Severe Convection

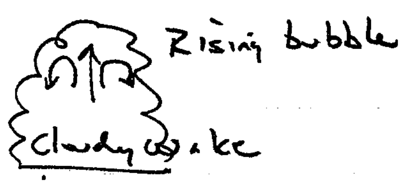
See Doswell reading & notes page 3-5

Convection is typically considered as the heat transport resulting from buoyancy. Advection (both horizontal & vertical) describes the heat transport due to nonbuoyant processes.

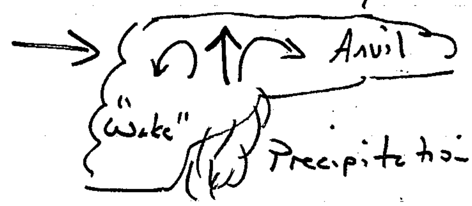
Convection releases large sums of heat as a result of condensation & release of latent heat. Most of this energy is dissipated by the work required to lift air in the gravitational field.

The stages of convection are summarized in Fig 1.3 (Doswell)

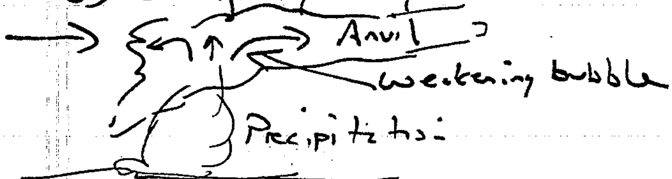
1) Towering cumulus stage



2) Mature stage



3) Dissipating Stage



Lifecycle may be in 30-60 minutes

The Dynamics of Convection

Let's generalize the 2-D perspective of convection done earlier (pg 11-12 & homework) to 3D.

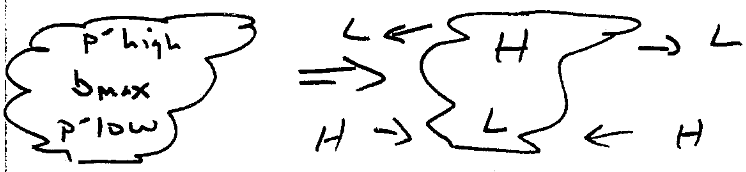
$$\frac{du}{dt} = -\frac{1}{\bar{\rho}}\frac{\partial p'}{\partial x}, \quad \frac{dv}{dt} = -\frac{1}{\bar{\rho}}\frac{\partial p'}{\partial y}, \quad \frac{dw}{dt} = -\frac{1}{\bar{\rho}}\frac{\partial p'}{\partial z} + b \qquad \text{C1.1}$$

where remember that p' is the pressure perturbation

So, in vector form
$$\frac{D\vec{V}}{Dt} = -\frac{1}{\bar{\rho}}\nabla p' + b\,\hat{k} \qquad \text{C1.2}$$

where the gradient operator is 3D : $\nabla p' = \frac{\partial p'}{\partial x}\hat{i} + \frac{\partial p'}{\partial y}\hat{j} + \frac{\partial p'}{\partial z}\hat{k}$

Review pgs 11-12 & recognize that the buoyancy leads to pressure perturbations, which in the vertical, tend to try to counteract the buoyancy.



You should be able to see, that rather than our 2-D slice here & earlier, a convective cell will generate pressure perturbations in all 3 Dimensions.

3-D Rotation

Rotation in thunderstorms & the effects of horizontal wind shear in convective complexes is critical. Undergrads are not responsible for the following derivation but are responsible for understanding the end results.

Define the 3D vorticity $\vec{\omega} = \nabla \times \vec{V} = \epsilon_{kji}\frac{\partial u_i}{\partial x_j}$ C2.1

Vertical component of vorticity $\zeta = \omega_3 = \epsilon_{3ji}\frac{\partial u_i}{\partial x_j} = \underset{+1}{\epsilon_{312}}\frac{\partial u_2}{\partial x_1} + \underset{-1}{\epsilon_{321}}\frac{\partial u_1}{\partial x_2}$

$\zeta = \omega_3 = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$ C2.2

$\hat{i}$ component of vorticity $\epsilon_{1ji}\frac{\partial u_i}{\partial x_j} = \underset{-1}{\epsilon_{132}}\frac{\partial u_2}{\partial x_3} + \underset{+1}{\epsilon_{123}}\frac{\partial u_3}{\partial x_2} = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}$

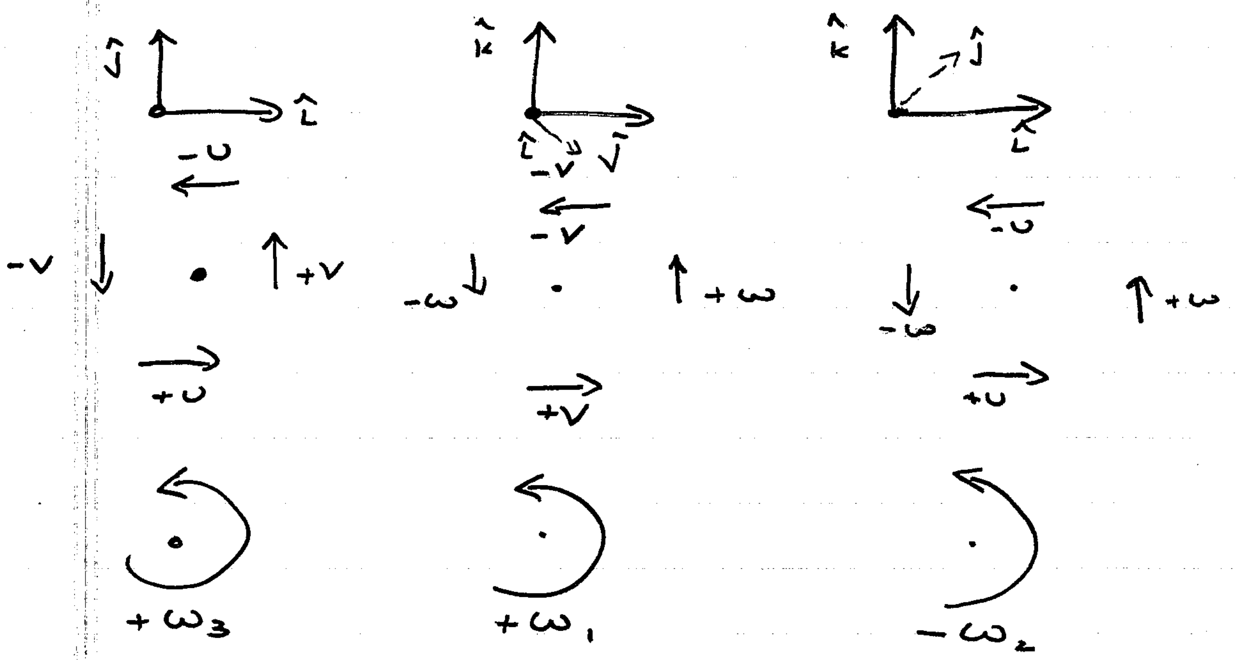
$\omega_1 = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}$ C2.3

$\hat{j}$ component of vorticity $\epsilon_{2ji}\frac{\partial u_i}{\partial x_j} = \underset{1}{\epsilon_{231}}\frac{\partial u_1}{\partial x_2} + \underset{-1}{\epsilon_{213}}\frac{\partial u_2}{\partial x_1} = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}$

$$\omega_2 = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \qquad \underline{C3.1}$$

Each component of vorticity measures rotation about its axis

$\hat{k}$ component $\qquad \hat{i}$ component $\qquad \hat{j}$ component

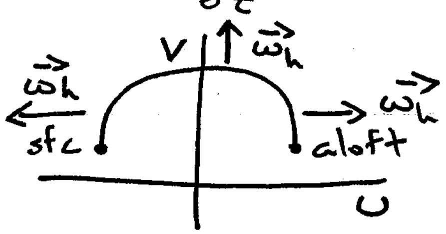


Use the right hand rule to determine the direction (axis) around which the fluid is rotating.

Interpretation of horizontal vorticity from hodograph

If the vertical ~~wind~~ shear of the horizontal wind is greater than the horizontal shear of the vertical wind then:

$$\omega_1 \cong -\frac{\partial v}{\partial z} \quad ; \quad \omega_2 \cong \frac{\partial u}{\partial z} \quad \text{or} \quad \vec{\omega}_h = \hat{k} \times \frac{\partial \vec{V}_h}{\partial z}$$

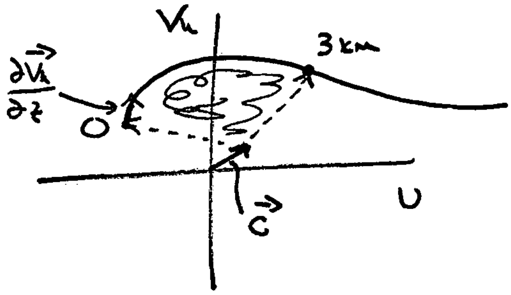


So direction of horizontal vorticity is directed at right angles to shear vector

Storm Relative Helicity

Tornadic environments tend to be characterized by clockwise turning horizontal wind shear. A measure of the magnitude of that shear is the storm-relative helicity $H = -\int_0^{3km} \hat{k} \cdot (\vec{V}_h - \vec{c}) \times \frac{\partial \vec{V}_h}{\partial z} dz$

$\vec{c}$ - storm motion $\vec{V}_h$ - horizontal wind. Graphically, H can be determined as follows:



Think of this as $H \sim -\int_{\vec{V}_0}^{\vec{V}_{3km}} \hat{k} \cdot (\vec{V}_h - \vec{c}) \times d\vec{V}$

which is the sum of the area enclosed in the figure

Generally larger values of H are associated with higher potential for cyclonic updrafts in right moving supercells.

Physical Mechanisms Controlling Storm Structure

The readings (Doswell, Weisman & Klemp) & COMET modules discuss how storm structure depends on the following:

1) Buoyancy : lapse rate, CAPE, moisture stratification

2) Gust front processes : strength of cold pool & low-level wind shear

3) Dynamics : • strength of vertical wind shear from sfc - 6 km
• development of favorable vertical pressure gradients on updraft flanks
• development of rotational (helical) updrafts