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EXPLANATION OF THE NORMAL WINTER ANOMALY FROM THE SEASONAL VARIATION OF SHORT-WAVE ABSORPTION

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INTRODUCTION

The frequency dependence of the winter anomaly (WA) of radio wave absorption (LAUTER et al., 1976; FRIEDRICH et al., 1979; VELINOV, 1975; SCHWENTEK et al., 1978; and NESTOROV, 1965) indicates the altitude range where the considered seasonal variation of absorption, L, takes place: 75-95 km. In this height region considerable seasonal variations of ionic composition and effective recombination coefficient, α_e, exist, which can cause seasonal variations of electron concentration, N, and absorption, L. In this paper we shall attempt to render a qualitative estimation of the normal WA, i.e. the increased ratio of winter over summer absorption, L_w/L_s, at medium latitudes 40° and 50°, for solar zenith angles χ = 60° and 75°, and compare this with existing experimental data.

IONIZATION RATE PROFILES

As it is well known, non-deviative radio wave absorption is determined both by the electron density profile, N(h), and by the collision frequency. Existing data prove (e.g., SMITH et al., 1978) that the seasonal variation of collision frequency at medium latitudes is insignificant. Therefore the observed increase of L_w/L_s must appear as a result of enhanced N under winter conditions. Profiles of ionization rate, q(h), needed for the calculation of N(h), are shown in Figure 1 for January and July (40°N, χ = 60°) at low solar activity ($F_{10.7}$ = 90). They are composed of (a) ionization by Lyman-α radiation, calculated by

$$q_{NO}^{+} = I_{L\alpha}^{\infty} \sigma_{NO} [NO] \exp(-Ch(\chi,h)N_{O_2}(h)\sigma_{O_2})$$

where $\sigma_{NO} = 2 \times 10^{-18}$ cm^2 and $\sigma_{O_2} = 10^{-20}$ cm^2, and

$$I_{L\alpha}^{\infty} = 4.3 + 1.5 \times 10^{-2} (F_{10.7} - 80) \quad \text{erg/cm}^2\text{s}$$

(b) ionization of $O_2(^1\Delta_g)$, obtained from PAULSEN et al. (1972),

$$q_{O_2}^{+} = [O_2(^1\Delta_g)] \times \{0.54 \times 10^{-9} \exp[-2.406 \times 10^{-20} N_{O_2}(h)Ch(\chi,h)] + 2.615 \times 10^{-9} \exp[-8.508 \times 10^{-10} N_{O_2}(h)Ch(\ ,h)]\}$$

(c) ionization by X-rays (λ<10 Å), found from

$$q(h) = \Sigma_\lambda I_\lambda^{\infty} k_\lambda \Sigma_i n_i(h)\sigma_{i,\lambda} \exp[-\Sigma_i N_i(h)\sigma_{i,\lambda} Ch(\chi,h)]$$

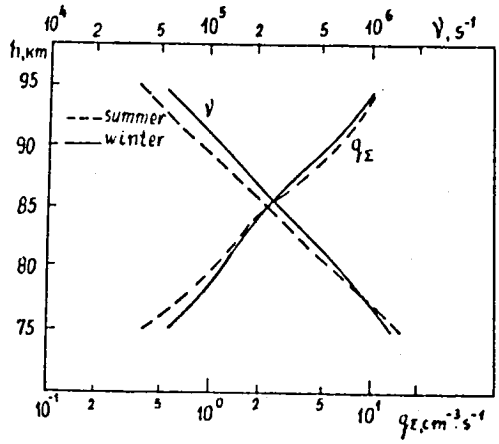

Figure 1.

where i = 1, 2 stands for O_2 and N_2, k_λ is the ionization coefficient, σ_i and $\bar{\sigma}_i$ are the ionization and absorption cross sections, respectively.

MODELING OF THE IONIZATION-RECOMBINATION CYCLE

After determining the q(h) profiles we proceed to determine $\alpha_e(h)$ in order to construct N(h) profiles. Presently, theoretical models of the D region are developed in two directions: Simple models (MITRA and ROWE, 1972) and detailed models (FERGUSON, 1974; REID, 1977). The latter are of great scientific value but a number of processes are still insufficiently known. The main shortcoming of these schemes, however, is in that they require much computer time so that they are unfit for practical use. In view of this it seems necessary to develop a model of ionization-recombination cycle which includes the advantages of the two kinds of models, i.e., relative simplicity under physical suitability (SMIRNOVA, 1982).

The proposed hybrid scheme of ion chemistry is shown in Figure 2. It consists of four ions: O_2^+, NO^+, CI_1^+, and CI_2^+, where CI^+ means cluster ions. The simpler cluster ions, CI_1^+, are formed from the primary ions, O_2^+ and NO^+, with formation rates $B(O_2^+)$ and $B(NO^+)$, respectively. These rates appear to be effective parmeters expressed by the rate constants in the detailed scheme (REID, 1977) and by the concentration of the neutral components involved. The more complex cluster ions, CI_2^+, are then formed from CI_1^+. The formation rates are calculated from the formulae:

$$B(NO^+) = r_1[H_2O][N_2] + C^{-1}r_2[N_2]^2r_4[H_2O] + \\ + r_6[H_2O](r_r[CO_2][N_2] + C^{-1}r_2[N_2]^2r_3[CO_2])/(r_{-5}[N_2] + r_5[H_2O])$$

with $C = r_{-2}[N_2] + r_3[CO_2] + r_4[H_2O]$, and

$$B(O_2^+) = \frac{k_1[O_2]^2 + v_1[N_2]^2}{\{k_2[O] + k_3[O_2(^1\Delta_g)] + k_{-1}[O_2]/k_4[H_2O]\} + 1}$$

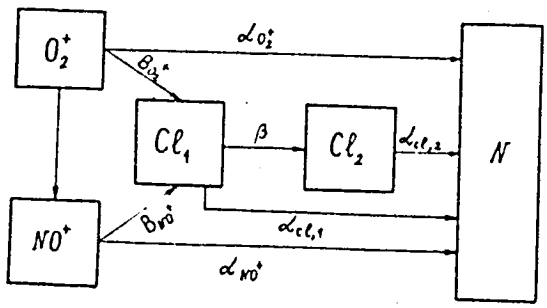

Figure 2.

All the coefficients, r_i, k_i, and v_i, are temperature-dependent. The temperature dependence of the rates is essentially different (cf. the next section): $B(NO^+)$ is proportional to $T^{-4.4}$, whereas $B(O_2^+)$ is proportional to T^{-14}.

The advantage of this hybrid quadri-ionic scheme consists in the simplicity of its calculations. The effective recombination coefficient, α_e, resulting from the ion composition calculated by this scheme, includes both a dependence on T and on $[H_2O]$. In Figure 3, calculated $\alpha_e(h)$ profiles are shown for winter (full curve) and summer (dashed curve).

TEMPERATURE DEPENDENCE

The temperature dependence of the lifetime of NO^+, $\tau_{NO^+} = 1/B_{NO^+}$, in the temperature range 120-230 K, has already been shown here (DANILOV, this volume, Figure 2 on page 19). It was calculated by the formula derived from REID's (1977) model. In that figure, the curve labelled 1 is for $[H_2O] = 1\times10^{-6}[M]$, curve 2 is for $[H_2O] = 5\times10^{-6}[M]$ with a fixed $[M] = 2\times10^{14}$ cm^{-3}. The full dots are values of τ_{NO^+} determined from simultaneous measurements of positive ion concentration, electron density, and temperature (ARNOLD, 1980). The theoretical temperature dependence of $B(NO^+)$ well reproduces ARNOLD's (1980) experimental data. From these data it follows that $B(NO^+)$ is approximately proportional to $T^{-13.9}$ in the range 120-230 K, and to $T^{-20.4}$ in the range 180-230 K. Comparison of curves 1 and 2 shows that the

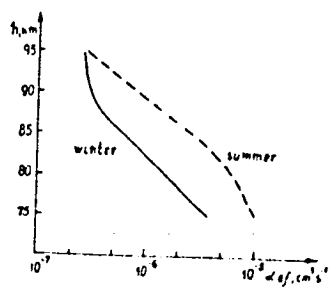

Figure 3.

influence of humidity on $B(NO^+)$ is considerable only in the range of high temperatures. The seasonal variations of $B(NO^+)$ at medium (40°N) and high latitudes, calculated for temperatures and densities taken from the CIRA-72 model have also been presented here (DANILOV, this volume, Figure 3 on page 20) together with B values experimentally determined from ion composition measurements (DANILOV and SIMONOV,1981). The theoretical $B(NO^+)$ curves are in good agreement with the data obtained in summer midlatitude experiments. Low B values under winter anomaly conditions are caused by an increase of T, which has been measured during the West European Winter Anomaly Campaign and other experiments. Large values of B in summer high-latitude experiments conducted under disturbed conditions can be explained by a large conversion rate of O_2^+ ions into Cl^+ under low summer temperatures. Larger values of B at the occurrence of noctilucent clouds result from a combination of low temperatures and high humidity.

ELECTRON DENSITY AND L_w/L_s

N(h) profiles have been calculated with q(h) as described above, and with α_e from the hybrid ion composition scheme, taking temperatures and density profiles from the CIRA-72 model, two variants of the water vapor concentration ($[H_2O] = 1\times10^{-6}[M]$ and $[H_2O] = 5\times10^{-6}[M]$), and with recombination coefficients $\alpha_{NO^+} = 2.3\times10^{-7}(300/T)^{0.5}$ and $\alpha_{O_2^+} = 1.9\times10^{-7}(300/T)^{0.5}$ after MUL and MCGOWAN (1977). The results are presented in Figure 4. N(h) profiles obtained in this way were used in the calculation of absorption L of radiowaves at an equivalent frequency of 1 MHz. The results of these calculations are given as winter-to-summer ratio, L_w/L_s, in Table 1, for α_{NO^+} and $\alpha_{O_2^+}$ after MUL and MCGOWAN (1977), and for another model with $\alpha_{NO^+} = 4\times10^{-7}(300/T)$ and $\alpha_{O_2^+} = 2\times10^{-7}(300/T)$ after LEU et al. (1973). Table 2 gives experimental data of seasonal absorption variations on radio paths with comparable equivalent frequencies. It is remarkable that the higher-latitude paths have a greater degree of manifesting the normal WA than the midlatitude paths. A greater seasonal L variation of the northern paths may be expected from larger seasonal variations in T, [NO], and air density.

DISCUSSION

Regardless of the fact that the calculated L_w/L_s ratios cannot be exactly compared with the experimental data because of the differences in latitude, f_{eq}, and χ, yet allowing for the tendencies of L_w/L_s with χ and latitude the results obtained in this paper can be considered as fully reasonable. From the fact that the excess of L_w over L_s is obtained already with very close q(h) profiles ($q_w \approx q_s$) it can be concluded that in order to explain the normal component of the WA, it is not necessary to assume an enhanced ionization rate, q, but only a decrease of α_e as a result of a lower

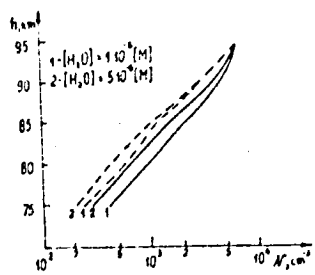

Figure 4.

Table 1

$\alpha(NO^+)$, $\alpha(O_2^+)$	Leu, Biondi a. Johnson		Mul and McGowan	
$[H_2O]$	$1x10^{-6}$[M]	$1x10^{-6}$[M]	$1x10^{-6}$[M]	$1x10^{-6}$[M]
$[H_2O]$	$1x10^{-6}$[M]	$5x10^{-6}$[M]	$1x10^{-6}$[M]	$5x10^{-6}$[M]
$(\frac{L_w}{L_s})$ 40°N, χ = 60°	1.5	1.77	1.67	1.96
50°N, χ = 78.5°	2.0	2.12	2.2	2.42

Table 2

f,kHz Radiopath/Distance	ϕ_{refl}, N°	f_e	cos χ	L_w/L_s
4050 Greece-Sofia/320 km	41.3	2	0.2	1.9
2831 Coburg-Graz/502	49.1	1	0.26	2
2775 Kiel-Neustrelitz/395	53.6	1.9	0.2	1.7
2775 Kiel-Panska Ves/520	52.5	1	0.2;0	1.5; 1.4
2614 Norddeich-Neustr./320	53.9	1.2	0.2;0	2.2; 1.1
1554 Nice-Roburent/80	44	1.5	0.2	1.5
1412 Pristina-Sofia/170	42.7	1.1	0.2	1.4
1223 St. Zagora-Sofia/200	42.5	0.8	0.26	1.2
1178 Horby-Kuhlungsb./218	54.9	0.8	0.2;0	1.7; 1.2
1730 Lindau Al	52.6	1.7	0.2	1.6
Ushuaia Al	-55	1.7	0.2	2.2

CI^+ formation rate in winter when temperatures are higher and air densities lower than in summer.

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