N. Sh. Bibilashvili, V. F. Lapcheva, and G. K. Sulakvelidze

1960

SovietRxiv

Abstract

Full Text

GEOPHYSICS

N. Sh. Bibilashvili, V. F. Lapcheva, and G. K. Sulakvelidze

WATER CONTENT IN SHOWER CLOUDS AND SOME QUESTIONS OF FORECASTING SHOWER PRECIPITATION

(Presented by Academician I. N. Vekua, 3 VIII 1959)

Radar and other data have led some authors to the conclusion that, in powerful cumulus, shower, and thunderstorm clouds, the water content does not exceed 8-10 g/m^3, and on average amounts to 2-4 g/m^3. These data cannot be regarded as indisputable, since direct measurements of water content in powerful cumulus and hail clouds have not been carried out, while indirect methods of determining water content suffer from many shortcomings. In calculations of water content in clouds of this type, gravitational coagulation and the change in the velocity of vertical currents with height were not taken into account; as a result, the calculated data on cloud water content, in comparison with the amount of precipitation falling out, were underestimated by almost an order of magnitude. Therefore the question of investigating water content in cumulus and powerful cumulus clouds is of undoubted interest, if only for forecasting the amount of possible shower precipitation and for developing a physically grounded method of intervention.

Let us attempt to calculate the maximum water content in powerful cumulus clouds, proceeding from the distribution of the velocity of vertical currents with height ([1])

$$\begin{aligned} W(z) &= az + W_0 && \text{for } z < z_1, \\ W(z) &= a(2z_1 - z) + W_0 && \text{for } z > z_1, \end{aligned} \tag{1}$$

where $W(z)$ is the velocity of the ascending current at level z; a is the velocity gradient in m/sec $\cdot$ km; W_0 is the initial velocity at $z = 0$; z_1 is the level of maximum vertical velocity; the origin of the z-axis is placed at the Earth' s surface.

In the course of the development of cumulus and powerful cumulus clouds, in the pre-summit part of the cloud above the level of maximum velocities, moisture accumulates ([1]). The weight of the accumulated moisture, acting on the ascending currents, reduces the magnitude of the vertical velocity, as a result of which precipitation begins to fall; moreover, in the precipitation zone the ascending currents cease. The droplet-liquid fraction accumulated in the upper part of the cloud is, as it were, "poured out," "washing out" the lower fine-droplet fraction. This accounts for the short duration of the fall and the intensity of shower precipitation.

The equation of motion of ascending air masses, taking into account the weight of water per unit volume and neglecting friction, is written in the form

$$\rho\,\frac{dW(z)}{dt} = \rho\,\frac{T' - T}{T}\,g - qg, \tag{2}$$

where W is the velocity; ρ is the mass of air per unit volume; g is the acceleration of gravity; T' is the temperature of the cloud; T is the temperature of the surrounding medium; z is height; q is the cloud water content in g/cm^3. Since we are interested in the maximum water content observed in the center of the cloud, and according to previous investigations ([3]) the vertical velocity in the central part of the cloud changes only slightly in the horizontal plane, then for the central part of the cloud $dW/dt = W\,dW/dz$. The water content in the lower part of the cloud, as experiments have shown, up to the level of maximum velocities ([1]) is 0.1–0.7 · 10^{-6} g/cm^3, and at the level z_1 reaches its maximum value.

Let us assume that above the level z_1 the liquid water content decreases linearly toward the cloud top (z_B). Taking into account that the liquid water content at the cloud top is $q(z_\text{B}) = 0$, we obtain

$$\text{for } z_1 \le z \le z_\text{B} \qquad q(z) = \sigma(z_\text{B} - z),$$

where σ is the gradient of liquid water content with height*.

On the basis of what was said above, equation (2) can be reduced to the form

$$W\frac{dW}{dz} = g\frac{T' - T}{T} - \frac{\sigma(z_\text{B} - z)}{\rho_\text{B}}g. \tag{3}$$

Integrating this equation, taking into account the variation of q with height, and denoting by W_p the value of the calculated velocity determined from equation (2) without allowance for liquid water content, we obtain

$$W^2 = W_\text{p}^2 - \frac{2g\sigma\overline{T}(z)}{\rho_0 T(z_1)}\int_{z_1}^{z}(z_\text{B} - z)e^{kz}\,ds. \tag{4}$$

Since $\overline{T}(z)/T(z_1) \approx 1$, from equation (4) we obtain for W^2

$$W^2 = W_\text{p}^2 - \frac{2g\sigma}{\rho_0 k}\left\{\left(z_\text{B} - \frac{1}{k}\right)\left(e^{kz} - e^{kz_1}\right) - \left(ze^{kz} - z_1e^{kz_1}\right)\right\}. \tag{5}$$

To facilitate the calculations, let us estimate the mean liquid water content of the cloud in the height interval from z_{B} to z_{K}, at which $W(z) = V_{\mathrm{K}}$, where V_{K} is the velocity of the vertical currents supporting drops with $R = 2.5$ mm, beginning with which splashing occurs. In this case the solution of equation (4) takes the form

$$W^2 = W_{\mathrm{p}}^2 - 2g\frac{\overline{q}}{\rho_0}\left(z_{\mathrm{B}} - z_{V_{\mathrm{K}}}\right). \tag{6}$$

From equation (6) we obtain the mean value of the liquid water content of a cumulonimbus cloud, if we take

$$W_{\mathrm{p}}^2 = \left(\frac{W_{pm} + W}{2}\right)^2, \tag{7}$$

where W_{pm} is the calculated maximum velocity of the vertical currents at the level z_1,

$$\overline{q} = \rho\frac{\left(\frac{W_{pm}+W}{2}\right)^2 - W^2}{2g\left(z_{\mathrm{B}} - z_{V_{\mathrm{K}}}\right)}. \tag{8}$$

Precipitation can fall out of the cloud only in the case when at all levels, and consequently at the level of the calculated maximum velocity, the real velocity of the ascending currents becomes less than V_{K}. As is known ([4]), at heights of 3-4 km the value of V_{K} is about 10 m/sec. Thus, the maximum possible mean liquid water content of the cloud is determined by the relation

$$\overline{q} = \rho\frac{\left(\frac{W_{pm}+V_{\mathrm{K}}}{2}\right)^2 - V_{\mathrm{K}}^2}{2g\left(z_{\mathrm{B}} - z_{V_{\mathrm{K}}}\right)}. \tag{9}$$

The amount of precipitation falling on 1 cm^2, without allowance for coagulation of drops in the lower part of the cloud and evaporation of falling drops from the lower boundary of the cloud to the earth' s surface, is equal to

$$Q = \rho\frac{\left(\frac{W_{pm}+V_{\mathrm{K}}}{2}\right)^2 - V_{\mathrm{K}}^2}{2g}. \tag{10}$$

* We consider stationary distributions of liquid water content because the process of variation of liquid water content proceeds much more slowly than the process of ascent of air masses.

Analysis of the equation shows that the mean liquid-water content of a cloud, for identical maximum vertical velocities, will be greater the more rapidly the magnitude of the velocity of the vertical currents decreases. This decrease is determined by the stratification of the atmosphere.

Equation (10) shows that, under the assumptions made above, the amount of precipitation that falls depends on the square of the mean velocity $\left(\frac{W_{pm}+V_k}{2}\right)$ and does not depend on the dimensions of the cloud.

The liquid-water content calculated by this method from atmospheric radiosonde data exceeds the value of liquid-water content proposed by other authors. Direct measurements of the microstructure and liquid-water content of cumulus congestus and cumulonimbus clouds, made with a released trap in 1958 during the Alazan expedition, showed that in the upper part of a cumulonimbus cloud the liquid-water content may vary from 20 to 30 g/m^3, which agrees well with the calculated data.

From equation (10) the following values are obtained for the amount of shower precipitation on days with hail:

W, m/sec	15	20	25	30	35	40	45
Q, mm	2.0	4.5	7.5	11.0	15.0	18.5	24.0

The calculations presented for the amount of precipitation falling from a cloud give fairly good agreement with the experimental data, although these values require further verification because of the insufficient number of experiments.

On the basis of work (1) and equation (2), it is possible to forecast not only the possibility of hail, but also the amount of hail and shower precipitation, as well as the sizes of the hailstones.

If the level of the 0° isotherm lies near or below the zone of maximum ascending currents, then the sizes of the falling hail are determined by the magnitude of the maximum velocity of the ascending currents W_m. If, however, the 0° isotherm lies above the zone of maximum velocities, then the sizes of the hailstones are determined by the magnitude of the vertical velocity at the level of the 0° isotherm.

We present the results of investigations of the melting of hailstones while falling through a 4-kilometer layer of air ($t = 0^\circ$ at an altitude of 4 km and $t = 20^\circ$ at the Earth' s surface; R is the radius of the hailstone):

R_{initial}, cm	2	1	0.7
R_{final}, cm	1.75	0.65	0

As follows from these data, the larger the initial radius of the hailstone, the smaller, other conditions being equal, the change in its radius as a result of melting while falling below the 0° isotherm.

Using atmospheric radiosonde data, the conclusions presented in work (1), equation (1), and the results given above from the investigation of hailstone melting, it is possible to forecast the probability of hail, the possible amount of precipitation, and the final size of the hailstones.

Verification of this method using materials from previous years has given positive results.

Elbrus High-Mountain
Complex Expedition

Institute of Applied Geophysics
Academy of Sciences of the USSR

Received
24 VI 1959

CITED LITERATURE

1. N. Sh. Bibilashvili, *DAN*, **128**, No. 3 (1959).
2. N. S. Shishkin, *Tr. Glavn. geofiz. obs.*, issue 54 (116), 96 (1955).
3. L. N. Gutman, *A Theoretical Model of a Cumulus Cloud, Investigation of Clouds, Precipitation, and Atmospheric Electricity*, L., 1957, pp. 60–65.
4. I. Langmuir, *Collection: Physics of Precipitation Formation*, IL, 1951, p. 96.
5. Horace R. Byers, Roscoe R. Braham Jr., *J. of Meteorol.*, **5**, No. 3, 71 (1948).

Note: Figure translations are in progress. See original paper for figures.