A METHOD FOR STUDYING COMPENSATORY DOWNDRAFTS NEAR DEVELOPING CUMULUS CLOUDS

1957

SovietRxiv

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GEOPHYSICS

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A METHOD FOR STUDYING COMPENSATORY DOWNDRAFTS NEAR DEVELOPING CUMULUS CLOUDS

(Presented by Academician V. V. Shuleikin, 18 XI 1956)

A method for indicating compensatory downdrafts caused by developing cumulus clouds is based on the following considerations.

Compensatory downdrafts begin near the upper boundary of clouds, where a comparatively weak decrease of temperature with height is usually observed, and sometimes an isothermal layer and even a temperature inversion. As a result, the air in compensatory currents, in the process of descent, becomes warmer than the surrounding atmosphere, since it is heated approximately according to the adiabatic law. In the layer in which cumulus clouds develop, the temperature gradient cannot be greater than the adiabatic one ([1]). Therefore, the excess temperature in descending currents that has arisen during descent in layers with a weak decrease of temperature with height, in the absence of mixing, must be preserved or even increase, if these currents have a sufficiently large extent and the temperature gradient in the surrounding air continues to remain less than adiabatic. Thus, compensatory downdrafts always have a temperature higher than that of the surrounding air. Owing to this they are readily recorded by a method entirely analogous to the method for indicating ascending convective streams ([2]), using a low-inertia sensitive thermometer installed on an aircraft.

Figure 1 presents samples of oscillograms recording air temperature, aircraft overloads, flight speed, and deviations from the assigned altitude on horizontal routes passing partly through cumulus clouds. From examination of the temperature trace it is evident that directly near the clouds and especially between them there are clearly revealed relatively narrow warm streams,* sufficiently distinct from the surrounding environment, with a temperature considerably higher than the temperature of cloudless air at the flight level. In accordance with what was said above, these warm streams may be interpreted as compensatory downdrafts. From the accelerometer record it is evident that at the moment when the aircraft leaves these streams, considerable overloads are observed; this indicates an abrupt change in vertical motions when passing from the stream into the surrounding air. The sign of the overloads (usually positive) and their abruptness confirm the descending character of the compensatory streams and the absence of a significant boundary layer between the descending streams and

Fig. 1

Figure 1: Fig. 1

the surrounding medium.

Study, by the indicated method, of compensatory downdrafts caused by developing cumulus clouds has shown the presence of a number of characteristic features of these currents:

1. Compensatory currents are localized directly near clouds and constitute relatively narrow streams (of the order of the size of the cloud), sufficiently distinct from the surrounding cloudless space.

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* The sharp decrease in temperature upon entering a cloud and its increase upon leaving it are caused by evaporation of droplets from the temperature sensor, which is always heated, owing to recovery temperature, more than the cloudy air ([2]). The same cause also gives rise to individual sharp decreases in temperature when crossing cloud fragments, which were not always marked by horizontal lines on the oscillogram because of their smallness.

Fig. 1. Samples of oscillograms obtained during crossings in flight: **a**—the middle part of flat fair-weather cumulus clouds; **b**—the upper part of towering cumulus clouds. **1**—air temperature; **2**—aircraft load factor; **3**—flight speed; **4** —deviation from a specified altitude. Horizontal lines indicate the time during which the aircraft was in the clouds; vertical lines indicate time marks (every 0.5 sec.). Temperature increases as the ordinate decreases (downward); positive load factors are directed upward; direction of flight is from left to right.

2. Aircraft accelerations caused by crossing descending currents are, as a rule, smaller than accelerations in clouds, but considerably exceed the accelerations recorded during flight in cloudless space at cloud level. The velocities of vertical motions were not determined from the obtained accelerations. However, on the basis of the indicated character of the accelerations one may suppose that the velocities of ascending currents in clouds are generally greater than the velocities of compensating descending currents; the latter, in turn, substantially exceed the velocities of vertical motions in cloudless air.

3. Compensating currents always occur near the upper part of clouds. With increasing distance downward from the cloud tops, the number of observed descending currents decreases sharply. The vertical extent of compensating descending currents near cumulonimbus clouds is small in comparison with the thickness of the cloud. Even near clouds with a thickness of approximately 3000 m, the vertical extent of descending currents does not exceed 700–800 m. Near cumulus clouds weakly developed in the vertical, descending currents may extend along the entire depth of the cloud and

even descend somewhat below its base. A considerable increase in the area of descending currents at the end of their path and a relatively very rapid decrease in the excess temperature within them indicate that intensive mixing of the descending currents with the surrounding medium is taking place here.

The relatively rapid damping of compensating currents, especially near cumulonimbus clouds, is apparently explained by the fact that, becoming warmer than the surrounding air, they acquire buoyancy directed opposite to their motion. Therefore the rate of descent of compensating currents decreases, in contrast to convective currents within cumulus clouds, which, on the contrary, move with acceleration owing to the continuous release in them of the latent heat of condensation during ascent [(3)]. This is also confirmed by the fact that larger accelerations are observed in clouds than in descending currents.

4. The area of descending currents near developing clouds is, on average, commensurate with the area of the cloud. Usually clouds develop not as a single whole, but through the growth of their individual parts (towers), which is also confirmed by the frequent observation of descending currents only on one side of a cloud or near individual towers. Therefore it may be considered that the area of ascending currents in clouds is smaller than the area of the cloud*. Thus, the rate of descent of air in descending currents must be less than the velocity of ascending motions in clouds, which is consistent with the accelerometer data, and these currents may be regarded as compensating.

These considerations, together with the experimental data presented, make it possible to conclude that compensating currents occur in a relatively narrow zone directly near developing clouds, with velocities substantially greater than in the surrounding cloudless air, and do not represent a slow descent of all the air located in cloudless space. The presence of such descending currents apparently explains the sharpness of the outlines of the upper part of cumulus clouds.

Received
10 VIII 1956

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[1] N. S. Shishkin, *Clouds, Precipitation, and Thunderstorm Electricity*, 1954. [2] N. I. Vul' fson, *Izv. AN SSSR, ser. geofiz.*, No. 5 (1956). [3] N. I. Vul' fson, *DAN*, 97, No. 1 (1954).

* This conclusion also follows from the data of (3), according to which the linear dimensions of ascending currents are approximately 70–90% of the size of the cloud.

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

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