DETERMINATION OF THE PARAMETERS OF SMALL-SCALE ATMOSPHERIC TURBULENCE FROM COMBINED METEOR OBSERVATIONS

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Abstract

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P. B. BABADZHANOV, R. Sh. BIBARSOV

DETERMINATION OF THE PARAMETERS OF SMALL-SCALE ATMOSPHERIC TURBULENCE FROM COMBINED METEOR OBSERVATIONS

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In a previously published paper (1) the principal results were given of parallel photographic and radar observations of meteors, on the basis of which the dependence of the ionization probability on the meteor velocity was refined and a relation was given between the absolute photographic stellar magnitude and the initial linear electron density of the meteor trail. The value of combined observations of meteors also lies in the fact that they make it possible to determine certain parameters of atmospheric turbulence in the meteor zone.

At the point of reflection of radio waves from the meteor trail, the concentration of electrons changes under the influence of ambipolar diffusion and the attachment of electrons to neutral air particles. Beginning at time t_2, turbulent diffusion with coefficient $D_e = \omega(t - t_2)^2$ (2) also becomes effective in the change of electron concentration, where ω is the specific energy of dissipation of atmospheric vortices; t is the time elapsed since the passage of the meteor; and t_2 is the time constant of the small-scale vortices. Consequently, the change in the volume density n_e of electrons can be represented by the equation

$$\frac{\partial n_e}{\partial t} = \frac{\omega(t - t_2)^2}{r}\frac{\partial}{\partial r}\left(r\frac{\partial n_e}{\partial r}\right) - Kn_e, \tag{1}$$

where r is the distance measured from the axis of the meteor trail and K is the attachment rate.

The solution of equation (1) has the form

$$n_e = \frac{q}{\pi\left[{}^4/_3\,\omega(t - t_2)^3 + 4Dt_2\right]}\exp\left[-Kt - \frac{r^2}{{}^4/_3\,\omega(t - t_2)^3 + 4Dt_2}\right], \tag{2}$$

where q is the initial linear electron density of the meteor trail at the point of radio-wave reflection, and D is the coefficient of ambipolar diffusion.

Figure 1. Dependence of the coefficient of turbulent diffusion on height. The dashed line shows the height dependence of the coefficient of molecular diffusion.

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Assuming that reflection of radio waves from the meteor trail exists as long as the electron density on the trail axis exceeds the critical value, from (2) we obtain

$$\omega = \frac{3D}{(\tau - t_2)^3}\left(\frac{\lambda^2}{4\pi^2 D}\frac{e^2}{mc^2}qe^{-K\tau} - t_2\right), \tag{3}$$

where τ is the observed duration of the meteor radio echo; λ is the wavelength of the radar station; e and m are, respectively, the charge and rest mass of the electron; and c is the speed of light.

Between the time constant of the small-scale vortices t_2 and the specific energy of dissipation of atmospheric vortices ω there is the relation (3)

$$t_2 = (\nu/\omega)^{1/2}, \tag{4}$$

where ν is the coefficient of kinematic viscosity.

The iteration method makes it possible, from (3) and (4), to find the required quantities ω and t_2, and consequently also D_e. In addition, it appears possible to calculate the sizes of small-scale vortices l_2 and the pulsation velocity v_2 (3)

$$l_2 = (\nu^3/\omega)^{1/4}, \qquad v_2 = (\omega\nu)^{1/4}. \tag{5}$$

The results of calculations of the parameters t_2, ω, l_2, D_e, and v_2 for 9 meteors, 7 of which were observed in Dushanbe and 2 in Manchester (4), are presented in Table 1, which also contains the observed values of the heights of the reflecting points h of the trails, the absolute photographic magnitude of the meteor M at the reflecting point, and the duration of the radio echo τ. In the calculations, the values q, D, and K were used as determined from the relations: $M = 34.3 - 2.5 \lg q$ (1), $\lg D = 0.054h - 4.373$ (5), and $\lg K = 4.99 - 0.07h$ (6), where q is expressed in cm^{-1}, D in $\mathrm{m}^2/\mathrm{sec}$, K in sec^{-1}, and h in km. The coefficient of kinematic viscosity ν is usually taken to be equal to the coefficient of molecular diffusion at the corresponding height (7).

Fig. 1. Dependence of the coefficient of turbulent diffusion on height. The dashed line shows the height dependence of the coefficient of molecular diffusion.

In Fig. 1 are presented the results obtained by us for determining the coefficient of turbulent diffusion D_e as a function of height (a). For comparison, results of determining D_e from visual observations of persistent meteor trails (8) (averaged by us over two-kilometer height intervals,) and from observations of artificial clouds (9) ( ) are also given here. A fairly good agreement is found among the results of different methods of measuring D_e up to heights of about 100 km, where intense turbulent motions of the atmosphere occur. Above 100 km the results of different methods differ somewhat, which, apparently, is connected with the influence of the geomagnetic field on the behavior of ionized meteor trails (10,11).

Table 1

Meteor No.	h, km	M	τ, sec	t_2, sec	ω, erg/g · sec	l_2, m	v_2, m/sec	D_e, cm^2/sec
670954	93.6	−4.8	25.8	4.5	2700	6.5	1.43	$1.2 \cdot 10^6$
1 (4)	94.9	−1.7	46	10.5	360	8.8	0.83	$6.8 \cdot 10^5$
670931	95.0	−5.8	63.7	14.7	280	9.4	0.64	$6.7 \cdot 10^5$
661345	97.3	−4.4	41.3	11.3	660	9.7	0.86	$5.9 \cdot 10^5$
661345	97.8	−6.3	86.5	19.5	220	12.2	0.64	$9.9 \cdot 10^5$
670805	98.2	−2.1	18.1	8.1	1600	9.7	1.20	$1.6 \cdot 10^5$
670821	99.0	−2.9	61.5	3.5	23	5.0	1.40	$7.7 \cdot 10^4$
670866	107.5	−3.0	42.0	2.0	140	1.6	0.80	$2.2 \cdot 10^5$
2 (4)	110.3	−1.8	11.0	1.0	660	1.3	1.30	$6.6 \cdot 10^4$

Thus, parallel photographic and radar observations of meteors, being one of the new and effective means of studying the atmosphere, make it possible to measure comparatively simply a number of parameters of atmospheric turbulence and, in particular, to determine the height dependence of the diffusion coefficient. Therefore the accumulation of a large and

homogeneous statistical material for this type of meteor observations becomes very necessary.

Institute of Astrophysics
Academy of Sciences of the Tajik SSR
Dushanbe

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REFERENCES

[1] P. B. Babadzhanov, DAN, **184**, No. 4 (1969). [2] H. G. Booker, R. Cohen, *J. Geophys. Res.*, **61**, No. 4, 707 (1956). [3] D. Batchelor, *The Theory of Homogeneous Turbulence*, IL, 1955. [4] J. Devis, J. E. Hall, *Proc. Roy. Soc.*, **A271**, 120 (1963). [5] J. S. Greenhow, J. E. Hall, *Planet. Space Sci.*, **5**, 109 (1961). [6] R. Sh. Bibarsov, *Astr. Tsirk.*, No. 458, 7 (1968). [7] V. P. Dokuchaev, *Izv. Vyssh. Uchebn. Zaved.*, *Radiophysics*, **4**, No. 1, 5 (1961). [8] A. P. Savrukhin, *Comets and Meteors*, No. 14, 11 (1966). [9] D. Golomb, M. A. MacLeod, *J. Geophys. Res.*, **71**, No. 9, 2299 (1966). [10] V. P. Dokuchaev, *Izv. Vyssh. Uchebn. Zaved.*, *Radiophysics*, **3**, No. 1, 50 (1960). [11] L. M. G. Pool, T. R. Kaiser, *Plan. Space Sci.*, **15**, No. 7, 1131 (1967).

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