DESTRUCTION OF DEVELOPING CUMULUS CLOUDS BY ARTIFICIALLY CREATED DOWNDRAFTS

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Abstract

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DESTRUCTION OF DEVELOPING CUMULUS CLOUDS BY ARTIFICIALLY CREATED DOWNDRAFTS

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In work ([1]) it was shown that in unstable atmospheric layers (as a result of some perturbations in the temperature or wind field) not only ascending stationary jets, but also descending ones, may arise spontaneously.

If the jet radius R and the degree of instability of the atmosphere are approximated by power functions of the height z, measured from the lower base of the unstable layer ([2], [3]),

$$R = bz^n, \qquad \gamma - \gamma_a = cz^{-p}, \tag{1}$$

where γ_a and γ are the adiabatic and actually existing temperature gradients in the atmosphere, and b, n, c, and p are positive constants ($p < \frac{3}{4}(n+1)$), then the vertical velocities along the axes of the ascending and descending jets, respectively, are equal to

$$W_0 = aA^{1/2} z^{1-p/2}, \tag{2}$$

$$W_0^* = \frac{z_1}{H^{n+1}} \sum_{k=0}^{\infty} A_k \left(\frac{z_1}{H}\right)^k. \tag{3}$$

Here H is the height of the unstable layer; $z_1 = H - z$; A is a certain constant ([1]), depending on the profiles of temperature and velocity in the jet, the convection parameter q/T, and the constants n and c; the constant

$$a = \left\{ \frac{4(n+1)^2}{3\left[8(n+1)^2 - 10p(n+1) + 3p^2\right]} \right\}^{1/2}; \tag{4}$$

the coefficients

$$A_k = A_k^* A^{1/2} H^{n+1-p/2}, \tag{5}$$

where the numerical values of A_k^* are determined on the basis of the recurrent formulas

$$2A_0^{*2} = 1/3,$$

$$\frac{1}{2}\sum_{k=0}^{i}\{k(n+k+1)+(i-k)(n+i-k+1)+$$

$$+4(n+k+1)(n+i-k+1)\}A_k^* A_{i-k}^* = \frac{(n+1)^2 p(p+1)\dots(p+i-1)}{3\,i!},$$

$$i = 1,\ 2,\ 3, \dots. \tag{6}$$

The ratio of the air velocities in the descending and ascending jets, according to (2), (3), and (5), is

$$W_0^*/W_0 = z_1 \sum_{k=0}^{\infty} A_k^* \left(\frac{z_1}{H}\right)^k / aH^{p/2} z^{1-p/2}. \tag{7}$$

Developing cumulus clouds constitute a substantially unstable medium, and to a first approximation they may be regarded as an unstable layer of large horizontal extent compared with the dimensions of the jets. In accordance with the theory ([4]), conical jets ($n = 1$) are observed in such clouds ([2]). The ratios, calculated from (7), of the air velocities in cloud jets at correspondingly equal heights h above their bases, for different laws of variation of the instability of the cloud layer with height (values of p), are given in Table 1*.

Table 1

Ratios of the velocities of descending and ascending jets

h/H	p	p	p	p	p	p	p	p	p	p
h/H	0	1/8	1/4	1/2	3/4	1.0	4/3	5/3	2.0	7/3
0.1	1.0	0.84	0.69	0.48	0.33	0.22	0.13	0.07	0.04	0.02
0.3	1.0	0.90	0.80	0.66	0.52	0.42	0.30	0.20	0.23	0.07
0.5	1.0	0.94	0.87	0.78	0.68	0.58	0.47	0.36	0.26	0.16
0.8	1.0	0.99	0.97	0.96	0.93	0.89	0.83	0.75	0.64	0.46
1.0	1.0	1.03	1.05	1.14	1.22	1.32	1.46	1.60	1.67	1.52

As can be seen from the data in the table, the terminal velocities of descending flows are either the same as those of ascending flows ($p = 0$) or exceed them, and sometimes considerably ($p \geq 1/2$). Thus, if the intensity of ascending flows is such that the adiabatic cooling of the rising air ensures condensation of water vapor in an amount sufficient for cloud growth, then the development of descending motions in such a cloud will proceed with velocities sufficient for, or greater than, what is necessary for the evaporation of all the droplets present in the jet.

Under real conditions, the instability of clouds, as a rule, decreases with height. According to ([2]), the value $p = 1/2$. Thus, in developing clouds the processes of cloud destruction should proceed more intensively than the processes of their growth, and this difference will be the greater, the more favorable the conditions for cloud development (i.e., the larger the value of c in (1)).

Nevertheless, under real conditions (in summer, in the daytime) growth of cumulus clouds is almost always observed, and only rarely their destruction. This is explained by the fact that an intramass cumulus cloud is periodically subjected to the action of upward-directed ascending flows caused by heating of the earth' s surface (convection) and partly by flow around its irregularities (turbulence). These flows create the impulses necessary for the formation of ascending spontaneous jets in clouds and at the same time feed the cloud with moisture. Therefore, as observations show ([2]), a developing cumulus cloud, as a rule, is an aggregate of ascending flows; compensating descending currents occur mainly near clouds.

The probability of occurrence in the upper part of a cloud of downward-directed velocity impulses is small, both because of the horizontal thermal homogeneity of the layer of air lying above the clouds and because of its comparatively weak turbulence. In addition, owing to the substantially smaller instability in the upper part of the cloud than in the lower part, the initial impulses necessary for the development of descending jets must be more intense than those that cause the occurrence of ascending flows in the lower part of the cloud. This is reflected,

* In the calculations, 30 terms of the series were used, since as $z_1 \to H$ the convergence of the series slows down, especially for $p > 1$. However, in developing clouds the value of p, apparently, cannot exceed 4/3, which corresponds to the case of invariance of the heat flux with height ([5]).

in particular, by the values of the relative velocities of the downdrafts at the beginning of ascent for $p \geq 1/2$ (see Table 1). Therefore, intense downdrafts in clouds are formed mainly as a result of the fall of substantial shower precipitation in the final stage of cloud development (5).

However, if sufficiently powerful downward-directed velocity impulses are artificially created in a developing cloud, then, in this cloud, at the expense of the energy of its instability, intense downdrafts will develop; these will not only prevent the cloud from developing further, but will lead to its substantial destruction and, in some cases, to its complete disappearance.

The considerations stated above were tested in 9 field experiments. Artificial downward-directed velocity impulses inside cumulus clouds (with a thickness of up to 5000–6000 m) were created by the passage through them of jet aircraft while climbing at large angles of attack. In all the experiments, on average approximately 5 min after the aircraft passages, the clouds broke up into parts, substantially lowered their upper boundary, or disappeared altogether; the experiments also confirmed that more intensely developing clouds are destroyed more strongly and more rapidly.

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