J. Geophys. 44, 27–34, 1977

Journal of Geophysics

Behaviour of Ionospheric Absorption in Winter 1975/76 at about 52° N, 9° E

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Abstract. In winter 1975/76, the diurnal variation of ionospheric absorption was measured daily at 1.73 MHz and 2.28 MHz by the pulse-reflection method, and at 2.61 MHz by field-strength recording of the transmitter DAN of Norddeich Radio. These measurements were made as a contribution to an Aeronomy Programme carried out mainly at El Arenosillo (Spain) in January 1976. The behaviour of characteristic absorption data in the period March 1975 to September 1976 is presented and discussed. It is stressed that the term "winter anomaly" can be applied to the variation of many parameters of the middle atmosphere, ionospheric absorption being only one of these.

Key words: Aeronomy – Ionospheric absorption – Winter anomaly.

Introduction

As a contribution to an Aeronomy Programme carried out in January 1976 at El Arenosillo, Spain, at Lindau, continuous measurements of ionospheric absorption were made. This work was mainly done from a synoptic point of view, using the behaviour of absorption as a diagnostic tool, in order to check to which extent the behaviour of absorption at El Arenosillo would be similar to that at Lindau, particularly, as far as excessive absorption, pointing to winter-anomaly conditions (Schwentek, 1976) is concerned. What could be expected? From synoptic studies it was clear that El Arenosillo, situated at 38° N, is near the southern border of the winter-anomaly zone (Elling et al., 1974; Schwentek, 1976). Moreover, the aeronomy programme had to be carried out near sunspot minimum, when the amount of winter-anomalous absorption is lowest (Röttger and Schwentek, 1974). Thus, the probability to meet winter-anomaly conditions was low. But monitoring absorption at Spain, conditions of winter-anomaly could be and were detected there (Rose and Widdel, 1977).

Concerning a correlation between the behaviour of absorption at Lindau (52.6°N) and El Arenosillo (38°N), it was shown earlier (Schwentek, 1974), that at the distance of 2000 km between Lindau and El Arenosillo, in general, the threshold of significance for a correlation is reached, but that just for these two stations still a significant correlation could be expected.

In this paper, the data obtained at Lindau are only discussed with respect to the behaviour of absorption at Lindau. But the data were made available to some other participants in the campaign mainly for correlation analysis.

A Remark Concerning the Term "Winter Anomaly"

Since the aeronomy programme carried out at El Arenosillo/Spain was mainly aimed at the study of the "winter anomaly", it seems to be reasonable to recall shortly the anomalous phenomena occurring in winter at middle latitudes. Originally, the term winter anomaly pointed to the fact that the seasonal variation of absorption of radio waves in the ionosphere does not depend merely on solar zenith angle χ. Whereas absorption is constant for constant χ at low latitudes, at middle latitudes it shows a considerable enhancement in winter, and very often superimposed excessive values. Moreover, during days of excessive absorption, the reflection heights are found to be relatively low, about 80 km, as was pointed out already by Dieminger (1952).

Considering other parameters of the middle atmosphere than absorption which are available as time series, as, for instance, the maximum electron density of the E layer, a very similar behaviour was found as for absorption; the same is true for stratospheric temperature (stratospheric warmings) Schwentek (1968). In other words, at temperate latitudes, the entire middle atmosphere, shows a more or less anomalous behaviour in winter. An effect should be found also on other parameters as atmospheric temperature, pressure, composition, wind systems etc. Since the variation depends on time as well as on space a region should be considered with a diameter of at least 2000 km, or even the entire Northern and Southern Hemisphere. As a matter of fact the events of excessive absorption appear as weather-like phenomena of regional extent distributed in patches over the entire middle latitude band of a hemisphere (Schwentek, 1974). – Finally, even if the particular electron-density profiles appearing during winteranomalous days may be attributed to corresponding height profiles of NO, as is suggested, it remains still unclear, how these particular NO profiles were produced, and how they are geographically distributed. This point is made in order to encourage a synoptic study of the NO distribution.

Methods of Measurement and Data Reduction

At Lindau, measurements were continued at 2.61 MHz, at oblique incidence of the waves, by recording the signal strength of the transmitter DAN of Norddeich Radio. By means of a statistical counter, frequency distributions of signal strength were produced for every half an hour (Schwentek, 1966). Simultaneously, measurements were made at 1.73 and 2.28 MHz, at vertical incidence, applying the pulse-reflection method; the equipment used was the same as earlier on board a ship (Barke et al., 1974). Details concerning the methods can

Table 1. Number of days and percentage of ranges in the correlation coefficients calculated from daily regression lines $\log L$ vs. $-\log\cos\chi$

A: 2.61 MHz; summer: 21 June–22 September 1975 plus 22 March–22 June 1976. B: 2.61 MHz; winter: 23. September 1975–21 March 1976. C: 1.73 MHz; winter 11 November 1975–21 March 1976. D: 2.23 MHz; winter: 11 November 1975–21 March 1976. C and D: corrected for τ

Correlation coefficient		1.0–0.951	0.95–0.901	0.90–0.851	0.85–0.801	0.80–0.751	0.75–0.701	0.70–0.651	0.65–0.601	< 0.60
A	(days)	37	69	31	30	5	3	2	0	2
	%	20.7	38.5	17.3	16.7	2.8	1.7	1.1	0	1.1
B	(days)	31	50	21	20	18	8	6	6	20
	%	17.2	27.8	11.7	11.1	10.0	4.4	3.3	3.3	11.1
C	(days)	41	43	20	14	4	4	2	2	3
	%	30.8	32.3	15.0	10.5	3.0	3.0	1.5	1.5	2.2
D	(days)	40	32	24	12	12	2	1	3	4
	%	30.8	24.6	18.5	9.2	9.2	1.5	0.8	2.3	3.1

be found in the Manual of Ionospheric Absorption Measurements edited by Rawer (1976).

The photographic recording of the reflected pulses used gives not only absorption data, but also accurate heights of pulse-reflection. The shapes of the reflected pulses give hints on irregularities in the layers, and on dynamic processes.

Data reduction was carried out by electronic desk calculators. The diurnal variation of absorption $L(t)$ was approximated by the equation

$$L(f;t) = L_0 \cos^n \chi(t-\tau), \tag{1}$$

with f operational frequency, t time, χ solar zenith angle, τ a delay time, L_0 subsolar absorption.

Characteristic values of the diurnal variation are subsolar absorption L_0, exponent n, and absorption at $\cos\chi = 0.2$; these data were obtained from plots of $\log L$ vs. $-\log\cos\chi$. Consecutive median values of five half (or quarter) hours were used to determine automatically the regression line. Experience showed that this special procedure gives the most reliable data for characterizing the average behaviour of absorption for each day and that short deviations in absorption due to local or solar effects are eliminated. Calculated distributions of correlation coefficients are given in Table 1. They show a rather regular behaviour in the diurnal variation of absorption in summer, and a larger scatter during winter, thus pointing to particular, disturbed conditions in the lower ionosphere. That is, the correlation coefficient may be considered to be a measure of the regularity or irregularity, respectively, of the diurnal variation of absorption.

The daily average of τ, which was applied to the data obtained by vertical-incidence pulse-amplitude measurements, was determined as follows.

At first, consecutive median values of absorption, L, were calculated for sets of every 5 consecutive absorption values floating over the entire diurnal variation. From such values, a series of regression lines $\log L(t) = \log L_0 + n \log\cos\chi(t-\tau)$ was determined, varying τ until the standard deviation of the data pairs

$\log L$ vs $-\log \cos\chi$ reached a minimum. Then, the corresponding value of τ is the wanted delay time. A comparison of the data in Table 1 shows that the procedure of taking into account τ leads to better correlation coefficients (C, C); such a computation, however, is time consuming.

Results of Measurements

A survey on the behaviour of absorption at constant zenith angle $\chi=78.5°$, $L(\cos\chi=0.2)$, in winter 1975/76, is given in Figure 1. Values $L(\cos\chi=0.2)$ may be considered as a characteristic parameter of the day. Since the period March 1975–September 1976 is near sunspot minimum, in summer (21 March–21 September) $L(\cos\chi=0.2)$ is nearly constant showing a pronounced minimum in April (see also Schwentek, 1971b). A weak period should be noted; it is not yet quite clear whether it is significant or not. In winter 1975/76, again the well known two types of absorption were found: the regular increase of absorption until the winter solstice, then the decrease until the end of March, and, superimposed on this regular trend, days of excessive absorption (Schwentek, 1971a).

Concerning the correlation of these data with those obtained at El Arenosillo see the analysis made by Rose and Widdel (1977).

In Figure 2 the variation in winter of reflection height *h'* (upper part), and absorption at $\cos\chi=0.2$ (lower part) is shown for the frequency 1.73 MHz. It shows that, in general, periods of days, or single days, of excessive absorption correlate with the occurrence of low reflection heights. This indicates that during extreme winteranomalous conditions increased electron densities at lower heights have to be expected. This correlation can be understood by considering electron-density profiles obtained from rocket-measurements in summer, and in winter, showing in winter a marked enhancement of electron concentration between 78 and 88 km (Dickinson et al., 1976). Correspondingly, during conditions of excessive winteranomalous absorption, at 1.73 MHz, and partly also at 2.28 MHz, stable reflections from heights between 70 and 85 km have been observed, the amplitudes of echoes simultaneously reflected from heights above 85 km being very weak because of strong deviatire absorption; that is, the associated profiles are thought to have ledges in the 70–85 km height range causing strong partial reflections.

The electron-density profiles presented by Dickinson et al. (1976) show also that the height gradients of electron density dN/dh, considered at 1.73 and 2.28 MHz, (electron densities 3.7×10^4 and 6.5×10^4 el/cm^3, respectively) are greater in summer than in winter. Because the deviative absorption is inversely proportional to dN/dh, the deviative absorption near the point of reflections is greater in winter than in summer. That is, in winter, in the morning and afternoon, the used operational frequencies are often rather near to E-layer critical frequency. – It was thought and discussed to check at El Arenosillo during the winter anomaly campaign the relation mentioned above between absorption, heights of reflection, and electron-density profile in detail by combining a multifrequency absorption measurement and a partial reflection measurement. But these experiments could not be carried out.

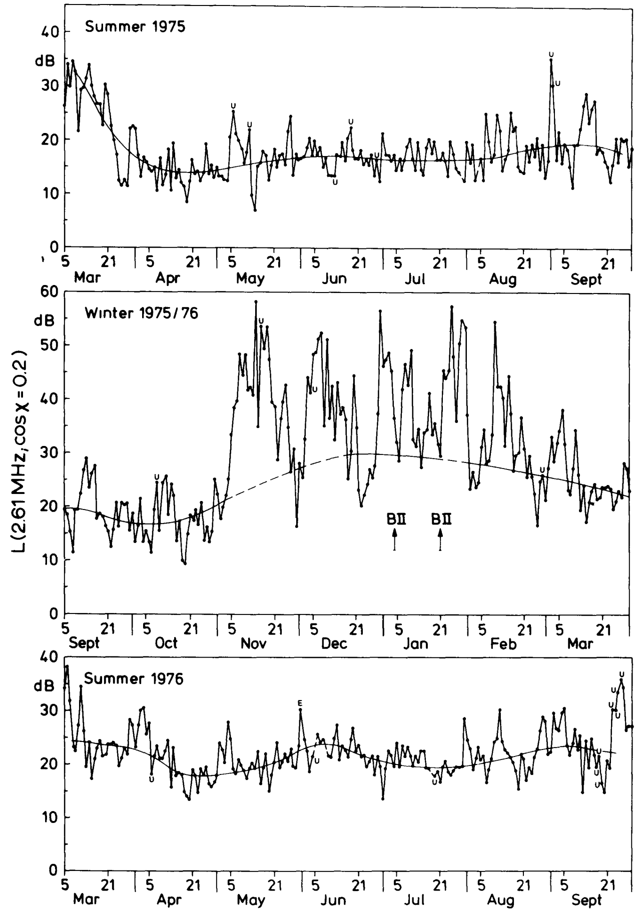

Fig. 1. Absorption in the ionosphere at a constant zenith angle $\chi = 78.45°$, $L(\cos\chi = 0.2)$, derived from the diurnal variation of each day in the period March 1975 –September 1976. Method A3 (field-strength recording), frequency $f = 2.614$ MHz, distance transmitter – receiver $d = 296$ km; equivalent frequency 1.5 ± 0.25 MHz corresponding to virtual heights of reflection of 105 ± 25 km. The point of reflection is at 52.6°N, 8.7°E. In summer, the included curve was drawn according to overlapping median values taken for 15 days periods; in winter, however, the regular seasonal variation is tentatively shown; on this the excessive, winter-anomalous absorption is considered to be superimposed. – BII, day on which the payload BII was launched at El Arenosillo/Spain. U uncertain value. E extraordinary diurnal variation

In winter the average height of reflection at noon is 103 km at 1.73 MHz, and 124 km at 2.28 MHz.

In Figure 3 the seasonal variation of an average of exponent n is presented. This exponent may be considered as the basic parameter for describing the diurnal variation of absorption. It depends not only on season, but also on geographic latitude, operational frequency, and angle of incidence of the radio wave. Two features should be noted in Figure 3, a wave-like variation, and a winteranomalous enhancement with a maximum around 15 January. It should

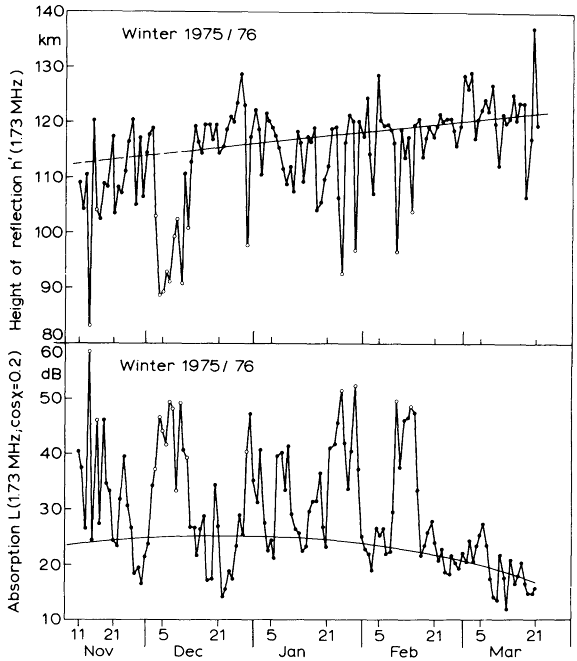

Fig. 2. Upper part: Daily mean values of apparent height of reflection h' taken from the time spans ± 18 min around the time of $\cos\chi = 0.2$ in the morning and in the afternoon; method A1 (vertical incidence), f: 1.73 MHz. Lindau: 51°39′N; 10°7.5′E. Lower part: Daily mean values of absorption taken from the time spans ± 18 min around the time of $\cos\chi = 0.2$ in the morning and in the afternoon. – Open circles indicate days of very low reflection heights *and* high absorption

be remembered that also the excessive values of $L(\cos\chi = 0.2)$ show a tendency to occur preferably in January, while the smaller values show a maximum centered around winter solstice.

The wave-like variation in the n values, as well as in L_0 and $L(\cos\chi = 0.2)$ values, was analysed. The power spectra obtained from a Fourier analysis shows predominent periods occurring simultaneously in the time series of $L(\cos\chi = 0.2)$, L_0, and n. The periods vary between 84 and 92, 28 and 30, 19 and 22 days. Applying a bandpass digital filtering (Kertz, 1965) using the above mentioned bands, average periods of 88.5, 29.5, and 21.5 days were found. The period of 88.5 days is the most dominant in the n values, and was observed throughout the observational time span. The periods of 29.5 and 21.5 days emerged only during the winter. It is interesting to note that the period of 88 days is the siderial period of Mercury, that of 29.5 days the synodial period of the Moon. However, this fact may be mentioned here without discussing whether this correlation is merely accidental, or not.

The enhancement of n in winter has to be considered as a distortion of the periodic variation in n, pointing to an additional physical process superimposed on the process causing the wave-like variation.

It should be recalled that exponent n has a physical meaning, while subsolar absorption L_0 is a formalistic factor, which becomes physically meaningful only

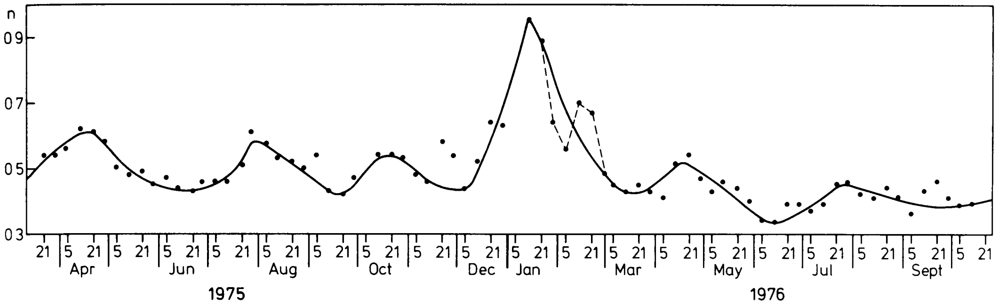

Fig. 3. Seasonal variation of an average value of exponent *n*. The plotted data were obtained from daily *n* values; $f = 2.61$ MHz. For every 15 or 16 days, starting with the period 5–21 March 1975, and proceeding in steps of about 8 days, the lower and upper quartile values were determined, and then the mean values of all the *n* data between the 2 quartile values were calculated. A similar result can be obtained also using the median values of the quoted periods. The curve was drawn tentatively to show the wave-like variation in the seasonal behaviour of exponent *n*; the mean period obtained from the plot is about 96 days. Note that the maximum in winter occurs at 15 January, that is about 4 weeks delayed related to the winter solstice

at latitudes where the solar zenith angle becomes 0; this occurs at latitudes between 23.5° North and South to the equator. In this region L_0 is really the measured subsolar absorption. It can be shown that L_0 may be presented as a function only of exponent *n*. This relationship will be presented and discussed elsewhere.

A comparison of the seasonal variation of $L(\cos\chi = 0.2)$ at 1.73 MHz, 2.23 MHz, and 2.61 MHz (equivalent frequency 1.5 ± 0.25 MHz; heights of reflection varying from 80–140 km) showed that the day–to–day variation is rather similar. The lowest frequency 1.73 MHz, however, reacted most sensitively on winteranomalous conditions, that is, showed the largest variation in absorption values.

Comparing Figure 1 and Figure 3 the long, weak periods in $L(\cos\chi = 0.2)$ and *n* appear to be out of phase. An analysis showed that the optimal correlation coefficient (=0.47) is obtained when values of $L(\cos\chi = 0.2)$ are shifted by 42 days against the *n* values. This result is reasonable, for, from plots $\log L$ vs. $-\log\cos\chi$ it is clear that, in general, a small *n* gives a high $L(\cos\chi = 0.2)$, and vice versa. Using the data obtained from the measurements made at 1.73 and 2.28 MHz, it was studied whether the delay time τ might be correlated with exponent *n*. The correlation coefficient is 0.04, it is not significant.

A correlation between atmospheric pressure at ground and the behaviour of ionospheric absorption might perhaps emerge. Very probably, it will be significantly observed only every tenth winter, but, in general, does not seem to exist (Schwentek, 1974). Therefore, during winter 1975/76, at Lindau, by means of a micro-barograph (sensitivity 3.75 mm per millibar), also atmospheric pressure at ground was recorded. A significant result did not reveal; this may be due also to the unregular behaviour of atmospheric pressure in winter 1975/76 which shows no particular wave-like variation.

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Received May 2, 1977