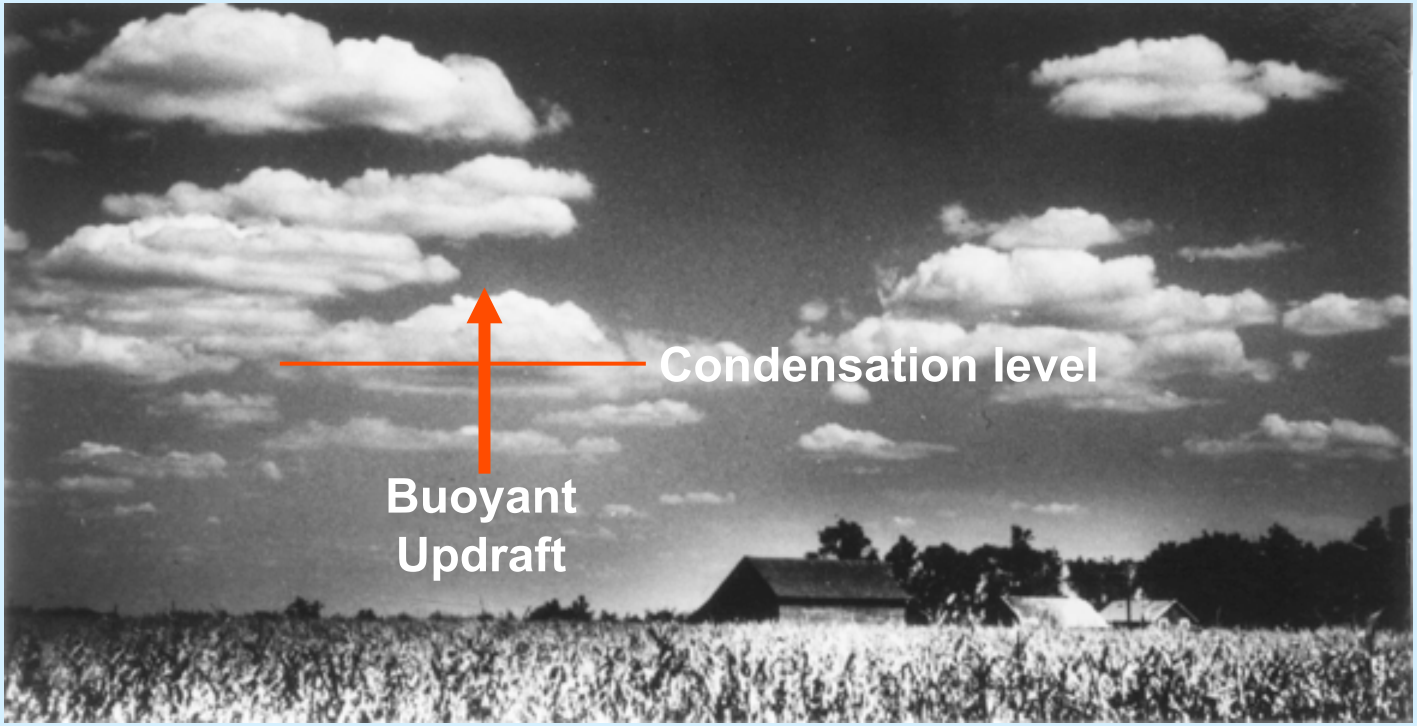
Basic Convective Cloud Dynamics

Cumulus and cumulonimbus

Cumulus



Fair weather type

Cumulus congestus

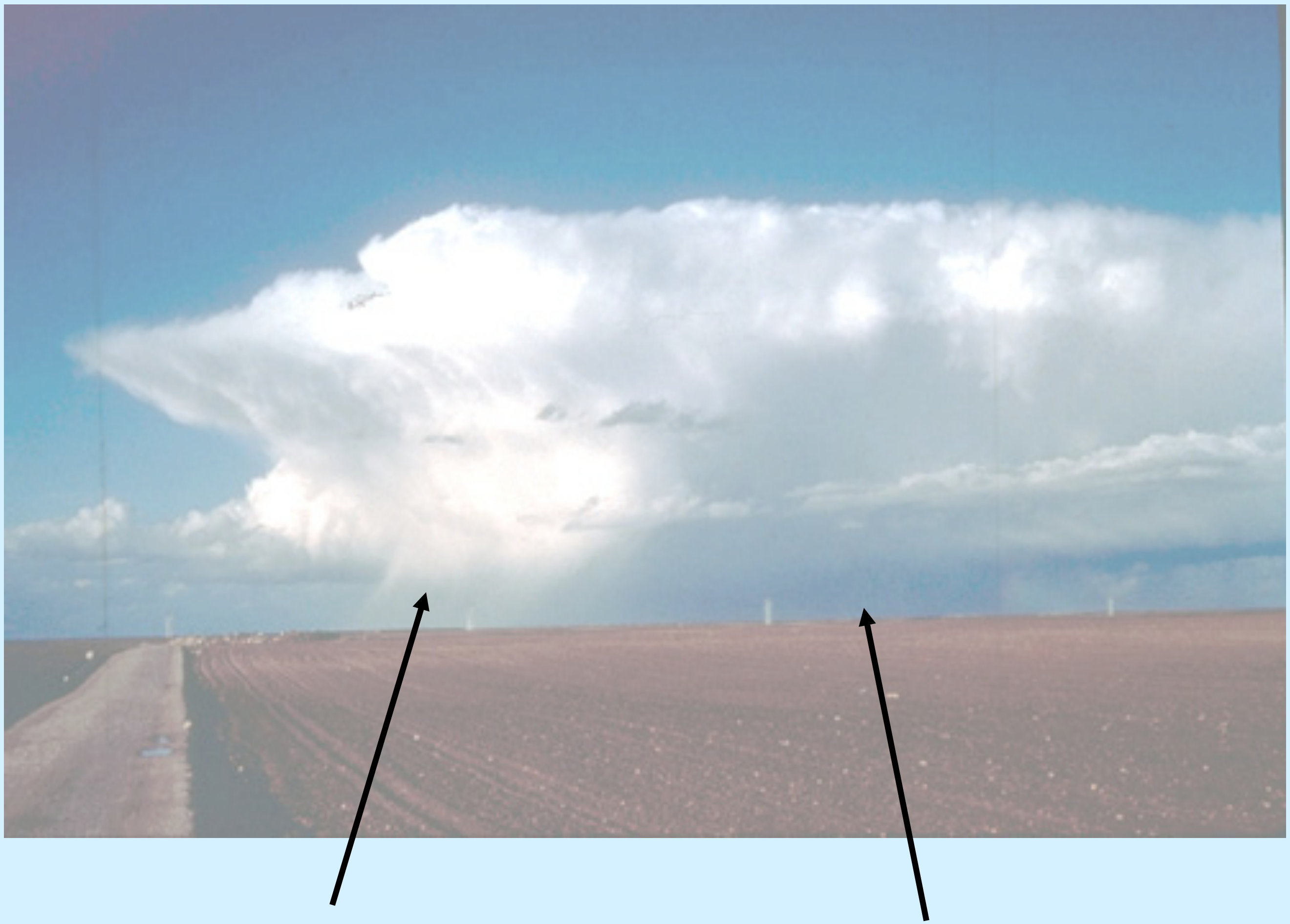
Cumulus congestus

Cumulonimbus

Rain

More often:
Cumulus congestus develops an anvil

Cumulonimbus with Anvil

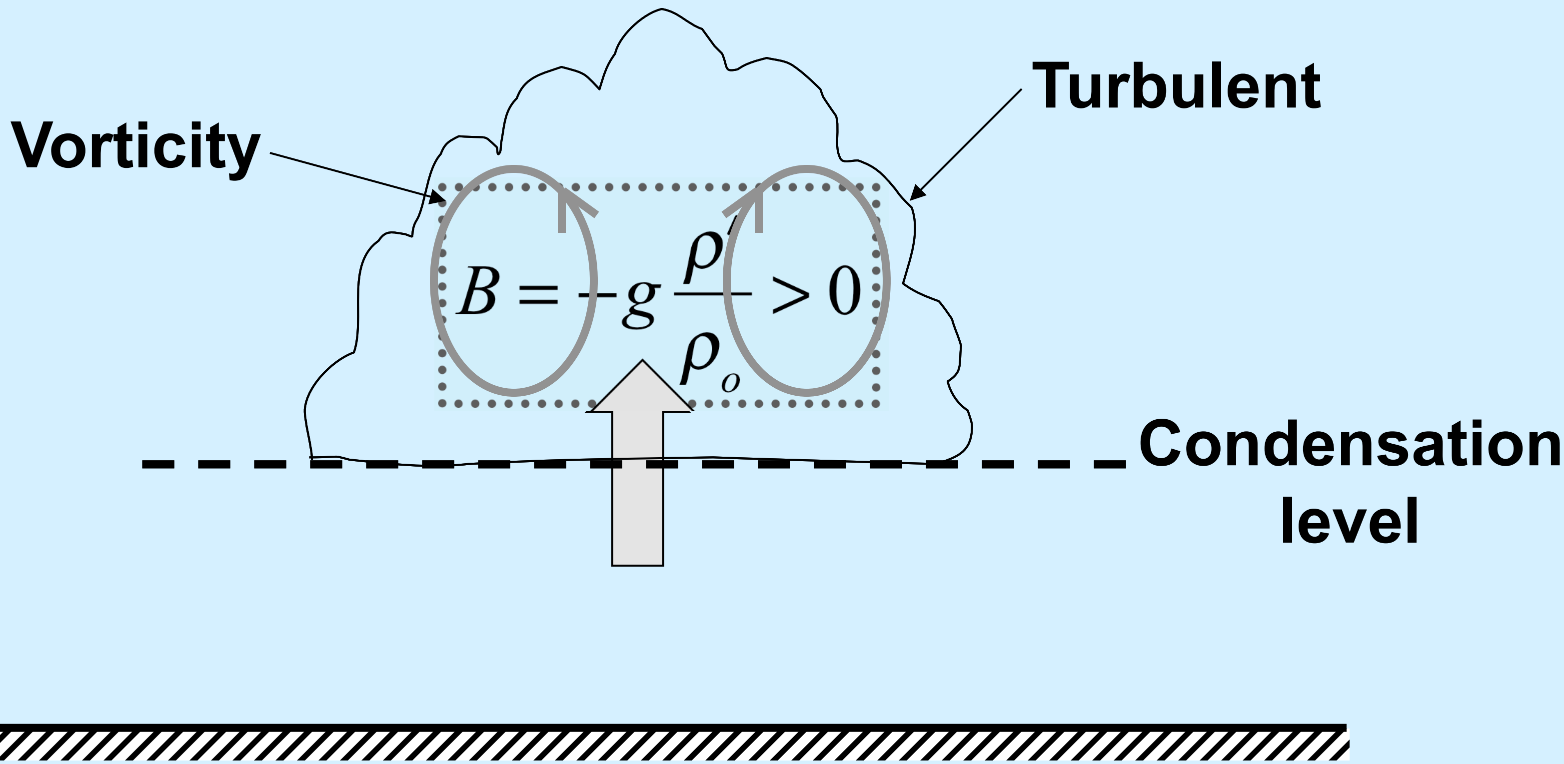


Tornadic Cumulonimbus

Tornado

All Cumulus and Cumulonimbus

Buoyancy phenomena



Basic equations for vertical acceleration, mass continuity, & buoyancy

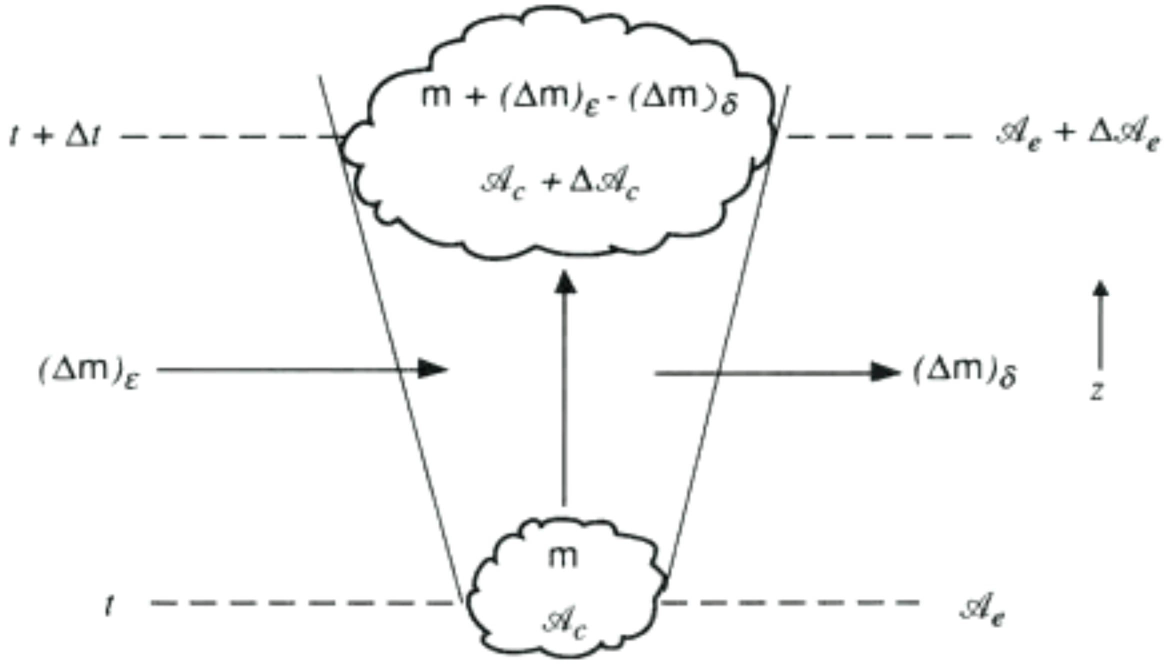
$$\frac{dw}{dt} = -\frac{1}{\rho_e(z)}\frac{\partial p'}{\partial z} + B$$

$$\nabla \cdot \rho_e(z)\vec{v} = 0$$

$$B = -g\frac{\rho'}{\rho_e(z)} = g\left[\frac{T'}{T_e} + .61 q_v' - \frac{p'}{p_e} - q_H\right]$$

1-D Lagrangian model

Based on classic model of continuous & homogeneous entrainment



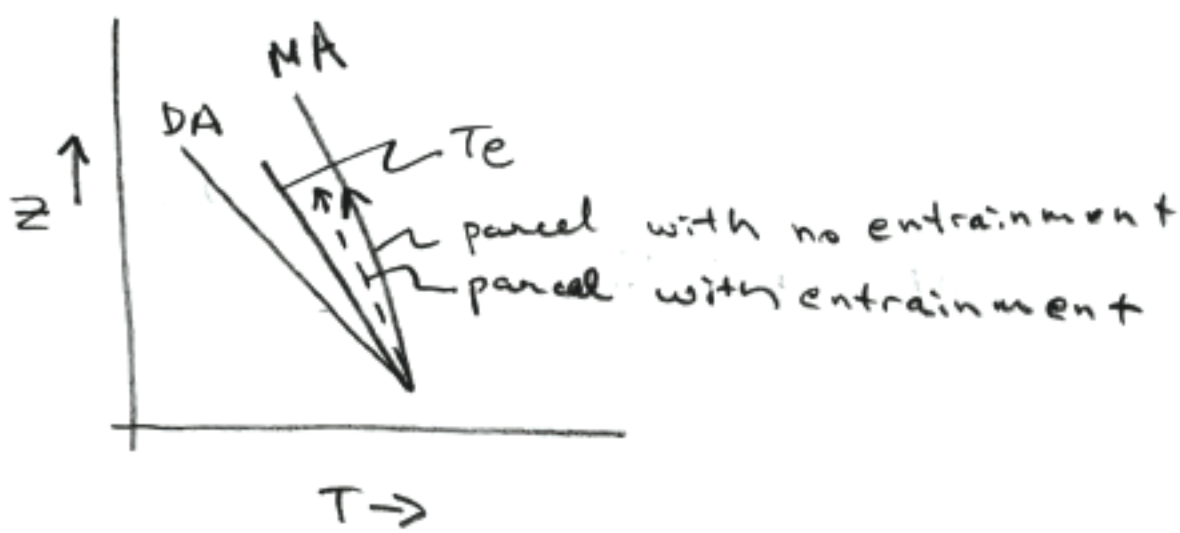
$$\frac{dA_c}{dt} = \frac{1}{m}\left(\frac{dm}{dt}\right)_\epsilon (A_e - A_c) + \left(\frac{dA_c}{dt}\right)_\delta$$

1-D Lagrangian model

Temperature equation

$$\frac{dT_c}{dz} = -\frac{g}{c_p} - \frac{L}{c_p}\frac{dq_{vc}}{dz} + \lambda\left[(T_e - T_c) + \frac{L}{c_p}(q_{ve} - q_{vc})\right]$$

Predicts parcel temperature & buoyancy



1-D Lagrangian model

Momentum equation

$$\frac{d}{dz}\left(\frac{1}{2}w_c^2\right) = -\frac{1}{\rho_e}\frac{\partial p'}{\partial z} + B + \lambda w_c \left(-w_c\right)$$

Kessler warm cloud microphysics

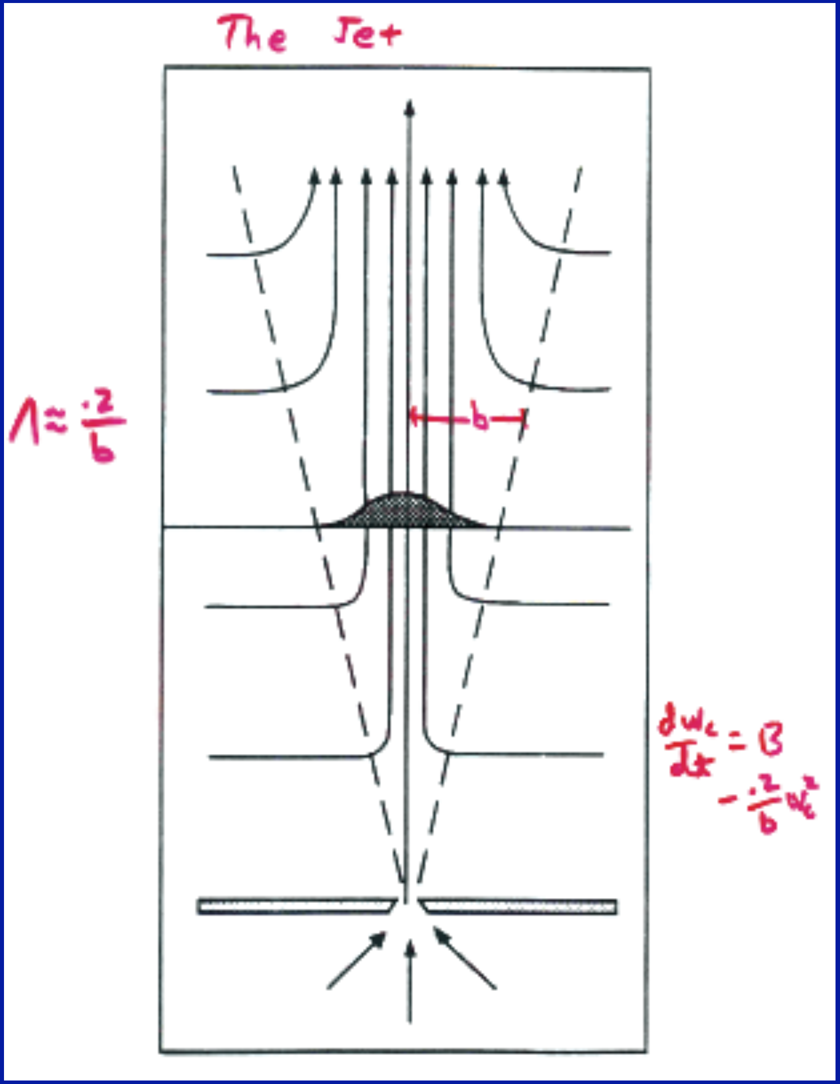
$$q_{vc} = q_{vs}[T_c, p(Z)]$$

$$w_c \frac{\partial q_c}{\partial z} = -w_c \frac{\partial q_{vs}}{\partial z} - A - K - w_c \lambda q_c$$

$$w_c \frac{\partial q_r}{\partial z} = A + K + F - w_c \lambda q_r$$

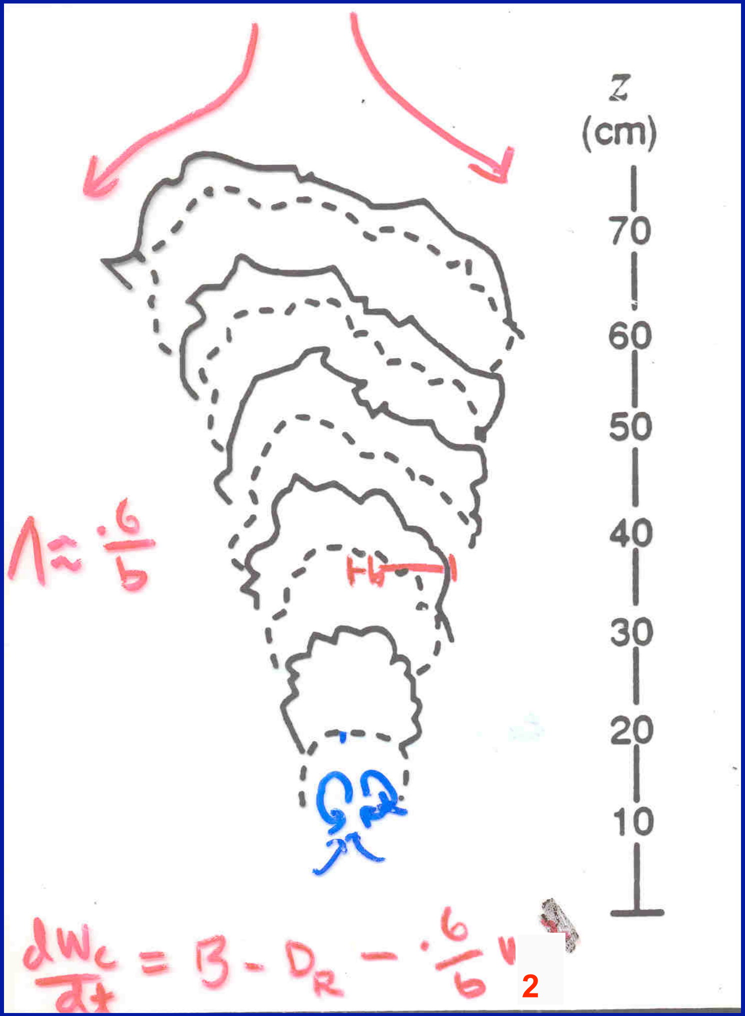
Entrainment

Turbulent jet



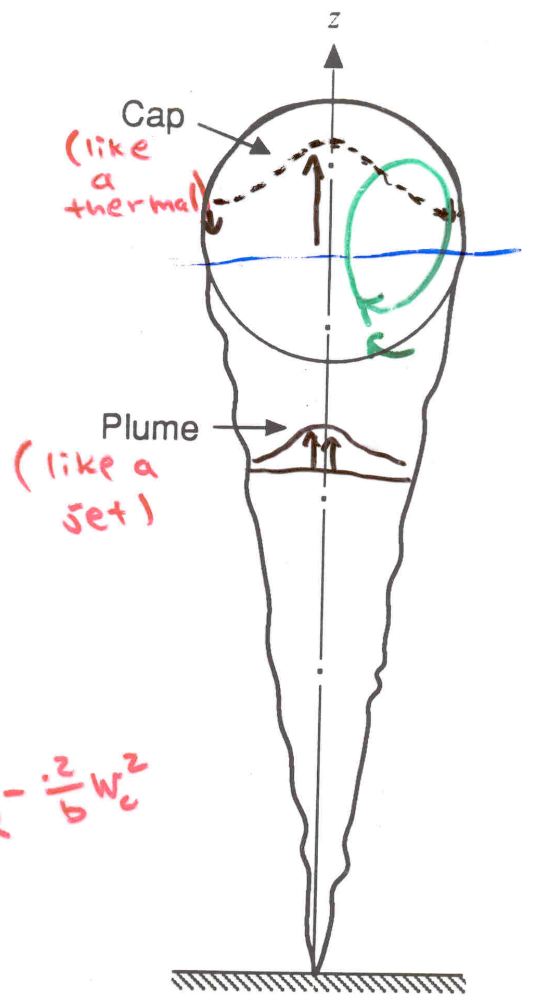
Entrainment

Thermal



Entrainment

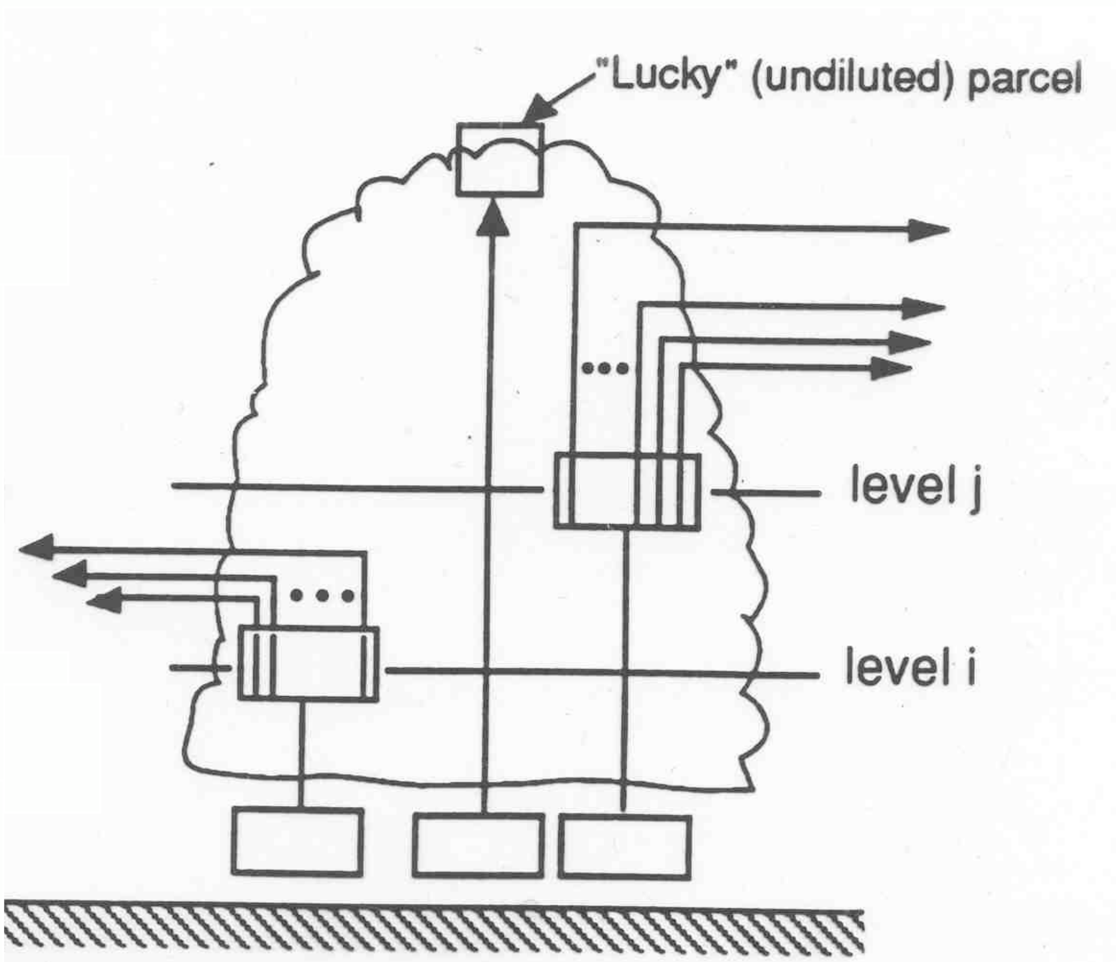
Starting plume



$$\frac{dw_c}{dt} = B - D_R - \frac{.2}{b} w_c^2$$

Entrainment

Raymond & Blyth's Model of discontinuous, inhomogeneous entrainment



Three-dimensional Vorticity

Vorticity equations under Boussinesq conditions

generation

$$\frac{d\eta}{dt} = B_y + \eta u_x + \xi u_y + \zeta_z$$

$$\frac{d\xi}{dt} = -B_x + \xi v_y + \zeta v_z + \eta v_x$$

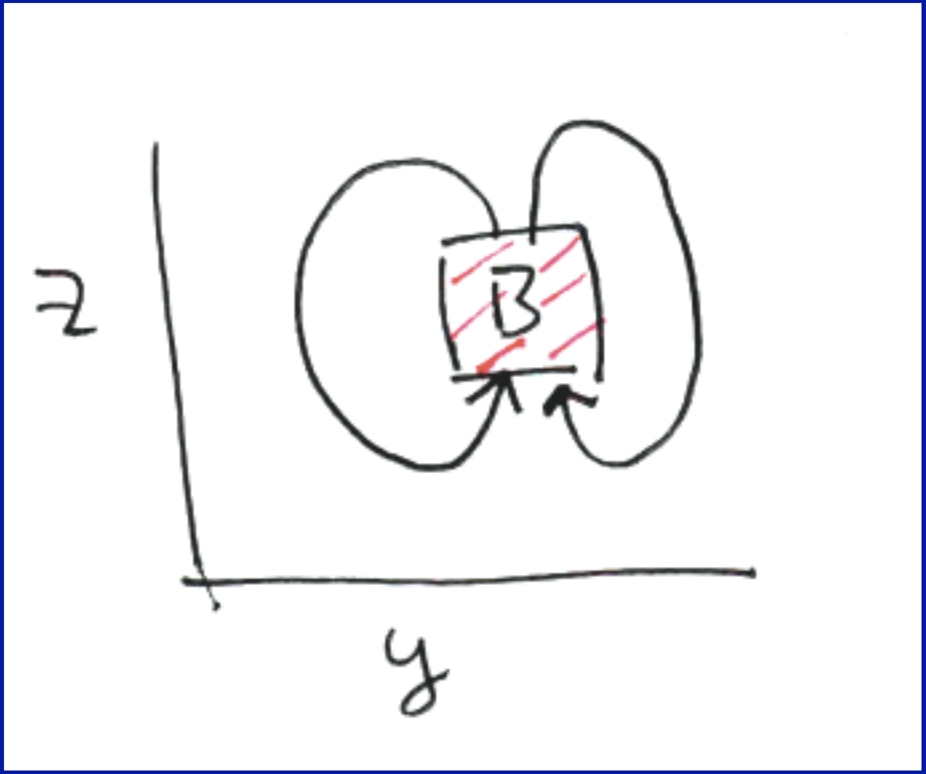
$$\frac{d\zeta}{dt} = \zeta w_z + \xi w_y + \eta w_x$$

stretching

tilting

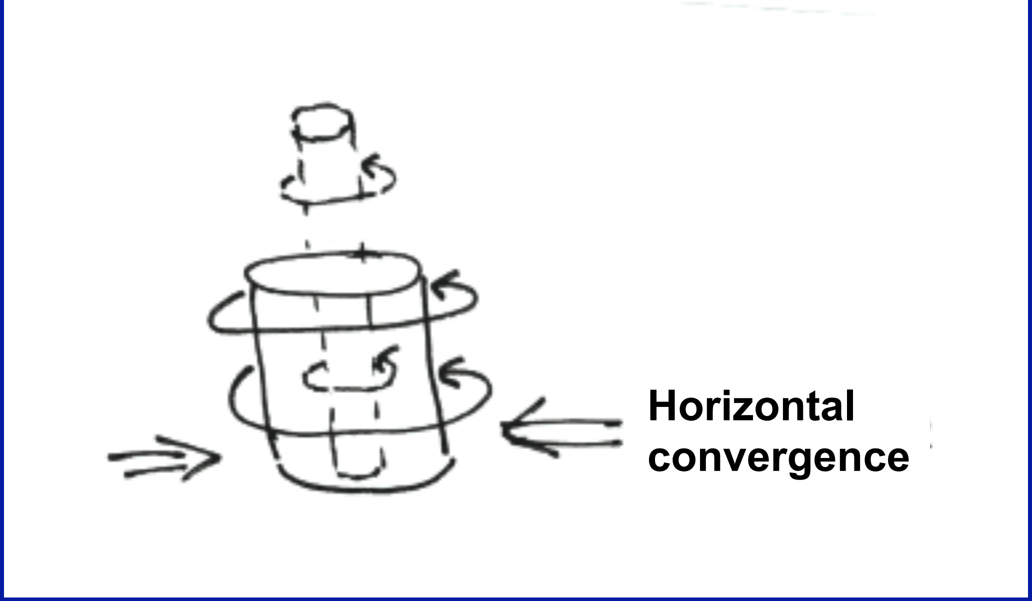
Three-dimensional Vorticity

Generation of horizontal vorticity by buoyancy



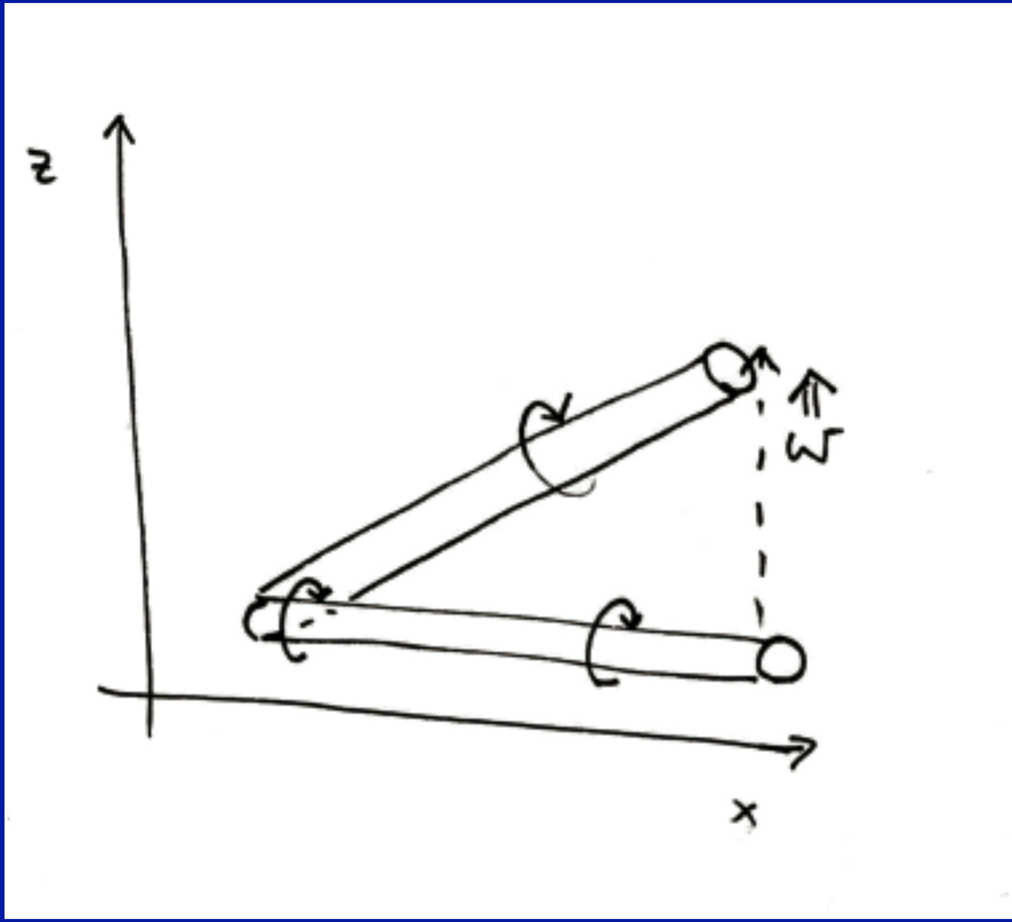
Three-dimensional Vorticity

Stretching of vertical vorticity



Three-dimensional Vorticity

Tilting of horizontal vorticity into the vertical



Three-dimensional Vorticity

Linearize vertical vorticity equation around the basic state:

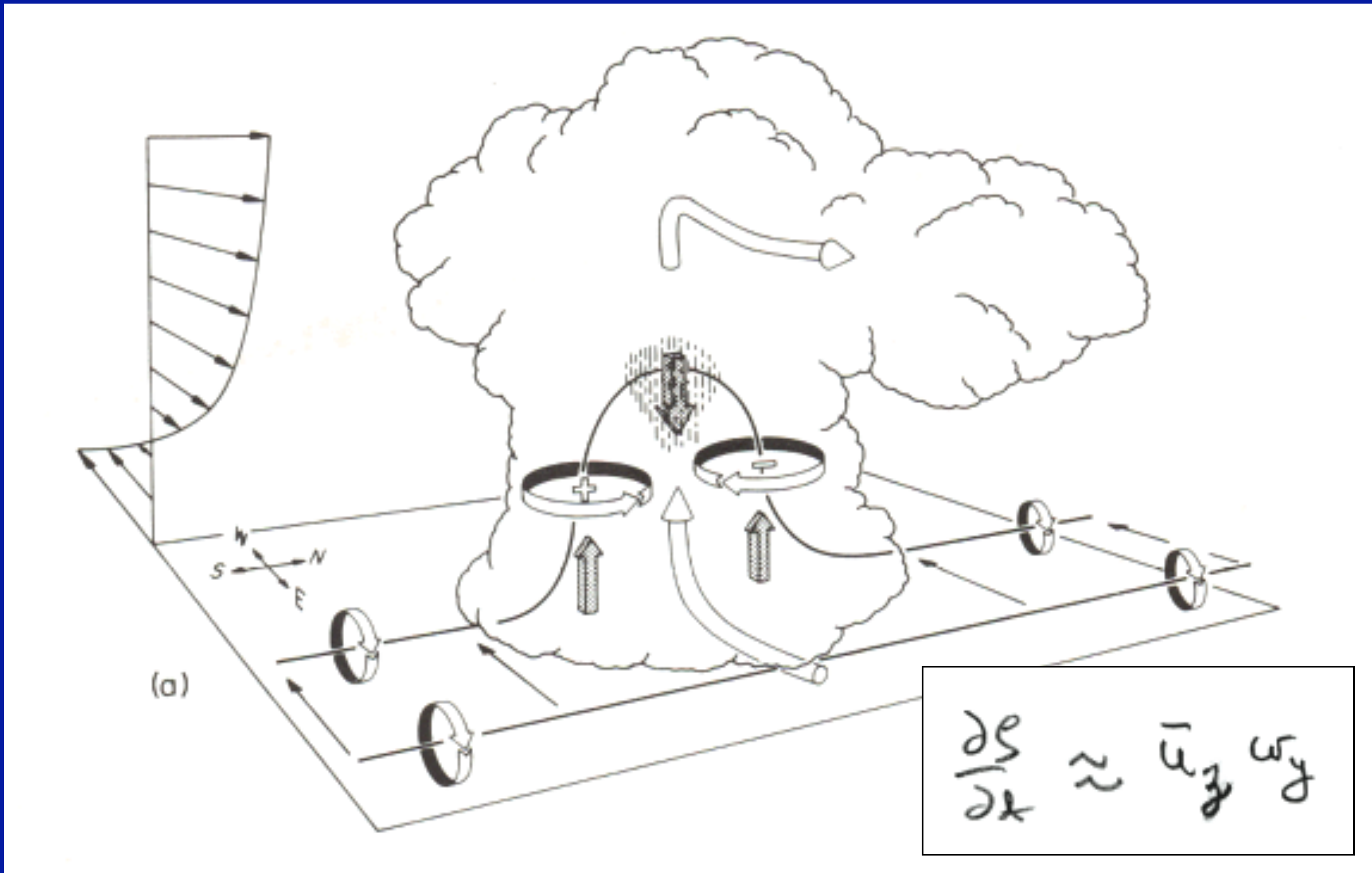
$$\vec{v} = [\bar{u}(z), 0, 0]$$

At a level in the cloud where the cloud is moving with the basic state velocity:

$$\frac{\partial \zeta}{\partial t} \approx \bar{u}_z \omega_y$$

Three-dimensional Vorticity

Linear process leads to vorticity couplet in an convective cloud that develops in a sheared environment



Pressure Perturbation

The pressure perturbation field in a convective cloud is governed by:

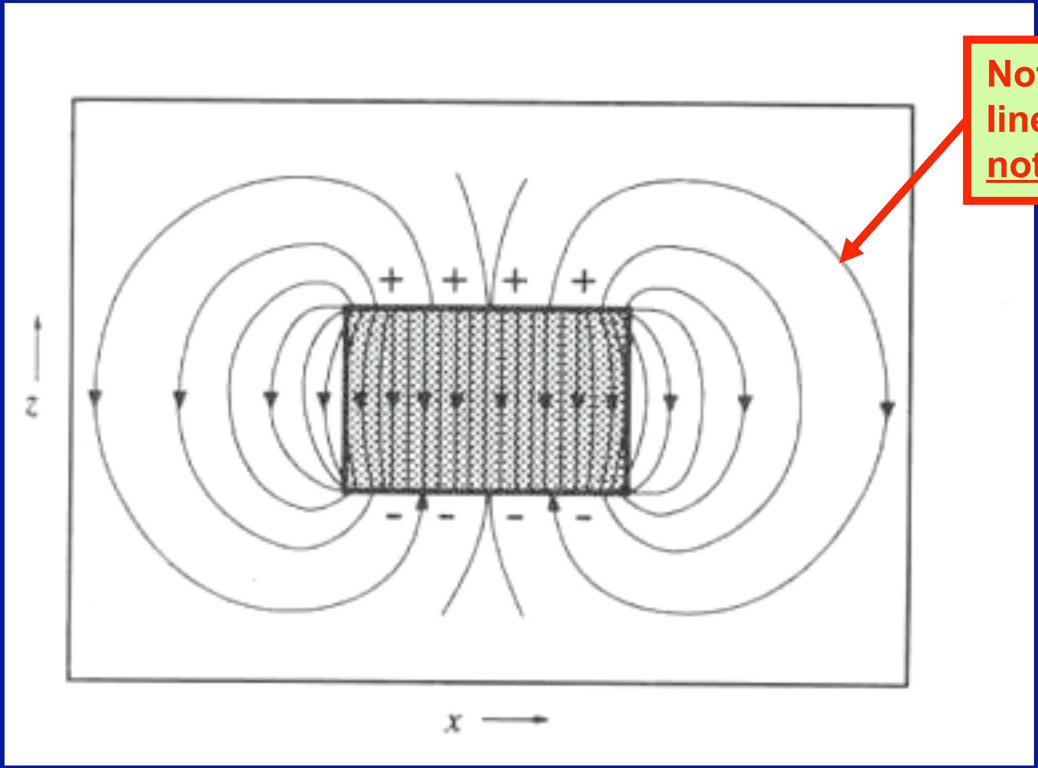
$$\nabla^2 p' = F_B + F_D$$

$$F_B = \frac{\partial}{\partial z}(\rho_o B)$$

$$F_D = -\nabla \cdot (\rho_o \vec{v} \cdot \nabla \vec{v})$$

Pressure Perturbation

Pressure gradient force required by the buoyancy field



Note! These are lines of force, not air motions

Figure 7.1 Vector field of buoyancy pressure-gradient force for a uniformly buoyant parcel of finite dimensions in the x–z plane. The plus and minus signs indicate the sign of the buoyancy forcing function $-\partial(\rho_o B)/\partial z$ along the top and bottom of the parcel.

Pressure Perturbation

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When vortices form in storms, this term requires a low pressure at the center of each vortex. These low pressure centers affect the storm dynamics by producing a pressure field in the storm that is different from that produced by buoyancy alone.