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Wind profiles from artificial luminous cloud observations and the theory of E_s formation based on wind shear

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Results are presented of wind profiles obtained between 80 and 150 km from five rocket launchings in 1968 and 1970 at Volgograd (48.7° N). E_s layers were observed in three experiments at 100, 106 and 105 km respectively in agreement with the levels given by wind-shear theory to within the limits of observational accuracy.

1. Introduction

In 1968 and 1970 experiments were carried out at Volgograd aimed at investigating the upper atmosphere wind régime. At the same time vertical soundings were carried out by means of an automatic ionospheric station. During one launching the vertical wind profile and the electron concentration were measured simultaneously. In this report we treat the wind profiles obtained with the aim of checking the theory of mid-latitude E_s-layer formation under the action of wind shear. Vertical ion velocity components and their convergence are calculated.

2. Wind profile characteristics

In 1968 and 1970 rocket experiments were carried out during which wind velocity and direction profiles were determined from luminous sodium clouds. Experimental details are given in table 1.

Table 1. Details of rocket launchings at Volgograd (48.7° N)

launching number	date	time (Moscow) h min	lower level of the cloud km	upper level of the cloud km	notes
1	16 July 1968	20 40	97	134	simultaneous ionospheric sounding (launchings 1–3)
2	25 July 1968	20 30	86	124	
3	26 July 1968	03 00	101	126	
4	6 July 1970	20 50	76	141	simultaneous rocket measurements of the electron profile
5	7 July 1970	02 40	98	154	

In launching no. 4, two probes (an impedance probe and a Langmuir probe for determining electron concentration and temperature) were installed in the head of rocket MR-12 in addition to the container for the artificial cloud formation. The electron concentration was measured on the ascent and the cloud was formed on the descent.

The artificial luminous cloud photos were analysed according to the method given in (Uvarov 1969). In calculating the wind velocity it was supposed that the wind had only horizontal components. Although the vertical component was not obtained, it seems that its value was less than the measurement error, which was about 3 to 5 m/s.

The horizontal wind velocity profiles obtained in 1968 and 1970 are given in figures 1*a* and *b*. They are similar to the profiles given in works by Kochanski (1966) and Blamont (1966). In all cases, except 26 July 1968, quasi-periodic wind velocity changes with increasing height were marked. However, the levels to which the oscillations are observed differ in all experiments. On 6 and 7 July 1970 they practically reached 130 km, on 16 July 1968 they were observed up to 120 km and on 25 July 1968 they ceased near 107 km. The mean amplitude of quasi-periodic velocity variations is about 30 m/s and the wavelength is 8 to 10 km. Some amplitude increase with increasing height is clearly seen from the profiles obtained on 16 and 25

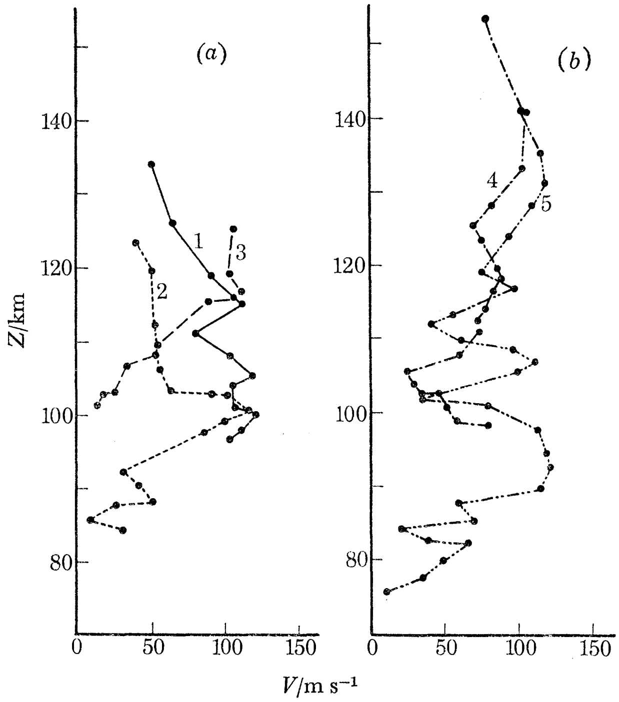

FIGURE 1. Horizontal wind amplitudes: (*a*) 1968 launchings; (*b*) 1970 launchings. Numbers on the curves are the launching numbers in table 1.

July 1968. The largest amplitude was registered in the 95 to 105 km height region and on 6 July 1970 it was about 50 m/s. Such velocity variations are typical of the heights considered and can perhaps be explained by internal gravity wave action.

Zonal and meridional wind components for the 1968 experiments are given in figures 2*a* and 3*a* and for the 1970 experiments in figures 2*b* and 3*b*. Quasi-periodic wind variations in zonal as well as in meridional components are clearly seen from the wind profile obtained on 6 July 1970 which covers the largest height interval. The wind variations on 16 July 1968 are more weakly defined.

The wind profile obtained on 26 July 1968 differs greatly from the others. In this experiment the resultant wind velocity increased with height; the increase above 107 km resulting mainly from the zonal wind component. It should be noted that on this day a weak geomagnetic disturbance was observed K_p being equal to 3 to 4; on other days the geomagnetic situation was quiet.

From figures 1 and 4 it is seen that at the main maxima the wind is towards the SW. Such

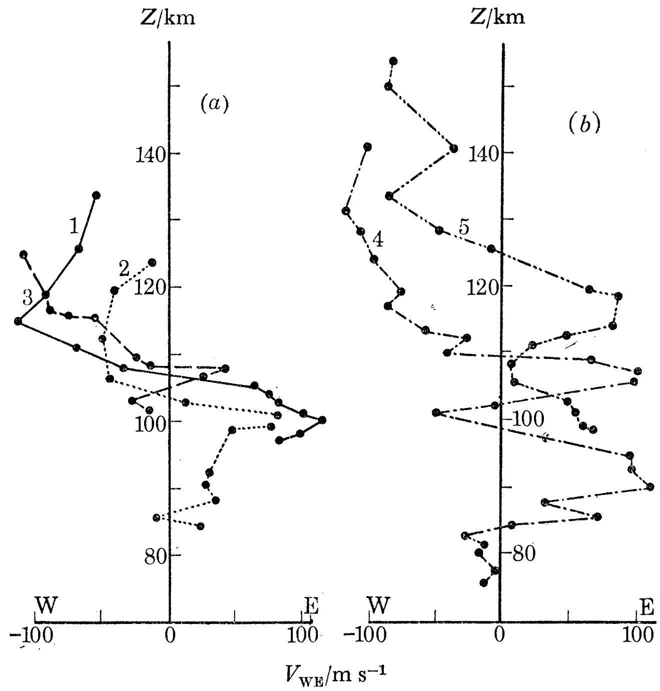

FIGURE 2. W–E wind components: (*a*) 1968, (*b*) 1970. Numbers on the curves are the launching numbers in table 1.

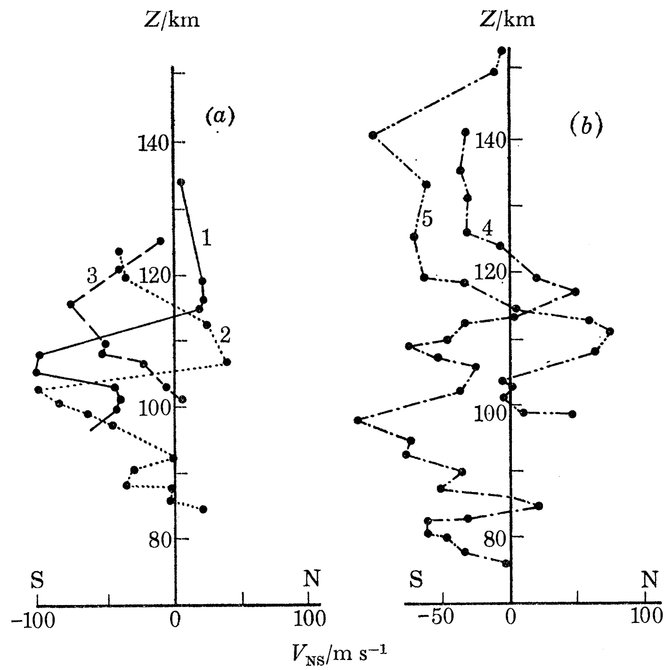

FIGURE 3. S–N wind components: (*a*) 1968, (*b*) 1970. Numbers on the curves are the launching numbers in table 1.

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a wind direction is constant for a given season and agrees with the seasonal circulation model (Kochanski 1966).

Wind components (figures 2 and 3) show that the zonal wind is directed to the east up to 105 and 108 km; above this level it is directed to the west. However, on 7 July 1970 the transition is observed at 124 km. The meridional components are generally directed to the south as discovered during the experiments at Heiss Island (80° 37′ N) and pointed out by Andreeva, Katasyev & Uvarov (1970).

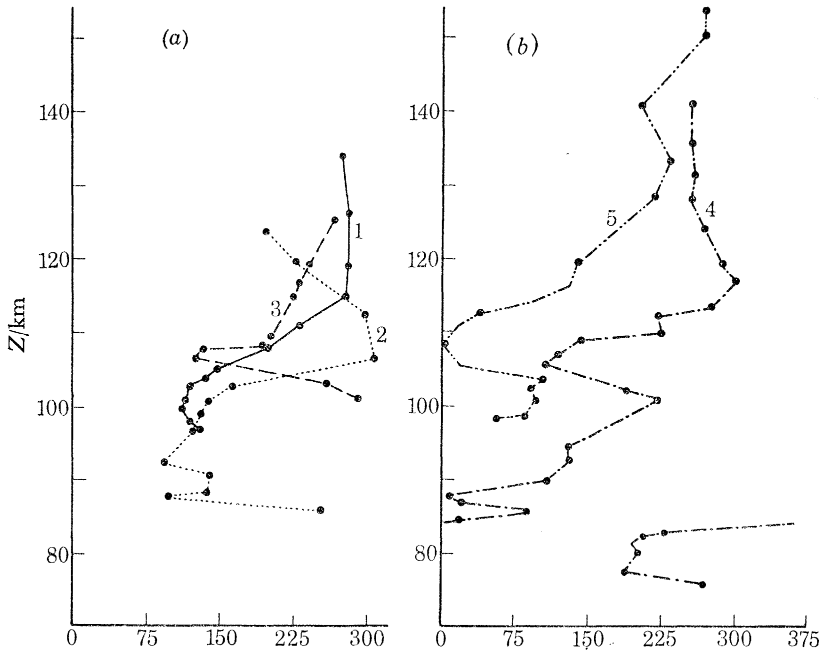

FIGURE 4. Directions towards which wind is blowing: (*a*) 1968, (*b*) 1970. Numbers on the curves are the launching numbers in table 1.

Variations of wind direction with increasing height are given in figure 4*a* and 4*b* (the wind direction is measured from the north in a clockwise direction). In almost all cases above 95 to 98 km the wind velocity vector is rotating clockwise in good agreement with tidal theory. The height of transition to the opposite direction of rotation is slightly different in various experiments. Clockwise rotation on 7 July 1970 is observed up to the maximum height of the wind profile. Anticlockwise rotation is observed in a small height region of about 102 to 105 km on 6 June 1970, 7 July 1970 and 26 July 1968; this effect can be explained by the simultaneous action of tidal and gravity waves.

Maximum vertical wind gradients are observed in the zonal component for the 110 to 115 km height region. In some cases the vertical gradient reaches about 140 m s^{-1} km^{-1} (on 26 July 1968 at 108 km), the average gradient being equal to about 10 m s^{-1} km^{-1} in the same height interval.

3. Test of the wind-shear theory

The experimental data given above have been used to verify the formation of midlatitude E_s under the action of a wind-shear (Whitehead 1967; Axford 1963).

For the stationary case with one type of particle and neglecting diffusion (Axford, Cunnold & Gleeson 1966; Nesterov & Chasovitin 1970), one can obtain expressions for the vertical ion velocity component and the convergence of the ion velocity field:

$$V_{iz} = \frac{1}{1+R^2}\left[XZU_x - XRU_y + (R^2+Z^2)\,U_z\right], \tag{1}$$

$$-\nabla V_i = -\frac{dV_{iz}}{dz} = \frac{1}{1+R^2}\left(R\frac{dU_y}{dz} - Z\frac{dU_x}{dz}\right) + \frac{X}{(1+R^2)^2}\left[2RZU_x - (1-R^2;\ U_y - RU_zX)\right]\frac{dR}{dz}. \tag{2}$$

Here $R = M_i\nu_i/Be$, where M_i is the ion mass, e is its charge, ν_i is the frequency of ion collision with neutral particles; U_x, U_y, U_z are the velocity components of the neutral wind; and B is the magnetic induction, $X = B_x/B$, $Z = B_z/B$.

Equations (1) and (2) are given for the rectangular coordinate system with the z axis vertical and horizontal axes x and y directed to the geomagnetic north and geomagnetic west respectively; the following assumptions are made (Axford *et al.* 1966; MacLeod 1966; Nesterov & Chasovitin 1970; Axford & Cunnold 1966):

$$\partial/\partial x = \partial/\partial y = 0 \quad \text{and} \quad \partial/\partial z = d/dz,$$

because the vertical size of the E_s layer is small in comparison to the horizontal one and therefore variations in the horizontal direction can be neglected. The ionospheric plasma in the E region is quasineutral, i.e. $N_e = N_i$ (N_i and N_e are the concentrations of positive ions and electrons). The influence of an electric field is small and in the first approximation it can be neglected. The vertical wind component is taken to be constant.

Knowing the wind profile, determined experimentally, we can calculate V_{iz} and $-\nabla V_i$ according to equations (1) and (2). From general considerations it follows that the charged particle accumulation (maximum electron concentration formation) must take place near the heights where $V_{iz} = 0$, $dV_{iz}/dz < 0$ and also in the height region where $-\nabla V_i$ has a positive maximum. Calculations according to formulae (1) and (2) make it possible to test the wind-shear theory experimentally if the wind and electron concentration profiles were determined simultaneously by the rocket method or if at least the E_s data were obtained by the vertical radiosounding method.

By using formulae (1) and (2) the vertical ion velocity component and its convergence were calculated for the wind profiles obtained. Values of R for various altitudes were taken from (Ratcliffe 1959); the value U_z was taken equal to 3 m s^{-1} (Bedinger & Smith 1967). Calculated results are given in figure 5. The altitudes at which E_s layers were registered by the ionospheric station are given by the horizontal lines.

It is seen from figure 5 (experiment 1) that the vertical ion velocity component is equal to zero at 109 km ($dV_{iz}/dz < 0$) and the region of positive ion convergence lies in the height interval 105 to 115 km with a maximum at 113 km. In experiment 2 (figure 5) $V_{iz} = 0$, $dV_{iz}/dz < 0$ at 104 km, and the convergence is positive in the height interval 101 to 107 km with a maximum at 103 km. For experiment 3, $V_{iz} = 0$ at 105 km, the convergence being positive in the 107 to 110 km region.

According to data from the ionospheric station E_s layers were registered at 110, 106 and 106 km for the three experiments respectively, which agrees within the limits of measurement accuracy with the levels given by the wind-shear theory. In these experiments the height of the E_s layer corresponds to the condition $U_y = 0$, $dU_y/dz < 0$ (figure 2a), therefore the simple wind-shear theory is valid (Whitehead 1967; Axford 1963; Nesterov & Chasovitin 1970). However, such a correspondence is not always observed, particularly at heights greater than

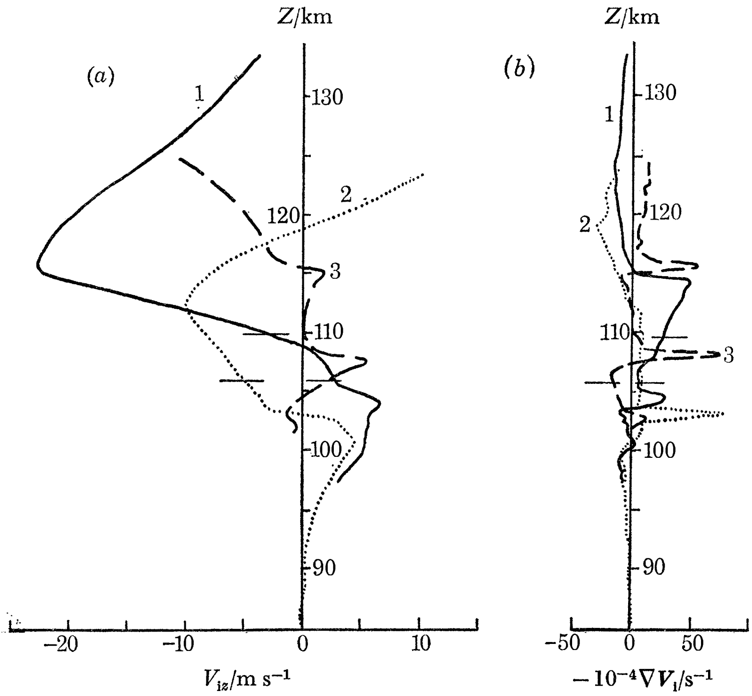

FIGURE 5. Values of V_{iz}, $-\nabla V_i$ calculated from equations (1) and (2) and experimental data obtained in launchings 1–3 (table 1).

110 to 120 km, where the N–S wind components become more important (Macleod 1966; Nesterov & Chasovitin 1970). From figure 5 (experiment 3) it is clear that the positive convergence takes place in the 114 to 125 km region with the maximum at 115 km. Here the vertical ion velocity component is also equal to zero and the E–W wind component differs from the latter. There was no data from the ionospheric station for the supposed electron concentration maximum at 115 km. As E_s-layer information could only be obtained by means of such a station, it was impossible to check the wind-shear theory in detail. For a detailed analysis it would be necessary to have rocket $N_e(z)$ profiles allowing us to draw conclusions on the fine structure of the electron concentration distribution with the height.

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