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WINTER ANOMALY OF THE LOWER IONOSPHERE AND ITS POSSIBLE CAUSES

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INTRODUCTION

It is a well-known fact that in winter the midlatitude lower ionosphere differs considerably from that in summer. This was first discovered as a result of the analysis of ground-based measurements of radio wave absorption in England (APPLETON, 1937). The phenomenon was named the radio wave ionospheric absorption winter anomaly. Later on, we began to speak about winter anomaly of the lower ionosphere, having in mind that a number of parameters of ionized and neutral components of the medium behaves anomalously in winter.

The winter anomaly at midlatitudes shows itself distinctly in MF and HF radio wave ranges. On a long-time average, the maximum value of absorption for a constant solar zenith angle is observed during the winter solstice; it decreases almost to summer values symmetrically towards the equinoctial periods. Another distinctive feature of the winter anomaly is the enhanced day-to-day variability of the absorption in winter compared with other seasons of the year. Beside the general increase of absorption level, called normal winter anomaly (SCHWENTEK, 1971), there are days and groups of days with excessively high absorption. The zone where the anomaly is observed has a low-latitude boundary below which the anomaly vanishes (see, e.g. LAUTER and SCHANING, 1970; ELLING et al., 1974). It should be also noticed that the magnitude of the effect and the duration of its occurrence decrease with latitude (e.g. RAPOPORT, 1974), that the anomalous region has a cloudy or spotted structure (e.g. SHRESTHA, 1971). The winter anomaly occurs also at high latitudes in the auroral zone in any case but here the effects caused by sporadic energetic particle fluxes are superimposed on those of the winter anomaly (RAPOPORT, 1979).

There have been many attempts to explain the winter anomaly. We should not like to dwell upon all hypotheses suggested. We only want to point out that some scientists regard direct precipitation of energetic particles as the unique cause of the anomaly at all latitudes where it is observed (e.g. SATO, 1981). Other authors assume that the winter anomaly may have also the causes completely independent of particle precipitation, i.e., changes of temperature and gas composition, mainly an increase of nitric oxide density ionized by Lyman-radiation (e.g. OFFERMANN et al., 1982). It seems to us that these opposite stand points do not exclude each other, that they may operate simultaneously, and their relative contribution is different in different cases, as it depends considerably on the latitude of observation (e.g. THOMAS, 1971; BREMER and LAUTER, 1982). We think, next, that the intensity of energetic particle fluxes in the auroral zone and the dynamical structure of the whole middle atmosphere on the levels of the lower thermosphere and mesosphere are definitive for the midlatitude mesosphere conditions. We also think that a correct interpretation of the midlatitude winter radio wave absorption changes is possible only if the whole spatial-time pattern of the event is taken into account. Our analysis is based on data obtained during an integrated experimental program carried out in the USSR in January 1981 and partially in January 1982.

INTEGRATED EXPERIMENTAL PROGRAM RESULTS

Integrated ground-based and rocket experiments were performed in the USSR in January 1981 and 1982 as a part of the International Middle Atmosphere Program. The rockets M-100B launched in Volgograd (φ = 48.7°N; λ = 44.3°E;

ϕ = 43.1°) provided height profiles of electron density, wind and temperature. Radio wave absorption data obtained by AI method in Volgograd and f_{min} parameter values obtained at a number of Soviet ionosonde stations were used to determine the situation in the lower ionosphere. The results of these integrated experiments have been presented at the COSPAR Symposium in Ottawa (PAKHOMOV et al., 1982) and in Alma-Ata (PAKHOMOV et al., 1983). The ground-based data showed that absorption in January 1981 was typical for winter conditions. The geomagnetic field during the whole month was rather quiet. Excessive absorption was observed on January 12-16.

Figure 1 shows electron density altitude profiles (Ne(h)) obtained by using the coherent frequency technique on rockets M-100B on the anomalous day of January 14 and on normal days of January 21 and 28 in the morning (Figure 1a) and in the afternoon (Figure 1b), the solar zenith angle being χ ≈ 78°. These profiles may be compared with that obtained on January 29, 1980, a day considered as free from the influence of winter anomaly. One may see that Ne values on quiet winter days (Figure 1a) exceed Ne values for the day free from anomaly in a considerable altitude range (≈ 75 to 90 km), whereas Ne values are higher on the day of the enhanced absorption than on a day with regular absorption (h ≈ 70 to 95 km).

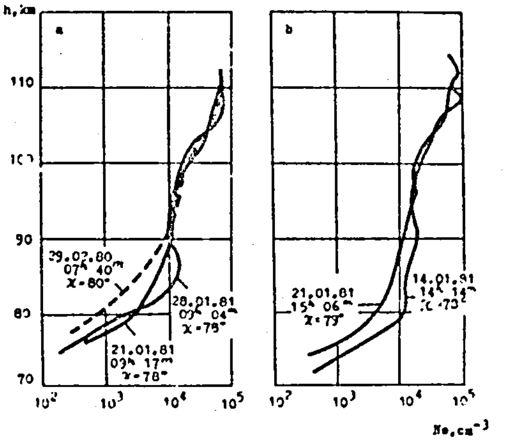

Figure 1. Electron density altitude profiles obtained by coherent frequency technique in Volgograd; solar zenith angle χ ≈ 78°. (a) forenoon profiles. (b) afternoon profiles. 14 January is the day of excessive absorption; 21 and 28 January are days of normal winter absorption. The profile obtained on 29 February 1980 at χ ≈ 80° is shown for comparison.

Figure 2a shows temperature profiles obtained on January 14, 21 and 28 as well as the CIRA-72 standard profile. The lower part of the figure (b), shows the measured temperature deviations from the corresponding standard profile. The characteristic shape of these ΔT (h) curves shows explicitly the influence of atmospheric wave processes on temperature distribution, not only during the excessive absorption but on normal days, too. It should be also noted that the temperature was lower than the standard one on the day of excessive absorption as well as on days of normal winter absorption in the region of enhanced electron density (above ~70 km). The temperature height distribution on the day

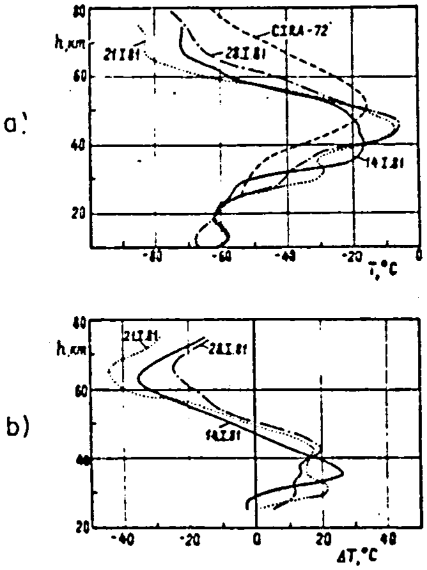

Figure 2. (a) Temperature altitude profiles above Volgograd obtained on 14, 21 and 28 January 1981. The dashed line shows the standard profile CIRA 1972. (b) Altitude profiles of temperature differences $\Delta T = T_{meas.} - T_{CIRA}$.

with excessive absorption does not show any peculiarities. We should like to call attention to this result, since a rise of the temperature is often considered as one of the most important causes of the winter anomaly because it must reduce the ion clustering rate which, in its turn, must cause a decrease of loss rate and, hence, an increase of electron concentration (see, e.g. SECHRIST, 1967).

The density of hydrated cluster ions which decisively affects the effective recombination effective coefficient in D-region is to a considerable extent dependent on the water vapour content of the medium (see, e.g. SECHRIST, 1970). Figure 3 (FEDYNSKI and YUSHKOV, 1979) displays water vapour density profiles obtained above Volgograd on January 10 and on February 2, 1978. The day of January 10 may be considered as an anomalous one (according to data from Moscow, mean of five near-noon values $f_{min} = 2.5$ MHz) while the day of February 2 is a normal one ($f_{min} = 1.3$ MHz). One may see that the water vapour density on an anomalous day is considerably lower than on a normal one: at 60 km altitude it is 6 times lower while it is 3.5 times lower at the altitude of 80 km. In this way, it seems that this result confirms the idea that the water vapour is one of the most important factors determining the electron density increase and excessive absorption in D-region. Water vapour density was also measured in January 1982 (Figure 4) -- the profiles have been obtained on 13 and 19 January 1932 at night at $\chi = 145°$ and 144°, respectively. Within the measurement accuracy these profiles coincide with that obtained in quiet winter conditions on 2nd February 1978 also shown in Figure 4. Yet, the absorption was rather high on these days in Volgograd (at 2.2 MHz about 50 and 40 dB). This suggests that it was not water but other factors that determined the lower ionosphere conditions during this period.

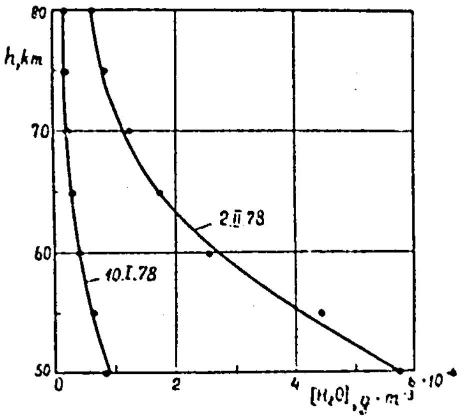

Figure 3. Water vapor density altitude profiles above Volgograd on anomalous (10 January 1978) and normal (2 February 1978) days.

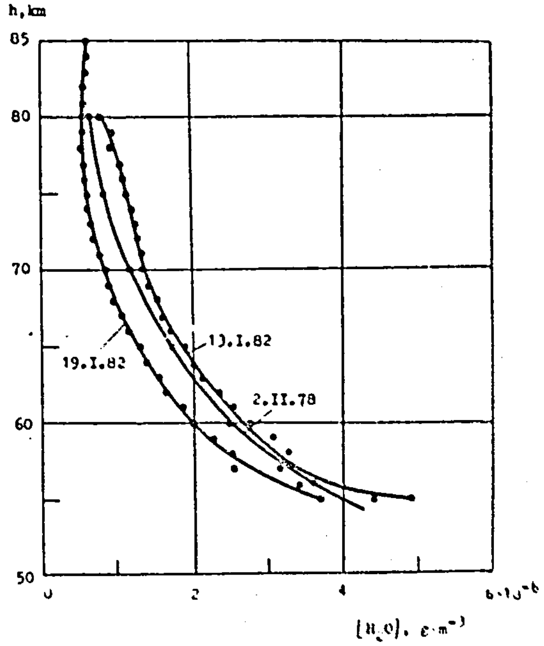

Figure 4. Water vapor density (H_2O) altitude profiles above Volgograd on 28 and 19 January 1982 (χ = 145° and 144°, respectively). The profile of 2 February 1978 is shown for the sake of comparison.

Thus the experiments in Volgograd in January 1981 and January 1982 show that both the temperature of the mesosphere and the water vapour density may serve only as additional factors and not as decisive factors which determine excessive anomalous winter absorption occurrence at midlatitudes.

DISCUSSION

First of all it should be borne in mind that whatever hypothesis we accept, it should explain all above mentioned peculiarities of the phenomenon. In agreement with other authors (OFFERMANN et al., 1982; BREMER AND LAUTER, 1982) we think that the enhancement of nitric oxide density is the main cause of electron density enhancement in the midlatitude lower ionosphere. We believe that nitric oxide is produced mainly at the ionospheric E region level, with highest rates at high latitudes and particularly in the auroral zone under the influence of precipitating particle (electron) fluxes.

More or less intense particle precipitation occurs permanently in the auroral zone, so that the density of NO caused by this precipitation has all features of the fluxes themselves, namely a very high time variability and spatial inhomogeneity (these features are to a certain extent smoothed out during the air transport). The auroral zone air being rich in NO is transported towards midlatitudes due to a stable winter cyclonic circumpolar vortex. As it moves the nitric oxide produced at high latitudes at an altitude of 90-100 km may be transported by turbulence and vertical motions towards lower altitudes (70-80 km) and it may produce there the above mentioned effects.

As there any experimental facts which might prove this assumption?

First of all let us consider the data on air circulation.

Constant pressure maps for the North Hemisphere plotted with a one week time resolution for every 5 km in the altitude range 35 km to 60 km are regularly issued by the Central Aerological Observatory (ATLAS, 1982). Figure 5 displays the maps of 60 km altitude for three weeks of January 1981, using geomagnetic coordinates. The dashed circle at a latitude of $\Phi = 67°$ gives a visualization of the auroral zone position. Points at this figure show positions of the observational stations. The wind at these altitudes may be considered as cyclo-geostrophic, so that air is transported along the isobars. One may presume that the circulation picture in general outlines the same at greater altitudes.

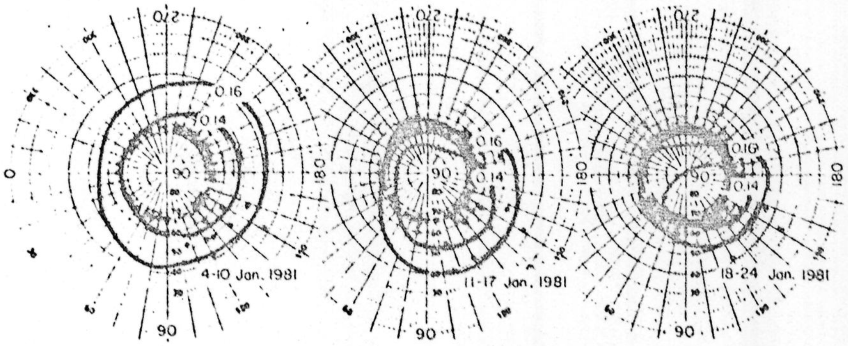

Figure 5. Constant pressure maps (the Northern Hemisphere) for the level of 60 km on 4-10 January and on 18-24 January 1981 (in geomagnetic coordinates). The dashed circle drawn at $\Phi = 67°$ indicates the auroral zone. Each isobar is labelled by its pressure (in millibars).

There is some basis for this assumption. Figure 6 shows velocity and direction of the zonal wind measured by meteor radar in Kuhlungsborn (GDR) (see also COSSART et al., 1982), at an altitude of about 95 km. One may see that the wind remained westward throughout the whole January which is natural if it follows the cyclonic vortex. Figure 5 shows that the isobars of the week preceding the disturbed days (4-10 January 1981) follow mainly the latitudes below the auroral zone. During the week of 11-17 January including the excessive absorption period they cross the auroral zone almost at halfway. The next week (18-24 January) they pass the auroral zone northward at a considerable portion of their path. It should be especially emphasized that the ionospheric disturbance on 12-16 January was preceded by a solar flare of importance 2N on 9 January with a subsequent weak magnetic storm with a gradual commencement (COSMIC DATA, 1981) followed by an increase of energetic particle precipitation into the lower ionosphere and by an equatorward shift of the auroral zone low latitude boundary. If our hypothesis is valid this should show itself through the time of the disturbance onsets at different stations as well as through the magnitude of the effects itself.

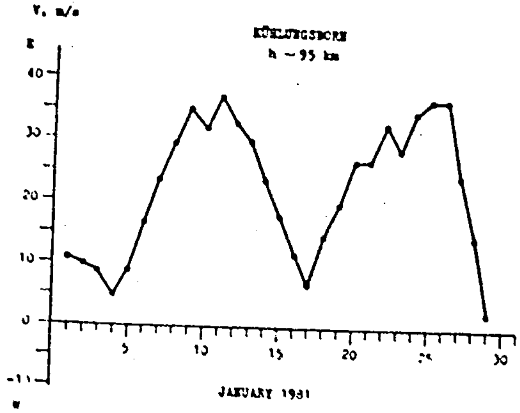

Figure 6. Zonal wind component above Kuhlungsborn in January 1981.

Figure 7a shows f_{min} (cos $\chi = 0.2$) values for a number of Soviet ionospheric stations (Kaliningrad, Moscow, Rostov-on-Don, Arkhangelsk, Gorky, Sverdlovsk, Salekhard, Alma-Ata, Novosibirsk, Yakutsk) during the event of the winter anomalous absorption in January 1981. The character of f_{min} variability is different at different stations, nevertheless there is an obvious tendency: the increase of absorption begins earlier at western stations than at eastern ones. This must be so if the disturbance source moves together with the air in the cyclonic vortex, i.e. from west to east.

The quantity Δf_{min} which is the maximum difference of f_{min} values observed on two successive disturbed days has been taken as a measure of the effect's magnitude. This difference versus the longitude of the stations is shown in Figure7b. One may see that effect decreases as the longitude increases from west to east, following the air moving in the cyclonic vortex. If one takes into consideration a certain space inhomogeneity of the winter anomalous absorption zone, the plot looks rather significant. The stations Moscow and Rostov-on-Don do not fit the general distribution of Δf_{min}. This may be partially explained by a more sensitive equipment of the Moscow station, while Rostov-on-Dov is the lowest latitude station of all European stations of the Soviet Union. Besides, the growth of f_{min} values at these two stations is slower than at other ones, taking more than one day.

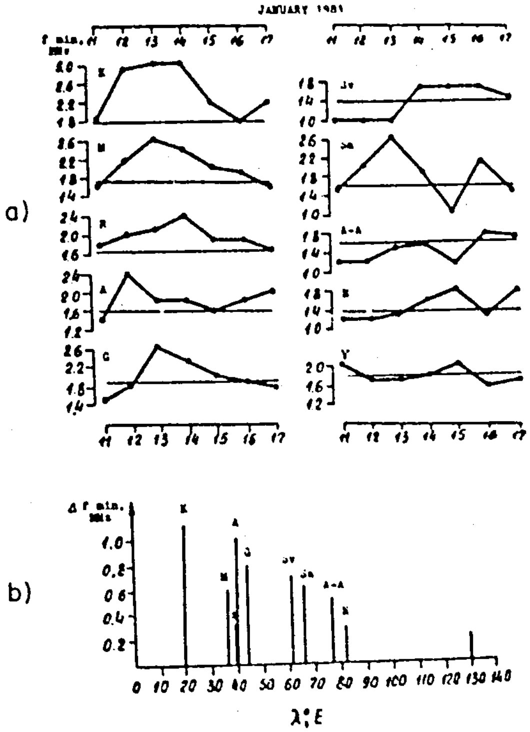

Figure 7. (a) fmin (cos X = 0.2) values at a number of Soviet stations on 11-17 January 1981. The thick horizontal lines show the position of the month by medians. K - Kaliningrad, M - Moscow, R - Roctov-on-Don, A - Arkhangelsk, G - Gorky, Sv - Sverdlovsk, Sa - Salekhard, A-A Alma-Ata, N - Novosibirsk, Y - Yakutsk.
(b) Δfmin, the maximum difference of fmin values for two successive days during the period 11 through 17 January 1981 for the stations shown in Figure 7a.

Midlatitude absorption changes (of f_{min} values) compared with constant pressure maps for January 1982 during a normal winter period free of excessive absorption occurrence also reveals a close relation between the two phenomena: f_{min} values are greater when the path along the isobars from the auroral zone to the observation station is short than in a case when this path is long (PAKHOMOV et al., 1983).

So, our hypothesis explains all the peculiarities of the phenomenon -- both the normal winter anomaly and the excessive one. In order to verify and to confirm the suggested hypothesis it is necessary to specify the character of circulation on levels of the mesosphere and of the lower thermosphere. Nitric oxide, water vapour and ozone densities in different geo-heliophysical conditions for different latitudes should be known more precisely, too.

REFERENCES

Appleton, E. V. (1937), Proc. Roy. Soc., A162, 451.

Atlas, (1982), Atlas of the altitudinal maps of the 35-60 km layer. Central Aerological Observatory, Gidrometeoizdat (in Russian).

Bremer, J. and E. A. Lauter (1982), Paper presented at the KAPG Symposium "Meteorological effects in the ionosphere", Sofia, Bulgaria, June, 1982 (unpublished).

Cosmic Data (1981), Cosmic Data, 1, Nauka, Moscow (in Russian).

Cossart von G., K. M. Greisiger, K. Sprenger, Yu. I. Portnyagin and I. A. Lysenko (1982), Phys. Solariterr. Potsdam, 18, 77.

Elling, W., H. K.Geisweid and H. Schwentek (1974), In: Methods of Measurement and Results of Lower Ionosphere Structure, (ed. by K. Rawer), Akademie-Verlag, Berlin, pp. 313.

Fedynski, A. V. and V. A. Yushkov (1979), In: Low Latitudinal Aeronomical Processes, (ed. by A. P. Mitra), Pergamon Press, Oxford, 263.

Lauter, E. A. and B. Schaning (1970), J. Atmos. Terr. Phys., 32, 1619.

Offermann, D., H. G. K. Bruckelmann, J. J. Barnett, K. Labitzke, K. M. Torkar and H. U. Widdel (1982), J. Geophys. Res., 87, 8286.

Pakhomov, S. V., Z. Ts. Rapoport and V. M. Sinelnikov (1982), Paper presented at the COSPAR Symposium on Solar-Terrestrial Physics (Ottawa, Canada, 1982).

Pakhomov, S. V., A. K. Knyazev, V. A. Yushkov, Z. Ts. Rapoport and V. M. Sinelnikov (1983), Paper presented at the MAP Symposium (Alma-Ata, USSR, 1983) (in Russian).

Rapoport, Z. Ts. (1974), In: Methods of Measurements and Results of Lower Ionosphere Structure, (ed. by K. Rawer), Akademie-Verlag Berlin, 305.

Rapoport, Z. Ts. (1979), Geomagn. and Aeronomy 19, 1042 (in Russian).

Sato, T. (1981), J. Geophys. Res., 86, 9137.

Schwentek, H. (1971), J. Atmos. Terr. Phys., 33, 1647.

Sechrist, C. F., Jr. (1967), J. Atmos. Terr. Phys., 29, 113.

Sechrist, C. F., Jr. (1970), Radio Sci., 5, 663.

Shrestha, K. L. (1971), J. Atmos. Terr. Phys., 33, 213.

Thomas, L. (1971), J. Atmos. Terr. Phys., 33, 157.