LETTER TO THE EDITOR

Comments on C. W. Newton's "Circulations in Large Sheared Cumulonimbus"[1]

Dr. Newton in part of his paper entitled "Circulations in Large Sheared Cumulonimbus" reviews the evidence for the updraught core of a severe CuNb rising virtually adiabatically. He calls attention to the fact that, at the height of its maximum penetration into the stratosphere, unmixed updraught air would be about 30°C colder than its environment and subjected to a powerful downward acceleration. He then supposes that this air in descending overshoots its equilibrium level by an amount depending on the degree of mixing with warmer stratospheric air and that it then undergoes a number of damped oscillations, eventually levelling out just below the level of the tropopause.

There are, unfortunately, relatively few detailed observations of severe storms against which this model can be tested. However, there are two sets of observations which it is appropriate to consider: one involves radar observations and the other U-2 photographs of the visible storm tops. First let us consider the radar evidence, in particular some data obtained in the severe Geary (Oklahoma) storm. This (Browning & Donaldson, 1963) appears to conflict in some ways with Dr. Newton's interpretation. The observations we refer to are precipitation streamers, the lower edges of which extended from a height of 9 km to the ground beneath the base of the anvil outflow. These streamers travelled at about 30 m sec^{-1}, some 3 times faster than the horizontal speed of propagation of the main updraught, and were due to secondary updraught cells within the anvil outflow. They were not associated with the ascending portions of an oscillatory outflow (as might possibly have been expected on the basis of Dr. Newton's model) because, if this had been the case, they would of course have remained in more or less stationary positions with respect to the main updraught. Not only did all of the secondary updraughts in the anvil outflow of the Geary storm travel at 30 m sec^{-1}, but their associated streamers also could be identified and tracked from a position several kilometres from the summit of the main updraught out to a distance of about 25 km. They first became identifiable in a region which, according to Dr Newton's model, should have been characterised by descending air surrounding the main updraught. Thus *the behaviour of the secondary updraughts in the Geary storm is indicative of an anvil outflow in which downward motions were rapidly damped out and in which small scale convection was able to occur.*

Secondary updraught cells within an anvil outflow may be induced by pulsations in the main updraught flow, by regions of static instability within the outflow, or by local dynamical instabilities due to large shears near the edge of the outflow. They are unlikely to generate much fresh precipitation and probably only determine the places where already-generated precipitation falls out. Their presence is indicative of considerable mixing within the outflow and this is likely to be a factor in helping to damp out inertial oscillations of the kind anticipated by Dr. Newton. (The updraught outflow may of course also lose energy in other ways and an adequate description will require a fluid dynamical approach.) A mixing process is also suggested by the knobbly appearance of anvil tops in the vicinity of the main updraught, as seen in U-2 photographs. These knobbly irregularities have horizontal dimensions of a kilometre or so, consistent with convection or shear waves in roughly a 1 km-thick outflow, whereas inertial oscillations would be expected to have had a much longer wavelength and to have appeared as rather regular waves roughly concentric with the dome of the main updraught.

Finally it should be emphasised that, even in severe thunderstorms whose vertical extent appears to be limited by buoyancy rather than by mixing, it is still unlikely that any more than a very small proportion of the updraught ac-

[1] *Tellus*, 1966.

tually reaches the highest level. Thus the magnitudes of the negative buoyancy effect may not be as severe as might be expected using a purely parcel approach. Considerations of this kind have led Roach (1966) to suggest that *air descends into the main anvil canopy without oscillation, i.e. as an overdamped oscillation.*

This note is contributed by permission of the Director General of the Meteorological office.

K. A. Browning and W. T. Roach,
Meteorological Office,
and F. H. Ludlam,
Imperial College, England

REFERENCES

Browning, K. A. & Donaldson, R. J., Jr. 1963. Airflow and structure of a tornadic storm. *J. Atmos. Sci. 20*, 533–545.

Newton, C. W. 1966. Circulations in large sheared cumulonimbus. *Tellus 18*, 699–713.

Roach, W. T. 1966. An analysis of eight flights by U-2 aircraft over severe storms in Oklahoma. NSSL Report No. 29, 23–51 (submitted for publication in the *Q. J. Roy. Met. Soc.*).