Reports of the Academy of Sciences of the USSR

GEOPHYSICS

1964

SovietRxiv

Abstract

Full Text

Reports of the Academy of Sciences of the USSR
1964. Volume 156, No. 6

GEOPHYSICS

A. A. ZAGORODNIKOV

SOME RESULTS OF RADAR MEASUREMENTS OF TURBULENCE IN THE FREE, CLEAN ATMOSPHERE

(Presented by Academician E. K. Fedorov, 20 V 1963)

Radar stations (radar) are widely used in meteorology, but their capabilities are still far from exhausted. They also make it possible to study the diffusion of impurities in the atmosphere, the velocity of which indicates the intensity of turbulence. For this purpose, pulsed centimeter-band stations are convenient, having automatic tracking in range and angular coordinates and range gating.

When light dipole vibrators (reflectors) are used as the impurity under investigation, the magnitude of the signal reflected from them at the receiver input of the radar is proportional ([1]) to the effective scattering area (e.s.a.) of that part of the cloud which lies within the pulse volume of the radar. The e.s.a. of the cloud, in turn, is directly proportional to the number of reflectors in it. Range gating makes it possible to measure the e.s.a., and consequently also the density of reflectors, of individual parts of the cloud. Smooth displacement of the gate makes it possible to measure the distribution of reflector density in the cloud along the radar axis.

Measurement of the distribution of reflector density in other directions requires the simultaneous use of 2–3 radars, or one radar but with a narrow directional pattern in angular coordinates. In the latter case, smooth deflection of the axis of the directional pattern relative to the maximum density of the cloud makes it possible to measure the density distribution of dipole vibrators in the cloud, respectively, in the plane of azimuth and elevation angle.

The results of records of the distributions of reflector density in the cloud are affected by the parameters of the directional pattern, the pulse, and the nonlinearity of the radar receiving path. In processing the experiments, all these factors, which distort the measurement results, must be taken into account. Successive measurements of the reflector-density distributions along the corresponding directions make it possible to judge the rate of scattering of the cloud and, consequently, the magnitude of atmospheric turbulence.

Fig. 1

Figure 1: Fig. 1

Let us consider some results of experiments carried out by the indicated method. Experiments on scattering of reflectors were conducted in the free, clean atmosphere in the altitude range 2-26 km. The reflectors were released from pilot balloons or aerostats upon actuation of a barometric or time relay. Continuous tracking of the ascending object was carried out with the aid of radar. The moment of release was recorded by the increase in the signal at the receiver output. After this, periodic measurements were made of the density distribution of the cloud of dipole reflectors, which changed continuously during the process of scattering.

Processing of the experimental data makes it possible to draw a number of conclusions about the character of impurity diffusion in a turbulent atmosphere. In the horizontal plane, scattering occurs approximately equally in all directions; the rate of scattering in the vertical plane is somewhat smaller. If D_1 and D_2 are the horizontal components of the turbulent-diffusion coefficient, with D_1 coinciding with the plane of the wind, and D_3—

vertical component, the following relations are approximately satisfied:

$$D_1 = D_2 = 1.5D_3. \tag{1}$$

The increased rate of scattering of the impurity in the horizontal plane in the direction of the wind, observed in practice, is explained not by a large value of D_1, but by the stretching of the cloud in the indicated direction under the action of the vertical gradient of the wind speed. It has been experimentally confirmed that the coefficient of turbulent diffusion has a different time dependence for different cloud sizes. If the cloud size is expressed through the root-mean-square deviation of the impurity-density distribution σ, then in the process of increasing the cloud size the diffusion rate changes continuously. For cloud sizes $\sigma \ll 25$ m, Kolmogorov—Obukhov diffusion takes place, for which $\sigma \sim t^{3/2}$ and $D \sim t^2$. For cloud sizes $25 < \sigma < 500$ m the relations $\sigma \sim t$ and $D \sim t$ are fulfilled. Finally, for $\sigma > 500$ m, $\sigma \sim t^{1/2}$ and $D = \text{const}$.

Fig. 1

It is necessary to note that the boundary $\sigma = 500$ m, at which the linear growth of the cloud size in time ceases and the diffusion coefficient becomes constant, is conditional and is valid for an averaged wind speed $U = 10$—15 m/sec. At higher wind speeds, cases were observed in which the linear growth of the cloud size in time could be traced up to $\sigma \approx 1000$ m; however, since the cloud went beyond the range of the radar, it was not possible to establish the boundary at which the diffusion coefficient may be regarded as a constant quantity. Thus, the sizes of the regions in which different laws of diffusion hold

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

apparently also depend on the meteorological state of the atmosphere; however, the comparatively limited number of experiments did not make it possible to establish quantitative relations.

Fig. 2

Nevertheless, it may be considered established that over a wide range of cloud sizes the relation

$$\sigma = bt. \tag{2}$$

is fulfilled.

The coefficient b [m/sec] has the meaning of the turbulent diffusion velocity of the cloud.

An attempt was made to find an empirical dependence of the coefficient b on the meteorological state of the atmosphere, for which the results of 50 experiments were used. The meteorological state of the atmosphere was esti-

···was represented by the Richardson number Ri and by the modulus of the mean wind speed U. The vertical distribution of the wind $U(z)$ was determined by means of radar, from tracking data on a rising object from which dipoles were released. The vertical temperature distribution $T(z)$ was taken from radiosonde observations of the atmosphere closest in time to the experiment.

During the time of observation of the cloud, its density maximum, under the influence of gravitational settling, descended by 1-3 km and even more. Over such a large altitude interval the functions $T(z)$ and especially $U(z)$ often differed substantially from linear. Therefore the derivatives $\partial U/dz$ and $\partial T/\partial z$, necessary for calculating the Richardson number Ri, were replaced in this altitude interval by finite differences, and for U and T their mean values were found.

Fig. 3

Figure 1 gives the values of the turbulent diffusion velocity b and the corresponding observed values of the mean wind speed. For the function $b = b(U)$ the most suitable dependence proved to be

$$b = 1.68 \cdot 10^{-2} U. \tag{3}$$

The relative root-mean-square deviation of the measured values of b with respect to curve (3) is 60%.

Figure 2 gives the values of b and the corresponding Richardson numbers Ri.

For the function $b = b(\mathrm{Ri})$ the most suitable dependence proved to be

$$b = k_1 \mathrm{Ri}^{-1/3}, \tag{4}$$

where $k_1 = 1$ [m/sec].

The relative root-mean-square deviation of the measured values of b with respect to curve (4) is 50%. If the turbulent diffusion velocity b is calculated simultaneously from the mean wind speed and the Richardson number Ri, the accuracy increases. Thus, for example, the relative root-mean-square deviation of the measured values of b with respect to the empirical dependence

$$b = 0.84 \cdot 10^{-2} U + 0.5 k_1 \mathrm{Ri}^{-1/3} \tag{5}$$

is only 35%.

The relation between the measured and calculated, by formula (5), values of b is shown in Fig. 3.

In some applied cases connected with atmospheric turbulence, it is necessary, from the meteorological state of the atmosphere, to determine the magnitude of the root-mean-square value of the pulsation components of the wind speed U'. Processing the dependences of the velocity of fluctuations of the amplitude of the reflected signal on the values of U and Ri observed at the moment of measurement makes it possible to propose the relation

$$U' = 0.58 k_2 U^{1/2} \mathrm{Ri}^{-1/6}, \tag{6}$$

where $k_2 = 1$ [$\mathrm{m}^{1/2} \cdot \mathrm{sec}^{-1/2}$]. A somewhat lower accuracy is given by another, simpler, empirical formula

$$U' = 7.5 \cdot 10^{-2} U. \tag{7}$$

Received
18 V 1963

CITED LITERATURE

1. A. G. Saibel, *Fundamentals of Radar*, Moscow, 1961.