ENTRAINMENT THROUGH THE TOP OF A HEAVY GAS CLOUD,

NUMERICAL TREATMENT

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INTRODUCTION

After termination of the slumping phase of a heavy gas cloud, the height slowly starts to grow again. In Jensen (1981) it was shown that this cannot be the result of entrainment through the side wall but must be due to entrainment through the cloud top. Further, conservation equations for the density excess, $\Delta \rho$, of the cloud relative to ambient air as well as for temperature difference, $\Delta T$, between cloud and surface were given. For a cold cloud, qualitative arguments were derived to the effect that the density-jump Ri-number, controlling entrainment, would vanish faster than the temperature-jump Ri-number, controlling the general level of in-cloud turbulence, thus predicting that vertical growth should be an accelerating function of time in this case.

The present paper gives a full numerical treatment of the problem, and vertical growth of clouds initially of equal $\Delta \rho$ but different $\Delta T$ is compared. In evaluating the effect of $\Delta T$ it is as in Jensen (1981) assumed that the wind speed advecting the cloud along is large enough to make the assumption of a constant surface temperature valid. In case of very low wind speeds and in cases where the release is rather like a plume, a heat budget for the soil would have to be taken into account. The two following paragraphs discuss other assumptions made in the model and the two last paragraphs recapitulate the system of equations which is being solved and discuss the results obtained.
The values of the advection speed of the cloud and the friction velocity $u^*_i$ inside the cloud was not given any discussion in Jensen (1981). We will here offer some remarks in order to justify the assumptions made.

The absolute size of the advection speed is not considered important in the present context provided it is large enough for the reason mentioned above, as we are only interested in the development of the cloud relative to its center of mass. Hence the advection speed of the cloud is put equal to the wind speed at some arbitrary level. However, its possible variation may have some implication for $u^*_i$.

When the gas cloud results from a pressurized liquid blow-up, the initial entrainment of air during the cloud formation may be 10 times the pure gas volume (van Ulden, 1974; Kaiser, 1979). Thus the horizontal momentum of the cloud will be dominated by the momentum of the ambient air, whereby the average velocity of the cloud will be

$$\bar{u} = \frac{1}{h} \int_{z_0}^{h} \frac{u^*_w}{k} \ln \frac{z}{z_0} \, dz = \frac{u^*_w}{k} \left( \ln \frac{h}{z_0} - 1 \right).$$  \hspace{1cm} (1)

Thus the wind shear $\Delta u$ over the top of the cloud will be small and of order $u^*_w/k$. Hence, the pressure force on the cloud as a result of action from the ambient air will be of order

$$p = \frac{1}{2} \rho_a \left( \frac{u^*_w}{k} \right)^2 2 rh,$$  \hspace{1cm} (2)

which already for $r > 2h$ is less than the frictional force exerted on the cloud top and on the surface in general.

The small shear $u^*_w/k$ over the top of the cloud will drive some entrainment, but this development is complicated by the slumping of the cloud which intensifies the shear on the upwind edge and reduce it or perhaps reverse it on the down wind edge of the cloud. Also, because the momentum of the cloud initially is determined as the average over the dept $h_0$, the cloud moves faster than the surrounding air while slumping. This effect will tend to eliminate or reverse the average shear over the cloud top. Further the slumping itself generates turbulent velocities of the order of

$$v^*_s = \kappa \sqrt{g T h / \ln(h/z_0)},$$  \hspace{1cm} (3)