absorption

Month	De Bilt		Ahmedabad	
	1976	1979	1976	1979
Jan.	0.37	(0.45)	0.96	0.48
Feb.	0.28	0.26	0.67	0.68
Mar.	0.56	0.46	0.74	0.69
Apr.	1.00	0.64	0.98	0.70
May	0.66	0.46	0.93	0.65
June	0.74	0.58	1.05	0.82
July	0.78	0.63	1.18	0.74
Aug.	0.72	0.60	0.89	0.59
Sept.	0.55	0.56	0.59	0.68
Oct.	0.63	0.29	0.74	0.53
Nov.	0.18	0.16	0.37	0.64
Dec.	(0.40)	(0.30)	0.55	0.58
Annual mean	0.57	0.45	0.80	0.64
Average excluding winter months	0.71	0.53	0.89	0.68

Note: Values in brackets are somewhat doubtful.

The magnitude of *n* at midlatitude is a little smaller than it is at low latitude, but it is roughly around 0.80 on the average during low solar activity if the values in winter months at the midlatitude station are disregarded. This value goes down to around 0.60 in high solar activity. The reason for disregarding the value of *n* in winter months at midlatitude for estimating the average is the so called winter anomaly[4,5] of enhanced absorption and the associated comparatively lower values of *n*.

3 Time-delay in the Daily Maximum of Absorption behind Noontime

The observed phenomenon of the time of maximum in the diurnal variation of electron density and hence the absorption of radio waves lagging behind the apparent noontime occurs as a result of some kind of sluggishness in the response of the ionosphere to the causal solar-geophysical factor. Such effect makes the diurnal variation asymmetric, afternoon values of L_{db} being higher than its forenoon values for the same SZA. The method of finding the time-delay τ has been described in our earlier works[2,6] and the values so obtained compare well with those obtained by the method adopted by Lustovica[7]. Fig. 1 gives the comparison of the index *n* and the time-delay τ for different months over a period of six years (1975-80) of ascending part of the solar cycle shown by the variation in sunspot number R_z (now renamed as R_i). It may be noted that the index *n* is generally higher in summer than in winter and the time-delay τ has a trend of variation opposite to that of *n*, barring the irregularity or disagreement in such opposite trend during midwinter. The time-shift sharply fluctuates from 40-60 min lag to about 20 min lead (max. L_{db} occurring before noon) during the winter months when anomalous increase in L_{db} (Refs. 8 and 9) occurs at the midlatitude. During the rest of the year, τ varies from -5 to about 30 min, the range decreasing with increase in solar activity. At Ahmedabad, on the other hand, τ is almost zero in summer or equinoxes corresponding to high values of *n* and *L*, and about 40 min delay in winter when *n* and *L* are low. Thus, although the index *n* varies similarly at both low and middle latitudes, τ and *L* differ at the two places in their seasonal variations. The 12-monthly running averages show that τ decreases with increase in R_z, while the index *n* shows only a small decrease at a slow rate. Also, the sharp peaks and troughs in τ during November-February decrease in their magnitudes as the solar activity increases.

4 Relation between *n* and τ

At Ahmedabad[2] the rate of diurnal variation of absorption is steep or *n* is large in the months when the diurnal maximum value of *L* is also large. Corresponding to these, the delay time is small. Values of *n* and τ were found for the years 1972-78 at Ahmedabad and 1975-78 at De Bilt, and averages of these calculated for each month separately over the above years were subjected to correlation analysis. The correlation coefficient for De Bilt turned out to be -0.71 while that for Ahmedabad was found to be -0.70. In the actual analysis and line fitting, the anomalous values of winter months at De Bilt were not taken into account. The straight line fits showing inverse relationship are expressed mathematically as follows.

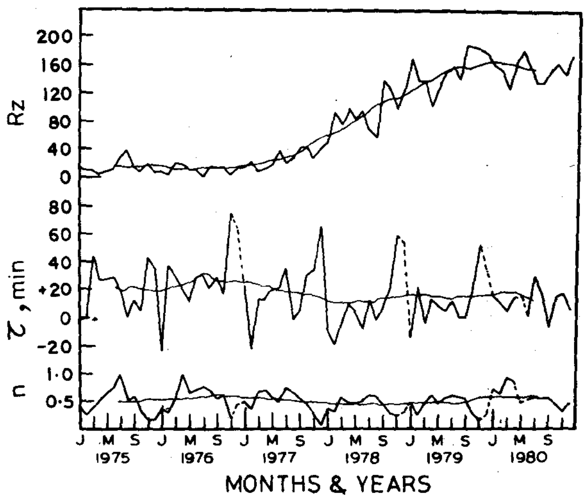

Fig. 1—Variation of the index *n* and the time-delay τ with season for a half solar cycle at De Bilt for f=2.3 MHz (The continuous curves through the monthly values give their 12-monthly running averages)

(i) Low latitude (Ahmedbad): for 1972-78
$\tau = 41.24 - 32.32\, n$ min
(ii) Midlatitude (De Bilt): for 1975-78
$\tau = 54.10 - 53.47\, n$ min

5 Variation of Absorption with Season and Solar Activity

Based on the arguments put forward in our earlier papers[2,6], it is more appropriate to compare absorption at fixed SZA with solar activity than at fixed time. Fig. 2 shows the variation of monthly median absorption at $\cos\chi = 1$ and $\cos\chi = 0.24$ observed at De Bilt over the years 1975-80. The variations of noontime L and R_z are also shown therein. It is at once seen that L at fixed $\cos\chi$ has better correspondence with R_z than that at noon. The correspondence is quite good for the months March-October and it is clearly brought out during the years of high solar activity, but it breaks down in the months November-February. Winter anomaly peaks of L are distinct at fixed SZA compared to those at noon. Another interesting feature to notice is that the anomaly peaks of L for overhead sun show a trend of increasing magnitude with solar activity but not so clearly the peaks at $\cos\chi = 0.24$. One puzzling observation is that of lower values of absorption, particularly at $\cos\chi = 1$, during April-October interval of 1979 than those during the same interval of 1978 in spite of the fact that the solar activity continued to rise in 1979 above that in 1978. Examination of L_{db} data of some other places also revealed a similar feature of decrease in 1979. However, the seasonal ups and downs in L at $\cos\chi = 1$ increased as against those in L at $\cos\chi = 0.24$ and the values of τ and n. The 12-monthly running averages of absorption also showed lower values in 1979 than in 1978 as against continuous increase of R_z.

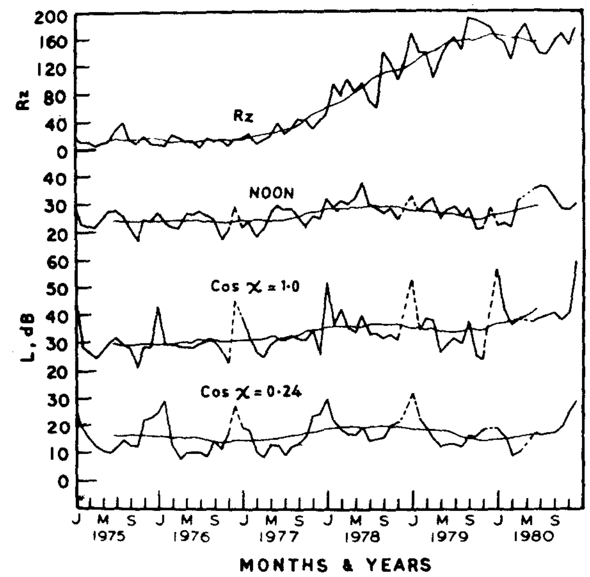

Fig. 2—Seasonal and solar cycle variations of monthly median L_{db} at noon, at $\cos\chi = 1$ and $\cos\chi = 0.24$ at De Bilt for $f = 2.3$ MHz (Smoothed yearly average curves are also drawn through them)

Since some workers[10,11] have reported on the good relation of L with solar X-ray flux (F_x) in 1-8 Å and 8-20 Å regions, an attempt was made to compare L_{noon} at De Bilt with 12 hrs UT monthly mean value of F_x and L_{noon} at Ahemdabad with 07 hrs UT monthly mean value of F_x. But this exercise gave no indication of F_x (1-8 Å) accounting for the decrease of absorption in 1979. Maybe that the absorption significantly increases during solar X-ray bursts classified into different groups of specified F_x-range of increase above a certain threshold value and no such good relationship between F_x and L may be found in their monthly mean values at the respective times or the whole day averages. It may be recalled that the seasonal variation of L at constant SZA has maxima in equinoxes at Ahmedabad while there is a sharp anomalous increase in winter and a shallow maximum in summer at De Bilt. It, therefore, appears that the phenomenon of the conspicuously subdued response of the D-region in the matter of radio wave absorption is not related to the solar activity but to some other factor, and since it is observed at several places, it is suspected that there might have been a widespread radical change in the constitution of the lower ionosphere.

6 Relation between L_{db} and Solar Activity

Mass plots of absorption values at De Bilt for constant $\cos\chi$ in all months against R_z were done in the same way as done earlier for Ahmedabad. For De Bilt, they were done for $\cos\chi = 1$ and $\cos\chi = 0.24$ (Figure not given here). Owing to their typical geographical location, only the above fractional values of $\cos\chi$ are available in all the months during daytime (08-17 hrs). In finding a linear fit, the values of L_{db} for winter months at De Bilt were excluded because of their irregular and anomalous character. The empirical relations governing the variation of absorption with solar activity are given below.

At Ahmedabad, for $\cos\chi = 1$,
$L_{db} = 34.42\,(1 + 0.00433\, R_z)$
$= 33.81\,\{1 + 0.00538\,(F_{10.7} - 60)\}$
At De Bilt, for $\cos\chi = 1$,
$L_{db} = 27.61\,(1 + 0.00261\, R_z)$
$= 27.02\,\{1 + 0.00342\,(F_{10.7} - 60)\}$

Similarly, for $\cos\chi = 0.6$ at Ahmedabad,
$L_{db} = 22.58\,(1 + 0.00443\, R_z)$
$= 22.17\,\{1 + 0.0055\,(F_{10.7} - 60)\}$
For $\cos\chi = 0.24$ at De Bilt,

$$L_{db} = 10.774\,(1 + 0.00661\ R_z)$$
$$= 10.33\ \{1 + 0.0085\,(F_{10.7} - 60)\}$$

When more data become available, the constants a and b in the general linear relation $L_{db} = a(1 + bR_z)$ or $a\ \{1 + b(F_{10.7} - 60)\}$ would be evaluated for each month separately at several fixed values of cos χ, from which it would be possible to predict the monthly median diurnal variation of absorption at any stage of the solar activity cycle. Absorption at several communication frequencies over different ground ranges could also be derived from the above work.

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