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Winter Anomaly in Ionospheric Absorption of Radio Waves over Half a Sunspot Cycle

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The winter anomaly in ionospheric absorption is studied at a mid-latitude station over half a solar cycle. It is shown that the anomalous increases of absorption on some days in winter are better correlated with 10 mb-level geopotential height than with temperature at that level. The anomaly is most marked in the month of January. It was about 168% in 1964 and 79% in 1969. The present results along with those reported by others earlier are evidences to suggest that the possible cause of winter anomaly in ionospheric absorption may be an increase in ionization in the D and probably in the E regions of the ionosphere following disturbances in the pressure and wind circulation system at stratospheric and mesospheric levels.

1. Introduction

ATTEMPTS WERE MADE earlier by some workers[1-3] to show that the so-called winter anomaly of increased ionospheric absorption was due to stratospheric warming. However, Kotadia and Patel have reported[4] that the anomalous increases, on some days, in ionospheric absorption of radio waves on 1·725 MHz at a mid-latitude station did not show a significant correlation with stratospheric warming. Later studies[5-10] showed that the specific instances of enhancement of absorption on some days in winter months were associated with increases in the D-layer ionization. From a comparison of day-to-day variations of absorption on different frequencies Patel and Kotadia[11] showed that the extent of unusual increase in absorption generally decreases at higher frequencies and the amount of anomaly changes from one winter to another. In this paper, an attempt is made to examine how good is the correlation of the unusual increases of absorption with the 10 mb-level geopotential height instead of temperature. An estimate of the winter anomaly is also made for the low and high sunspot periods.

2. Results

Frequency dependence of the variations in ionospheric absorption — The day-to-day variations in absorption are expressed as deviations of absorption (L) from its 27-day running averages eliminating the effect of solar rotation. These variations on the frequencies 1·725, 2·05, 2·44, 2·90 and 3·45 MHz for the winter of 1963-64 are compared in Fig. 1. The variations in the 10 mb-level temperature T and the sunspot number R_z are also shown therein. It will be seen that the extent of variations decreases as the frequency increases. The increases occurring on some days of stratospheric warming become more distinct at lower frequencies. However, there are significant differences in the structure of the variations from one warming to another and also with respect to the frequency of the radio wave. For example, L around 11 December 1963 was greater on some frequencies than it was on a much warmer day around 31 January 1964 on other frequencies. Curiously, a large distinct increase in L was observed on all frequencies on a day of stratospheric cooling by more than 8°C around 12 January 1964. R_z was also not high, but this increase in L agreed with the increase

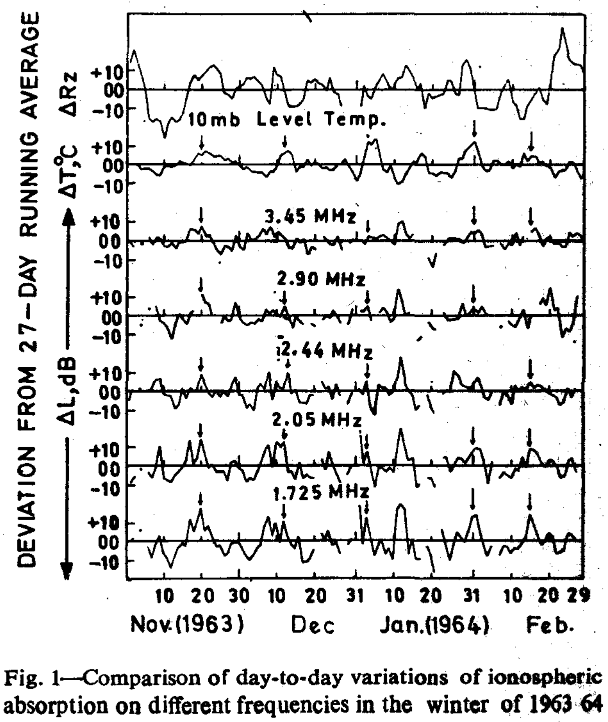

Fig. 1—Comparison of day-to-day variations of ionospheric absorption on different frequencies in the winter of 1963-64 at Freiburg

in 10 mb-level geopotential height (Δhg) as seen from Fig. 2.

Absorption and geopotential height—For showing the association of the day-to-day variations of ionospheric absorption (L) on 2·05 MHz with the geopotential height (hg) of 10 mb-level, the noon observations of L and morning observations of hg at Freiburg (48°N, 7·8°E; I = 64°N) are plotted in Fig 2 for the winter of 1963-64. The variations of 10 mb-level (31 km altitude) temperature T are also shown in Fig. 2. It will be noticed that marked increases in absorption occur when hg is lifted up. This is shown by vertical arrows. The coincidence of ΔL with Δhg is more distinct than with ΔT. The variability in absorption is particularly large in mid-winter months, and the correlation of L and hg is seen very distinctly in these months only. It was shown earlier by Kotadia and Patel[4] that the changes in absorption during the months March-November are generally controlled by the solar activity represented by either 10·7-cm solar radio flux or sunspot number.

Fig. 3 shows comparison of day-to-day variations of L, T and hg for the winter of 1968-69 of high sunspot activity. It is seen that the correlation between L and hg or even between L and T is less marked than that observed in the winter of 1963-64.

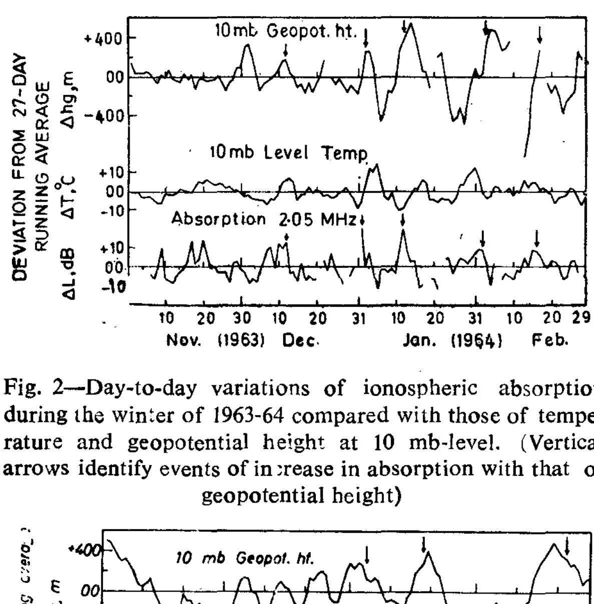

Fig. 2—Day-to-day variations of ionospheric absorption during the winter of 1963-64 compared with those of temperature and geopotential height at 10 mb-level. (Vertical arrows identify events of increase in absorption with that of geopotential height)

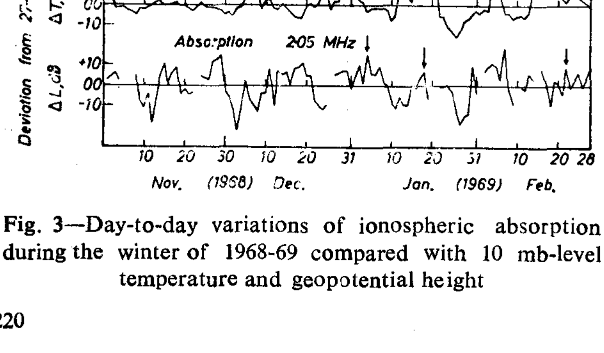

Fig. 3—Day-to-day variations of ionospheric absorption during the winter of 1968-69 compared with 10 mb-level temperature and geopotential height

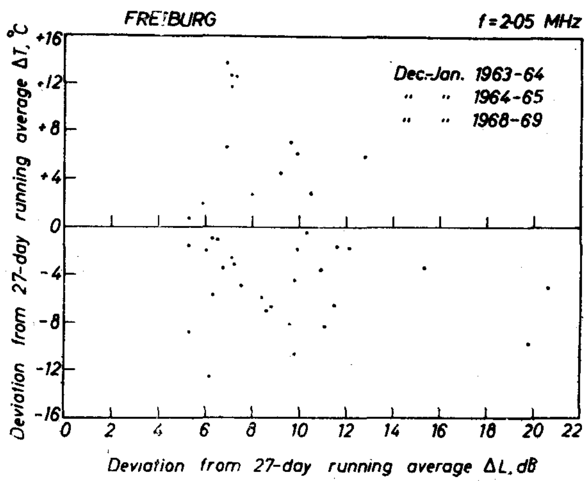

Fig. 4—Mass-plot of deviations from 27-day running averages of 10 mb-level temperature on days when the increase in absorption was greater than 5 dB above the average

Mass-plot of deviations L, hg and T—In order to get a general picture of the relation, if any, of the unusual increases in ionospheric absorption to the 10 mb-level temperature and geopotential height, all days of the three mid-winters, viz. December-January each of 1963-64, 1964-65 and 1968-69 on which L increased by more than 5 dB above the average were sorted out. The deviations ΔT on these days from the 27-day running average of 10 mb-level temperature are plotted against those of absorption, ΔL for 2·05 MHz in Fig. 4. One may notice a large scatter of points showing both increases and decreases of temperature for enhanced absorption. The stratospheric temperature was below the average even on days when the absorption was abnormally high by 16 - 20 dB. There are more number of points showing decrease of temperature than its increase on days of abnormal increases in absorption. The correlation coefficient between ΔL and ΔT turns out to be negative, about —0·22 at significance level P = 0·17.

In Fig. 5 is shown a similar mass-plot of deviations Δhg of 10 mb-level geopotential height against ΔL for days when ΔL exceeded 5 dB. It is seen that the situation is almost reversed from that in Fig. 4. Although hg is sometimes below and sometimes above the average corresponding to enhanced absorption, there are many points of positive Δhg (almost double) than of negative Δhg. However, it is difficult to connect ΔL with Δhg by a linear relation. The correlation coefficient r turns out to be only about + 0·10 at significance level P=0·59. It may be said that the uplifting of stratospheric level rather than its warming may serve as a trigger for changing the conditions at higher levels up to the D and E regions of

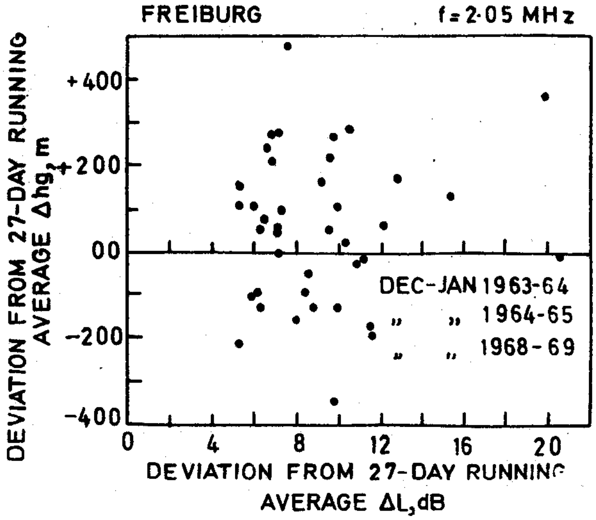

Fig. 5—Mass-plot of deviations from 27-day running averages of 10 mb-level geopotential height on days when the increase in absorption was greater than 5 dB above the average

the ionosphere as a result of which the gas composition there may also be disturbed.

Dependence on solar activity—The ionospheric absorption at a particular place depends on solar activity and the sun's zenith angle. The dependence of absorption on solar activity for a particular month is expressed by the relation

$$L = a\,(1 + bR_z) \quad \ldots(1)$$

where L is monthly median (or mean) absorption, R_z is monthly mean sunspot number, a is a constant representing absorption for quiet sun or $R_z = 0$ and b is a constant showing linearity of L with R_z.

It is seen from Fig. 1 that the variations in L on 1·725 MHz were not much different from those on 2·05 MHz except that the variations on 2·05 MHz were a little smaller. Similar results have also been reported elsewhere[12]. Fig. 6 shows the plots of observed median noon L on 1·725 MHz against mean R_z for each month for the years 1960-1969. The intercepts on the L axis and the slopes of the straight lines give the values of a and b respectively for the different months. It will be seen that there is considerable scatter in December and January, i. e. during the mid-winter months, when large anomalous variations occur depending on atmospheric conditions rather than on solar activity. In other months, the points lie close to a straight line. The values of a and b for different months are given in Table 1. It is to be noted that the absorption of hf radio waves is most sensitive to solar activity in November ($b = 0{\cdot}01$) and least sensitive in January ($b = 0{\cdot}0018$). There are two maxima in the value of a, one in July and the other in January. The former is the expected normal one and the latter is the anomalous one indicating the 'winter anomaly' in ionospheric absorption. The yearly mean value of a and b for the whole 10-year period is found to be 28·5 and 0·0041 respectively. These mean values are practically the same as those obtained by plotting 12 - monthly running averages of L and R_z.

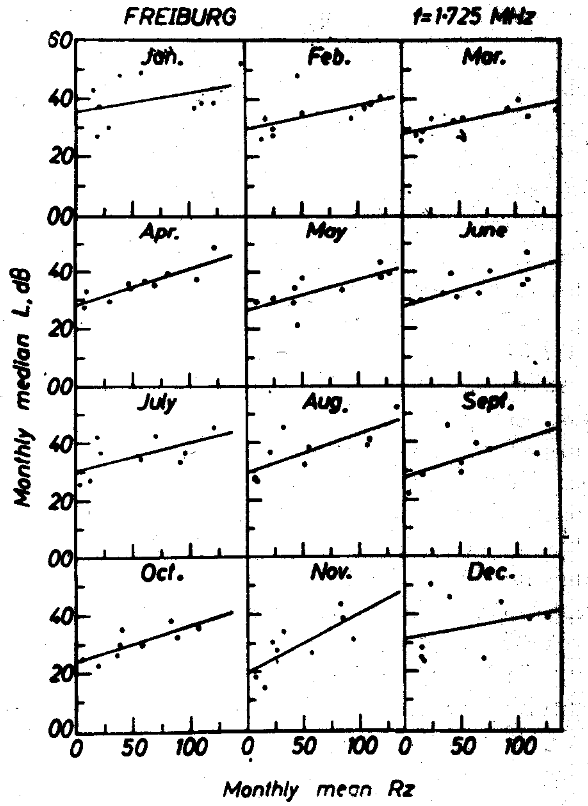

Fig. 6—Variation of ionospheric absorption (monthly mean) on 1·725 MHz with the month's sunspot number for different months of the years 1960-69

Table 1—Values of a and b in the Expression $L = a\,(1 + bR_z)$ for Different Months

Month	a	$b \times 10^3$
Jan.	35·7	1·8
Feb.	30·3	2·7
March	28·4	2·7
April	28·1	4·7
May	26·5	4·1
June	27·8	4·3
July	31·1	2·9
Aug.	30·1	4·3
Sept.	28·1	4·3
Oct.	24·3	4·9
Nov.	19·8	10·2
Dec.	31·7	2·2
Mean	28·5	4·1

Estimate of winter anomaly—In order to estimate the winter anomaly (departure from the value expected normally according to cos χ-law) in ionospheric absorption, the value of L normalised with respect to the sunspot number given by $L/(1 + bR_z)$ should be plotted against cos χ. The cos χ-law for this is written as

$$a = \frac{L}{1 + bR_z} = A \cos^n \chi \quad \ldots(2)$$

where A is a constant representing ionospheric absorption when $R_z = 0$ and the sun is at zenith. Fig. 7 shows plots of log $(L/1 + bR_z)$ against log (cos χ) for sunspot minimum period (1964-65) and sunspot maximum period (1968-69) of the present solar cycle, the value of cos χ being that on the 15th day of the month. The maximum monthly mean sunspot number in 1969 was hardly 120 as against about 200 in 1957-58. (We have also found one-to-one correlation between the solar radio flux on 10·7-cm and R_z). Two appropriate boundary lines are drawn to cover most of the points for the winter months of December, January, and February. The slope of these lines which is exponent n of cos χ in Eq. (2) is found to be 0·73 in 1964-65 and 0·47 in 1968-69. The corresponding values of A for $\chi = 0$ are 33·9 dB and 28·2 dB respectively. The slight difference in the value of A is probably due to the change in slope n with solar activity. The departure from the mean absorption represented by the middle course of the boundary lines gives the amount of anomaly in absorption. It was found to be about 168% in January 1964, 66% in January 1965 for the sunspot minimum period and 89% in January 1968 and 79% in January 1969 for the sunspot maximum period. However, if we plot the average for the 10-year period, the values come out as follows: $A = 31·7$ dB, $n = 0·42$ and winter anomaly of about 78% in January (figure not reproduced here). Among the winter months, the ionospheric absorption showed highest anomaly in the month of January meaning that the stratospheric and probably the mesospheric pressure and wind circulation system are frequently disturbed in January. It is quite likely that such disturbances may be accompanied by temperature rises at those levels in some cases.

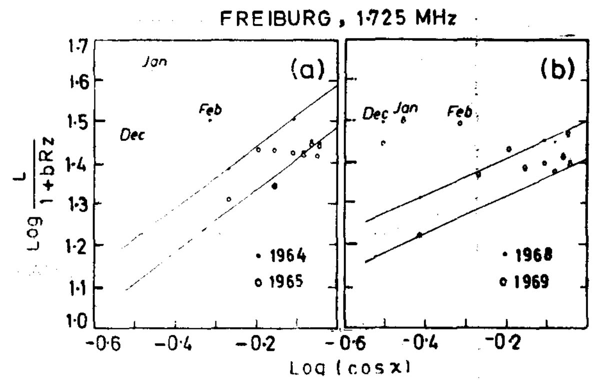

Fig. 7—Relation between ionospheric absorption on 1·725 MHz with solar zenith angle during 1964-65 and 1968-69 (Note the high anomalous values of absorption in winter months)

3. Summary of Results

The following are some of the important conclusions arrived at as a result of the present study made on the noon values of ionospheric absorption data on 1·725 MHz and 2·05 MHz obtained by Al-method at Freiburg (48°N, 7·8°E).

(i) The abnormal increases in ionospheric absorption L on some days in mid-winter months are better correlated with increases of 10 mb-level geopotential height hg than with those of temperature.

(ii) On the whole, the correlation between L and hg cannot be said to be very good for some obvious reasons to be discussed later.

(iii) The anomaly of increased absorption changes from one winter to another. It is most pronounced in the month of January every year. The estimate shows that the absorption was about 168% anomaly in 1964 and about 79% in 1969.

(iv) In midwinter months, day-to-day changes and the monthly mean values of absorption do not show correlation with those of the sunspot number.

4. Discussion

Gregory and Mansion[13] have shown the coincidence of a pressure ridge at 10 mb-level and the increase in absorption at Christchurch, New Zealand (43·5°S, 172·8°E). Shrestha[14] observed large undulations in ground level pressure at Brisbane, Australia (27·5°S, 152·9°E) on days of large f_{min} values. These are evidences in agreement with the increases of 10 mb-level geopotential height on days of unusually large aborption, although linear relation between L and hg is not found. This linearity is masked probably because of the contributions to the overall state of the D and E regions of ionosphere from other factors such as day-to-day changes in the ionizing radiation, magnetic activity, gas composition and other irregular processes of which we have little information. Schwentek[15] suggested a change in the whole structure of the atmosphere from ground level up to the E-layer on days of anomalous increases in ionospheric absorption. According to Rowe *et al.*[9] and Beynon and Williams[16], the electron collisions are of secondary importance and increase in electron density could well account for the enhanced absorption on some days. Sechrist *et al.*[10] found an increase in ionization at about the level of D-layer maximum in a coordinated rocket flight measurement when the ionospheric absorption was also abnormally large. Thus it appears that the most likely cause for the winter anomaly in ionospheric absorption is a net increase of ionization which may occur due to changes in the gas composition, loss of ionization and production rates of ionization in the D and, probably, the E region following a shake-up in the structure of the whole atmosphere below.

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References

1. Bossolasco, M. & Elena, A., *C.R. hebd. Séanc. Acad. Sci. (Paris)*, **256** (1963), 4491.
2. Shapley, A. H. & Beynon, W. J. G., *Nature, Lond.*, **206** (1965), 1242.
3. Sechrist, C. F., *J. atmos. terr. Phys.*, **29** (1967), 113.
4. Kotadia, K. M. & Patel, B. M., *Z. Geophys.*, **37** (1971), 1043.
5. Lauter, E. A. & Triska, P., *Geomagn. Aeronom.*, **5** (1965), 822.
6. Bowhill, S. A., Mechtly, E. A., Sechrist, C. F. & Smith, L. G., *Space. Res.*, **7** (1967), 246.
7. Piggott, W. R., *Progr. Radio. Sci. Part I*, (URSI, Paris), 1967, 826.
8. Thomas, L., *J. atmos. terr. Phys.*, **30** (1968), 1211.
9. Rowe, J. N., Ferraro, A. J., Lee, H. S. & Mitra, A. P., *J. atmos. terr. Phys.*, **31** (1969), 1077.
1 . Sechrist, C. F., Mechtly, R. A., Shirke, J. S. & Theon, J. S., *J. atmos. terr. Phys.*, **31** (1969), 145.
11. Patel, J. C. & Kotadia, K. M., *Annls. Geophys.*, **28** (1972).
12. Kotadia, K. M., *Proceedings of the COSPAR symposium*, Rep. No. 48 (University of Illinois, Illinois). (1972), 398.
13. Gregory, J. B. & Mansion, A. H., *J. atmos. terr. Phys.*, 32 (1970), 837.
14. Shrestha, K. L., *J. atmos. terr. Phys.*, **33** (1971), 213.
15. Schwentek, H., *Z. Géophys.*, **34** (1968), 123.
16. Beynon, W. J. G. & Williams, E. R., *J. atmos. terr. Phys.*, **32** (1970), 1325.