Letters To The Editor

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ON THERMODYNAMICS OF DOWNDRAFTS

The purpose of this note is to treat the thermodynamic properties of downdrafts in some detail to bring out certain features which have not been explicitly brought out by previous workers, *viz.*, Kaplan[1] and Byers and Braham[2].

1. *The Parcel Method of Kaplan*[1]—ABCD in Fig. 1 represents a sounding on a summer afternoon where a large amount of latent instability is present. B represents the convective condensation level and PRST represents the wet bulb curve. Let rain falling from the cloud reach a point immediately below B. If the rain is sufficient and other conditions are favourable, it can saturate a parcel of air at B. The temperature of the parcel of air will then fall to R.[3] The parcel of air will thus acquire a temperature much lower than the environment and will consequently sink. The following cases may arise—

(*a*) If there is sufficient rain water still present and other conditions are favourable, the parcel of air can remain saturated until it reaches the surface at P_1. The fall in temperature in this case will be represented by AP_1 and the fall in wet bulb temperature by PP_1.

(*b*) If all the rain water present is consumed in saturating the parcel at B, its further descent will be along the dry adiabatic RA_1, and the fall in temperature will be represented by AA_1, the fall in wet bulb still being PP_1.

(*c*) If all the rain water is not used up at B, but some is left to keep the parcel saturated for some distance more but not upto the surface, the fall in temperature will be represented by a point between A_1 and P_1, the fall in wet bulb temperature being again represented by PP_1.

It should be noted that the wet bulb temperature in all the cases is represented by P_1, the wet bulb potential temperature of the air at B, irrespective of what the fall in air temperature is.

If the descent is from a point further below on the sounding, it is easy to see that we will still have a fall of both dry and wet bulb, although to a smaller degree and all the three cases considered above may arise.

Now let us consider a unit at C, above B. Byers and Battan[4] have shown that, due to vertical shear, clouds giving heavy rain may move away leaving the heavy rain behind. It is thus possible to have a region in the environment above B, where a large quantity of rain water is available to initiate a downdraft. The saturation of air at C will lower its temperature to S and the air would descend along the saturation adiabat through S. Again, all the three cases (*a*), (*b*) and (*c*) considered above may arise; the lowest temperature attainable will be P_2 and the actual temperature attained may be anywhere between A_2 and P_2, the wet bulb temperature in all cases being P_2.

If we take a point further up on the sounding, say at C′, then case (*b*) cannot arise, as the potential temperature of the air cooled by saturation to S′ will still be higher than the potential temperature of the surface air and the descent of air will stop at a level above the surface. If, however, the descent due to loss in buoyancy stops at a level only slightly above B, the momentum of its fall may carry it to the surface, thus causing a slight rise in air temperature.

We have up till now considered the case where wet bulb potential temperature decreases with height. Under certain circumstances, advection of fresh moist air may so modify the lowest layer that there is a slight increase in the wet bulb potential temperature with height in this layer. Under such conditions, a descent of air in the lowest layer may cause a slight rise in wet bulb temperature at the surface.

It can easily be seen that the lowest temperature attainable by purely adiabatic process is the lowest wet bulb potential temperature in the sounding, in our illustration, P_3

corresponding to point D in the ascent curve. It does not, however, follow that this lowest temperature will, in general, be attained, as the descent need not necessarily be from the level D. It should further be observed that almost any fall, as also a slight rise, in dry and wet bulb temperatures, can be accounted for by adiabatic processes.

Again, as has been pointed out by Kaplan (loc. cit) and is obvious from Fig. 1, the positive area increases as the air descends from higher level upto D, when the descent occurs under same conditions. This is due to the fact that the wet bulb potential temperature decreases with height upto this level. Thus, if one can neglect the horizontal momentum of the air carried by the downdraft and assume the squall to be due to downdraft alone, one can obtain an idea of the strength of the squall by following the downdraft on the tephigram.

2. *Entrainment and mixing*—In the parcel method of treatment discussed in the previous section it has been assumed that the downdraft is initiated in the environment. Work of Byers and Braham[2] has, however, shown that the downdraft most frequently originates in cumulus cell itself. In Fig. 2, BY, saturated adiabatic through B, represents the conditions in the cumulus cell in the updraft region when there is no entrainment of environment air. If there is entrainment of environment air, the lapse rate in the updraft region is represented by BXX′, when the rate of entrainment is 25 per cent in 50 mb. According to Byers and Braham, when rain commences at a weak point X in the updraft region, it drags down some of the cloud air at X. The cloud air dragged down by rain would have followed the saturated adiabat XE, if there was no entrainment. Due, however, to entrainment of environment air, the cloud air from X follows the path XC and when it is pushed down below C, it is denser than the environment. It will continue to sink due to loss of buoyancy and constitute the downdraft originating at C.

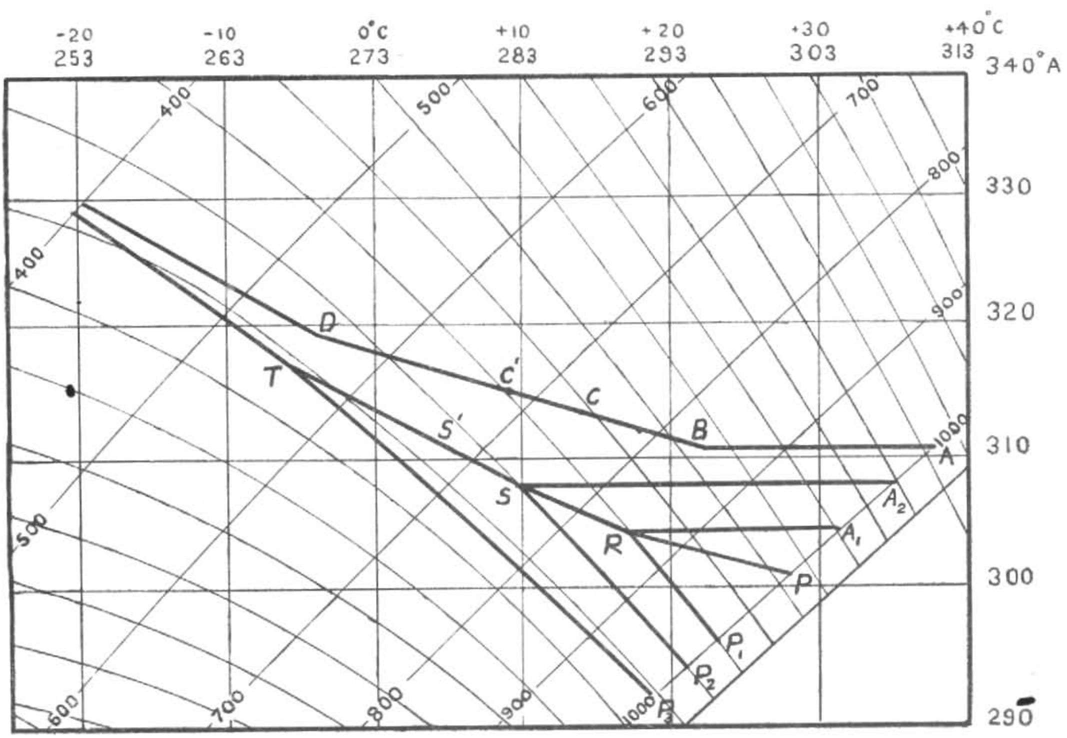

Fig. 1

Following up the downdraft below C, it is seen from Fig. 2, that the temperature of the downdraft approaches the wet bulb temperature of the environment and ultimately reaches the wet bulb temperature of the environment at the level R_1. If the downdraft is still saturated, it will now acquire a temperature slightly higher than the wet bulb temperature of the air at the level R_1 and reach the surface at P_1. By the parcel method of Kaplan, the downdraft originating at level C is brought down to P_2. The parcel method thus gives an exaggerated picture of the cooling to be obtained by downdraft.

If at any stage the downdraft goes out of the precipitation field, or if the precipitation ceases, the water carried by the downdraft due to frictional drag and viscous forces may be able to keep it saturated for some short time. After this water is used up, the downdraft would follow the dry adiabatic if there is no further entrainment of air. It is probably reasonable to assume, although no evidence is available, that there is no appreciable entrainment of air during the dry adiabatic descent. If, therefore, the downdraft has reached a level below R_2 before the water is consumed, it will still reach the surface, although as a dry downdraft. The wet bulb temperature of the downdraft on reaching the surface will in this case be lower than the wet bulb temperature of the downdraft in the precipitation area. If the water in the downdraft is consumed above the level R_2, the downdraft will normally not reach the surface, but if the water is consumed at a level only slightly above R_2, the momentum of the draft may carry it to the surface as a slightly warmer air (vide Section 1).

When there is no vertical shear or the shear is inappreciable, the downdraft will usually remain within the cell, adjacent to the updraft region, until it reaches the cloud base. So long as it is within the cell, it can entrain air both from the cloud, as well as the environment. As the cloud air is saturated and has a higher temperature, it will, if entrained into the downdraft in appreciable quantity, tend to nullify the effect of entrainment and mixing with the environment and

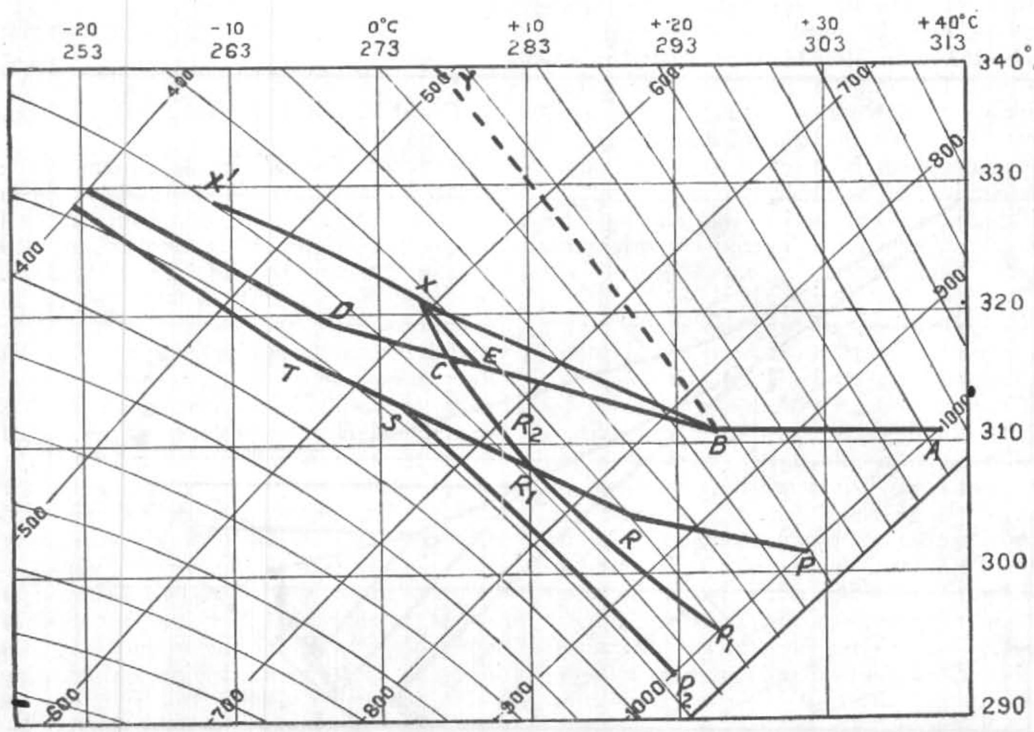

Fig. 2

may arrest the downdraft, unless it is surrounded by cloud air on all sides. If it is completely surrounded by cloud air, it can continue to fall through the cloud air, which has acquired a lapse rate steeper than the saturated adiabatic due to entrainment at the updraft stage. However, as has been shown by Byers and Braham (loc. cit.), the downdraft is not surrounded by cloud air but is exposed to the environment, and the the downdraft is maintained by the cooling by evaporation of environment air. The course of the downdraft will thus be along the curve CR_2R_1R, on the assumption of 25 per cent entrainment. After the downdraft has left the cloud base at B, it will be surrounded by environment air only and will continue to entrain air from the environment if it is in the precipitation field. It is not strictly justifiable to assume the same entrainment rate when the downdraft is within the cell, exposed to the environment only on one side, as when it is outside, but the assumption of a different rate at the two stages will not affect the qualitative nature of the result.

In a later work, Byers and Battan[4] have shown that, due to vertical shear, the hydrometeors may be displaced away from the updraft region. In this case, if the hydrometeors fall outside the cloud, they can initiate a downdraft outside the cell. However, when the rate of entrainment of environment air is assumed to be the same, irrespective of whether the downdraft is within the cell, or outside, the result will be the same, when the downdraft originates at the same level.

In conclusion, it may be stated that, although the treatment in Section 2 is more in accord with the factual evidence, the difference in the result to be obtained by the two methods is quantitative rather than qualitative. In the latter method, when one part of environment air is entrained by four parts of cloud air, the increase in density is obtained by the cooling of only one fifth of the total volume of air involved in the downdraft. The difference in the result by the two methods may, therefore, appear large at first sight. But, as the downdraft of Section 2 descends and entrains more of environment air, the difference is progressively reduced. The difference may increase again slightly after the stage where the wet bulb temperature of the downdraft equals the wet bulb temperature of the environment, *i.e.*, beyond R_1 (Fig. 2). Thus, referring again to Fig. 2, a downdraft descending from the level C reaches the surface at P_1, when entrainment is taken into account and at P_2 by the usual parcel method.

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